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## TABLE OF CONTENTS

**VOLUME 16, NUMBER 3**

<table>
<thead>
<tr>
<th>Page</th>
<th>Article Title</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EDITORIAL</strong></td>
<td>To Reconstruct the Anterior Cruciate Ligament or Not? – Put into Panther Perspective. Thorborg K</td>
</tr>
<tr>
<td></td>
<td>606 The Efficacy and Treatment Fidelity of Kinesiology Taping in Conjunction With Conservative Treatment Interventions Among Individuals With Shoulder Pain: A Systematic Review with Meta-Analysis. Salamih PA, Hanney WJ, Cory CS, Condon HE, Liu X, Kolber MJ.</td>
</tr>
<tr>
<td><strong>ORIGINAL RESEARCH</strong></td>
<td>620 Reliability and Validity of the Functional Movement Screen™ with a Modified Scoring System for Young Adults with Low Back Pain. Alkhathami K, Alshehre Y, Wang-Price S, Brizzolara K.</td>
</tr>
<tr>
<td></td>
<td>628 Reliability and Validity of the Y-balance Test in Young Adults with Chronic Low Back Pain. Alshehre Y, Alkhathami K, Brizzolara K, Weber M, Wang-Price S.</td>
</tr>
<tr>
<td></td>
<td>636 A Targeted Approach to Evaluating the Golfing Athlete with Low Back Pain: A Resident’s Case Report. Deckard L.</td>
</tr>
<tr>
<td></td>
<td>689 The Effects of Soft Tissue Flossing on Hamstring Range of Motion and Lower Extremity Power. Maust Z, Bradney D, Collins SM, Wesley C, Bowman TG.</td>
</tr>
<tr>
<td></td>
<td>741 Lumbopelvic Stability and Trunk Muscle Contractility of Individuals with Chronic Ankle Instability. McCann RS, Johnson K, Suttiller AMB.</td>
</tr>
<tr>
<td></td>
<td>749 The Effects of Whole Body Vibration on the Limits of Stability in Adults With Subacute Ankle Injury. Young S, Wallmann HW, Quambaro KL, Grimes BM.</td>
</tr>
</tbody>
</table>
EDITORIAL

TO RECONSTRUCT THE ANTERIOR CRUCIATE LIGAMENT OR NOT? – PUT INTO PANTHER PERSPECTIVE

Kristian Thorborg PT, PhD, RISPT1,2

The anterior cruciate ligament, AKA the ACL, is the number one ligament of attention to the sports medicine professional. No other has received research and public attention like the ACL injury. Everyone knows and dreads it, from athlete to coach and young to old!

Forty years ago, the ACL injury retired most pivoting sport athletes, and the big game-changer came in the late 80s when “the cure” arrived. The ligament was then primarily reconstructed with one’s own tendon tissue, and the instability problem solved long-term. The narrative around the ACL injury changed…it was no longer career ending. Problem solved – except not quite.

I’ll never forget my first sports physical therapy conference in the United States. In a symposium debate on ACL injury, the conversation was entirely focused on graft choice – seemingly overlooking rehab as a first option. I was flabbergasted when the panel and floor together discussed and consented that the allograft was graft choice for the “couch potato,” due to it not being as strong/good as an autograft. But, did I hear this “consensus” right? When we know 50 percent of athletes who go through rehab first with optional delayed surgery, can proceed without surgery for the first 2-5 years?1,2 Unfortunately, I did! The idea of a specific graft type waiting for all who rupture their ACL is not driven by the scientific evidence. While ACL surgery is not cost-effective in the public healthcare system,3 it may be “cost-effective” in the private health care system – at least for those getting paid to do it. This may provide different perspectives and difficult conversations among healthcare professionals from different health care systems.

Recently, the Panther consensus paper was released, including healthcare professionals from different countries and healthcare systems.1 The Panther consensus panel agreed 100% that both operative and non-operative care for ACL injury is acceptable1 – so far so good. However, whether rehab first with optional delayed surgery is an acceptable approach was not clearly addressed, although tackled in high-level randomized controlled trials (RCTs).1,2 The Panther group disagreed on delayed operative care as an option for temporary return to athletic participation, following non-operative care and accepting the risk of additional injury.4

According to the experts, the elite athlete competing in pivoting sports needs a reconstruction4 – but despite lots of ACL research, we still only have Level 5 evidence from consensus.4 Even if we as experts promote shared decision-making,4 the expectations from younger athletes are already so high1 and the procedure offered so quickly that it seems questionable if athletes are ready and receptive for grasping mean outcomes and return to sport odds. Can we expect them to make truly informed and thoughtful decisions in a few weeks?

So, how does it go with those who receive the procedure? Several graft choices later, the injury and its devastating consequences for many athletes still prevail.6-7 Many do not return to play at their pre-injury level, and of those who do, many have their sports career significantly shortened.6-7 At the same time, the rehab period these days is long – suggest-

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2 Department of Health Sciences, Lund University, Lund, Sweden

Keywords: Anterior Cruciate Ligament, Return-to-Sport, Optional, Delayed, Reconstruction
ed to be up to two years⁸ – so many career dilemmas for the elite athlete exist. Future knee health may only play a small part in the decision on surgery and return to play times. The dream of ACL reconstruction as a career savior is understandable and a more attractive initial mind-set than the uncertainty around odds for successful recovery. But do we “sell” them a dream by suggesting immediate surgery? Why not delay the final decision and increase the athlete’s experience in life without an ACL? Why not see delayed optional surgery as a way to provide athletes with individual experiences on dynamic knee stability, strength and performance,⁹ as well as to form realistic expectations concerning different rehab strategies? It is suggested that the question “should you return to play?” needs posing. But is asking this question early in the process even feasible? In less than 50 milliseconds the life and identity of an athlete is turned upside down. With such an injury comes both shock and a grieving process!⁸ Athletes finding themselves again require time – not immediate surgery or definite career decisions. ACL rehab is much more than graft choice, open versus closed kinetic chain exercises, and return to sport at pre-injury level. Psychological recovery and support may be important for athletes who want to return to sport – but what about those who can’t or won’t? They need just as much support. So, more focus and research on these perspectives, please, for the benefit of all athletes! The ligament “fixation” has stolen too much of our attention.

References:
Systematic Review/Meta-Analysis

Platelet-Rich Plasma versus Corticosteroid Injection for the Treatment of Lateral Epicondylitis: A Systematic Review of Systematic Reviews

Jordyn A Kemp, MA, ATC1, Megan A Olson, MA, ATC1, Matthew A Tao, MD2, Christopher J Burcal, PhD, ATC1

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Keywords: corticosteroid injection, elbow epicondylitis, lateral epicondylitis, platelet rich plasma injection, tennis elbow

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Background

Lateral epicondylitis (LE) is one of the most commonly reported musculoskeletal disorders in the upper extremity. The mechanism of LE is repetitive motion that causes a strain of the extensor tendons. This consequently causes pain and tendinosis at the tendinous attachment site on the lateral epicondyle. Most cases of LE are treated nonoperatively with a variety of interventions, such as injections.

Purpose

The aim of this systematic review (SR) is to synthesize the current evidence on the efficacy of platelet rich plasma (PRP) injections versus corticosteroid (CS) injections as treatment interventions for LE.

Study Design

Systematic Review

Methods

Online databases were searched from database inception to February 24th, 2020 for relevant SR's evaluating PRP vs. CS injections as treatment methods for LE. Two independent researchers searched and screened for articles that were systematic reviews that directly compared PRP to CS injections for LE.

Results

A total of five SR's were included in this review that were published between 2016 and 2020. CS injections were more efficacious for short-term pain relief, and PRP injections were more efficacious for long-term pain relief and improved function.

Conclusion

PRP injections appear to be a more effective long-term treatment option than CS injections for those with LE who did not respond to conservative management.

Level of evidence

1

BACKGROUND

Lateral epicondylitis (LE) is one of the most commonly reported non-traumatic musculoskeletal disorders in the upper extremity.1–3 First defined in 1873, Runge proclaimed it “a chronic, symptomatic degradation involving the wrist extensor tendons on their attachment at the lateral epicondyle of the humerus”.4 While debate exists about the exact mechanism for this injury, many researchers believe that it is due to the repetitive motions that cause strain to the origins of the extensor tendons at the lateral epicondyle.5,6 Most commonly affected is the extensor carpi...
radialis brevis (ECRB), but other muscles such as the supinator, extensor carpi radialis longus, extensor digiti- rum, extensor digiti minimi and extensor carpi ulnaris can be involved. The ECRB is particularly susceptible to the tissue degeneration associated with LE given the relative avascularity of the undersurface. Lateral epicondylitis was given the nickname "tennis elbow" due to repetitive arm movements of the extensors and supinators that tennis demands. An estimate of 5-10% of all patients reporting LE actually play tennis, indicating that LE is attributed to additional overuse mechanisms relative to the upper limb, such as playing an instrument, consistent typing or repetitive manual work. The prevalence rates of LE in the general population range from 1-3%, in patients ranging from 30-55 years old. Risk factors for developing LE include increased age, elevated body mass index, oral corticosteroid use, history of smoking, and history of additional tendinopathies such as a rotator cuff disease or De Quervain’s syndrome. The dominant arm is more frequently affected than the non-dominant arm. Most researchers report no gender based differences among the reported cases of LE, but several studies have indicated a slightly higher rate in female patients. Common symptoms of LE are lateral elbow pain, pain with active wrist extension, weakened grip strength, and some report mild disability or disuse of the affected limb. Mild daily activities such as shaking hands, turning door knobs, or grasping objects for a moderate length of time have been known to aggravate symptoms. Although the medical suffix ‘-itis’ implies an ‘inflammation of’, most clinicians agree that LE is a more chronic, degenerative pathology. A failure of normal tendon microtrauma and subsequent repair has been expressed in the histological findings associated with epicondylitis. Histopathologic studies have shown an insufficient amount of inflammatory cells, such as neutrophils or macrophages, in tissue samples, suggesting that the term 'tendinosis' may be more appropriate for this condition.

Current treatments for LE include both nonoperative and operative interventions. Nonoperative methods include rest, bracing, physical therapy, therapeutic ultrasound, extracorporeal shockwave therapy, dry needling, local corticosteroid (CS) injections, interventions of biological agents such as platelet-rich plasma (PRP) and autologous blood (AB), botulinum toxin injections (BT), rest, bracing or acupuncture. Surgical interventions are not commonly utilized, as physicians frequently deem LE a self-limiting injury, and are reserved for patients who have been unresponsive to nonoperative methods for approximately 6-12 months. It has been estimated that approximately 90% of all reported cases can be treated nonoperatively. Surgery typically involves debridement of the ECRB tissue through open, arthroscopic, and percutaneous techniques. Open surgical approaches often use a suture-anchor repair of the ECRB tendon to the lateral epicondy. Other surgical techniques include denervation of the lateral epicondyle, a V-Y slide of the common extensor tendon, extensor fasciotomy, intra-articular repairs, epicondylar resection with anconeus transfer, and lengthening of the extensor tendons. Historically, the injection of choice for LE has been CS injection to target pain relief and improve function and strength due to their anti-inflammatory properties. Most agree that LE is not an inflammatory condition, so the question remains on whether this treatment is optimal and ultimately beneficial. In fact, some believe such intra-tendinous CS injections may be detrimental to the long-term healing process and may compromise the tensile strength of the target tissue. More recently proposed is the use of biologic agents to stimulate the body’s natural healing process on the involved tissue. AB, or whole blood, was first understood to trigger an inflammatory reaction and promote tissue healing with cellular and humoral mediators. Since PRP is derived from the patient’s whole blood, it consists of higher concentrations of platelets and potential healing factors released from alpha and delta granules. Among others, PRP contains transforming growth factor beta (TGF-β) and vascular endothelial growth factor (VEGF), which promote recruitment, proliferation, and differentiation of cells involved in tissue repair and regeneration. Previous systematic reviews (SR’s) have assessed the effects of PRP injections compared to CS injections, and the purpose of this review was to synthesize previous SR results into a systematic review of SR’s evaluating PRP injections compared to CS injections in the treatment of LE.

METHODS

SEARCH STRATEGY

The focus of this review was on previous SR considering the comparison of CS injections to PRP injections as a treatment for LE. The search strategy for this review included articles obtained from the Cochrane Library, ProQuest, and PubMed databases from date of inception to February 24th, 2020. The search key-words include the terms "platelet-rich plasma", "corticosteroid" and "lateral epicondylitis".

INCLUSION AND EXCLUSION CRITERIA

Studies were included from the search if they matched the following criteria: (1) designed as a SR; (2) written in English, (3) involved a direct comparison of CS to PRP for the intervention. Studies were excluded based on the following criteria: (1) involved interventions other than the direct comparison of CS and PRP; (2) grouped PRP into treatments involving AB or whole-blood platelets; (3) used the broad term "regenerative therapies" or "regenerative injections" without specification to what the specific intervention was.

RISK OF BIAS ASSESSMENT

Two authors (JK, MO) independently assessed the risk of bias for each SR. There was no involvement of third-party analysis for the review of sources of bias. Any disagreement was discussed between the two authors until they came to a consensus.

QUALITY ASSESSMENT

Table 1 summarizes A MeaSurement Tool to Assess systematic Reviews 2 (AMSTAR 2) results for each SR article in-
Table 1: Assessment of Multiple Systematic Reviews 2 (AMSTAR 2)

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<th>Arirachakaran et al. 2015</th>
<th>Ben-Nafa et al. 2018</th>
<th>Huang et al. 2019</th>
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<td>Did the research questions and inclusion criteria for the review include the components of PICO?</td>
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<td>Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?</td>
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<td>Did the review authors explain their selection of the study designs for inclusion in the review?</td>
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<td>Yes</td>
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<td>Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?</td>
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<td>Did the review authors report on the sources of funding for the studies included in the review?</td>
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<td>If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?</td>
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<td>If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?</td>
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<td>Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?</td>
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<td>Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?</td>
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Overall Methodological Quality (CL=critically low, L=low, M=moderate, H=high) | H | M | L | H | M

included in this review. The AMSTAR 2 tool is a critical appraisal tool for health professionals to assess the quality of conduct of SR.\textsuperscript{15} Rather than focusing on an overall score, the AMSTAR 2 emphasizes the presence of critical flaws or weaknesses within the critical domains, which may influence the risk of bias.\textsuperscript{15} We also calculated the corrected covered area (CCA) index in order to account for overlap in the included original studies in each individual SR. We calculated and interpreted the CCA using the methods and guidelines suggested by Pieper et al.\textsuperscript{16} In brief, the overlap of original studies identified and included in the individual SRs can be seen in Supplementary Table 1. The CCA represents the % overlap of included original studies compared to a corrected total amount of possible original studies; higher values (≥15%) indicate more significant overlap.\textsuperscript{16,17}
RESULTS

Figure 1 shows the PRISMA flow diagram for the search of the SR. The primary search resulted in 583 articles. After all duplicates were removed, a total of 294 articles were screened. Based on abstract searches, title searches, and filtering for SR, the number of full text articles that qualified were 18. Out of those 18 articles, there were five SR that met the inclusion and exclusion criteria for this review and can be seen in Appendix A.

STUDY DESIGN CHARACTERISTICS OF INCLUDED SYSTEMATIC REVIEWS

All five of the included SR used Medline to search for their included literature. Other common databases that were used among the included SR were: Embase (n=4), Cochrane Library (n=4), Scopus (n=2), and Web of Science (n=2). Several additional databases were searched in the individual studies. The number of databases used ranged from two to 11. These five SR's included a range of five to 20 randomized control trials. Additionally, all of these SR’s evaluated multiple patient reported outcome measures (PRO’s) for the treatment of LE. These PRO’s included the Visual Analogue Scale for pain (VAS) (n=5), Disabilities of Arm, Shoulder and Hand (DASH) (n=5), Pain Pressure Threshold (PPT) (n=2), Patient-Related Tennis Elbow Evaluation (PRTEE) (n=3), modified Nirschl score for pain (MNS) (n=1), and modified MAYO score (MMS) (n=1).

AMSTAR 2 AND CCA RESULTS

The AMSTAR 2 methodological assessment showed varying qualities amongst the five included SR’s. The results indicated two high quality SR, two moderate quality SR, and one low quality SR. All five reviews included a statement of publication bias, a comprehensive literature search, a list of included and excluded studies, scientific evaluation of the quality of the included studies, documentation and evaluation of the specific quality of the included studies, and appropriate methods to assess the data and formulate conclusions. The one study that was low quality lacked an appropriate acknowledgement or assessment of risk of bias during synthesis and discussion. The CCA for all five included SRs was 28.3%, indicating a high amount of overlap among the original included studies.

LATERAL EPICONDYLITIS TREATMENT RESULTS

The main treatment interventions used in all of these SR’s were CS injections in comparison to PRP injections. Two of the studies included a third treatment intervention, sepa-
rately comparing AB to CS and PRP. Four out five studies revealed that CS injections proved beneficial for short-term (2-8 weeks) pain relief and improved function, while PRP injections proved more beneficial for long-term (>8 weeks) pain relief and function.\(^1\)\(^-\)\(^3\),\(^6\),\(^8\) One SR involving AB concluded it was superior to CS in all categories; however, PRP was significantly better than both AB and CS in all categories.\(^3\) Another study involving AB revealed that PRP was the best treatment for reducing pain, whereas AB injection was the best treatment for improving disabilities scores and increasing PPT.\(^8\)

**DISCUSSION**

The purpose of this study was to consolidate current evidence on the effectiveness of PRP injections versus CS injections for the treatment of LE. This study assessed SR to determine the best comparative intervention for treating epicondylitis. This systematic review of SRs conveyed evidence to support the use of PRP injections as an effective, long-term treatment option over CS injections for those with LE. Collectively, all five SR’s assessed pain through VAS and function through DASH scores as primary PRO.\(^1\)\(^-\)\(^3\),\(^6\),\(^8\) Three out of five SR’s evaluated Patient-Related PRTEE scores, providing condition-specific PRO results.\(^1\)\(^-\)\(^3\),\(^6\),\(^8\) The evidence suggests that PRP is more effective than CS long-term in all of the investigated PRO including pain, function, disability, and PPT.\(^1\)\(^-\)\(^3\),\(^6\),\(^8\) In contrast, one study reported that a third intervention, autologous blood (AB), was more effective for improving disabilities scores and increasing pressure threshold within and after two months.\(^8\) Congruence and consistency of results existed among all 5 SR in favor of using PRP injections for optimal long-term outcomes.

This SR aimed to observe the short- and long-term effects of CS injections to PRP injections in the treatment of LE, without specification to the observable outcomes. Many of the studies in this review observed pain (VAS) and function (DASH) as their main outcomes, with few studies focusing on additional outcomes such as strength. One SR yielded results that showed there was no difference in strength between the PRP and CS injection groups before or after the treatment intervention.\(^3\) The reviews included in this SR had minor inconsistencies regarding measurable outcomes, duration of symptoms, and the timing of follow-ups amongst participants. The variability of reported PROs is notable but ultimately does not detract from the overall conclusion of this SR. Evidence regarding the comparison of CS injections to PRP injections can be applied to other overuse injuries that present with impaired function and significant pain.

A major inconsistency in the literature regarding PRP injections is the controversy between factors of the injection, including optimal volume, timing, injection technique, and the quality of the PRP preparations. Amongst the studies in this review, the volume of PRP concentrations range from 1.0-5.0 mL, while some studies stated the amount of autologous blood taken and the time it was centrifuged. Many trials in these studies did not specify the amount of PRP or the concentration relative to resting levels of platelets in the patient’s blood. Previous studies also fail to report whether the plasma sample contains leukocyte-rich or leukocyte-poor PRP formulations. Castillo et al.\(^18\) compared three centrifuge systems and reported significant differences in white blood cell (WBC) and growth factor concentrations in all three samples. These factors could indicate varying amounts of healing factors within different plasma concentrations obtained from different separation systems. Multiple studies reported using centrifuge systems but gives no indication to the concentration of platelets derived from the blood or utilized in the injection. Castillo et al.\(^18\) also reported obtaining similar volumes of PRP from all three of the centrifuge systems studied, despite each system utilizing different volumes of whole blood.

Three techniques seem to be most commonly reported in the reviewed literature for delivering the PRP concentration to the tissue: (1) ultrasound guided injection, in which a clinician injects the most vulnerable or degraded tissue with the injection; (2) peppering, in which the clinician injects small amounts of the PRP concentration in multiple sites around the target tissue to enhance the effects of the PRP; (3) blind injection at the point of maximal tenderness. Future research should aim to resolve such inconsistencies in PRP injections, including the outcomes from different PRP concentrations to observe the minimum amount of platelet concentration required for the desired effects. Creating optimal guidelines for PRP injections would help both clinicians and researchers investigating the effects of PRP injections. Despite the inconsistencies in reporting preparation techniques, injection techniques, and concentrations of PRP, the results remain in favor of PRP as a long-term treatment for LE. Further studies should aim to identify the role that each of these factors play into the efficacy of PRP in the treatment of LE.

Inconsistencies involving CS injections were similar to the previously mentioned inconsistencies of PRP injections. Many of the included SRs contained studies with several different reported CS injections, if not a combination of two CS drugs. Whether there are benefits to an individual CS drug versus a combination of CS drugs is unknown.\(^19\) Additionally, there are several reported injections involving anesthetics as well, aiming to alleviate both the symptoms of LE and the potential pain caused by the injection. The three previously mentioned injection delivery techniques were utilized amongst all the included reviews. Incongruity, or lack of reporting entirely, of the delivery technique was observed in all the included SR. Although the evidence still supports the use of CS for short-term improvements, respectively, a lack of consensus remains on the optimal technique.

Injection therapies such as CS and PRP have several useful properties that are applicable to clinical practice. However, their proposed mechanisms and effects on the tissue differ significantly. Injections containing autologous material such as PRP have been proven to facilitate tissue healing through higher concentrations of growth factors, which promote tissue repair and have a direct influence on angiogenesis and inflammation.\(^2\) The effects of PRP treatments are not observed as acutely when compared to the effects of CS injections, yet, they have a longer duration of pain relief and improved function.\(^1\)\(^-\)\(^3\),\(^6\),\(^8\) The use of CS injections have been identified in literature to provide short-term re-
lief for a multitude of inflammatory pathologies such as bursitis, tendinitis, and osteoarthritis (OA). Some studies have concluded CS injections provide short-term pain relief and slightly improved function, though these effects decrease over time. Furthermore, receiving multiple CS injections may be a risk factor for surgical intervention and possible future surgical revision. Multiple sources discuss the possible deleterious effects that can occur with chronic CS use, which has yet to be observed with PRP injections. Because the underlying pathology of LE is degenerative in nature, PRP injections may provide more benefit due to their potential regenerative properties.

The overall quality of the evidence presented in this SR is moderate-to-high quality based on our assessment of bias using the AMSTAR 2 tool (Table 1). The included reviews all investigated the same interventions of PRP and CS injections. Two out of the five reviews included a third comparative treatment (AB). However, the specific PRP preparation methods and specific CS injection drug type varied across studies. In the reporting process, all of the reviews included in this SR completed a comprehensive literature search, had duplicate selection and data extraction, provided a list of included and excluded studies, used scientific evaluation methods to assess article quality and combine their findings to form conclusions, and evaluated publication bias. Additionally, 80% of the included studies stated the potential conflicts of interest in their reviews. One potential explanation for the consistency in the cumulative findings of all five SR’s comes from the high CCA score, which indicates a high degree of overlap of original studies that were included in the individual SR (Supplementary Table 1). Based on these findings, it appears that the most recent SR on this topic by Tang et al. builds on the findings of Arirachakaran et al. There is also significant overlap between the SR conducted by Li et al. and Huang et al., which is not surprising considering how close together the two are in their search dates.

The evidence evaluated in this SR shows a strong consensus that PRP injections are superior to CS injections for long-term treatment of LE. However, these results have certain limitations. One limitation is the variability of contents and preparation for both PRP and CS injections in all studies. It is important to note that even though certain methodological details were inconsistent across the studies, all 5 reviews yielded similar results. Furthermore, these limitations we have identified are primarily due to reporting practices. Therefore, the authors encourage authors of future clinical trials utilizing injection therapies to include information regarding their injection parameters (e.g. dose, centrifuge time, drug concentrations, injection technique).

CONCLUSION

In conclusion, the results of this systematic review of SR demonstrates that PRP is a superior long-term treatment option for LE when compared to CS, while CS has been proven to create a short-term decrease in pain. Further research should be conducted on specific PRP procedures such as preparation and injection methods, platelet concentrations, and centrifugation time to determine whether certain methodological protocols are more effective than others at decreasing pain and improving function in LE. Furthermore, longer follow-up periods should be used in future research to understand the full extent of the long-term effects of PRP injections, specifically the duration of the effects and if patients require a secondary injection. Based on the evidence presented in these SR’s, PRP is an efficacious long-term treatment option for reducing pain and improving function for patients with LE who have otherwise failed conservative management.

CONFLICT OF INTEREST DISCLOSURE

None of the authors have any conflicts of interest pertinent to this manuscript to disclose.

Submitted: July 09, 2020 CDT, Accepted: February 23, 2021 CDT
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A

Systematic Review/Meta-Analysis

The Efficacy and Treatment Fidelity of Kinesiology Taping in Conjunction With Conservative Treatment Interventions Among Individuals With Shoulder Pain: A Systematic Review with Meta-Analysis

Paul A Salamh, PT, DPT, PhD, William J Hanney, PT, PhD, Christopher S Cory, PT, DPT, Haley E Condon, PT, DPT, Xinliang Liu, PhD, Morey J Kolber, PT, PhD

1 Krannert School of Physical Therapy, University of Indianapolis, 2 School of Kinesiology and Physical Therapy, University of Central Florida, 3 Franciscan Health, 4 Select Physical Therapy, 5 Department of Health Management and Informatics, University of Central Florida, 6 Department of Physical Therapy, Nova Southeastern University

Keywords: shoulder pain, treatment fidelity, kinesiology taping, intervention, conservative care

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Purpose

Kinesiology taping is a common intervention used to treat individuals with shoulder pain. While there have been several studies published to date evaluating the effectiveness of this intervention, a systematic review with meta-analysis synthesizing the collective effectiveness of kinesiology taping is not available. Therefore, the purpose of this study was to perform a systematic review with meta-analysis investigating the efficacy and treatment fidelity of kinesiology taping (KT) in combination with conservative interventions for shoulder pain.

Methods

Databases (PubMed, EMBASE, SportDiscus, CINAHL) of studies published in English meeting criteria were searched to October 2019. Methodologic quality was assessed utilizing the Modified Downs and Black checklist. Treatment fidelity was evaluated using a modified fidelity tool. Random effects meta-analyses were performed when an outcome (disability, pain, range of motion (ROM)) was reported by two or more studies. Overall effect size (pooled random effects) was estimated for studies with acceptable clinical homogeneity.

Results

When KT was used with conservative treatments, meta-analysis revealed large effect sizes for improvements in disability (standard mean difference (SMD) = -1.35; 95% CI, -2.09 to -0.60) and ROM (SMD = 0.96; 95% CI, 0.60-1.33) with no significant effects for pain. The average Modified Downs & Black score for bias was 11.5 ± 3.9. Of 10 retained studies, only two had good treatment fidelity.

Conclusions

Adding KT to interventions performed in clinical settings appears to demonstrate efficacy regarding disability and ROM when compared to conservative interventions alone. However, despite reasonably good methodologic quality, fidelity was lacking in a majority of studies. Because of its impact on the implementation of evidence-based practice, lower fidelity should be considered when interpreting results.

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INTRODUCTION

Shoulder pain affects up to 67% of the adult population throughout their lifespan.1,2 The etiology of shoulder pain is multifactorial and inclusive of various impairments, including but not limited to restricted range of motion (ROM), pain, decreased strength, and impaired motor coordination.3–5 A variety of interventions are utilized in a multimodal approach for treating shoulder pain and dysfunction with the primary focus on restoring pain free shoulder mobility and mitigating ensuing activity restrictions.3–7 In recent years, kinesiology taping (KT) procedures have become increasingly popular. The proposed benefits of KT include providing a tactile cue via the skin to assist or limit movements, modulate pain, and increase microcirculatory flow which is thought to assist in reducing inflammation.8–12 Kinesiology tape refers to various types of elastic adhesive materials applied to joints in order to achieve various therapeutic effects.13,14 In particular, KT is widely utilized to treat impairments of the shoulder due to ease of accessibility and the ability to adapt to various body morphologies. Current evidence investigating the effects of KT on shoulder movement and overall function among both asymptomatic and symptomatic individuals has been contradictory. Some studies have concluded that KT assists in improving shoulder joint mechanics and functional movement, while others suggest KT has no impact on joint position sense and in some cases can even negatively impair joint position sense.9,14–18 Furthermore, KT may impair muscular performance and not be well-tolerated by some individuals.12 Results from other studies have demonstrated that KT has no significant difference when compared to placebo treatment, manual therapy, or different types of tape.12,13 This contradictory evidence makes it difficult to determine the clinical utility of KT for those individuals with shoulder disorders seeking conservative treatment options. Additionally, the treatment fidelity associated with studies investigating the efficacy of KT has not been investigated but is a requisite for the implementation of evidence based clinical practice. Treatment fidelity is utilized in order to ensure that the particular intervention being studied is carried as described in the original protocol of an investigation. Without treatment fidelity it is uncertain as to whether those providing the intervention did so in the same manner each time and also makes it difficult to recreate similar investigations in the future.

Currently, systematic reviews have attempted to synthesize the literature surrounding KT. However, these systematic reviews either focus on musculoskeletal conditions as a whole or a specific shoulder pathology such as neurological conditions and rotator cuff tendinopathy.18–20 A recent systematic review sought to investigate the impact of KT in combination with a therapeutic intervention but focused solely on subacromial pain syndrome (SAPS) and retained only 4 studies which did not allow for any meaningful conclusion to be drawn.21 Given that the combination of applying KT in addition to traditional physical therapy intervention closely mirrors how KT is utilized in a majority of clinic settings, it would appear most relevant to investigate this relationship if our analysis is to offer clinical utility.22–25 Thus, the purpose of this study was to perform a systematic review with meta-analysis investigating the efficacy and treatment fidelity of KT in combination with conservative interventions for shoulder pain. Multi-modal interventions were considered for inclusion as a means of supporting external validity and clinical impact.

METHODS

GUIDELINES

This systematic review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines during the search and reporting phase of the research process. The PRISMA 2009 statement includes a 27-item checklist developed to improve reporting of systematic reviews and meta-analyses.26

LITERATURE SEARCH

An online literature search was conducted utilizing PubMed, EMBASE, SportDiscus and CINAHL from the dates of their origin until October 2019. The search strategy was created and performed by a biomedical librarian. An example of the search strategy used for the PubMed database can be seen in Supplement 1 and similar strategies were utilized for the three remaining databases. This study was registered using the International Prospective Register of Systematic Reviews (PROSPERO) in July 2017 with the corresponding reference number CRD42017074147.

STUDY SELECTION

Appraisal of all titles was performed independently by two authors (CC) and (HC) after the initial online literature search. The abstracts of the retained titles were then reviewed to determine if inclusion criteria were met. Full-text versions of those studies whose abstracts met the inclusion criteria were accessed and read to determine their eligibility for the review. The same two authors undertook the study selection process throughout with discrepancies being decided by an independent author if necessary (no discrepancies were present). The inclusion criteria consisted of: (a) studies where KT was applied to the shoulder complex only; (b) studies including subjects diagnosed with shoulder pathology; (c) studies reporting objective measures of pain and function; and (d) studies comparing KT in conjunction with conservative treatment interventions. In addition, all study designs (including case studies) were included without restrictions on publication date or age of subjects, or duration of symptoms. Studies were excluded if (a) they were not published in the English language or (b) they had a mixed patient population (individuals with other orthopedic and neurological conditions).

DATA EXTRACTION

The data and results from each study selected for review was extracted using a standardized Population, Treatment, Comparison, Outcome and Setting (PICO)S format.27 This format includes the characteristics of the population studied, treatments performed, comparative treatments, pri-
mary and secondary outcomes, and the setting in which the data was collected. Data was extracted, analyzed and reviewed by two authors (PS) and (HC). A single author (PS) extracted data and this was verified by a second author (HC). No discrepancies were identified between authors.

METHODOLOGICAL QUALITY TOOL

The Modified Downs and Black checklist was used to evaluate methodological quality within the individual studies.38 The Downs and Black checklist in its original format contains 26 items and has been shown to be a valid and reliable measure of methodological quality for randomized and nonrandomized studies.28 Given that various study designs were present among those articles retained for review, the authors chose to utilize a modified version of the Downs and Black checklist. The Modified Downs and Black checklist has been widely utilized to assess methodological quality.29–32 Six sections are present as part of the modified checklist and include patient selection bias (items 1–4), comparison (item 5), outcomes (items 6–8), reporting findings/statistical analysis (items 9–11), confounding (12 & 15), and power (items 14 & 15). Each item within the Downs and Black tool corresponds to a question and answered either yes (Y), no (N), or unable to determine (U). The maximum score for the checklist is 16 with all individual items rated as either yes (= 1) or no/unable to determine (= 0) except for item 12 that may be rated as yes (= 2), partially (= 1), or no/unable to determine (= 0). Two authors (PS) and (CC) independently scored the retained articles for methodological quality. Discrepancies were handled through discussion to reach a consensus.

TREATMENT FIDELITY ASSESSMENT

Treatment fidelity assessments were performed to determine if the studies included in this review followed appropriate procedures to ensure that valid comparisons of replicable interventions were being executed.33–35 We chose to assess treatment fidelity by utilizing a modified version of a tool developed by Borelli et al.36 The original scale was appropriate for psychological interventions, which contained domains that are outside the scope of clinical interventions. A modified version of the tool was utilized to identify the 11 items that represented the essential items pertaining to a study investigating clinical interventions and not phycological interventions. Although this modified scale has not been validated, it has been utilized by others in similar reviews to examine treatment fidelity.37,38 Items are scored as 0 (not present), 1 (minimally described), or 2 (more than minimally described). Scores were recorded as both the summary (number present, maximum possible score 11) and total score (maximum possible 22) and were determined by a single author (PS), a researcher with a clinical background in musculoskeletal orthopaedics and experience in fidelity scoring. We identified item summaries > 6 and total scores ≥ 12 as studies that exhibited good treatment fidelity. These scores are based on prior investigations in this area and less likely to misrepresent the actual effect of the treatment provided in any given study.38

DATA SYNTHESIS AND ANALYSIS

The mean and standard deviation in the outcome variables of pain, disability, and ROM preintervention and postintervention, as well as sample sizes for the experimental and control groups were extracted. The assessments administered at the end of the intervention or closest to one-month post intervention were used in the meta-analysis. Effect sizes based on standard mean differences (SMDs) were calculated for each outcome variable. When not provided, the standard deviation of the change score was computed from the standard deviations of the pre-post scores, using a correlation of 0.50.39 Studies were grouped by the comparison category (e.g., kinesiology taping plus exercise vs. exercise only). Random effects meta-analyses were performed for each subgroup of studies to examine an outcome variable when an outcome was reported by two or more studies. A pooled random-effects estimate of the overall effect size was estimated for all studies with acceptable clinical homogeneity. For pain and disability scales (the numeric pain rating scale (NPRS) and visual analog scale (VAS) for pain, Disability of Arm and Shoulder Questionnaire (DASH), and Shoulder Pain and Disability Index (SPADI)), higher scores indicate greater pain or disability. By contrast, higher scores reflect higher quality of shoulder function in the Constant score. Therefore, the direction of Constant score was reversed when pooled with other disability scales. For an increase in ROM, a positive effect size favors the experimental group over the control group. The effect size of the interventions was categorized into one of the three levels based on SMD (<0.40 = small, 0.40 to 0.70 = moderate, >0.70 = large).37

The presence of heterogeneity was evaluated using the Q statistic after the meta-analysis.39,40 The Q statistic follows a chi-squared distribution with n-1 degrees of freedom. A small p-value (p<0.05) for the Q statistic indicates that heterogeneity is present, and the meta-analysis model has some unaccounted-for bias. All meta-analyses were conducted in Stata (version 12.1) statistical software (StataCorp, College Station, TX) and the metan command. All data analysis was performed by (XL), an academician with a specialty in biostatistics and health informatics.

RESULTS

SEARCH STRATEGY

Database searches yielded 618 independent study titles, resulting in 357 after duplicates were removed. After a title and abstract search, 345 studies were removed because they did not meet the a priori inclusion/exclusion criteria. After review of the full-text studies, 10 were ultimately retained for analysis (Figure 1).22,23,25,41–47 Study characteristics for each of the 10 included studies are included in the PICOS table (Appendix A).

METHODOLOGICAL QUALITY

Methodological quality assessment revealed a range of values (Table 1). Of a 15 total item maximum and 16 total possible points, the average score was 11.5 ± 3.9 (median 12,
range 2-16). Only one of the 10 studies retained for analysis contained elements for each item resulting in a score of 16.\textsuperscript{42} There was one study that demonstrated a low quality and received a total score of 2.\textsuperscript{41} The remaining studies received a total score of 10 or greater.\textsuperscript{22,23,25,43–47} Although there are no validated cut points for what constitutes a good, fair, or poor score for methodological quality as identified by the modified Downs and Black Checklist, most of the retained studies received a score greater than half of the total possible score. Item 7 (Were the main outcome measures used accurate (valid and reliable)? Accuracy not reported but method clearly described) was scored as yes in only two of the retained studies.\textsuperscript{42,46}

**TREATMENT FIDELITY**

Treatment fidelity assessments produced a wide value range (Table 2). Out of a maximum of 11 items and 22 total points, the average items identified were 7 ± 1.9 (median 7.5, range 3-9) and the total score average was 9.4 ± 3.0 (median 10.5, range 3-13). No individual study had all of the items represented; items 3 (If more than one intervention is described, are they all described equally well?) and 6 (Characteristics to be sought and avoided by treatment provider are addressed a priori, make some mention of credentials) were identified in all studies and item 15 (Were non-specific treatment effects evaluated) was not identified in any of the studies. While no validated cut-off exists for this tool, using our criteria, two studies\textsuperscript{25,46} had item scores ≥ 6 and total scores ≥ 12; these studies were independently identified as good treatment fidelity.

**META-ANALYSIS**

Of ten studies retained in this systematic review,\textsuperscript{22,23,25,41–47} all but one\textsuperscript{41} provided sufficient data to be included and pooled in the meta-analysis. One study\textsuperscript{41} did not report standard deviation information for baseline and post-intervention assessments and was excluded from the meta-analysis. Figures 2-4 represent the meta-analyses for pain, disability, and ROM outcomes, respectively.

**Pain meta-analysis.** Seven studies\textsuperscript{25,42–47} investigating pain outcomes compared KT with exercise to other interventions. One study compared the addition of KT and exercise to non-steroidal anti-inflammatory drugs (NSAIDs)\textsuperscript{45} vs. a comparator treatment that did not include KT. One study\textsuperscript{42} utilized the NPRS while the remaining studies\textsuperscript{25,43–47} utilized the VAS. Five subgroups were analyzed depending on the intervention comparisons. The overall meta-analysis for comparing KT to no KT or sham KT for pain resulted in a small effect size in favor of the experimental group, but the difference was not statistically sig-

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**Figure 1: PRISMA flow diagram outlining study selection process**
nificant (SMD = -0.16; 95% CI, -0.40 - 0.08). Significant heterogeneity was present among the included studies (homogeneity statistic Q = 42.92; df = 14; p < 0.001), indicating that the variability in the SMD values were greater than that expected by sampling error alone (Figure 2).
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1=yes, 0=no/unsure, (item 12 scoring only; 2=yes, 1=unsure, 0=no). Criteria 1-15, per the Modified Downes and Black Checklist.
Figure size (SMD = 0.96; 95% CI, 0.60 - 1.33) in favor of the experimental group. The homogeneity statistic Q= 303.18 (df = 29, p<0.001) indicated significant heterogeneity among the included studies, and the variability in the SMD values were greater than that expected by sampling error alone (Figure 4).

**DISCUSSION**

The aim of this study was to perform a systematic review and meta-analysis of the current literature to determine the efficacy and treatment fidelity related to the application of KT on the shoulder complex in conjunction with conservative treatment interventions within a symptomatic population. Within this review, KT was paired with various interventions in order to best mirror how KT is currently utilized in the clinical setting and was compared to other standard practices seen in the treatment of patients with shoulder pathology. Essentially, clinical practice often dictates multi-modal approaches to care, thus adding KT to conservative care would offer improved clinical translation.

All but one study41 scored greater than or equal to 10/16 on the modified Downs and Black checklist. The majority of studies included in this systematic review described a

### Table 2: Fidelity Scoring

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0 = not present; 1 = minimally described; 2 = more than minimally described

Key to Fidelity criteria:
1. Is there information about treatment dose in the intervention condition?
2. Is there information about treatment dose in the control/comparison condition?
3. If more than one intervention is described, are they all described equally well?
4. Method to ensure dose is equivalent between conditions.
5. Method to ensure dose is equivalent within conditions.
6. Characteristics to be sought and avoided by treatment provider are addressed a priori, make some mention of credentials.
7. Is there mention of a theoretical model or clinical guidelines upon which the intervention is based?
8. Do the authors indicate how providers were trained? Do the authors indicate that provider training was standardized?
9. Was there a method to ensure that the content of the intervention was being delivered as specified?
10. Was there a method to ensure that the dose of the intervention was being delivered as specified?
11. Were non-specific treatment effects evaluated.

Disability meta-analysis. Seven studies23,25,42–44,46,47 assessing disability were included that compared KT in addition to exercise (as well as manual therapy and high-intensity laser therapy in a single study25) versus a comparator treatment that did not include KT. Two studies42,47 utilized the Constant score, four studies23,25,46 utilized the SPADI, and two studies44,47 utilized the DASH. The overall meta-analysis for disability and function resulted in a large and statistically significant effect size (SMD = -1.35; 95% CI, -2.09 to -0.60) in favor of the experimental group. The homogeneity statistic Q= 121.35 (df = 9, p<0.001) indicated significant heterogeneity among the included studies, and the variability in the SMD values were greater than that expected by sampling error alone (Figure 3).

ROM meta-analysis. Seven studies22,23,25,43,45–47 assessing ROM outcomes were included that compared KT in addition to other conservative treatment with comparator treatments that did not include KT. Two studies23,25 measured shoulder external rotation (ER), abduction (ABD), and flexion and the remaining studies43,45–47 measured shoulder internal rotation (IR), ER, ABD, and flexion. The meta-analysis revealed a large and statistically significant effect size (SMD = 0.96; 95% CI, 0.60 - 1.35) in favor of the experimental group.
patient population similar to that which is typically seen in the clinical setting with their characteristics clearly described, adding to the clinical utility of this review. All studies utilized a comparison group, which allowed comparison of kinesiology taping to commonly-used intervention strategies such as therapeutic exercise,22,23,25,42–45,47 manual therapy techniques,22,41,44 injections,43,46 and NSAIDs.45 These studies appeared to demonstrate clinical utility and ease of transference to practice; however, there appears to be lower methodological quality and questionable validity and reliability of outcomes measured. Only two studies42,46 clearly described the accuracy and reliability of the outcomes used; four studies22,42,43,47 clearly demonstrated appropriate adjustment for confounding variables; and only half of the studies22,23,42–44,47 had sufficient power to determine a clinically important effect. While the populations and treatments resemble those commonly seen in the clinic, the included studies may lack the internal validity needed to accurately assess the use of KT in place of interventions that are already supported by literature and currently utilized in practice.

Attention to the critical aspects of treatment fidelity underpins the validity of clinical research and is a prerequisite for the implementation of evidence-based clinical practice. Despite the importance of treatment fidelity, it is an often-neglected component of intervention. To our knowledge, this is the first study to evaluate treatment fidelity of clinical KT interventions. Only two studies25,46 were identified to have good treatment fidelity based on the criteria set forth.38 These results suggest the majority of studies included in this review could have been influenced by factors such as a lack of researcher training, lack of adherence to protocols, or interventions not performed as specified. Lack of treatment fidelity could also help to explain why results of studies investigating similar interventions may produce different results.35 This is important to note, especially when considering the use of KT in place of a more invasive or higher cost treatment, such as receiving injections or the prescription of NSAIDs. For example, Goksu et al.43 reported significant improvements after either injections or KT for shoulder impingement patients, although this study demonstrated a lack of treatment fidelity. In comparison, Subasi et al.46 had similar findings but demonstrated increased adherence to items associated with treatment fidelity; therefore, KT may be favored as a less invasive clinical treatment. Treatment fidelity should be considered when comparing outcomes of different studies utilizing similar interventions.

The meta-analysis revealed a large effect size for both disability and ROM favoring the experimental group and a
small, statistically insignificant effect size for pain in favor of the experimental group. Although the meta-analysis favors the experimental group for both disability and ROM, these findings must be considered in the presence of both the methodological quality and treatment fidelity of the included studies. Of those studies investigating the effect of KT and other conservative treatment on disability as well as ROM, only two studies\textsuperscript{25,46} had a treatment fidelity score considered to be "good." Furthermore, of the 10 studies retained for analysis, only four\textsuperscript{22,25,41,47} demonstrated a significant between-group improvement when compared to the paired intervention alone considering their chosen outcome measures. One of these studies\textsuperscript{41} had the lowest scores of both methodologic quality and treatment fidelity among those included.

The findings of these studies, even in the context of this review, cannot be interpreted alone without methodological quality and treatment fidelity being considered. When fundamental limitations in treatment fidelity exist such as those found among a majority of the retained studies; lack of reported clinician training, lack of adherence to protocols, and interventions not performed as specified, the validity of the findings may be questioned. Adhering to and appropriately reporting elements related to treatment fidelity are necessary to maintain the integrity of intervention-based research.

**LIMITATIONS**

There are limitations to this study, such as the inclusion of only those studies published in the English language. The authors also did not include a search of the grey literature as the content area being investigated with this type of search would not produce results beyond our current search given the search strategy initially implemented. Methodological quality was assessed utilizing the Modified Downs and Black Assessment Tool, which requires categorization of sub-elements within each study based on the assessor’s determination, which could introduce bias. However, this was minimized by having two authors independently score each of the retained studies and discuss any discrepancies. The same limitation may also be considered regarding the assessment of treatment fidelity. Finally, the tool we utilized to evaluate treatment fidelity has not been validated in the modified form.
Although the addition of KT to conservative interventions may demonstrate some efficacy with regard to disability and ROM when compared to conservative interventions alone, these findings must be considered in light of the quality and treatment fidelity associated with these studies. A majority of the identified studies demonstrate fair methodologic quality; however, there were limitations surrounding treatment fidelity. Treatment fidelity is paramount to the implementation of evidence-based practice; thus, limited fidelity may in fact be of greater clinical value than quantitative changes when interpreting the result. Clinicians should consider these findings when determining if KT would be an appropriate adjunct in the treatment of those individuals presenting with shoulder pathology. Future studies on KT that adhere to the attributes of treatment fidelity may serve to reduce variability of results and provide a more practical outcome that can be replicated in the clinic.

ACKNOWLEDGEMENTS
Leila Ledbetter

CONFLICTS OF INTERESTS
The authors report no conflicts of interest.

Submitted: August 06, 2020 CDT, Accepted: November 26, 2020 CDT
REFERENCES


SUPPLEMENTARY MATERIALS

Supplement 1

Appendix A
Reliability and Validity of the Functional Movement Screen™ with a Modified Scoring System for Young Adults with Low Back Pain

Khalid Alkhathami, PT, PhD1, Yousef Alshehre, PT, PhD2, Sharon Wang-Price, PT, PhD, OCS, FAAOMPT3, Kelli Brizzolara, PT, PhD, OSC3

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Keywords: interrater reliability, intra-rater reliability, construct validity, lumbar spine, movement impairments movement system

Background
Low back pain (LBP) is one of the most common complaints in individuals who seek medical care and is a leading cause of movement impairments. The Functional Movement Screen (FMS™) was developed to evaluate neuromuscular impairments during movement. However, the reliability and validity of the FMS™ have not yet been established for the LBP population because of a limitation of its original scoring system.

Purpose
The purposes of this study were to determine the reliability and validity of the FMS™ with a modified scoring system in young adults with and without LBP. The FMS™ scores were modified by assigning a zero score only when there was an increase in LBP during the FMS™, not simply for the presence of pain, as in the original FMS™ scoring system.

Study Design
Reliability and validity study.

Methods
Twenty-two participants with LBP (8 males and 14 females, 26.7 ± 4.68 years old) and 22 age- and gender-matched participants without LBP (26.64 ± 4.20 years old) completed the study. Each participant performed the FMS™ once while being scored simultaneously and independently by two investigators. In addition, each participant’s FMS™ performance was video-recorded and then was scored by another two investigators separately. The video-recorded performance also was scored twice six weeks apart by the same investigator to determine intra-rater reliability.

Results
The results showed excellent inter-rater and intra-rater reliability of the FMS™ composite score with intraclass correlation coefficients ranging from 0.93 to 0.99 for both groups. In addition, the LBP group scored significantly lower than the group without LBP ($p = 0.008$).

Conclusions
The results indicate that the FMS™ is able to distinguish between individuals with and without LBP, and that it could be a useful test for clinicians to quantify movement quality and to assess movement restrictions in individuals with LBP.

Levels of Evidence
2b.

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INTRODUCTION

Low back pain (LBP) is a musculoskeletal disorder that affects more than 80% of people at least once in their lifetime. LBP is considered one of the most common complaints prompting individuals to seek medical care. The total direct and indirect medical spending for LBP is estimated to be between $100 and $200 billion a year. Although a large proportion of individuals who experience an acute episode of LBP experience rapid improvement, the condition is often associated with high recurrence rates. In people with LBP, the behavior of fear-avoidance related to LBP and the presence of pain may cause patients to attempt to reduce pain by restricting motions of the spine. In addition to subjective pain complaints, aberrant movement patterns such as painful arc, lateral shifting, or Gower’s sign are commonly observed in this patient population. Furthermore, these aberrant movements have been associated with lumbar instability as a result of passive supportive structural lesions and/or lack of muscle control. Although aberrant movements can be detected and quantified using imaging, there is no consensus regarding an objective clinical test for quantifying the severity of the abnormal movement patterns in LBP.

The Functional Movement Screen (FMS™) was developed to assess functional performance by identifying restrictions and compensations of movement patterns. The FMS™ consists of seven component tests, and each test is scored on a scale of 0 to 3, with the total composite score ranging from 0 to 21 points. FMS™ scores less than or equal to 14 have been found to be associated with a higher risk of musculoskeletal injury among firefighters, football players, and female collegiate athletes. Additionally, rowers with lower FMS™ scores had a high risk of injury and a higher likelihood of developing LBP. Furthermore, people with chronic pain demonstrated a lower FMS™ composite score as compared to healthy controls.

The reliability of the FMS™ has been established in different healthy populations. The inter-rater reliability of FMS™ composite scores in these studies ranges from good (ICC = 0.76) to excellent (ICC = 0.98). In addition, the standard error of measurement (SEM) was found to be 0.92 points, and the minimum detectable change (MDC) was 2.54 points on the 21-point scale. However, these reliability variables were established from physically active populations, such as active-duty service members and athletes. Therefore, these results may not be applied to a general population or a patient population.

The inter-rater reliability and intra-rater reliability of the FMS™ test have been studied in individuals with LBP by Ko et al., using its original scoring system, in which a zero score is assigned when there is presence of pain, regardless of the severity of the pain level. However, Ko et al. did not describe whether or not their patient participants had LBP at the time of testing (baseline). It is likely that some of their participants did not have LBP at baseline testing, because if they did, their FMS™ scores would have been zero. Therefore, it is necessary to modify the original scoring system, as it would underscore severely for those participants who perform movements in proper form but have zero scores simply because they have existing LBP at baseline. In this modified scoring system, a zero score is given only when the participant reports an increase in LBP. Subsequently, when pain intensity does not change during a movement test, it indicates that the movement is performed properly, whereas when there is an increase pain from the baseline during a movement test, it is indicative of an abnormal movement pattern. Therefore, the purposes of this study were to determine inter-rater and intra-rater reliability and construct validity of the FMS™ with a modified scoring system in young adults with and without LBP.

METHODS

STUDY DESIGN

This study is a repeated measure study of the FMS™ with a modified scoring system. In order to determine the inter-rater reliability, two raters scored the same participant simultaneously in real time, and two additional raters scored the same participant independently by reviewing video-recorded sessions. Further, the video-recorded performance was scored twice six weeks apart by the same investigator to determine intra-rater reliability. The construct validity was determined using the known-groups method by comparing the modified FMS™ scores between the participants with and without LBP. Prior to data collection, this study was approved by the Institutional Review Board of Texas Woman's University.

PARTICIPANTS

Using G*Power version 3.1, an a priori power analysis was performed to calculate the sample size needed to detect a significant difference between participants with and without LBP. A total of 44 participants, 22 for each group were needed to achieve a power of 0.80 using an α of 0.05 and an effect size of 0.80. The effect size of 0.80 was chosen based on the findings of a previous FMS™ study in an LBP population.

A convenience sample of the participants for the study was recruited from local communities. The eligible participants were young adults between 18 and 40 years of age. In addition, the eligible participants for the LBP group were young adults who experienced repeated episodes of persistent or recurrent LBP in the past year and were not receiving care at the time of the study from a physician or other practitioners, such as a physical therapist or chiropractor. The asymptomatic participants, the group without LBP, were young adults who did not have current LBP and had not had any episode of LBP in the previous year. Participants in both groups were excluded from the study if they had any of the following conditions which might affect the performance of the FMS™: (1) previous surgery to the lumbar spine or abdomen, (2) current pregnancy, (3) any neurological symptoms in the lower extremities, or (4) any congenital abnormality in the lumbar spine.

RATERS

Four investigators scored the FMS™ test with the modified scoring system for each participant in this study. Prior to data collection, all investigators were required to read the
FMS™ manual and to watch FMS™ videos at least once in order to be familiar with each test of the FMS™. Additionally, before data collection began, all investigators practiced the FMS™ for three hours using the modified scoring system, with the principal investigator (KA) who is a certified in FMS™.

INSTRUMENTATION

FUNCTIONAL MOVEMENT SCREEN

The Functional Movement Screen™ kit (Functional Movement Systems Inc., Chatham, VA), consisting of a two-inch by six-inch board, one four-foot-long dowel, two short dowels, and an elastic cord, was used to administer the FMS™.10 The FMS™ includes seven movement tests: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight-leg-raise, trunk stability push-up, and rotary stability.10 In addition, there are three clearance screens (impingement-clearing test, press-up clearing test, and posterior-rocking clearing test), which are used to determine if the participants have pain associated with internal rotation and flexion of the shoulder, spinal flexion, and spinal extension, respectively.10,11 Three FMS™ test components are associated with a clearance screen: the shoulder mobility task with the impingement clearance screen, the push-up test with the press-up clearance screen, and the rotator stability test with the posterior rocking clearance screen. However, because this study focused on LBP population, the impingement-clearing test was excluded because it is not related to LBP area and the other two clearing tests (press-up clearing test and posterior-rocking clearing test) were included in this study. In the original scoring system, each FMS™ test is scored on a four-point scale: 5 if the movement task is performed perfectly without compensations, 2 if completion of the task requires compensatory movements, 1 if the participant is unable to perform the movement as required, or 0 if a participant feels pain during the movement task.10 However, for the purpose of this study, the FMS™ scores were modified so that a zero score was given only if the participants reported an increase in LBP rather than simply for the presence of pain. The total composite score ranging from 0 to 21 was calculated for analysis.10

DIGITAL VIDEO CAMERAS

Two digital video cameras (Nikon, Sendai, Japan) were used to record the participant’s performance on all of the FMS™ test components. The cameras were positioned to obtain the frontal and sagittal views of each participant from a distance of approximately 10 feet.

PROCEDURES

Participants who met inclusion criteria were informed of the risks and the procedures of the study, and then signed an informed consent form if they agreed to participate. After consent was obtained, the demographic characteristics (i.e., age, sex, height, weight, leg dominance) of each participant were collected, followed by a physical examination to determine the eligibility of the participant. Next, participants with LBP were asked to rate their current pain using the Numeric Pain Rating Scale (NPRS) and to complete the Modified Oswestry Low Back Pain Disability Questionnaire (OSW) to determine their disability level. Both the NPRS and OSW have been shown to be reliable and valid measurements for LBP.25–26

Next, each participant performed the seven tests of the FMS™ in the same order as described in Cook et al.’s studies.10,11 The two cameras were used to record the entire FMS™ testing session, and the two investigators (Rater 1 and Rater 2) were responsible for video recording. Another two investigators (Rater 3 and Rater 4) independently scored the FMS™ test in real time in order to determine intra-rater reliability. One of these two investigators was responsible for the verbal instructions required for performing the FMS™, while the other investigator was responsible for the demonstration of each test of the FMS™. The verbal instructions and demonstration were repeated if necessary. The participants were asked to rate their pain level using the NPRS before each of the FMS™ tests. This pain score was used as baseline to monitor changes of pain level during and after each test. Participants performed three trials for each of the seven FMS™ tests, and the best score from the three trials was recorded. In addition, each participant performed two clearance screens, namely the press-up clearing screen after the push-up test and the posterior-rocking clearing screen after the rotator stability test. The clearance screens were graded as negative or positive. For example, if a participant had no pain or if the pain level was the same as that at the baseline, the clearance screen was considered negative. Conversely, if there was an increase in pain, the clearance screen was considered positive and the associated FMS™ test was scored zero. Five of the seven FMS™ tests (hurdle step, in-line lunge, shoulder mobility, active straight-leg-raise, and rotary stability test) were performed on both sides, first on the participant’s right side first and then on the left. For the FMS™ tests that were scored on both limbs, the lower score was used to compute the composite score. The scores from the seven FMS™ tests were added together to get a composite score. Later, the two investigators (Rater 1 and Rater 2) who were responsible for video-recording scored the FMS™ tests independently while viewing the video-recorded sessions. To determine intra-rater reliability, two raters scored each participant separately through watching the video-recording at two separate times, six-weeks apart.27 Participants were asked whether or not pain increased throughout the FMS™ testing and video-recording, so that the Rater 1 and Rater 2 could score it accordingly when viewing the videos later.

STATISTICAL METHODS

The collected data was analyzed using IBM SPSS Version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including mean and standard deviation (SD), were used to describe the participants’ demographic characteristics, NPRS scores, OSW scores, and FMS™ composite scores. An independent t-test was used to compare the demographic characteristics between the participants with and without LBP. Inter-rater reliabilities were assessed by using model 2 form k intraclass correlation coefficients (ICC_{kk}) with a 95% confidence interval (CI) for each group.28 Intra-rater reliability
Table 1: Participants’ Characteristics for the Low Back Pain and Asymptomatic Groups

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<td>26.73 ± 4.68</td>
<td>26.64 ± 4.20</td>
<td>0.946</td>
</tr>
<tr>
<td>Gender</td>
<td>8 men; 14 women</td>
<td>8 men; 14 women</td>
<td>1.000</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 ± 0.06</td>
<td>1.71 ± 0.07</td>
<td>0.826</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.08 ± 18.47</td>
<td>66.31 ± 8.73</td>
<td>0.193</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.57 ± 5.63</td>
<td>22.51 ± 1.95</td>
<td>0.113</td>
</tr>
<tr>
<td>NPRS (0-10)</td>
<td>2.82 ± 1.01</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>OSW (%)</td>
<td>12.27 ± 7.38</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Modified FMS™ (0-21)</td>
<td>14.07 ± 2.80</td>
<td>16.16 ± 2.08</td>
<td>0.008</td>
</tr>
</tbody>
</table>

BMI= body mass index; FMS™= functional movement screen; n= sample size; NPRS= numeric pain rating scale; OSW= modified Oswestry low back pain disability questionnaire.

Table 2: Participants’ Characteristics for Intra-rater Reliability Analysis.

<table>
<thead>
<tr>
<th>Variables</th>
<th>LBP Group (n = 12)</th>
<th>Asymptomatic Group (n = 12)</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>26.08 ± 4.03</td>
<td>25.33 ± 2.99</td>
<td>0.610</td>
</tr>
<tr>
<td>Gender</td>
<td>3 men; 9 women</td>
<td>4 men; 8 women</td>
<td>0.653</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.73 ± 0.05</td>
<td>1.70 ± 0.08</td>
<td>0.245</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.31 ±16.64</td>
<td>65.85 ±9.25</td>
<td>0.426</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.26 ± 4.67</td>
<td>22.66 ±2.13</td>
<td>0.692</td>
</tr>
</tbody>
</table>

BMI= body mass index; LBP= low back pain.

*Independent t-tests for ratio data and chi-square tests for categorical data.

RESULTS

All of the 44 participants who met the inclusion criteria completed the study. The characteristics of the 44 participants, 22 (8 men, 14 women) in each group, are displayed in Table 1. There were no significant differences in the participant characteristics (i.e., gender, age, height, weight, and body mass index) between individuals with and without LBP.

In addition, 22 of 44 participants were video-recorded. The characteristics of these 22 participants are shown in Table 2. Similarly, there were no significant differences in the participant characteristics between the video-recorded participants with LBP and those without LBP.

Table 3 illustrates the means and standard deviations of the modified FMS™ composite score and each test component scores for each group. Table 4 shows the means, SDs, and range of the FMS™ total composite score for each rater. The inter-rater reliability results and the 95% CI for the FMS™ composite scores are shown in Table 5. Overall, the inter-rater reliability and intra-rater reliability were excellent for the modified FMS™ composite scores collected in real-time, via watching videos, and in real-time vs. via watching videos for each group. In addition, participants with LBP had significantly lower modified FMS™ composite scores as compared to the asymptomatic group (LBP group: 14.07 ± 2.80 points, asymptomatic group: 16.16 ± 2.08 points, p = 0.008).

DISCUSSION

The results of this study showed good-to-excellent intra-rater reliability and inter-rater reliability using the modified FMS™ scoring system for both groups when the scores were collected in real time. These results are consistent with what has been reported in previous studies for the asyp-
Table 3: Mean and Standard Deviation of the Modified Functional Movement Screen Scores for both Low Back Pain and Asymptomatic Groups. Reported as score ± SD.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Low Back Pain Group (n=22)</th>
<th>Asymptomatic Group (n=22)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep squat</td>
<td>1.9 ± 1.0</td>
<td>2.5 ± 0.6</td>
<td>0.033*</td>
</tr>
<tr>
<td>Hurdle step</td>
<td>2.2 ± 0.7</td>
<td>2.3 ± 0.5</td>
<td>0.813</td>
</tr>
<tr>
<td>In-line lunge</td>
<td>2.5 ± 0.9</td>
<td>2.6 ± 0.5</td>
<td>0.774</td>
</tr>
<tr>
<td>Shoulder mobility</td>
<td>2.5 ± 0.7</td>
<td>2.5 ± 0.7</td>
<td>0.881</td>
</tr>
<tr>
<td>Active straight leg raise</td>
<td>2.0 ± 1.0</td>
<td>2.5 ± 0.5</td>
<td>0.158</td>
</tr>
<tr>
<td>Trunk stability push-up</td>
<td>1.3 ± 1.2</td>
<td>2.0 ± 1.0</td>
<td>0.037*</td>
</tr>
<tr>
<td>Rotary stability</td>
<td>1.7 ± 0.7</td>
<td>1.8 ± 0.4</td>
<td>0.847</td>
</tr>
<tr>
<td>Total score (0-21)</td>
<td>14.1 ± 2.8</td>
<td>16.2 ± 2.1</td>
<td>0.008*</td>
</tr>
</tbody>
</table>

*pStatistically significantly different at p < 0.05.

Table 4: The Modified Composite Scores of the Functional Movement Screen for Both Low Back Pain and Asymptomatic Groups. Reported as mean ± SD

<table>
<thead>
<tr>
<th>Rater</th>
<th>LBP Group</th>
<th>Range</th>
<th>Asymptomatic Group</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>(Min -Max)</td>
<td>n</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Rater 1 (real-time)</td>
<td>14.1 ± 2.8</td>
<td>9 - 18</td>
<td>22</td>
<td>16.2 ± 2.1</td>
</tr>
<tr>
<td>Rater 2 (real-time)</td>
<td>14.0 ± 2.8</td>
<td>8 - 18</td>
<td>22</td>
<td>16.1 ± 2.1</td>
</tr>
<tr>
<td>Rater 3A* (video)</td>
<td>14.3 ± 2.1</td>
<td>11 - 17</td>
<td>12</td>
<td>16.4 ± 2.1</td>
</tr>
<tr>
<td>Rater 4 (video)</td>
<td>13.9 ± 2.4</td>
<td>10 - 18</td>
<td>12</td>
<td>16.2 ± 2.0</td>
</tr>
<tr>
<td>Rater 3B* (video)</td>
<td>14.4 ± 2.4</td>
<td>11 - 18</td>
<td>12</td>
<td>16.3 ± 1.8</td>
</tr>
</tbody>
</table>

LBP= low back pain; SD= standard deviation.

*3A and 3B were performed 6 weeks apart.

Table 5: Intraclass Correlation Coefficient (ICC), Standard Errors of Measurement (SEM), and Minimal Detectable Change (MDC) Values for Inter-rater and Intra-rater Reliability of the Modified Functional Movement Screen.

<table>
<thead>
<tr>
<th>Reliability Type</th>
<th>Low Back Pain Group</th>
<th>Asymptomatic Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC [95%CI]</td>
<td>SEM</td>
</tr>
<tr>
<td>Inter-rater (real-time)</td>
<td>0.99 [0.98, 0.99]</td>
<td>0.38</td>
</tr>
<tr>
<td>Inter-rater (video)</td>
<td>0.94 [0.70, 0.98]</td>
<td>0.58</td>
</tr>
<tr>
<td>Inter-rater (real-time vs. video)</td>
<td>0.98 [0.42, 0.99]</td>
<td>0.35</td>
</tr>
<tr>
<td>Intra-rater (video vs. video)</td>
<td>0.98 [0.93, 0.99]</td>
<td>0.33</td>
</tr>
</tbody>
</table>

CI= confidence interval; MDC95= minimal detectable change at the 95% level of confidence.

tomatic group, such as in Onate et al.‘s study29 (ICC = 0.98) and Parenteau-G et al.‘s study27 (ICC = 0.96) in, which the inter-rater reliability was examined on a young active population by using two raters and the real-time method for scoring.27,29 Excellent inter-rater reliability (ICC = 0.97) was also found in a study in which physically active individuals aged between 18 and 40 years were examined.30 Similar to this current study, only two investigators performed scoring in real time. On the contrary, Teyhen et al.20 reported a fair inter-rater reliability (ICC = 0.76) of the FMS™ for an active young population. The conflicting results could be due to the use of eight raters in the study by Teyhen et al., thus increasing variance among the raters, and therefore, resulting in a lower ICC value.31

In addition, when using the video-recording method, the intra-rater and inter-rater reliability of the FMS™ composite score was excellent for both groups. Leeder et al.32 reported a high inter-rater reliability (ICC = 0.90) of the FMS™ scores among 20 raters in a young adult athletic population who were pain free. In the study by Leeder et al.
three cameras were used and were positioned to the front, side, and overhead. Similar to this current study, Gulgin et al. also used two cameras positioned in the sagittal and frontal views to record the FMS™ tests. They also demonstrated good inter-rater reliability (ICC = 0.880) of the FMS™, which was assessed by four raters with various experiences in administering the FMS™. Both the Gulgin et al. study and this current study indicated that the FMS™ does not appear to require extensive experience in order to achieve good reliability. Good reliability achieved by a novice user can be due to the inherent standard criteria of the FMS™ for performance interpretation and scoring.

Further, the inter-rater reliability was excellent between the modified FMS™ scores assessed by one investigator watching the video recordings and by the other investigator in real-time. This result suggests that scoring a recorded FMS™ performance was as consistent and reliable as scoring the test in real-time.

The ICC values showed good-to-excellent intra-rater reliability of the FMS™ with the modified scoring system for both the asymptomatic and LBP populations. The result of the current study is in agreement with a study which reported ICC = 0.96 for an asymptomatic group using a similar research design. However, experience did not appear to be a factor in this current study because the investigator who scored the video-recorded FMS™ performances twice was a novice rater. Consequently, the MDC95 values of this study differed from those reported by Teyhen et al., who found a higher MDC95 value (2.54 points) in active duty service members. The variances in MDC95 values result from the differences in the ICC values between the two studies as the level of reliability affects the MDC based on the calculation formula.

The results showed a significant difference in the modified FMS™ scores between the asymptomatic group and the LBP group, indicating that the modified FMS™ was capable of distinguishing young adults with LBP from those without LBP. The result was in agreement with those in the Ko et al. study, in which the authors also found differences between individuals with and without chronic LBP. Although the FMS™ composite scores were similar in both studies for the asymptomatic participants, the FMS™ composite score for the patient participants of this study (14 points) was higher than that in the Ko et al. study (11 points). Chronicity of LBP in the Ko et al. study could have contributed to a difference between the two studies. In addition, the participants in their study were much older (42.2 years) as compared to those in this current study (26.7 years). It has been found that age affects the performance of the FMS™ with younger individuals performing the FMS™ better. Coincidently, an FMS™ score of 14 or lower is associated with a higher risk of musculoskeletal injury among competitive athletes. Furthermore, the result of each FMS™ test component revealed that the LBP group appeared to have more deficits in movement performance on the deep squat test and the trunk stability push-up test than the asymptomatic group. These findings are not surprising because both deep squat and push-up demand spinal stability and motor control of the core musculature and participants with LBP likely had deficits in the spinal stabilizers. However, Ko et al. used the original scoring system, which could have under-scored the FMS™ performance for those who had existing LBP, as presence of pain at baseline was given a zero score. Using the modified scoring system in our study, participants who performed movement correctly were awarded a score that was more representation of their quality of movement. It was necessary to make the modification as the FMS™ was designed to assess quality of movement.

This study has some limitations. One limitation was that the participants in this study were young and the intensity of their LBP was low. Therefore, the results might not be generalized to the other ranges of age and to individuals with higher intensities of LBP. Although the two raters who viewed and scored the FMS™ performance four days later after they recorded the real-time performance for inter-rater reliability, and viewed and scored again six weeks later, it is not certain if the two raters could recall the performance.

**CONCLUSION**

These results of the current study indicate good-to-excellent intra-rated and inter-rater reliability of the FMS™ with a modified scoring system when the scores were collected in both real-time and video-recorded sessions from the young adults with and without LBP. In addition, the modified FMS™ scoring system allows clinicians to quantify the quality of movement in young adults with LBP and identify restrictions and limitations to common body movement patterns requiring minimal time and financial costs. Identification of such factors may allow therapists to address movement impairments in their plan of care. For future study, researchers should assess the reliability and validity of the FMS™ in individuals with older ages and with varying stages of LBP.

**DISCLOSURE STATEMENT**

No conflicts of interest were present in this study.

**ACKNOWLEDGEMENTS**

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Reliability and Validity of the Y-balance Test in Young Adults with Chronic Low Back Pain

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1 Physical Therapy Department, University of Tabuk, 2 Department of Health Rehabilitation, Shaqra University, 3 School of Physical Therapy, Texas Woman's University

Keywords: dynamic balance, interrater reliability, lumbar spine, movement system, postural stability

Background

Individuals with chronic low back pain (CLBP) may demonstrate reduced ability to perform dynamic tasks due to fear of additional pain and injury in response to the movement. The Y-balance test (YBT) is a functional and inexpensive test used with various populations. However, the reliability and validity of the YBT used for assessing dynamic balance in young adults with CLBP have not yet been examined.

Purpose

To determine the inter-rater reliability of the YBT and to compare dynamic balance between young adults with CLBP and an asymptomatic group.

Study Design

Reliability and validity study.

Methods

Fifteen individuals with CLBP (≥ 12 weeks) and 15 age- and gender-matched asymptomatic adults completed the study. Each group consisted of 6 males and 9 females who were 21-38 years of age (27.47 ± 5.0 years). The YBT was used to measure participant’s dynamic balance in the anterior (ANT), posteromedial (PM) and posterolateral (PL) reach directions. The scores for each participant were independently determined and recorded to the nearest centimeter by two raters. Both the YBT reach distances and composite scores were collected from the dominant leg of asymptomatic individuals and the involved side of participants with CLBP and were used for statistical analysis.

Results

The YBT demonstrated excellent inter-rater reliability, with intraclass correlation coefficients ranging from 0.99 to 1.0 for the YBT scores of both asymptomatic and CLBP groups. The CLBP group had lower scores than those of the asymptomatic group in the reach distances of the ANT (p = 0.023), PM (p < 0.001), and PL (p = 0.001) directions, and the composite scores (p < 0.001).

Conclusions

The results demonstrated excellent inter-rater reliability and validity of the YBT for assessing dynamic balance in the CLBP population. The YBT may be a useful tool for clinicians to assess dynamic balance deficits in patients with CLBP.
Level of Evidence
2b.

INTRODUCTION

Evidence has shown that dynamic balance is diminished in individuals with chronic low back pain (CLBP)²,³ and in individuals with a history of low back pain (LBP) who are pain-free at the time of testing as compared to asymptomatic controls.² Individuals with LBP often stiffen their lower back, relying more on ankle movement and less on hip movement to perform dynamic tasks in an upright standing position.³ Once individuals with LBP lose their balance, they have more difficulty regaining it, and these deficits can persist even after an episode of LBP has subsided.² In addition, individuals with LBP are apprehensive of performing dynamic tasks, primarily due to fear of additional pain and re-injury of their low back.²,⁴ Therefore, it is not surprising to find that the severity of a dynamic balance deficit is associated with chronicity of LBP.

Dynamic balance is essential for performing daily functional activities (e.g., leaning forward, navigating stairs, walking), work tasks, and recreational activities. Although balance has been evaluated in individuals with LBP using expensive laboratory-based equipment, this laboratory equipment is impractical in clinical settings.⁵,⁶ The Y-balance test (YBT) is a portable and inexpensive tool designed to measure dynamic balance. It was developed from the Star Excursion Balance Test (SEBT) to improve the repeatability of reach measurement and standardize performance of the test.⁷ The YBT evaluates single-leg-balance, dynamic neuromuscular control, proprioception, and strength while an individual reaches with the non-stance limb in three directions.⁵–⁷ The YBT has been a reliable measure of dynamic balance in healthy asymptomatic adults, with intra-rater correlation coefficients (ICCs) ranging from 0.85 to 0.91 for intra-rater reliability and from 0.85 to 1.00 for inter-rater reliability.⁷,⁸ The YBT also has been used in various populations to predict general risk for musculoskeletal conditions and injury recurrence, typically in younger athletic populations.⁵,⁷,⁹ In addition, the YBT has been capable of detecting residual postural control deficits in asymptomatic individuals with a history of LBP.² Therefore, the YBT may be a promising tool for measuring dynamic postural control of young adults with CLBP.

To date, there has been no consensus regarding the utilization of the YBT for assessing dynamic balance in individuals with LBP. However, two research studies used the YBT to compare dynamic balance performance between individuals with and without LBP.²,¹⁰ Hooper et al.² found that reach distances of the dominant leg were reduced in all directions except the anterior (ANT) direction in adults with LBP and in adults with a history of LBP as compared to asymptomatic controls. Haag et al.¹⁰ found no significant differences in the three reach directions for lower extremities between two groups of adolescent female soccer players with and without LBP. However, Haag et al.¹⁰ did not consider limb dominance, and Hooper et al.² assessed the reach distances of the dominant limb only. In both studies, the comparison of YBT performance did not consider the painful side of the participants with LBP.

Literature also has indicated that specific reach directions of the YBT correlate with specific impairments of the lower extremities.¹¹ For example, poor performance in the posterolateral (PL) direction has been reported as a predictor of ankle sprain.¹¹ In addition, composite YBT scores can assess an individual’s ability to perform a multiplanar motion.¹² Scores of separate reach directions along with the composite score may be used as different indices of dynamic balance for patients involved in specific types of work or sports activities. To date, there is little evidence to demonstrate the reliability and validity of the YBT when used for assessing dynamic balance in young adults with CLBP. Therefore, this study determined the inter-rater reliability and validity of the YBT in young adults with CLBP. Specifically, the YBT scores of the young adults with CLBP were compared to those of asymptomatic young adults to establish the construct validity of the YBT for this population.

METHODS

STUDY DESIGN

This study is a cross-sectional reliability and validity study approved by the Institutional Review Board of Texas Woman’s University.

PARTICIPANTS

The sample size was determined based on prior YBT studies,¹,² which showed a large effect size of 1.25 between individuals with LBP and asymptomatic individuals. Using a more conservative approach, an effect size of 1.0 was used to estimate the sample size for this study. A power analysis performed with G*Power version 3.1.9. indicated that at least 24 participants would be needed to ensure an adequate power level of 0.80 for an independent t-test at an alpha level of 0.05. To allow for attrition, 30 participants, 15 in each group, were planned for the study.

Thirty 18- to 40-year-old young adults, 15 individuals with CLBP and 15 age- and gender-matched asymptomatic participants, were recruited and completed the study. Age and gender were matched between groups to reduce the possible influence of these variables on dynamic balance. Asymptomatic participants were individuals who had not experienced LBP within a year before the testing and no known LBP-related injury in their lives. Participants in the CLBP group were individuals who had experienced repeated episodes of persistent or recurrent LBP of musculoskeletal origin for a duration of over 12 weeks and an average pain intensity score ≥2/10 on the Numeric Pain Rating Scale (NPRS) in the past week.

Participants were excluded from the study if they reported or demonstrated any of the following: (1) pregnancy, (2) systemic joint disease (e.g., neurological or rheumatologic disorders), (3) serious spinal conditions, such as tumor, infection, or fracture, (4) signs of nerve root compression, (5) a history of hip, knee, or ankle pain in the
previous two years, (6) previous surgery to the lower extremity or lumbar spine, (7) a concussion within the previous three months, (8) vestibular or other balance disorders, (9) ongoing treatment for inner ear, sinus, or upper respiratory infection, and (10) a need for any form of walking aid, such as a cane or walker. In addition, participants were excluded if they were receiving medical care from a physician or other practitioner at the time of the study. Each participant was informed of the study procedures, benefits, and possible risks and then signed a written informed consent form. Potential participants were screened with a neurological examination (e.g., strength, sensation, and reflexes) performed by one investigator to determine their eligibility for the study.

INSTRUMENTATION AND OUTCOME MEASURES

The Y-Balance Test Kit (Functional Movement Systems, Inc. Chatham, VA) was utilized for evaluating dynamic balance. This kit consists of a single central stance platform which is connected to three plastic tubes with three moveable reach indicators arranged in the ANT, posteromedial (PM), and PL directions. Each tube is marked at intervals of one centimeter (cm). The outcome measures of interest were the reach distances of the three directions and the composite score of the YBT.

EXAMINERS

Four investigators, all doctoral-level physical therapy (PT) students, administered the YBT test in this study. Before commencing the study, these four investigators completed three hours of training in the YBT protocol given by the principal investigator (YA), who had attended a YBT online course and was certified in performing the YBT. Each participant was assessed by two of the four investigators based on the availability of the investigators; however, the same two investigators took measurements from each participant for the testing sessions. To examine inter-rater reliability, the YBT scores for participants in the CLBP group were independently determined and recorded to the nearest cm by two investigators.

PROCEDURES

Once a participant was determined to be eligible for the study, the participant was asked to complete an intake form, including questions asking their age, gender, limb dominance, level of physical activity (minutes per week), and past surgical and medical history. Participants with CLBP also were asked questions related to their pain location and duration. In addition, they were asked to rate their average pain levels in the past week using the NPRS, their disability level using the modified Oswestry LBP Disability Questionnaire (OSW), and their fear-avoidance level using the Fear-Avoidance Beliefs Questionnaire (FABQ). The NPRS, OSW, and FABQ have been reliable and valid tools for assessing LBP-related pain intensity, perceived disability, and fear-avoidance beliefs, respectively. Last, the height (cm), body weight (kg) and leg length (LL) were collected from all participants. Because LL has been shown to be a factor in affecting YBT performance, LL was used to normalize reach distances. The LL was measured from the inferior tip of the anterior-superior iliac spine to the distal border of the ipsilateral medial malleolus with the hips and ankles in a neutral position while the participant was in a supine position. LL was measured two times for each participant, and the average of the two measurements was used for data analysis.

Next, the participants were instructed in the proper performance of the YBT following the procedures described by Plisky et al. The lower limb being tested was defined as the stance limb, and the reaching direction was defined based on the orientation of the stance limb. For the asymptomatic group, the dominant leg was determined by the participant’s self-reported preferred leg used for kicking a ball. For participants with unilateral LBP, the painful side was designated as the involved side. For participants with bilateral LBP, the most painful side was designated as the involved side. If both sides were equally painful, the dominant leg was designated as the involved side.

Participants performed the YBT barefoot to eliminate potential effects of varying footwear. In addition, each participant performed six practice trials in each direction on each leg before taking measurements of reach distances. A break was given when the participant requested during the practice trials. These practice trials were performed to minimize the learning effect, as performance on the YBT has been shown to reach a plateau after six practice attempts. During the YBT, the participants were instructed to maintain single-leg stance on the center foot-plate with the foot behind the marked starting line. Next, the participants used the foot of their non-stance leg to slide the reach indicator along the designated tube as far as possible and then returned their foot to the starting position while maintaining their balance.

Participants could use their arms for balance or for safety, if necessary. After the practice trials, each participant performed three trials used for data analysis. However, the trial was discarded and retried if the participant did any of the following: (1) moved the foot of the stance leg from the platform or crossed the marked line, (2) pushed, kicked, or stepped on the reach indicator, (3) touched the floor with the foot of the non-stance leg, or (4) lost balance before returning the foot of the non-stance leg to the starting position. To reduce fatigue, participants were given a rest of at least 10 seconds between each trial, and at least 30 seconds between each reach direction. In addition, the testing order of the reaching directions and the testing order of the limbs were randomized. The successful reach distance was measured by reading the demarcated line at the proximal edge of the reach indicator closest to the participant to the nearest cm.

For each direction, the reach distances collected from the three trials were averaged and then normalized to leg length, using the following formula: (reach distance/LL) x 100%. The YBT scores were collected from the dominant leg of asymptomatic participants and the involved side of participants with CLBP. To determine the inter-rater reliability, two investigators, including the investigator who provided the instructions, took turns and independently recorded the participant’s reach distances. Considering that

International Journal of Sports Physical Therapy
Table 1: Participants’ Characteristics for the Asymptomatic and the Chronic Low Back Pain (CLBP) Groups.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Asymptomatic group (n=15)</th>
<th>CLBP group (n=15)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>27.4 ± 4.9</td>
<td>27.5 ± 5.3</td>
<td>0.943</td>
</tr>
<tr>
<td>Gender (female/male), n</td>
<td>9/6</td>
<td>9/6</td>
<td></td>
</tr>
<tr>
<td>Leg dominance (right/left), n</td>
<td>14/1</td>
<td>12/3</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>67.7 ± 7.3</td>
<td>76.6 ± 21.1</td>
<td>0.133</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167.5 ± 10.4</td>
<td>168.9 ± 9.7</td>
<td>0.710</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.4 ± 4.4</td>
<td>27.1 ± 8.4</td>
<td>0.282</td>
</tr>
<tr>
<td>Physical activity level (minute/week)</td>
<td>224.3 ± 132.2</td>
<td>140.3 ± 185.9</td>
<td>0.165</td>
</tr>
<tr>
<td>FABQ-Work</td>
<td>–</td>
<td>10.1 ± 6.2</td>
<td></td>
</tr>
<tr>
<td>FABQ-Physical activities</td>
<td>–</td>
<td>10.7 ± 7.7</td>
<td></td>
</tr>
<tr>
<td>OSW (%)</td>
<td>–</td>
<td>16.8 ± 7.0</td>
<td></td>
</tr>
<tr>
<td>NPRS (0-10)</td>
<td>Current</td>
<td>3.4 ± 1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average in the past week</td>
<td>4.5 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>Duration of CLBP (months)</td>
<td>–</td>
<td>57.9 ± 66.9</td>
<td></td>
</tr>
<tr>
<td>Painful side (right/central/left), n</td>
<td>–</td>
<td>5/5/5</td>
<td></td>
</tr>
</tbody>
</table>

SD, standard deviation; BMI, body mass index; FABQ, fear-avoidance beliefs questionnaire; OSW, modified Oswestry low back pain disability questionnaire; NPRS, Numeric Pain Rating Scale.

pain, aggravation, and fatigue could occur with repeated testing of the YBT on the participants with CLBP, only one session of the YBT was administered for inter-rater reliability.

DATA ANALYSIS

SPSS Statistics, Version 25 (IBM Corp., Armonk, NY, USA) was used to perform statistical analysis. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were used to describe the demographics for both groups, as well as pain duration, the NPRS score, the OSW score, and the FABQ score for the CLBP group. In addition, independent t-tests or chi-square tests were performed to compare differences in the demographic data between groups, such as age, gender, body mass index (weight (kg) ÷ height² (m)), and physical activity level.

Intraclass correlation coefficients (ICC₁,₃,κ) were calculated to determine the inter-rater reliability of the composite score and the normalized reach distances of the three reach directions for the CLBP group. Next, paired t-tests were used to compare the differences in the three normalized reach distances and the composite score between limbs in asymptomatic participants. If there were no differences between limbs, the YBT scores of the dominant leg were used for between-group comparisons. To assess construct validity using the known-groups method, independent t-tests were performed to examine between-group differences in the three reach distances and the composite score of the YBT. The alpha was set at 0.05 for all statistical analyses. Lastly, effect sizes were calculated for the group comparisons using Cohen's formula: \( d = (M_2 - M_1) / SD_{pooled} \).

RESULTS

Fifteen asymptomatic controls and 15 participants with CLBP with similar age- and gender-matched (9 women and 6 men in each group) completed the study. A summary of participants’ characteristics for both groups is presented in Table 1. Independent t-tests showed that there were no statistically significant differences between the CLBP group and the asymptomatic group in age (\( p = 0.943 \)), BMI (\( p = 0.282 \)), and physical activity levels (\( p = 0.165 \)). The participants with CLBP had an average NPRS score of 4.5 and an average OSW score of 16.8, indicating that the CLBP group had relatively moderate pain levels and low disability levels.

For inter-rater reliability, the results showed that the YBT had excellent inter-rater reliability for the ANT (ICC = 0.99; 95% CI: 0.99–1.0), PM (ICC = 1.0; 95% CI: 1.0), and PL (ICC = 1.0; 95% CI: 0.99–1.0) reaches and the composite score (ICC = 1.0; 95% CI: 1.0).

Table 2 displays the YBT scores for both groups. Because there were no significant differences in the YBT scores between the dominant and non-dominant limbs of the asymptomatic participants, the YBT scores of the dominant leg of asymptomatic participants were compared to those of the involved side with CLBP. The results of four independent t-tests showed that the CLBP group had a significantly lower composite score (\( p < 0.001 \)) and shorter reach distances in the ANT direction (\( p = 0.025 \)), PM (\( p = 0.001 \)), and PL (\( p = 0.001 \)) directions than the asymptomatic group (Figure 1, Table 3).
The results of our study showed excellent inter-rater reliability for the ANT, PM, and PL reaches and the composite score for the CLBP group, indicating that the YBT can be used by different testers to reliably assess dynamic balance in those with CLBP. Our reliability results follow reported work by Plisky et al., who also demonstrated excellent reliability (ICC = 0.99–1.00) of the YBT for assessing dynamic balance in asymptomatic active young adults between 18 and 35 years old. Using two raters to observe each trial and score it independently may have contributed to the reliability shown in both studies. However, Plisky et al. used two experienced raters with at least seven years of clinical experience, whereas novice raters scored the YBT in this current study. Shaffer et al. also showed good inter-rater reliability (ICC = 0.85–0.95) when raters with limited experience used the YBT to assess dynamic balance in active duty service members. The slightly lower ICC values in the Shaffer et al. study could be in part due to the collection of their data by seven raters and on separate days. The YBT can reliably assess dynamic balance with both novice and experienced raters.

The results of our study also showed that the CLBP group demonstrated significantly lower YBT scores in all three reach distances and the composite scores, indicating that the YBT can be used to distinguish the CLBP groups from asymptomatic healthy controls. Similar to our study results, Ganesh et al. also found that individuals with CLBP had significantly reduced ANT, PM and PL reach distances of

Table 2: Comparison of Y-balance test (YBT) normalized reach distances and composite scores between dominant and non-dominant legs for both the asymptomatic and the chronic low back pain (CLBP) groups.

<table>
<thead>
<tr>
<th></th>
<th>Asymptomatic Group (n=15)</th>
<th>CLBP Group (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant Leg *</td>
<td>Non-dominant Leg *</td>
</tr>
<tr>
<td>ANT † (%LL)</td>
<td>68.6 ± 6.1</td>
<td>70.4 ± 6.0</td>
</tr>
<tr>
<td>PM † (%LL)</td>
<td>112.4 ± 12.7</td>
<td>112.7 ± 13.6</td>
</tr>
<tr>
<td>PL † (%LL)</td>
<td>108.7 ± 16.0</td>
<td>107.6 ± 13.6</td>
</tr>
<tr>
<td>Composite Score ‡ (%LL)</td>
<td>96.6 ± 10.2</td>
<td>96.9 ± 10.2</td>
</tr>
</tbody>
</table>

CLBP, chronic low back pain; 95% CI, 95% confidence interval; ANT, anterior; PM, posteromedial; PL, posterolateral; %LL, normalized to leg length expressed as a percentage.

*Values are mean ± SD.
†Normalized reach was calculated as [reach distance (cm)/leg length of stance leg (cm) x 100].
‡Composite score is the average of the three reach distances (ANT, PM, PL) divided by three times the leg length (LL) and multiplied by 100
‡‡Statistically significant difference at the 0.05 level.

Table 3: Comparison of the Normalized Reach Distances and Composite Score of the Y-balance Test (YBT) Between the Asymptomatic Group and the Chronic Low Back Pain (CLBP) Group.

<table>
<thead>
<tr>
<th>YBT Scores (%LL)</th>
<th>Asymptomatic Group (n=15)</th>
<th>CLBP Group (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant Leg *</td>
<td>Non-dominant Leg *</td>
</tr>
<tr>
<td>ANT † (%LL)</td>
<td>68.6 ± 6.1</td>
<td>65.2 to 71.9</td>
</tr>
<tr>
<td>PM † (%LL)</td>
<td>112.4 ± 12.7</td>
<td>105.4 to 119.5</td>
</tr>
<tr>
<td>PL † (%LL)</td>
<td>108.7 ± 16.0</td>
<td>99.9 to 117.6</td>
</tr>
<tr>
<td>Composite Score ‡ (%LL)</td>
<td>96.6 ± 10.2</td>
<td>90.9 to 95.8</td>
</tr>
</tbody>
</table>

YBT, Y-balance test; CLBP, chronic low back pain; 95% CI, 95% confidence interval; ANT, anterior; PM, posteromedial; PL, posterolateral; %LL, normalized to leg length expressed as a percentage.

*Statistically significant difference between groups (p < 0.05).
†Normalized reach was calculated as [reach distance (cm)/leg length of stance leg (cm) x 100].
‡Composite score is the average of the three reach distances (ANT, PM, PL) divided by three times the leg length (LL) and multiplied by 100, using the following formula: [(ANT)+(PM)+(PL)/3×LL]=100%.

DISCUSSION

The results of our study showed excellent inter-rater reliability for the ANT, PM, and PL reaches and the composite score for the CLBP group, indicating that the YBT can be used by different testers to reliably assess dynamic balance in those with CLBP. Our reliability results follow reported work by Plisky et al., who also demonstrated excellent reliability (ICC = 0.99–1.00) of the YBT for assessing dynamic balance in asymptomatic active young adults between 18 and 35 years old. Using two raters to observe each trial and score it independently may have contributed to the reliability shown in both studies. However, Plisky et al. used two experienced raters with at least seven years of clinical experience, whereas novice raters scored the YBT in this current study. Shaffer et al. also showed good inter-rater reliability (ICC = 0.85–0.95) when raters with limited experience used the YBT to assess dynamic balance in active duty service members. The slightly lower ICC values in the Shaffer et al. study could be in part due to the collection of their data by seven raters and on separate days. The YBT can reliably assess dynamic balance with both novice and experienced raters.

The results of our study also showed that the CLBP group demonstrated significantly lower YBT scores in all three reach distances and the composite scores, indicating that the YBT can be used to distinguish the CLBP groups from asymptomatic healthy controls. Similar to our study results, Ganesh et al. also found that individuals with CLBP had significantly reduced ANT, PM and PL reach distances of...
the SEBT as compared to healthy controls. The results of Ganesh et al.\textsuperscript{1} study and the present study may demonstrate an impairment in functional activities for those with CLBP. Therefore, restoring dynamic balance should be considered in the management of CLBP. Pain-related fear avoidance of movement could have contributed to the reduction of the YBT performance. However, CLBP group had a very low OSW and FABQ scores. Therefore, it is unlikely that fear avoidance of movement could have impacted the results.

Hooper et al.\textsuperscript{2} found significantly reduced PM and PL reach distances of the YBT in the CLBP group as compared to those of asymptomatic controls, but there was not a significant difference in the ANT reach distance. Hooper et al.\textsuperscript{2} speculated that the impairments of their participants could be less severe because their criteria for inclusion in the CLBP group was noticeably different from that of the Ganesh et al.\textsuperscript{1} study. The individuals with CLBP in the Hooper et al.\textsuperscript{2} study were those with current LBP and a history of LBP over the previous 18 months, whereas the participants had LBP for more than 6 months in the Ganesh et al.\textsuperscript{1} study. Considering that the participants with CLBP in this current study had pain for an average of 57 months, they could have had more severe impairments (e.g., strength loss and deconditioning) than those in the Hooper et al.\textsuperscript{2} study, resulting in decreased ANT reach distance. In addition, hip extension range of motion (ROM) is required to perform the ANT reach. Therefore, decreased hip extension mobility could have affected the ANT reach distance, as hip extension was found to be reduced in the individuals with CLBP.\textsuperscript{25} but not in those without LBP.\textsuperscript{26} However, hip ROMs were not measured in this current study to confirm this hypothesis.

On the contrary, Haag et al.\textsuperscript{10} reported that the YBT reach distances for those with LBP were not different from healthy controls. The difference in findings of the two studies could be attributed to differences in the age of the participants. The participants in the Haag et al.\textsuperscript{10} study were adolescents (15.9 ± 0.9 years of age), who have been shown to have better YBT performance than adults.\textsuperscript{27} The adolescents with LBP may have a greater hip range of motion, thus allowing them to compensate for reduced low back mobility while performing the YBT.\textsuperscript{28} In addition, the pain in Haag et al.’s LBP group was less severe and less chronic, thus further contributing to the lack of difference in the YBT performance between the LBP group and health controls, as literature has shown that adolescents with higher intensity of LBP demonstrate reduced ability to perform a single-leg stance balance task.\textsuperscript{29}

LIMITATIONS

One limitation of this study is the use of convenience sampling. In addition, the participants in this current study were young adults only; therefore, these participants may not have been representative of the general population with regard to age. Furthermore, although efforts were made to control the potential influence of confounding factors that may affect YBT performance, factors such as hip, knee, and ankle strength and joint ROM were not measured. Future studies should examine the impact of these factors on the reduced YBT performance in patients with CLBP.

CONCLUSION

The results of this study indicate that the YBT demonstrated excellent inter-rater reliability, and that young adults with CLBP had impaired dynamic balance as compared to young asymptomatic adults. The YBT may be a useful tool for clinicians to assess dynamic balance deficits in patients with CLBP. Our study adds to the existing body of literature by showing that the involved side of participants with CLBP may influence YBT scores, as the participants with CLBP in this current study scored lower than the asymptomatic group on both the YBT reach distances and the composite score for the YBT. However, further investigation is warranted in order to ascertain the effect of the involved side on dynamic balance performance as related to functional daily activity or sport tasks of LBP populations.

DISCLOSURE STATEMENT

No conflicts of interest were present in this study.

ACKNOWLEDGEMENTS

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REFERENCES


A Targeted Approach to Evaluating the Golfing Athlete with Low Back Pain: A Resident’s Case Report

Luke Deckard, PT, DPT, CSOMT

1 ProRehab Physical Therapy

Keywords: golf, low back pain, movement system, regional interdependence, titleist performance institute

Background and Purpose
Low back pain is one of the most common conditions occurring in the golfing population. Many approaches have been utilized throughout the years to address this condition including the concept of regional interdependence. The purpose of this case report is to describe the evaluation process and treatment approach of a golfer with low back pain using the principles of regional interdependence.

Case Description
A thirty-year-old male with right-sided low back pain was evaluated using a comprehensive approach including golf specific movement screening and a swing evaluation. The patient had mobility restrictions in his thoracic spine and hips that appeared to be contributing to a hypermobility in the lower lumbar spine. Based on the evaluation, he was placed into the treatment-based classification (TBC) of stabilization but would also benefit from mobilization/manipulation techniques.

Outcomes
After seven visits over a four-week span, the patient’s mobility and core stability both improved and he was able to play golf and workout pain free. His outcome measures also improved, including the revised Oswestry Disability index from 26% disabled to 10%, the Fear Avoidance Behavior Questionnaire (FABQ) Work from 10/42 to 3/42, and the FABQ Physical Activity from 19/24 to 6/24.

Discussion
Evaluating and developing a plan of care to address low back pain in an avid golfer can be challenging as a variety of demands are placed on the spine during the movement. This case report describes the evaluation process and treatment approach to specifically target the demands that are required during the golf swing. Utilizing a targeted approach that includes golf specific movement screening and a swing evaluation can help guide the therapist in their treatment and improve the patient’s outcome.

Level of Evidence
Level 4

INTRODUCTION
Low back pain (LBP) is one of the most common conditions in the golfing population accounting for nearly 25% of total injuries. Most golfers report chronic pain that is likely due to overuse. Research has shown a greater incidence of injuries in those who played four or more rounds per week or hit over 200 balls on a weekly basis. Physical therapists have utilized a plethora of approaches in the treatment of this condition, moving from passive modalities to more active treatment styles. Regional Interdependence is a term that has been used more frequently in the world of physical therapy over the past ten years when describing one of many treatment philosophies. It is the concept of treating an adjacent segment to that of the primary region, in order
to fully address the primary complaint. Mike Boyle and Gray Cook describe the body as an alternating pattern of stable segments that are connected by mobile joints that can become altered at times leading to movement dysfunctions and compensations. This concept can be applied throughout the body for example in the case of addressing a hip or ankle deficit in the treatment of patellofemoral pain. The current literature demonstrates a variety of treatment approaches that use this concept to address LBP including improving core stability as well as thoracic and hip mobility. The staff of the Titleist Performance Institute (TPI) has vast experience working with golfers of all ages and handi- caps and is a leading resource when it comes to golf fitness, rehabilitation, and instruction. They have developed a screening tool to help golfers raise body awareness in regard to their fitness capabilities as well as identifying golf swing characteristics that are more commonly associated with pain and dysfunction. They utilize a philosophy called the Body-Swing connection, which consists of identifying swing characteristics that are likely present based on the results from their golf specific movement screen. During the swing evaluation, there are twelve characteristics which the golfer is being assessed. Since the movement screen has already identified which swing characteristics are more likely to be present, it is important to pay careful attention to these specifically. Reverse spine angle (RSA), early extension, and S-posture are all found to influence the lower back during the golf swing and are likely related to an injury occurring in this region related to the number of repetitions. Depiction of each of these swing characteristics can be found in Figure 1. Several other identified factors help determine who is more likely to sustain a low back injury from playing golf. The highest predictor for LBP is having a BMI < 25.7 kg/m². This suggests that the tall, slender golfer is actually at a higher risk than someone with greater mass relative to their height. The second known predictor is having a right-side deficit (in right-handed golfers) of >12.5 seconds on the side-plank endurance test compared to the left. Several authors have examined the relationship between lead and non-lead hip rotation in golfers with low back pain. A decrease in lead hip internal rotation (IR) compared to the non-lead hip has been correlated with the presence of low back pain in both amateur and professional golfers. However, the same relationship was not found when examining lead and non-lead hip rotation in LPGA tour players with a history of LBP. Kim et al found that lumbar axial rotation and right side bending were significantly greater in golfers with < 20 deg of passive lead hip IR at several phases throughout the golf swing. These findings are consistent with one of the principles used by TPI staff where a dysfunctional segment (decreased hip ROM) will lead to compensation in an adjacent region (hypermobility in the lumbar spine). Hypermobility can be described as a joint that moves outside of its expected norm. It can be identified through physiologic and accessory mobility testing. It is generally surrounded by hypomobile or stiff joints in the adjacent regions such as a lum- bar hypermobility presenting with a hypomobile thoracic spine. An increase in lateral bending to the right in the lumbar spine during the impact phase (where the golfer is making contact with the ball) in golfers with limited lead hip IR is also a result of RSA. Reverse spine angle (RSA) presents with greater left side bending during the back swing (for a right-handed golfer), which has been observed in professional golfers with LBP. Pain will generally occur in the right lower back with this population as the facet joints on that side are repeatedly compressed during the downswing.
With the focus of treating low back pain expanding outside of the local musculature, the core has also become a region for further examination. When looking at lumbo-pelvic control in collegiate baseball pitchers, greater than 50% of the subjects demonstrated deficits that were characterized by a coupled movement pattern of the hip and low back. The ability to dissociate the torso from the pelvis is important in the golf swing as it allows for proper power transfer from the ground up through the legs and into the torso. Lumbo-pelvic control is an area that has not been well studied in the golfing population but needs further assessment since it is now demonstrated in other rotary athletes.

An EMG study of the golf swing found that golfers with a history of LBP have significantly earlier activation of their erector spinae during the initiation of the backswing. This altered pattern of activation may suggest the global muscle is acting as a primary stabilizer in this population. One of the tests that TPI staff recommend for core stability assessment is the pelvic tilt test. Seventy-two percent of amateurs demonstrate "shake and bake" patterns, which are vibratory movements in the soft tissue throughout the torso. This indicates a core stability deficit and is only observed in 24.2% of PGA tour players.

Previous researchers used the principles of regional interdependence in their approach to treating LBP in the athletic population. Lejkowski & Poulsen completed a case report involving a 56-year-old male golfer with chronic LBP using these principles. With previously failed conservative treatments addressing the lumbar spine solely through a stabilization program, these authors maintained his stabilization program while also addressing the deficits found in his hip ROM. Through addressing hip ROM with manual therapy and a flexibility program, they saw a complete resolution of the patient’s symptoms during and after a round of golf in two weeks (two treatment sessions). Kaplan used similar treatment techniques when addressing LBP in a high school athlete who played both hockey and baseball. After initially focusing on minimizing localized pain in the low back for the first two treatment sessions, they were able to decrease the patient’s Oswestry Disability Index (ODI) score from 16% to 0% impaired and a global rating of change of 7 (the highest score) by more specifically addressing hip mobility and core stability over the next five visits.

Goshtigian & Swanson used the selective functional movement assessment (SFMA) as well as several other soft tissue mobility tests including FABER’s and the Modified Thomas Test when treating an adolescent male athlete with LBP. Through this type of testing they identified restrictions in the soft tissue structures surrounding the hips as well as dysfunctional movement patterns throughout the spine. With treatment focused on addressing these identified dysfunctions along with treating the specific area of pain, the athlete returned to weightlifting without experiencing any pain.

The purpose of this study was to describe the evaluation process and treatment approach used with a golfer with LBP using the principles of regional interdependence. This included TPI screening and a swing evaluation as well as treatment to the thoracic spine, core stabilizers, and hips as needed. These tests and interventions were incorporated into one treatment approach for a young male golfer with low back pain.

CASE DESCRIPTION

HISTORY

The patient was a 50-year-old male presenting with chronic right sided low back pain beginning three months ago. He reported that he "threw out his back" while getting out of his truck, which led him to being unable to move the next day and required transportation by ambulance to a hospital for treatment. Upon arrival he reported receiving an oral steroid prescription and then being discharged home to rest for a few days. Over the next few weeks, he reported taking things easy and refraining from all of his previous exercise and activity. After two to three weeks, he reported that he began playing golf and resumed his prior resistance training program with full return to all normal activities within the next month. His complaints consisted of a tight achy pain in the right lower back with prolonged sitting, sleeping (slept on his side and/or back) and with playing golf. He stated that it was typically worse the day following exercise or activity. The patient reported that he can gain relief from the pain with stretching his lower back and taking a hot shower. He reported playing a full 18-hole round of golf two times per month and is at the driving range every other day. When he is at the range, he reported that he would hit both a large and small bucket each time (approximately 150 balls) with twenty of those consisting of chips and pitches. His current workout routine consisted of rotating through chest, back, arm, and leg workouts 2-3 times each week. Overall his past medical history is unremarkable, and he is not currently taking any medications to manage his pain. His goal with physical therapy was to play golf and resistance train without LBP. The patient was informed that the data concerning his case would be submitted for publication. The U.S. Health Insurance Portability and Accountability Act (HIPPA) was discussed and an informed consent was obtained to allow for the use of his medical information.

SYSTEMS REVIEW

The results from the review of systems can be seen in Table 1. Significant findings were found in the neuromuscular system for balance, as well as several deficits within the musculoskeletal system. The details of the deficits found in the musculoskeletal system can be found within Table 2.

CLINICAL IMPRESSION I

With the patient’s complaints of mainly right sided lower back pain beginning approximately three months prior, there were multiple diagnoses to consider for this patient. The working hypotheses were a facet joint dysfunction, lumbar intervertebral disc protrusion, and SI joint dysfunction. The hospital visit and his intake forms did not yield any positive red flag findings. The subject was referred to skilled physical therapy to address his LBP with a goal of returning to playing golf. Based on his history, there were concerns about his core stability and endurance as well as general mobility since he is very active and hitting a large
Table 1: Review of Systems Results

<table>
<thead>
<tr>
<th>Review of Systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular/Pulmonary</td>
<td>Not formally tested</td>
</tr>
<tr>
<td>Integumentary</td>
<td>No impairments</td>
</tr>
<tr>
<td>Cognition/Communication</td>
<td>Alert and Oriented x 3</td>
</tr>
<tr>
<td>Neuromuscular</td>
<td>Balance impairments as noted in his TPI screen below Dermatomes, myotomes, and DTRs were not tested since radicular symptoms were not present</td>
</tr>
<tr>
<td>Musculoskeletal</td>
<td>See Table 2 below for details</td>
</tr>
</tbody>
</table>

Figure 2: Positive test results from the PT exam.
A. Spinal Rotation, B. Spinal Extension, C. Spinal Side-Bending

Figure 2 (continued): Positive test results from the PT exam.
D. Quadruped Alternating Leg Extension, E. Supine Marching

EXAMINATION
TEST & MEASURES

The results from the initial evaluation can be found in Table 2 with significant findings being represented in Figure 2. The patient was taken through a standard physical therapy evaluation as well as the TPI level one screen. A swing evaluation was performed after obtaining a recording that was taken at the range prior to the third visit. The results from the TPI screen as well as the patient’s swing characteristics can be seen in Tables 3 and 4 respectively. Figure 3 presents a few of the failed tests from the TPI level one screen.

Pain was evaluated using the numeric pain rating scale from 0 to 10 where 0 is the absence of pain and 10 is the worst imaginable pain. Upon arrival the patient had reported his pain level at a 1/10 with it being at worst a 4/10 and at best a 0/10. Two outcome measures were utilized to track the patient’s progress over his POC. The revised Os-
### Table 2: Physical Therapy Exam Findings

<table>
<thead>
<tr>
<th>Physical Therapy Evaluation</th>
<th>Initial Exam Findings</th>
<th>Discharge Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spinal ROM</strong></td>
<td>Right rotation: mildly limited</td>
<td>Right rotation: full</td>
</tr>
<tr>
<td></td>
<td>Left rotation: moderately limited</td>
<td>Left rotation: full</td>
</tr>
<tr>
<td></td>
<td>Right SB: moderately limited and painful</td>
<td>Right SB: full</td>
</tr>
<tr>
<td></td>
<td>Left SB: mildly limited</td>
<td>Left SB: full</td>
</tr>
<tr>
<td></td>
<td>Flexion: full without pain</td>
<td>Flexion: full</td>
</tr>
<tr>
<td></td>
<td>Extension: mildly limited but with pain and hinging at L4</td>
<td>Extension: full without pain- hinging at L4</td>
</tr>
<tr>
<td><strong>Functional Stability</strong></td>
<td>+ for extension, rotation pattern bilaterally</td>
<td>+ for extension, rotation pattern bilaterally</td>
</tr>
<tr>
<td><strong>Testing:</strong></td>
<td>+ for inability to dissociate</td>
<td>+ for inability to dissociate on the right only</td>
</tr>
<tr>
<td><strong>Joint Mobility</strong></td>
<td>No pain with PA gliding at any level</td>
<td>No pain with PA gliding Increased mobility at L4/5</td>
</tr>
<tr>
<td></td>
<td>Increased mobility at L3/4/5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stiff TL junction and upper thoracic spine</td>
<td></td>
</tr>
<tr>
<td><strong>SLR</strong></td>
<td>+ for moderate hamstring tightness bilaterally</td>
<td>+ for mild hamstring tightness bilaterally</td>
</tr>
<tr>
<td><strong>Modified Thomas Test</strong></td>
<td>Tight RF on the left (65 deg)</td>
<td>No restrictions present</td>
</tr>
<tr>
<td></td>
<td>No limitation on the right</td>
<td></td>
</tr>
<tr>
<td><strong>Hip IR and ER ROM - Prone</strong></td>
<td>IR: right: 43, left: 29</td>
<td>IR: right: 35, left: 40</td>
</tr>
<tr>
<td></td>
<td>ER: right: 51, left: 56</td>
<td>ER: right: 46, left: 41</td>
</tr>
<tr>
<td><strong>Functional Movement/Asterisk Sign</strong></td>
<td>OHS: mild forward trunk lean, slightly early butt wink, increased lumbar lordosis, feet in ER</td>
<td>OHS: very mild forward trunk lean, slightly early butt wink, feet in ER</td>
</tr>
<tr>
<td></td>
<td>MSE: pain and limited</td>
<td>MSE: full and pain free</td>
</tr>
<tr>
<td><strong>Quadrant Test</strong></td>
<td>Negative bilaterally</td>
<td>Not tested</td>
</tr>
<tr>
<td><strong>Plank Holds:</strong></td>
<td>• Front</td>
<td>• 50 sec</td>
</tr>
<tr>
<td></td>
<td>• Right side</td>
<td>• 35 sec</td>
</tr>
<tr>
<td></td>
<td>• Left side</td>
<td>• 36 sec</td>
</tr>
<tr>
<td></td>
<td>• Biering-Sorensen</td>
<td>• 22 sec</td>
</tr>
<tr>
<td></td>
<td>41 sec w/pain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>36 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 sec w/pain</td>
<td></td>
</tr>
<tr>
<td><strong>Hip Strength</strong></td>
<td>Posterior Glute Medius:</td>
<td>Posterior Glute Medius:</td>
</tr>
<tr>
<td></td>
<td>3-/5 bilaterally</td>
<td>Lt: 3-/5, Rt: 4-/5</td>
</tr>
<tr>
<td></td>
<td>Hip abduction:</td>
<td>Hip abduction:</td>
</tr>
<tr>
<td></td>
<td>4-/5 bilaterally</td>
<td>Lt: 4-/5, Rt: 4/5</td>
</tr>
<tr>
<td></td>
<td>Glute max:</td>
<td>Glute max:</td>
</tr>
<tr>
<td></td>
<td>4-/5 bilaterally</td>
<td>4-/5 bilaterally</td>
</tr>
<tr>
<td><strong>Pain Rating</strong></td>
<td>Current: 1</td>
<td>Current: 0</td>
</tr>
<tr>
<td></td>
<td>Best: 0</td>
<td>Best: 0</td>
</tr>
<tr>
<td></td>
<td>Worst: 4</td>
<td>Worst: 0</td>
</tr>
<tr>
<td><strong>Functional Outcome Measures</strong></td>
<td>FABQ (W): 10/42</td>
<td>FABQ (W): 3/42</td>
</tr>
<tr>
<td></td>
<td>FABQ (PA): 19/24</td>
<td>FABQ (PA): 6/24</td>
</tr>
<tr>
<td></td>
<td>Revised ODI: 13/50</td>
<td>Revised ODI: 5/50</td>
</tr>
</tbody>
</table>

Abbreviations: ROM= range of motion, SB= side-bend, PA= posterior to anterior, TL= thoracolumbar, SLR= straight leg raise, RF= rectus femoris, IR= internal rotation, ER= external rotation, OHS= overhead squat, MSE= multi-segmental extension, FABQ= Fear-avoidance behavior questionnaire, ODI= Oswestry disability index

Westry Disability Index (ODI) was utilized to measure the patient’s functional disability related to his LBP.16 His initial score indicated a 26% disability due to low back pain. The Fear-Avoidance Beliefs Questionnaire (FABQ) was utilized to assess how the patient’s own fear avoidance beliefs about physical activity (PA) and work (W) may contribute to his lower back pain.17 His FABQ W was 10/42 and his FABQ PA was 19/24. During the examination, the subject demonstrated deficits in both mobility as well as stability throughout the trunk and lower extremities. Care was taken to examine the ROM above and below the painful region, joint mobility, soft tissue extensibility, and core stability. Spine ROM was evaluated using the Selective Functional Movement Assessment (SFMA) top tier for multi-segmental flexion, extension, and rotation, as well as frontal plane side-bending. He demonstrated limitations in his spinal ROM in all planes with the exception of flexion being full. Limitations were also found in hip internal rotation bilaterally. After examining his spinal ROM in standing, an overhead deep squat was used for a functional movement assessment. During this movement he demonstrated several deficits including a mild forward trunk lean, increased lumbar lordosis, an early posterior tilting of the pelvis before the hips reach parallel, and he elected to use an externally rotated position for his feet. Accessory mobility utilizing posterior to anterior springing revealed a stiff thoracic spine particularly from T6-T12 with hypermobile segments at L3/4 and L4/5 but without any pain reproduction. The Modified Thomas
Table 3: Titleist Performance Institute Level One Screen Results

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup Posture</td>
<td>S-posture</td>
<td>Neutral</td>
</tr>
<tr>
<td>Pelvic Tilt*</td>
<td>Cannot arch the back, shake and bake quality</td>
<td>Can pelvic tilt in both directions, shake and bake quality</td>
</tr>
<tr>
<td>Pelvic Rotation*</td>
<td>Limited bilaterally without assistance, no improvement with assistance, some LBP on the right</td>
<td>Limited bilaterally without assistance, improves in each direction with assistance</td>
</tr>
<tr>
<td>Torso Rotation</td>
<td>Limited turning right without assistance, improves with assistance</td>
<td>Limited turning right without assistance, improves with assistance</td>
</tr>
<tr>
<td>Overhead Deep Squat</td>
<td>Arms down limited, Good DF bilaterally, weight evenly distributed</td>
<td>Arms down limited, Good DF bilaterally, weight evenly distributed</td>
</tr>
<tr>
<td>Toe-Touch</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>90-90*</td>
<td>Right side &gt; spine angle, same in golf posture Left side = spine angle, same in golf posture</td>
<td>&gt; Spine angle in both positions bilaterally</td>
</tr>
<tr>
<td>Single-leg Balance*</td>
<td>0-5 seconds bilaterally</td>
<td>6-10 seconds on the right 0-5 seconds on the left</td>
</tr>
<tr>
<td>Lat Length Test*</td>
<td>Between the nose and wall bilaterally</td>
<td>Left side touches the wall Right side between the nose and wall</td>
</tr>
<tr>
<td>Lower Quarter Rotation</td>
<td>Limited rotation bilaterally in backswing and downswing</td>
<td>Limited rotation bilaterally in backswing and downswing</td>
</tr>
<tr>
<td>Seated Trunk Rotation*</td>
<td>Right side &gt; 45 deg Left side = to 45 deg</td>
<td>&gt; 45 deg bilaterally</td>
</tr>
<tr>
<td>Bridge w/Leg Extension</td>
<td>Weak glutes bilaterally</td>
<td>Weak glutes bilaterally</td>
</tr>
<tr>
<td>Cervical Rotation</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Forearm Rotation</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Wrist Hinge</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Wrist Flexion</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Wrist Extension</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Fitness Handicap</td>
<td>36</td>
<td>21</td>
</tr>
</tbody>
</table>

Abbreviations: LBP= low back pain, DF= dorsiflexion

*Change in test results from initial to discharge

A targeted approach to evaluating the golfing athlete with low back pain: A resident’s case report

Test and straight leg raise (SLR) were used to assess soft-tissue extensibility of the hip musculature. The SLR demonstrated hamstring tightness bilaterally where the modified Thomas test demonstrated a tight rectus femoris on the left leg. Core endurance and functional stability were assessed using plank holds for max time as well as supine marching (hook lying alternating hip flexion), and alternating hip extension in quadruped. His plank times revealed that he had poor core endurance for his age in each direction and was limited by pain in his front plank at forty-one seconds and his Biering-Sorensen hold at eight seconds. Both of his functional stability tests (quadruped alternating hip extension and supine marching) revealed poor motor control strategies with the inability to dissociate his hip motion from his lower back. When assessing his alternating hip extension in quadruped, the subject moved into an extension-rotation pattern incorporating the lower back into the movement. With supine marching he demonstrated moderate movement at his ASIS with each march.

The TPI level one screen was used to assess movement and identify deficits within his golf posture, particularly any that are limited related to pain provocation. Initially he demonstrated deficits with his set up posture as well as upper and lower body dissociation. According to data collected by TPI, setting up in an S-posture places him at a higher risk for low back pain because of the stress it places on the facet joints of the spine. This may be one of the reasons for failing the pelvic tilt test since the player is unable to “arch their back” as they are already in this posture with their setup. With the pelvic rotation test, he demonstrated deficits in both directions and the pain in his lower back was reproduced. When external stability was provided.
Table 4: Swing Evaluation Results

<table>
<thead>
<tr>
<th>The Big 12 Swing Characteristics</th>
<th>Initial</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-Posture*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C-Posture</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Loss of Posture</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Flat Shoulder Plane</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Early Extension*</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Over-the-Top</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sway</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Slide</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reverse Spine Angle (RSA)*</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Hanging Back</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Casting/Early release/Scooping</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chicken Winging</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Increased frequency in golfer’s with LBP

Figure 3: Failed tests from the Titleist Performance Institute level one screen at the initial eval.
A. Overhead Squat, B. Pelvic Tilt, C. Torso Rotation D. 90-90 Shoulder Test

Figure 3 (continued): Failed tests from the Titleist Performance Institute level one screen at the initial eval.
E. Lat length test, F. Lower-quarter rotation test, G. Seated trunk rotation

there were no improvements in this test indicating a likely mobility deficit. Torso rotation showed a deficit when turning to the right (his down swing) and improved when external support was provided, again indicating a likely sta-
bility deficit. His overhead deep squat indicated that there were likely deficits in the thoracic spine due to his forward trunk position as well as the hips/knees since he demonstrated appropriate dorsiflexion bilaterally when assessed in half kneeling. Since these areas were already identified in the physical therapist's exam, special attention was paid to the upcoming tests to see if the findings would remain consistent. When assessing his single leg balance with his eyes closed, he demonstrated large deficits with times between 0 and 5 seconds bilaterally. He also showed significant deficits with his lower quarter rotation testing with limitations in both hips in his backswing and downswing. With latissimus dorsi length testing performed in a mini squat position against the wall, he demonstrated mild limitations bilaterally being unable to touch the wall while maintaining a neutral spine. The seated trunk rotation test showed limitations with turning to the left which would be toward his backswing. The last deficit that was found during the TPI screen was that the subject demonstrated weak gluteal musculature bilaterally during the bridge with leg extension test. All other tests demonstrated acceptable/passing levels.

Based on the body-swing connection, his TPI level one screen would suggest that he was at a very high likelihood for demonstrating the following characteristics: S-posture, loss of posture, early extension, sway, slide, hanging back, and reverse spine angle (RSA). When performing a swing evaluation utilizing down-the-line view (from behind the player) and face-on view (facing the player) several of these characteristics were confirmed. From the down-the-line view of the patient’s golf swing two characteristics were identified: early extension and loss of posture. The face-on view of his golf swing identified swaying, sliding, and RSA. Despite setting up in S-posture during his screen, he did not demonstrate this characteristic when setting up to hit a golf ball.

**CLINICAL IMPRESSION II**

Based on the examination findings, this patient was placed into the treatment-based classification of stabilization and was designated with a PT diagnosis of chronic low back pain with movement coordination impairments. He demonstrated some findings that would suggest that mobilization/manipulation techniques would also be important to include in his plan of care. It was noted that the subject had demonstrated a hypermobile segment in the L4-5 region with accessory mobility testing that was consistent with his hinge point during his spinal extension. The lumbar spine was surrounded by a stiff thoracic spine and mobility deficits in his left hip. The large deficits in his core stability, as demonstrated by his plank times and functional stability tests (alternate leg extension in quadruped and supine marching), suggested that with the repeated microtrauma of the golf swing, he may have experienced excessive stress in the lumbar spine. These limitations are consistent with the theory of regional interdependence as previously discussed. The risk for an injury is higher when a stable joint begins to sacrifice its role in order to obtain mobility that has been lost in the adjacent joints.4

The swing characteristics identified were consistent with the findings in his physical therapy evaluation. Early extension and RSA are two of the three characteristics that have a high correlation with low back pain in golfers and would seem to be related to the extension rotation pattern that he utilized during other movements. Identifying sway and slide during his swing are supported by the weak lateral hip musculature that was identified upon exam.

**PROGNOSIS**

Based on the subject's age, motivation, active lifestyle, and lower FABQ scores he was designated with a good prognosis for recovering from his chronic LBP. With improvements in his spinal and hip mobility, core stability, lower extremity strength, and education on his golf swing and overall volume, it was anticipated that he would be able to make a full return to playing golf and lifting weights without experiencing any pain or discomfort. Discharge criteria would consist of a full return to activity and completing the TPI screen without experiencing pain or discomfort.

**INTERVENTIONS**

**PATIENT EDUCATION**

Therapists provided education to the patient including his PT diagnosis, plan of care (POC), prognosis with skilled physical therapy, as well as a home exercise program (HEP). The initial goal of his POC was to modify his activity level during his range sessions and then begin to address his mobility deficits, which should help to reduce the stress to his lower back. The initial HEP consisted of open books (side lying thoracic rotation) to address deficits in thoracic spine mobility, a prone quad stretch to address soft tissue extensibility at the hips, and front planks and a modified side plank to begin addressing his core stabilization deficits. Education was provided concerning the swing characteristics that he had demonstrated during the evaluation, particularly the ones that placed him at a higher risk for low back pain. Discussion of the best sleep postures was also completed with education on trying to maintain a neutral spine when sleeping on his side and to minimize prone/stomach sleeping postures. The final aspect of his HEP consisted of education regarding the volume of golf balls that he was hitting during his range sessions (approximately 130 full swings) in comparison to the amount necessary to complete a round of golf (40–60 full swings depending on golf handicap).5

**PROCEDURAL INTERVENTIONS**

The subject was treated for seven visits over a span of four weeks. The visits ranged from 50–60 minutes in duration and began at two visits a week before decreasing to one visit the last week. Intervention consisted of manual therapy and therapeutic exercise, predominantly. Manual therapy techniques consisted of grade III/IV posterior hip mobilization and mobilizations with movement for hip rotation as well as spinal manipulation to both the thoracic and lumbar spine. Therapeutic exercise consisted of flexibility, strength, core stabilization, and motor control activities. Asterisk signs, which can be defined as a movement that re-
produces the patient’s pain, were utilized throughout each treatment session to check his progress towards his goals and consisted of multi-segmental extension and an overhead squat.

With the initial goals of decreasing his pain and improving his spinal mobility, high velocity- low amplitude anterior-posterior (AP) thrusts were performed to both the thoracic and lumbar spines during the first session. This improved his multi-segmental rotation to normal levels bilaterally. Manual therapy was followed by the HEP that was mentioned above to address this mobility deficit and initiate early core stabilization activities until the first follow up appointment. Detailed outlines of each session can be found in Table 5.

Each subsequent session began with an aerobic warm-up activity which consisted of the elliptical to encourage some spinal rotation with the use of the arms and then progressing to the rower to increase the aerobic demands. The aerobic warm-up was followed by re-checking the previous asterisk signs, multi-segmental extension (MSE) and multi-segmental rotation (MSR). During the first few sessions these motions continued to demonstrate deficits but were without pain. Manual therapy consisting of a supine CT junction/lower thoracic manipulation and a side-lying lumbar gapping manipulation targeting the upper lumbar spine were then applied to address these deficits, followed by a re-assessment of the asterisk signs. Upon reviewing these motions, he demonstrated full multi-segmental rotation (MSR) and multi-segmental extension (MSE) without pain. After completing the manual therapy interventions, the patient began performing therapeutic exercise. The first exercises were focused on addressing his mobility deficits. These consisted of activities focused on the thoracic spine, bilateral hips, as well as soft-tissue extensibility of the lower extremities. Motor control and core stability activities were then performed consisting of items from the initial evaluation including plank holds and quadruped alternating leg extensions. These activities were progressed throughout the plan of care to include lifts and rows while maintaining proper positioning, as well as becoming more golf specific. Motor control exercises consisted of working on upper and lower body dissociation initially with support from a dowel rod and trying to perform them in a golf posture. Beginning on the fourth visit, a dynamic warm up followed his aerobic activity with an emphasis on functional movements to generate improved spine and hip mobility. This visit also initiated the use of circuits to begin training his muscles and skills under fatigue as well as lower extremity strengthening activities targeting the gluteal musculature and lateral stabilizers of the hips.

As he continued to progress, the warm-up was adjusted to using the rowing machine to help build further cardiovascular endurance and incorporate full body mobility from the ankles up through the spine. Manual therapy shifted to focus more on the hips since his spinal mobility had consistently improved over the first few sessions and was consistently maintained at a full level upon his arrival to the clinic. With deficits present in hip flexion, as noted by the early posterior pelvic tilt in his squat and with his hip rotation in prone, techniques were used to help improve these motions and then followed up with further hip mobility activities. Circuit training was now also being utilized during his strength exercises and activities were progressed with a few single-leg exercises to further address the lateral hip stabilizers.

His HEP was updated throughout the POC as new exercises were incorporated into his program and mastery was displayed by the subject in the clinic. After the last session, a more detailed program was emailed to the patient that consisted of exercises that had been performed in the clinic and that could be completed at home with minimal equipment. He was educated on the importance of completing this program a few times weekly to continue making progress since our POC was shortened due to COVID-19 restrictions. Table 6 shows his updated HEP that was sent after he was discharged.

OUTCOMES

The subject of this study showed excellent progress towards his goals. He demonstrated full spinal ROM, improved hip mobility in both joint play and soft tissue extensibility, and improvements in all of his plank holds without any pain. He did not reach the goals for his plank times to exceed one and a half minutes for the front hold and for > 1 min in all other planes, but they were tested at four weeks instead of six weeks due to the shortening of his POC based on COVID-19 restrictions. Despite his functional stability testing still being (+) for the inability to fully dissociate hip movement from the lower back, his awareness of his body in space during these motions was improved. When assessing his improvements based on his functional outcome measures, both showed large improvements after four weeks. His revised ODI improved 16% from 26% disabled to 10%. The Minimally clinically important difference (MCID) for acute low back pain with the FABQ is 13 points, which would show clinical significance for the physical activity portion. Although his timeframe falls out of this stage, this is the most appropriate data available at this time. Full details can be seen in Table 2 from status at discharge. Overall, he was able to achieve his goal of being pain free after golfing and working out.

His TPI level one screen showed improvements as well moving from a fitness handicap of 36 with pain present during the pelvic rotation test to a 21 without any pain experienced. A few tests of importance were that he was able to Pelvic tilt in both directions though still demonstrating a “shake and bake” quality, his seated trunk rotation was full in both directions, and his pelvic rotation test was pain free and did improve with support showing that it was more limited by his ability to stabilize. A more detailed report of his screening results can be seen in Table 3. Tests that had improvements have been marked with an asterisk (*).

At this time, the Body-swing connection would suggest that he still had a high likelihood of demonstrating the following characteristics: sway, slide, loss of posture, early extension. Although, the likelihood of these characteristics...
### Table 5: Individual Treatment Sessions

<table>
<thead>
<tr>
<th>Treatment Day 1 (LE)</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT: Spine CT/Lower Thoracic manipulation, Lumbar gapping manipulation</td>
<td>HEP: Open books (side lying thoracic rotation), Prone Quad stretch, Front plank holds x 30 sec, Modified Side plank hold x 20 sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment Day 2</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT: Spine CT/Lower Thoracic manipulation, Lumbar gapping manipulation</td>
<td>TE: Warm-up: Elliptical x 8 min, Mobility: Open books (side lying thoracic rotation) x 15 bilaterally, Thread the needle (quadruped thoracic flexion/rotation) x 10 each side, Quadruped rock backs x 10 with hips neutral, x 10 with hips in IR, HK OH trunk rotations x 10 each side, Motor Control: Alternating leg extensions in quadruped 2 x 10 each side, Dead Bugs (spine alternating arm flexion + leg extension) 2 x 10 each side, Single leg hip rotation with dowel assist 2 x 10 each side</td>
</tr>
<tr>
<td>Core Stability: Front Plank holds 3 x 30 sec, Modified Side-plank holds 3 x 20 sec each side</td>
<td>HEP: Open books (side lying thoracic rotation), Prone Quad stretch, Front plank holds x 30 sec, Modified Side plank hold x 20 sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment Day 3</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT: Spine CT/Lower Thoracic manipulation, Lumbar gapping manipulation</td>
<td>TE: Warm-up: Elliptical x 8 min, Mobility: Thread the needle (quadruped thoracic flexion/rotation) x 15 bilaterally, Cat/Camel (quadruped spinal flexion/extension) x 10 each, Quadruped rock backs x 10 with hips neutral, x 10 with hips in IR, HK OH trunk rotations x 10 each side, Motor Control: Dead Bugs (supine alternating arm flexion + leg extension) x 10 each side, HK chops without trunk motion 2 x 10 each side with blue TB, Single leg hip rotation with dowel assist 2 x 10 each side, Torso Turns with hips blocked at wall x 20 each side</td>
</tr>
<tr>
<td>Core Stability: Front Planks with leg extension lifts 3 x 30 sec, Modified Side-plank holds with 5 lb DB row 2 x 15 each side</td>
<td>HEP: Open books (side lying thoracic rotation), Prone Quad stretch, Front plank holds x 30 sec, Modified Side plank hold x 20 sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment Day 4</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT: Spine CT/Lower Thoracic manipulation, Lumbar gapping manipulation</td>
<td>TE: Warm-up: Elliptical x 8 min, World’s greatest stretch (split stance thoracic rotation with opposite hand on the ground), Walking figure 4, Reverse toe-touch into inchworm x 10 yards each</td>
</tr>
<tr>
<td>Mobility: Quadruped rock backs x 20 each with leg in cross body position, Leg elevated lunge for posterior hip mobility</td>
<td>Motor Control: Circuit A x 2 rounds: Dead Bugs (supine alternating shoulder flexion + leg extension) x 10 each side, Circuit B x 2 rounds: Hip rotation with dowel assist x 10 each side, Torso Turns with hips blocked at wall x 10 each side</td>
</tr>
<tr>
<td>Core Stability: HK chops without trunk motion 2 x 10 each side with blue TB, Split stance paloff press 2 x 15 each side with medium strength band</td>
<td>Strength: Side-stepping with green band at knees 2 x 20 yards, Kettlebell Deadlift with 12 kg 3 x 10, Lateral eccentric tap downs from 4 in step 2 x 12 each side</td>
</tr>
<tr>
<td>HEP: Open books (side lying thoracic rotation), Prone Quad stretch, Front plank holds x 30 sec, Modified Side plank hold x 20 sec, WGS (split stance thoracic rotation with opposite hand on the ground), Quadruped figure 4 rock backs, leg elevated lunges</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment Day 5</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT: Spine CT/Lower Thoracic manipulation, Lumbar gapping manipulation, Posterior hip mobilization grades III/IV bilaterally, Hip IR/ER mobilization with movement (MWM) bilaterally</td>
<td>TE: Warm-up: Rower x 500 meters, World’s greatest stretch (split stance thoracic rotation with opposite hand on the ground), Walking figure 4, Reverse toe-touch into inchworm x 10 yards each</td>
</tr>
<tr>
<td>Mobility: Quadruped rock backs x 20 each with leg in cross body position, Leg elevated lunge for posterior hip mobility</td>
<td>Motor Control: Circuit A x 2 rounds: Dead Bugs (supine alternating shoulder flexion + leg extension) 2 x 10 each side, Circuit B x 2 rounds: Single leg Romanian Dead lifts with dowel assist 2 x 10 each side</td>
</tr>
<tr>
<td>Core Stability and Strength:</td>
<td>Circuit C x 2 rounds: Front plank with leg extension lifts x 10 each leg, Kettlebell Deadlift with 12 kg x 12, Lateral eccentric tap downs from 4 in step 2 x 12 each side</td>
</tr>
<tr>
<td>HEP: Open books (side lying thoracic rotation), Prone Quad stretch, Front plank holds x 30 sec, Modified Side plank hold x 20 sec, WGS (split stance thoracic rotation with opposite hand on the ground), Quadruped figure 4 rock backs, leg elevated lunges</td>
<td></td>
</tr>
</tbody>
</table>

International Journal of Sports Physical Therapy
to continue to occur in his swing has been reduced from his initial screen. When re-evaluating his swing, he still demonstrates the following characteristics: slide, loss of posture, early extension, and RSA. He no longer demonstrates the characteristic of swaying during his back swing which could be a result of improving his left hip IR and improving his understanding of upper and lower body dissociation. Although he demonstrated a slide during the downswing, it improved since his initial swing evaluation.

DISCUSSION

This case report demonstrates the application of the TPI level one screen, a golf swing evaluation, and the principles of regional interdependence in guiding the initial evaluation, overall POC, exercise selection, and HEP for the golfing athlete with low back pain. With this approach, the subject was able to make significant progress with his overall mobility and core stability which allowed him to resume playing golf and weightlifting without experiencing any pain.

Initial focus was on restoring the joint mobility in the thoracic spine as well as the hips to help alleviate the stress being placed on the lower back. This is consistent with the principle of regional interdependence and has been shown to be effective in previous case studies for addressing the rotational athlete with LBP. Although he did not present with the common pattern of a greater deficit in lead hip IR (right hip for a left-handed golfer) from previous literature, he did demonstrate deficits in hip IR bilaterally and with some soft-tissue extensibility. This was addressed with manual therapy to both regions and then followed up with therapeutic exercise to help maintain these gains. Once this had been improved as noted by his asterisk signs of MSR and MSE, the treatment session would transition to focus on motor control activities to help upper and lower body dissociation with a specific focus on the hips and lower back. TPI instructors discuss the importance of being able to dissociate to allow for the proper power transfer up from the ground during the swing as demonstrated by a proper kinematic sequence.

According to Evans et al., this patient was at a higher risk for experiencing low back pain as his BMI was 23 kg/m. Although his side plank deficits were not largely different side to side, his overall hold times in all positions were poor. Anderson et al. found the average side-plank hold in healthy males with an average age of 28 in their study to be 68.2 sec on the right and 69.5 sec on the left. Their Biering-Sorensen on average was 95.6 sec onds. These all improved over the course of his care but would still be lower than the average for his age and exercise category. McGill et al. compared plank hold ratios in healthy subjects and those with LBP. One large difference was the extension holds (performed using the Biering-Sorensen test) which was much better in those without LBP. When looking at the ratios dividing the side-plank holds by the extension hold time, they are .57 and .58 for the healthy group while the LBP group was at a 1. The current subject had an initial ratio of 2 for the right side and 2.4 for the left side when comparing his side planks/Biering-Sorensen, which is much

<table>
<thead>
<tr>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment Day 6</strong></td>
</tr>
<tr>
<td>MT: Posterior hip mobilization grades III/IV bilaterally, Hip IR/ER mobilization with movement (MWM) bilaterally</td>
</tr>
<tr>
<td>TE: Warm-up: Row 575 meters, World's greatest stretch (split stance thoracic rotation with opposite hand on the ground), Walking figure 4, Reverse toe-touch into inchworm x 16 yards each</td>
</tr>
<tr>
<td>Mobility: Quadruped rock backs x 20 each with leg in cross body position, Leg elevated lunge for posterior hip mobility</td>
</tr>
<tr>
<td>Motor Control: Circuit A x 2 rounds: Torso turns with hips blocked at wall x 10 each side, Pelvic rotations while maintaining ball against wall in golf posture x 10 each side, Single leg hip rotation with dowel assist x 10 each side</td>
</tr>
<tr>
<td>Core Stability and Strength: Circuit B x 2 rounds: Single leg Romanian Dead lifts with dowel assist x 10 each side, Single-leg hip thruster x 8-10 from bench, Side-step up with opposite knee drive with torso angled away from box with 4 kg KB ball hold x 10 each side</td>
</tr>
<tr>
<td>Circuit C x 2 rounds: Front plank with leg extension lifts x 12 each leg, Goblet squat with 15 lb KB x 12, Modified side-plank with 5 lb DB row x 15 each side</td>
</tr>
<tr>
<td>Split stance Paloff press x 15 each side with medium strength band</td>
</tr>
<tr>
<td>HEP: Open books (side lying thoracic rotation), Prone Quad stretch, Front plank holds x 30 sec, Modified Side plank hold x 20 sec, WGS (split stance thoracic rotation with opposite hand on the ground), Quadruped figure 4 rock backs, leg elevated lunge</td>
</tr>
</tbody>
</table>

| **Treatment Day 7** |
| MT: Posterior hip mobilization grades III/IV bilaterally, Hip IR/ER mobilization with movement (MWM) bilaterally |
| TE: Warm-up: Row 755 meters, |
| Mobility: Quadruped rock backs x 20 each with leg in cross body position, Leg elevated lunge for posterior hip mobility |
| Core Stability and Strength: Circuit A x 2 rounds: Single leg Romanian Dead lifts with dowel assist x 10 each side, Single-leg hip thruster x 8-10 from bench, Side-step up with opposite knee drive with torso angled away from box with 4 kg KB ball hold x 10 each side |
| Circuit B x 2 rounds: Single leg Romanian Dead lifts with dowel assist x 10 each side, Single-leg hip thruster x 8-10 from bench, Side-step up with opposite knee drive with torso angled away from box with 4 kg KB ball hold x 10 each side |
| HEP: Updated detailed program can be found in Table 6. |

*MT= manual therapy, TE= therapeutic exercise, HEP = home exercise program, CT= cervicothoracic, HK= half-kneeling, WGS= world's greatest stretch, IR= internal rotation, ER= external rotation*
Table 6: Home Exercise Program given at discharge

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Repetitions</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility/Dynamic Warm-Up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>World’s Greatest Stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking Figure 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inchworm into Reverse Toe Touch</td>
<td>X 15 ea side</td>
<td></td>
</tr>
<tr>
<td>Open Books/Thread the needle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heel rock with leg crossed behind body</td>
<td>X 15 ea side</td>
<td></td>
</tr>
<tr>
<td>Leg elevated lunge for hip mobility</td>
<td>X 10 ea side</td>
<td></td>
</tr>
<tr>
<td>Motor Control- perform as a circuit x 3 rounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torso turns with hips at wall</td>
<td>X 10 ea direction</td>
<td></td>
</tr>
<tr>
<td>Single leg stork turns with dowel</td>
<td>X 10 ea direction</td>
<td></td>
</tr>
<tr>
<td>Bird-dogs</td>
<td>X 10 ea leg</td>
<td></td>
</tr>
<tr>
<td>Strength Circuit A x 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL RDL</td>
<td>X 12 ea side</td>
<td>BW, progress to DB hold in hand</td>
</tr>
<tr>
<td>SL hip thruster from bench/couch</td>
<td>X 10 ea side</td>
<td>BW, progress to weight across hips</td>
</tr>
<tr>
<td>Front plank with leg extension lifts</td>
<td>X 15 ea</td>
<td>BW</td>
</tr>
<tr>
<td>Strength Circuit B x 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL palloff press (close leg down)</td>
<td>X 15 ea side</td>
<td>Heavy resistance band</td>
</tr>
<tr>
<td>Side-stepping with Band</td>
<td>X 20 yards</td>
<td>Green Theraband</td>
</tr>
<tr>
<td>Modified side-plank with row</td>
<td>X 15 ea side</td>
<td>Band/ DB</td>
</tr>
</tbody>
</table>

*SL= Single Leg, BW = Body Weight, DB = Dumbbell
†Alternative Exercises for Substitution during strength program: Goblet squat with 15 lb KB x 12, Lateral tap downs x 12 ea, Kettle bell Deadlift with 12 kg x 12, Half-kneeling chops without moving the trunk x 10 ea side

more consistent with the LBP group from the above-mentioned study. This was improved to a ratio of 1.6 by the end of our POC but is still more consistent with the LBP group and could use continued focus for his HEP. To address these deficits in core stability a variety of exercises were performed and included a variety of positions. Outside of performing plank holds with various extremity movements, the subject also performed half-kneeling chops, and palloff presses in multiple positions (Shoulder-width, Lunge, SL stance) to improve his core stability. These exercises add an anti-rotation component that is important when trying to train the core musculature, particularly when training the rotational athlete. Core activation would also be obtained during his LE strengthening through medicine ball or kettlebell holds.

The TPI level one screen provides further functional information about how ab athlete moves within their golf swing, which can be important when it is one of the pain-generating movements. It can provide an asterisk sign that can be re-checked by the therapist to assess if their treatments are making any changes and is directly related to their overall goal. Using the Body-Swing connection identifies swing characteristics that may be present during the swing evaluation. This is particularly important when evaluating low back pain as it is important to identify the likelihood of S-posture, RSA, and early extension, since they have all been associated with LBP. If these characteristics are not being addressed with their swing coach, the golfer would stay at a higher risk of their LBP to reoccur.

The golf swing evaluation can help the therapist put into context some of their evaluation findings such as weak lateral hip stabilizers or decreased hip mobility with a golfer who sways or slides during their swing. It also allows the medical provider to be able to discuss their findings with the player’s swing coach as they look to improve upon any injury inducing mechanics or be aware of functional deficits that may need to be intentionally compensated for such as turning the feet out to help improve one’s hip mobility in their swing. This patient was not currently working with a golf instructor; therefore, he was not able to fully address these characteristics. Ideally, each golfer would be working with a multidisciplinary team including a medical provider, golf professional, and fitness professional to maximize their results as this has been found to be the best approach for rehabilitation and prevention of further injury. Further research is necessary to fully understand how this comprehensive evaluation can enhance the rehabilitation approach to the golfing athlete with LBP.

LIMITATIONS

The single subject that is followed in a case report limits the conclusions that can be drawn according to the results, and
cause and effect cannot be assumed. This affects the utility of using this approach on other subjects with similar presentations. Exercise prescription related to the TPI screen may vary between treating therapists based on their own judgement and experience. There is no way to determine if other treatment approaches for this patient would have elicited similar results. The POC for this patient was also cut short due to the clinic closing amid COVID-19 restrictions which may have limited the overall progress that was observed.

CONCLUSION

The results of this case report indicate that the application of the TPI level one screen and a golf swing evaluation were helpful in providing functional movement screening during the initial evaluation and assisting with treatment selection in a golfing athlete with low back pain. In this case, the TPI level one screen and the swing evaluation allowed the therapist to learn more about how the patient’s body responded to the functional demands of his sport and identify areas where compensations were occurring that may not be identified with a traditional physical therapy exam. This case report demonstrated that utilizing TPI-based exam procedures as well as considering the principle of regional interdependence were effective contributors to the evaluation and treatment of the golfing athlete with low back pain.

CONFLICT OF INTEREST

The author reports no conflicts of interest.

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REFERENCES


4. Blackburn M, Gill L, Glass J. Titleist Performance Institute Level 1 Seminar. Presented at the: 2018 August 16-17; Dallas, TX.


18. George SZ, Fritz JM, Mcneil DW. Fear-avoidance beliefs as measured by the fear-avoidance beliefs questionnaire: Change in fear-avoidance beliefs questionnaire is predictive of change in self-report of disability and pain intensity for patients with acute low back pain. Clin J Pain. 2006;22(2):197-203. doi:10.1097/01.ajp.0000148627.92498.54


Background
Iliotibial Band Syndrome (ITBS) is a common clinical condition likely caused by abnormal compressive forces to the iliotibial band (ITB). Stretching interventions are common in ITBS treatment and may predominantly affect tensor fascia latae (TFL). Another ITBS treatment is foam rolling, which may more directly affect the ITB. Shear wave ultrasound elastography (SWUE) measures real-time soft tissue stiffness, allowing tissue changes to be measured and compared.

Purpose
To examine effects of foam rolling and iliotibial complex stretching on ITB stiffness at 0˚ and 10˚ of hip adduction and hip adduction passive range of motion (PROM).

Study Design
Randomized controlled trial.

Methods
Data from 11 males (age = 30.5 ± 9.0 years, Body Mass Index (BMI) = 27.8 ± 4.0) and 19 females (age = 23.5 ± 4.9, BMI = 23.2 ± 2.1) were analyzed for this study. Subjects were randomly assigned to one of three groups: control, stretching, and foam rolling. Shear wave ultrasound elastography measurements included ITB Young’s modulus at the mid-thigh, the distal femur and the TFL muscle belly. ITB-to-femur depth was measured at mid-thigh level. Hip adduction PROM was measured from digital images taken during the movement.

Results
No significant interactions or main effects were found for group or time differences in ITB Young’s modulus at the three measured locations. The ITB stiffness at the mid-thigh and distal femur increased with 10˚ adduction, but TFL stiffness did not increase. A main effect for adduction PROM was observed, where PROM increased 0.8˚ post-treatment (p = 0.02).

Conclusion
A single episode of stretching and foam rolling does not affect short-term ITB stiffness. The lack of ITB stiffness changes may be from an inadequate intervention stimulus or indicate that the interventions have no impact on ITB stiffness.
Levels of Evidence

1b

INTRODUCTION

Iliotibial band syndrome (ITBS) is a common clinical condition characterized by sharp, localized, lateral knee pain, often experienced around 30° of knee flexion during repetitive knee flexion-extension activities. This entity is reported to account for 10% of all lower extremity overuse syndromes in runners and up to 24% of all overuse syndromes in cyclists. The pain is often severe enough to result in activity discontinuation. The type of force causing impingement between the lateral femoral condyle and the iliotibial band (ITB) is debated. Several authors concluded that repetitive ITB movement in an anterior-posterior direction produced friction resulting in microtrauma. Conversely, Fairclough et al suggested that the ITB moves in a lateral to medial direction causing lateral knee compression forces. Increased ITB tissue stiffness may increase compression or friction forces along the lateral femoral epicondyle, potentially leading to ITB tissue irritation.

Previous authors have assessed structural changes associated with ITB complex stretching. These investigators questioned the ability of clinical stretching to produce lasting lengthening effects caused by ITB complex stretching maneuvers. In accordance, a study of in vitro ITB and tensor fascia latae (TFL) complex tissue specimens determined that significantly greater tissue elongation occurs in the proximal region hosting the TFL muscle during a simulated clinical stretch protocol, suggesting that elongation may be due to TFL elongation versus actual ITB lengthening. Data from that study indicated that the ITB tissue itself was not likely "stretched" during normal clinical stretching protocols. Seeber et al in a cadaveric investigation further confirmed this hypothesis. Despite the lack of ITB tissue elongation, global hip adduction ROM improves with hip adduction stretching maneuvers. TFL-related neuromuscular factors associated with interventions such as stretching and foam rolling might contribute to perceived clinical benefits and increased ROM following ITB stretching. These include easing symptoms that may decrease stiffness in the muscular system components.

An additional treatment commonly used for ITBS symptom management is foam rolling. Prior systematic reviews sought to determine foam rolling treatment effects on joint ROM post-exercise muscle recovery and performance. The findings revealed increased hip extension ROM after one week of foam rolling with return to baseline values after an additional week. Subjects reported pain reduction following foam roller treatment, although pain was reduced in both the treated and non-treated legs, which implies that a mechanism other than myofascial release is responsible for reduced pain responses. Despite this, other evidence supporting a potential role for myofascial release suggests it may contribute to reducing ITBS-related pain.

Various studies have investigated plastic, viscoelastic, and piezoelectric connective tissue property changes following myofascial release treatments. Trigger points, muscle contractures, and fascial adhesions are suggested to contribute to ITBS pain patterns. Therefore, foam rolling could be effective in "releasing" myofascial restrictions. However, a narrative literature review suggests this "release" phenomenon does not accurately describe the mechanisms associated with foam rolling. Instead, foam rolling might promote tissue warming, increasing pliability by transforming tissue into a more fluid-like form and eliminating fibrous adhesions between fascial layers, thus restoring soft tissue extensibility. Others have suggested that connective tissue may become denser with overuse, but it is unknown if this is related to alterations of collagen composition, fibroblasts, or ground substance. Ajimsha et al concluded that further evidence regarding the possible mechanism of action behind myofascial release is needed to make a logical basis for choosing it as an optimal intervention. An in vivo measurement of tissue stiffness using shear wave ultrasound elastography (SWUE) can potentially detect any changes associated with ITB stretching and foam rolling, thereby supporting the insufficient body of evidence surrounding myofascial release techniques.

SWUE is a non-invasive ultrasonographic imaging technique useful for evaluating soft tissue properties by measuring propagation velocity of shear waves produced in biological tissues and ultimately calculating the shear elastic modulus. Although studies regarding reliability, validity, and responsiveness of SWUE for the ITB and TFL are lacking, studies in similar tissues reveal that this method has good to excellent inter- and intra-operator reliability and that SWUE stiffness measurements correlate well with established testing methods. Previous studies have used SWUE to investigate ITB tissue changes in different loading positions and demonstrated a 32% increase in ITB stiffness during one-leg standing with increased hip and knee adduction. In a follow-up study, Tateuchi et al determined that ITB stiffness increased most with hip extension, adduction, and external rotation during a one-leg standing position. However, it is not known if the ITB stretch produced any change to tissue elastic properties when the tissue is returned to its resting length. Additionally, it is unknown whether elasticity changes occur when applying a foam rolling intervention.

The purpose of this study was to examine the effects of foam rolling and ITB stretching on ITB stiffness at 0° and 10° of hip adduction and hip adduction PROM. Hypotheses include the following: (1) resting ITB stiffness measured with SWUE will not change with clinical stretching techniques; and (2) resting ITB stiffness at 0° and 10° of hip adduction measured with SWUE will decrease with application of a foam rolling intervention.

METHODS

EXPERIMENTAL DESIGN

This study was a single blind, randomized controlled trial (RCT). The independent variables included (1) ITB intervention with three levels (control, stretching, and foam
The Immediate Effects of Foam Rolling and Stretching on Iliotibial Band Stiffness: A Randomized Controlled Trial

Table 1: Group demographics (mean and standard deviation) with male (M) and female (F) subjects in each group

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>BMI</th>
<th>Sex (M / F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam Rolling (n=10)</td>
<td>27.1 (6.5)</td>
<td>1.7 (0.1)</td>
<td>70.0 (13.4)</td>
<td>23.7 (3.2)</td>
<td>3 / 7</td>
</tr>
<tr>
<td>Stretching (n=10)</td>
<td>26.7 (8.6)</td>
<td>1.7 (0.1)</td>
<td>76.6 (14.8)</td>
<td>25.0 (2.9)</td>
<td>4 / 6</td>
</tr>
<tr>
<td>Control (n=10)</td>
<td>24.5 (7.2)</td>
<td>1.7 (0.1)</td>
<td>76.6 (19.6)</td>
<td>26.0 (4.6)</td>
<td>4 / 6</td>
</tr>
</tbody>
</table>

rolling), and (2) time with two levels (before intervention and immediately following intervention). The dependent variables included shear modulus (kilopascals, kPa) of the ITB at mid-thigh level and distal thigh level as well as the TFL; all measured at neutral (0˚) and 10˚ of hip adduction, and (2) hip adduction PROM.

PARTICIPANTS

The local institutional review board approved this study (# L19-076). An a priori power analysis to detect changes in stiffness was performed to determine the number of subjects to be included in each group. A previous study38 found a moderate effect size (Cohen’s d=0.53) for ITB stiffness between standing with and without hip adduction and contralateral pelvic drop. With alpha = 0.05 and a moderate effect size of Cohen’s d = 0.50, the number of subjects required to detect a statistically significant within-factors stiffness difference with power = 0.80 was 30 total subjects. To account for subject attrition and other potential errors, 36 total subjects were recruited from the university’s student and employee populations via posted notices of solicitation and in-class recruitment.

Study inclusion criteria included: (1) healthy males and females 18 to 50 years of age; (2) able to provide informed consent for participation. Exclusion criteria were: (1) history of ITB syndrome; (2) regular use of ITB complex stretching or foam rolling; (3) history of hip, knee, or lumbar spine surgery; (4) history of autoimmune disease including fibromyalgia or rheumatoid arthritis; (5) any neurological disease/disorder that impairs lower extremity function (e.g., spasticity) and/or sensation; (6) presence of skin lesions or skin rash on the involved lower extremity; (7) history of deep venous thrombosis; (8) hemophilia; (9) history of hip dysplasia.

Data from 11 males (age = 30.5 ± 9.0 years, Body Mass Index (BMI) = 27.8 ± 4.0) and 19 females (age = 23.5 ± 4.9, BMI = 23.2 ± 2.1) were analyzed for this study (Figure 1). All subjects provided informed consent before study participation.

EXPERIMENTAL PROTOCOL

Subjects were randomly assigned to either control (n=10), stretching (n=10), or foam rolling (n=10) groups (Table 1). The foam rolling group performed an ITB foam rolling technique described previously.15 Participants received video instruction regarding uniform foam roller use to standardize the training measures. A foam roller (OPTP PRO-Roller® Standard; OPTP Minneapolis, MN, USA) with medium firmness and smooth texture was used. Subjects were positioned with the body parallel to the floor and the foam roller placed between the floor and the left thigh. Pressure was adjusted by applying body weight to the roller and using the hands and feet to offset weight for balance as needed. The roller was positioned with its long axis perpendicular to the long axis of the left thigh at the target tissue area (ITB). The subject rolled over the foam roller, where the body was moved back and forth across the foam roller from the greater trochanter to the lateral femoral epicondyle. Participants were instructed to practice up to three times with investigator guidance to achieve the correct foam rolling technique required for this study. Then, the technique was performed on the target tissue using short, kneading-like motions along the length of the tissue and then quickly rolling back to the starting position in one fluid motion. This was repeated for 1-minute, followed by a 30-second rest period and performed for five total repetitions.30 Investigators provided feedback to participants regarding correct foam roller technique as needed.

The stretching group performed a stretch described by Fredericson et al15 with a modification of hip external rotation according to Teteuchi et al38. Subjects began by standing upright with the target left leg placed in a hip extended, externally rotated, and adducted position behind the other leg (i.e., right leg). Subjects raised and clasped their hands overhead, inhaled and slowly flexed the trunk in a direction lateral to the opposite side. This motion was continued until an uncomfortable stretch was felt around the greater trochanter of the treatment side hip or until further motion was not possible. Investigators ensured proper positioning for effective ITB complex stretching. The stretch was performed in three bouts of a 7-second submaximal contraction in hip abduction followed by a 15-second stretch.14 Each bout was followed by 30-second rest interval and 5 total bouts were performed.

Subjects in the control group were placed on a treatment table in supine with the hip in neutral rotation for five minutes between measurements.

The left lower extremity was tested due to laboratory setup requirements and limitations in moving the ultrasound device and cameras between each subject. Researchers were blinded to the assigned intervention and the same researchers examined pre- and post-intervention outcomes. Prior to the intervention, tissue stiffness was measured three times at neutral hip adduction (0˚) and 10˚ of hip adduction with the subject in supine. Pilot testing showed that 10˚ of hip adduction was sufficient to demonstrate SWUE changes. These measurements were repeated within 10 minutes following the randomized intervention. In addition, hip PROM was recorded pre- and post-inter-
SWUE measures a soft tissue’s stiffness as Young’s modulus (kPa). Minimal detectable change for muscle and tendon tissue, respectively, is 1.72 kPa and 32.90 kPa. An Aixplorer (SuperSonic Imagine, Version 10.0, Aix-en-Provence, France) ultrasound system measured the ITB Young’s modulus at three anatomical locations: (1) lateral mid-thigh, (2) lateral thigh at the level of the patella’s superior border, and (3) TFL (Figure 2a and 2b). The two ITB points were measured with a 15–4 MHz linear transducer with the "Tendon" setting. The TFL was measured halfway between the anterior superior iliac spine (ASIS) and the femoral greater trochanter (10-2 MHz linear transducer with a "Muscle" setting). The mid-thigh location was halfway between the greater trochanter and lateral femoral epicondyle. The transducer was placed along the long axis at each location.

HIP ADDUCTION RANGE OF MOTION

Hip adduction PROM was determined in real time using an electrogoniometer (Noraxon Ultium, USA). End range hip adduction PROM measurements were performed from video taken from a ceiling-mounted camera (GoPro, Hero5) and analyzed visually.

Markers were placed on bony landmarks at the ASIS bilaterally and on the left lower limb’s patella midline for photographic measurement. End range hip adduction was measured by evaluating when ASIS first began to move. Subjects were placed supine on a plinth, where the contralateral leg was held in a flexed knee position over the measurement leg allowing for full hip adduction.

RESULTS

There were no statistically significant differences among the three groups for age (p = 0.57), height (p = 0.76), or body mass (p = 0.96). No significant interactions or main effects were found for Group or Time differences in ITB complex tissue Young’s modulus at the mid-thigh, the superior border of the patella, or the TFL at 0° or 10° of hip adduction (Table 2).
Figure 2: Shear wave elastography and B-mode ultrasound images at each location, at 0° and 10° adduction. TFL = tensor fascia latae.
Table 2: Interaction and main effects of time (pre- and -post intervention) and group on stiffness (kPa) of the iliotibial band complex at the level of the patella and mid-thigh and the tensor fascia latae (TFL) at 0° and 10° hip adduction. Data presented as mean (SD).

<table>
<thead>
<tr>
<th>Position and Location</th>
<th>Time by Group Interaction</th>
<th>Time Main Effect</th>
<th>Group Main Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Main Effect</td>
<td>Group Main Effect</td>
<td></td>
</tr>
<tr>
<td>Patella Pre</td>
<td>Control* (n=10)</td>
<td>Stretching* (n=10)</td>
<td>Foam Rolling* (n=10)</td>
</tr>
<tr>
<td></td>
<td>257.9 (130.2)</td>
<td>182.2 (160.0)</td>
<td>233.0 (180.8)</td>
</tr>
<tr>
<td></td>
<td>247.3 (140.7)</td>
<td>171.9 (152.8)</td>
<td>232.5 (143.4)</td>
</tr>
<tr>
<td></td>
<td>218.1 (96.3)</td>
<td>231.8 (117.6)</td>
<td>283.1 (111.6)</td>
</tr>
<tr>
<td></td>
<td>216.6 (91.9)</td>
<td>244.9 (82.4)</td>
<td>259.3 (92.4)</td>
</tr>
<tr>
<td></td>
<td>24.4 (7.3)</td>
<td>22.9 (6.3)</td>
<td>23.3 (8.0)</td>
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<td></td>
<td>25.3 (4.1)</td>
<td>21.5 (7.3)</td>
<td>25.3 (7.8)</td>
</tr>
<tr>
<td>Thigh Pre</td>
<td>247.0 (130.1)</td>
<td>321.5 (180.3)</td>
<td>380.0 (178.5)</td>
</tr>
<tr>
<td></td>
<td>393.0 (74.5)</td>
<td>361.4 (109.7)</td>
<td>383.3 (84.3)</td>
</tr>
<tr>
<td></td>
<td>403.5 (90.2)</td>
<td>360.5 (126.1)</td>
<td>405.2 (91.3)</td>
</tr>
<tr>
<td></td>
<td>25.0 (7.9)</td>
<td>24.5 (10.4)</td>
<td>21.8 (4.2)</td>
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<tr>
<td></td>
<td>24.8 (4.6)</td>
<td>22.1 (6.7)</td>
<td>23.4 (7.5)</td>
</tr>
</tbody>
</table>

*Data are presented as mean (SD).
Table 3: Interaction and main effects of time (pre- and post intervention) and group on iliotibial band to femur depth (cm) at 0° and 10° hip adduction and hip adduction PROM (degrees). Data presented as mean (SD).

<table>
<thead>
<tr>
<th>Position and Location</th>
<th>Control* (n=10)</th>
<th>Stretching* (n=10)</th>
<th>Foam Rolling* (n=10)</th>
<th>Time by Group Interaction</th>
<th>Time Main Effect</th>
<th>Group Main Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F-Value</td>
<td>p-Value</td>
<td>Effect Size (Ƞp2)</td>
</tr>
<tr>
<td>Hip Adduction Pre</td>
<td>6.97 (2.55)</td>
<td>7.30 (3.18)</td>
<td>8.07 (3.49)</td>
<td>0.32</td>
<td>0.73</td>
<td>0.023</td>
</tr>
<tr>
<td>Hip Adduction Post</td>
<td>7.57 (2.10)</td>
<td>8.50 (2.65)</td>
<td>8.77 (3.09)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Statistically significant Bonferroni-corrected p value.
For hip adduction PROM, no significant interactions were observed. A significant main effect was found for Time, where the mean adduction PROM was 0.8˚ greater post-treatment. Additionally, the Group main effect difference was nonsignificant (Table 3).

DISCUSSION

This study examined ITB and TFL complex stiffness at 0˚ and 10˚ hip adduction before and immediately following one of three interventions: ITB foam rolling, stretching, or no intervention.

Neither the stretching intervention nor foam rolling altered ITB or TFL stiffness. These results suggest that tissue stiffness does not change with short term static stretching interventions or foam rolling; however, the intervention duration might have been insufficient to elicit tissue change or indicates that the interventions have no impact on healthy subjects ITB and TFL tissue stiffness. Another possibility is that multiple interventions are required. The myofascial plasticity theory may be a reasonable explanation for the lack of stiffness changes in the current study. 25 Tissue changes occur slowly over time and therefore, may require additional time and intervention repetition to demonstrate changes in ITB stiffness. Wilke et al 49 found that anterior thigh stiffness did not change immediately following foam rolling, but decreased after 5 and 10 minutes.

Hip adduction PROM improved post-intervention. However, this change was only 0.8˚ and occurred in the control group as well as the two intervention groups, suggesting that it may be due to measurement error and is likely not clinically relevant.

Future research should consider recruiting from a symptomatic population. Doing so may assess whether these results change when pathology is present. This could provide information on the effect of pain on clinical measures of ROM, muscular force production, and end range mobility. Finally, evaluating a longer treatment interval time is necessary to assess changes in these variables with long-term interventions.

CONCLUSION

The study findings indicate no effect of stretching and foam rolling on short-term ITB stiffness in vivo in healthy subjects, thus supporting previous cadaveric ITB stretching studies. 9,10 Single bouts of foam rolling and stretching do not change ITB stiffness in healthy subjects and may have limited value in reducing ITB compression. The lack of ITB stiffness changes may be from an inadequate intervention stimulus or indicate that the interventions have no impact on ITB stiffness.

CONFLICT OF INTEREST

None of the authors have any conflicts of interest to report.

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REFERENCES


Background
Approximately 24% of physical therapists report regularly using yoga to strengthen major muscle groups. Although clinicians and athletes often use yoga as a form of strength training, little is known about the activation of specific muscle groups during yoga poses, including the gluteus maximus and medius.

Hypothesis/Purpose
The purpose of this study was to measure gluteus maximimus and gluteus medius activation via electromyography (EMG) during five common yoga poses. A secondary purpose of the current study was to examine differences in muscle activation between sexes and experience levels.

Study Design
Cross-Sectional

Methods
Thirty-one healthy males and females aged 18-35 years were tested during five yoga poses performed in a randomized order. Surface EMG electrodes were placed on subjects’ right gluteus maximus and gluteus medius. Subjects performed the poses on both sides following a maximal voluntary isometric contraction (MVIC) test for each muscle. All yoga pose EMG data were normalized to the corresponding muscle MVIC data.

Results
Highest gluteus maximus activation occurred during Half Moon Pose on the lifted/back leg (63.3% MVIC), followed by the stance/front leg during Half Moon Pose (61.7%), then the lifted/back leg during Warrior Three Pose (46.1%). Highest gluteus medius activation occurred during Half Moon Pose on the lifted/back leg (41.9%), followed by the lifted/back leg during the Warrior Three Pose (41.6%). A significant difference was found in %MVIC of gluteus medius activity between male and female subjects (p = 0.026), and between experienced and inexperienced subjects (p = 0.050), indicating higher activation among males and inexperienced subjects, respectively.

Conclusion
Half Moon Pose and Warrior Three Pose elicited the highest activation for both the gluteus maximus and the gluteus medius. Higher gluteus medius activation was seen in males and inexperienced subjects compared to their female and experienced counterparts.

Level of Evidence
3
INTRODUCTION

Yoga is an ancient discipline involving physical, mental, emotional, and spiritual training. It includes dynamic and static postures, breathing techniques, meditation, and relaxation methods that aim to improve body-mind awareness.\(^1\) Yoga has also been used as a form of treatment for chronic low back pain with moderate efficacy,\(^2\) although there has been little research on which poses are best suited for alleviating low back pain.

Yoga has become increasingly popular in the prior two decades. Among other common complementary health approaches, yoga was the most used and growing in popularity from 2002 to 2012.\(^3\) Yoga participation saw an increase in participation from the 18-44 age group in the United States between the years 2007 to 2012 (7.9% to 11.2%), and twice the increase it saw between 2002 and 2007.\(^3\) Approximately 24% of physical therapists in one survey (N = 153) reported regularly using yoga to strengthen major muscle groups at moderate or high intensity.\(^4\) Although physical therapists use yoga as a form of strength training, little is known about the activation of specific muscle groups during yoga poses, especially that of the gluteus maximus and gluteus medius.

Gluteal muscle strength is correlated with low back pain. Cooper et al.\(^5\) discovered a significant decrease in gluteus medius strength in subjects with low back pain compared to a control group. Kumar et al.\(^6\) concluded that gluteus maximus strengthening combined with core muscle strengthening and lumbar flexibility can be an effective intervention for low back pain. Similarly, Jeong et al.\(^7\) reported that strengthening the gluteal and abdominal muscles reduces low back pain, increases stabilization of the lower trunk, and improves balance more effectively than strengthening the abdominal muscles alone. Furthermore, people with gluteus medius weakness have more chronic low back pain as well as increased adduction and internal rotation in the hip joint during walking, potentially leading to knee injury.\(^5,8,9\) Gluteal strengthening aids in pain relief, improves gait patterns in patients after menisceus surgeries, and may also prevent lower extremity injuries in college athletes.\(^10,11\)

In previous studies performing electromyographic (EMG) analysis of yoga poses, none have examined both gluteus medius and maximus activity across the five poses selected for this study (Tree, Warrior Two, Warrior Three, Half Moon, and Bird Dog). These poses were chosen because of their relative simplicity and low range of motion demands compared to other poses. They were also chosen because the position of the hip during these common poses was expected to elicit significant gluteal activation. The gluteus medius has been examined in each of these five poses at least once, but further study is warranted to confirm these findings.\(^12-15\) No study has examined gluteus maximus activation during Warrior Three Pose or Half Moon Pose, which were expected to elicit the highest gluteal activation.

As a control pose, this study was to measure gluteus maximus and gluteus medius activation via electromyography (EMG) during five common yoga poses. Identification of the poses that have the highest gluteal activation will help guide exercise selection and prescription.

The differences between male and female trunk and hip muscle activation during yoga poses has been investigated by one study that found females demonstrated higher activity compared to males.\(^16\) A secondary purpose of the current study was to examine differences between sexes and experience levels. It was hypothesized that experienced and female subjects would have higher average gluteal activation compared to inexperienced and male subjects, respectively.

METHODS

Thirty-one healthy subjects (18 female, 13 male) between 18 and 35 years of age (mean age = 24.0 years; height = 1.7 m; weight = 74.7 kg) were recruited from a local university for this cross-sectional study. Subjects completed a survey to determine their classification of either inexperienced or experienced, which was defined as performing yoga directed by a certified yoga instructor one or more times in the prior year. Seven out of thirty-one (22.6%) were classified as experienced. Subjects completed an informed consent form and health questionnaire approved by the study institution’s Internal Review Board (IRB) for the protection of human subjects prior to testing. Potential subjects were excluded if they had any of the following: an upper or lower extremity injury requiring attention from a medical professional within the prior six months; an upper or lower extremity surgery within the prior year; current lower or upper extremity pain; history of any heart condition; or current pregnancy.

Prior to data collection, subjects were familiarized with the testing procedures, including a stationary bicycle warm-up, EMG electrode placement, MVIC testing, and the selected yoga poses. Subjects were asked to remove shoes and socks and perform the yoga poses on a standard yoga mat. Subjects underwent one familiarization trial for each of the five poses as shown in Figures 1-5. The descriptions in the table refer to the use of a right stance/forward leg, although both sides were tested.

As a warm-up, subjects pedaled a stationary bicycle for two minutes at a work rate of 60 Watts. Following the warm-up, the skin was shaved and abraded with alcohol wipes, and bi-polar wireless surface EMG electrodes (Noraxon, Scottsdale, AZ) were placed on the right gluteus maximus and right gluteus medius of each subject. No significant differences in muscle activity were noticed previously between sides in healthy individuals.\(^15\) One female researcher placed electrodes on all female subjects, and one male researcher placed electrodes on all male subjects. Electrode placement followed that of similar studies and standard practice.\(^17,18\) (Table 1)

Muscle MVIC testing was then performed on the right gluteus maximus followed by the right gluteus medius. A strap attached to an immobile object was used to standardize resistance during MVIC testing. Subjects were positioned prone with the knee flexed to 90 degrees and the strap resistance was placed at the distal femur to test the gluteus maximus. For the gluteus medius, subjects were in
Table 1: Descriptions of electrode placement on the gluteus maximus and gluteus medius.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Electrode Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus Maximus</td>
<td>Midway between the lateral border of the sacrum and the posterosuperior edge of the</td>
</tr>
<tr>
<td></td>
<td>greater trochanter on the muscle belly</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>Anterosuperior to the gluteus maximus, inferior to the lateral aspect of the iliac</td>
</tr>
<tr>
<td></td>
<td>crest on a line towards the greater trochanter on the muscle belly</td>
</tr>
</tbody>
</table>

Table 2: Descriptions of subject positions and sites of resistance for maximal voluntary isometric contractions

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Subject Position</th>
<th>Site of Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus Maximus</td>
<td>Prone with the knee flexed to 90°</td>
<td>Distal femur</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>Side lying with the hip to be tested nearest to the ceiling, abducted to</td>
<td>Proximal to the ankle</td>
</tr>
<tr>
<td></td>
<td>end-range, and slightly extended</td>
<td></td>
</tr>
</tbody>
</table>

Subjects completed two MVIC trials for each muscle. Subjects were asked to perform each MVIC for seven seconds, with 30 seconds of rest between each trial. All surface EMG data were collected at 4000 Hz using a Noraxon 880-16 Ultium Dash/ESP 16 Myomuscle and MyoMuscle 3.12 software (Noraxon, Scottsdale, AZ). Peak MVIC values for each subject and muscle were identified as the maximum value of a 50-millisecond moving average within the two corresponding MVIC trials and visually verified using custom written code (Matlab, The Mathworks, Natick, MA).

Each subject performed Tree Pose (Figure 1), Warrior Two Pose (Figure 2), Warrior Three Pose (Figure 3), Half Moon Pose (Figure 4), and Bird Dog Pose (Figure 5) on a standard mat as instructed by a certified yoga instructor using a standardized script. During Half Moon Pose, subjects were allowed to use a standard yoga block if needed (sturdy foam 9” by 6” by 4”). The order in which the poses were tested was randomized, and the subjects were blinded to the EMG activity levels. Subjects performed one trial of each pose bilaterally, holding the pose for seven seconds. For each pose and each side, five seconds of EMG data excluding the first and last second were analyzed. All pose EMG data were rectified and filtered using a 15 Hz high-pass and 500 Hz low pass fourth-order Butterworth digital filter. The filtered pose EMG data were then smoothed with a 150-millisecond mean absolute algorithm and normalized to the corresponding peak MVIC value. The maximum values from the smoothed and normalized EMG data (i.e., %MVIC) from each subject (31), muscle (2), pose (5), and leg (2) were identified and recorded (620 peaks total) for analysis. As a method previously used for interpretation, the following ranges were used for %MVIC data: low (0-20% MVIC); moderate (21-40% MVIC); high (41-60% MVIC); very high (higher than 60% MVIC).

The mean and standard deviation of the maximum %MVICs were calculated and analyzed. Independent t-tests (α = 0.05) to examine differences between males and females and between subjects who had participated in yoga in
the past year (experienced) and those who had not (inexperienced) were performed for each muscle tested in the five poses. SPSS v23.0 (SPSS Inc, Chicago, IL) were used for data analysis.

RESULTS

Data from thirty-one subjects were included. (Table 3) No significant difference was found in the measured mean %MVIC of gluteus maximus activity between male (33.3 ± 38.2) and female (27.8 ± 25.3) subjects (p = 0.133), or between experienced (26.8 ± 25.1) and inexperienced (30.9 ± 31.5) subjects (p = 0.328). However, a significant difference was found in the measured mean %MVIC of gluteus medius activity between male (11.6 ± 13.6) and female (9.3 ± 6.9) subjects (p = 0.026), and between experienced (7.8 ± 6.4) and inexperienced (10.6 ± 11.1) subjects (p = 0.050), indicating more gluteus medius activation among males than females, and more activation among inexperienced versus experienced subjects.

Greatest gluteus maximus activation occurred during Half Moon Pose on the lifted/back leg (63.3% MVIC), followed by Half Moon Pose on the stance/front leg (61.7% MVIC), then on the lifted/back leg during Warrior Three Pose (46.1% MVIC). The highest gluteus medius activation was recorded during Half Moon Pose on the lifted/back leg (41.8% MVIC), followed by Warrior Three Pose on the lifted/back leg (41.6% MVIC). Means and standard deviations of the EMG activity expressed as the %MVIC for each analyzed muscle in each of the five yoga poses are listed in Table 4, and presented in Figure 6.

DISCUSSION

The primary purpose of this study was to determine the gluteus maximus and gluteus medius activation during five common yoga poses. The electrode placement and EMG analysis procedures of this study were similar to those used in previous studies.17,18 Exercises that generate moderate EMG activity (21-40% MVIC) have been proposed to produce a stimulus that will improve muscle endurance, whereas those generating high and very high EMG activity (41-60% MVIC and higher than 61% MVIC, respectively) have been proposed to produce an appropriate stimulus to induce strength gains.18 A key finding from this study is that the Half Moon and Warrior Three poses can serve as strengthening stimuli for both the gluteus maximus and gluteus medius muscles.

The secondary purpose of this study was to examine whether there was a significant difference between gluteus medius and gluteus maximus activation between male and female subjects and experienced and inexperienced subjects. There was not a significant difference in gluteus maximus activation between inexperienced and experienced or male and female subjects. But a significant difference in gluteus medius activation was found between male and female subjects and between experienced and inexperienced subjects. Males produced higher %MVIC of gluteus medius activity than females, and inexperienced subjects demonstrated higher gluteus medius activation than experienced subjects. Body weight distribution differences between

International Journal of Sports Physical Therapy
Table 3: Subject demographics including age, height, weight, and yoga experience

<table>
<thead>
<tr>
<th></th>
<th>Mean ± Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>23.97 ± 3.29 years</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td>18 female, 13 male</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>1.70 ± 0.08 meters</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>74.72 ± 15.78 kilograms</td>
</tr>
<tr>
<td><strong>Performed yoga from a certified yoga instructor in the past year</strong></td>
<td>22.58% (7/31)</td>
</tr>
</tbody>
</table>

Table 4: Electromyographic activity of gluteus maximus and gluteus medius during five yoga poses.

<table>
<thead>
<tr>
<th></th>
<th>Gluteus Maximus (Mean ± SD of %MVIC)</th>
<th>Gluteus Medius (Mean ± SD of %MVIC)</th>
<th>Pose Position Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stance/ Front Leg</td>
<td>Lifted/ Back Leg</td>
<td>Stance/ Front Leg</td>
</tr>
<tr>
<td><strong>Tree Pose</strong></td>
<td>12.9 ± 8.9</td>
<td>29.0 ± 17.2</td>
<td>11.5 ± 10.9</td>
</tr>
<tr>
<td><strong>Warrior Two Pose</strong></td>
<td>12.9 ± 8.7</td>
<td>11.8 ± 9.6</td>
<td>7.7 ± 5.9</td>
</tr>
<tr>
<td><strong>Warrior Three Pose</strong></td>
<td>43.6 ± 32.2</td>
<td>46.1 ± 25.4</td>
<td>27.9 ± 23.1</td>
</tr>
<tr>
<td><strong>Half Moon Pose</strong></td>
<td>61.7 ± 43.4</td>
<td>63.3 ± 49.0</td>
<td>37.1 ± 51.8</td>
</tr>
<tr>
<td><strong>Bird Dog Pose</strong></td>
<td>13.1 ± 13.1</td>
<td>37.3 ± 26.8</td>
<td>11.7 ± 10.3</td>
</tr>
</tbody>
</table>

MVIC= maximal voluntary isometric contraction; SD= standard deviation.

sexes may account for the difference between males and females. The difference between experience levels may be explained by the possibility that experienced subjects might adopt a more relaxed and muscurally efficient posture with decreased muscle activation due to improved balance.

**TREE POSE**

Electromyographic activity for the gluteus medius during Tree Pose (Figure 1) was lower than expected. Wang et al. recorded mean gluteus medius EMG activity as 24.6% MVIC on the stance leg during a modified version of Tree Pose with older adults (mean age 70.7 years) who received 32
Figure 6: Mean EMG activity of the gluteus maximus and gluteus medius during yoga poses

weeks of training. This was higher activation than the value found in the current study for the stance leg (11.5% MVIC) which may be due to the age and experience level differences between the subjects in the two studies. The lifted leg during the Tree Pose in the current study demonstrated 18.6% MVIC gluteus medius activation on average, for which there are no current literature comparisons. This level of activation does not reach the threshold for moderate activation that would make Tree Pose suitable for developing strength in the gluteus medius. These results were unexpected as Tree Pose seems likely to specifically activate the gluteus medius due to its leveling action on the pelvis that occurs during single-leg stance. One possible explanation for this unexpected finding is that subjects were not cued to maintain a level pelvis and consequently might have been resting on hip soft tissues in a position of contralateral hip drop instead of a level pelvis position that required stronger gluteus medius activation.

Gluteus maximus EMG activity was higher than gluteus medius activity for both the stance leg (12.9% MVIC) and lifted leg (28.9% MVIC). To the authors' knowledge, no studies have determined gluteus maximus activation during Tree Pose.

WARRIOR TWO POSE

In Warrior Two Pose (Figure 2), the front and back leg demonstrated low levels of gluteus medius activity (7.7% MVIC and 10.5% MVIC, respectively). These values are lower than those found by Wang et al. for the leading or front leg (16.4% MVIC); however, the trailing or back leg demonstrated similar activation (9.4% MVIC). Wang et al. used subjects with an average age of 70.7 years and included a certified yoga instructor performing the poses alongside the subjects, whereas the current study had the instructor reading standardized instructions to much younger subjects. This common pose is a double-limb stance pose, so it was not expected to produce large EMG activity for gluteus medius.

Gluteus maximus EMG activity during Warrior Two Pose was similar but higher than gluteus medius activity for both the front leg (13.0% MVIC) and back leg (11.8% MVIC). Bezazley et al. examined gluteus maximus activity during Warrior Two Pose in untrained yoga subjects and also found low activation of the gluteus maximus at a level of 18.9% MVIC on the dominant side and 20.4% MVIC on the non-dominant side. The authors mentioned those with more yoga experience may have more activation of the gluteus maximus compared to relatively inexperienced subjects because those with experience learned to engage the muscles required for stabilization to a higher degree. The current study did not recruit based on yoga experience, and seven of the 51 subjects reported participating in yoga with a certified instructor the prior year. The relatively small number of experienced subjects recruited for the current study may account for the insignificant difference in gluteus maximus activity between experienced and inexperienced subjects.

WARRIOR THREE POSE

It was expected that Warrior Three Pose (Figure 3) would produce high EMG activity in both the gluteus medius and the gluteus maximus given its use of single-leg stance, a lower extremity extended against gravity, and a horizontal trunk held against gravity by the stance leg. Gluteus medius EMG activity was higher in the lifted/back leg (41.6% MVIC) compared to the stance/front leg (27.9% MVIC). In a study by Kelley et al., there was similar moderate gluteus medius activation (30% MVIC) for the stance leg during Warrior Three Pose. Those authors studied experienced practitioners who had at least five years of yoga experience and practiced a minimum of two times per week.

No literature was found about EMG activation of gluteus maximus during Warrior Three Pose. This pose has similar characteristics to the single-limb deadlift studied by Boren et al. who found gluteus maximus EMG activity to be 58.9%
MVIC on the stance leg. That level of gluteus maximus activation for the Warrior Three Pose is higher than the activation level seen in the current study (43.6% MVIC of the stance/front leg and 46.1% of the lifted/back leg). The differences seen may relate to the difference between the yoga pose and the deadlift. Warrior Three Pose requires the upper extremities to be lifted next to the ears while the single-limb deadlift allows one hand to reach toward the floor, potentially increasing trunk and hip flexion, affecting hip extensor activation. Also, the single-limb deadlift allowed subjects to have the knees straight or bent, and the exercise was not statically held like the Warrior Three Pose. During the deadlift, subjects moved through a range of motion, and data collected for %MVIC were based on the highest peak value of three repetitions during the middle 3/5ths of the time to perform the exercise, which could explain the 15% difference in gluteus maximus activation.

HALF MOON POSE

Half Moon Pose (Figure 4) was expected to also have high EMG activation of the both the gluteus medius and the gluteus maximus. Activity of the gluteus medius during the Half Moon Pose was higher than all poses in the current study on the lifted/back leg (41.9% MVIC). The stance/front leg showed 37.2% MVIC for the gluteus medius. This was higher than the 25-30% MVIC for the gluteus medius found by Kelley et al. for the stance leg during the Half Moon Pose. The moderate demand for gluteus medius activity is likely due to the hip abduction, single-leg stance, and balance requirements during this pose.

There was no prior research found for gluteus maximus activation during Half Moon Pose. As expected, this pose had one of the highest gluteus maximus activation values for the stance/front leg (61.7% MVIC) as well as the lifted/back leg (63.3% MVIC). The very high activation of gluteus maximus during Half Moon Pose may be due to the bilateral hip external rotation requirement while holding the raised leg and trunk against gravity. The very high gluteus maximus activation during this pose on both legs may be beneficial as a strengthening stimulus.

BIRD DOG POSE

Bird Dog Pose (Figure 5), sometimes referred to as a quadruped arm and leg lift, elicited low to moderate activity of the gluteus medius (11.7% MVIC and 23.1% MVIC for the stance/front and lifted back legs, respectively). Ekstrom et al. did not study activity in the stance/front leg, but they found almost twice as much gluteus medius activity (42% MVIC) on the lifted/back leg. This difference in activation of the gluteus medius may be due to the number of practice trials allowed. Subjects in the current study performed one familiarization trial, while subjects were allowed an unspecified number of familiarization trials in the study by Ekstrom et al. Small and unreported differences in electrode placement may also contribute to the difference between studies.

The current study found moderate activation of the lifted/back leg (37.3% MVIC) and low activation of the stance/front leg (13.1% MVIC) for the gluteus maximus during the Bird Dog Pose, suggesting it could be an appropriate stimulus for endurance training but not strength training. Ekstrom et al. found 56% MVIC for the gluteus maximus of the lifted/back leg. This difference in activation levels could be due to the aforementioned study differences as well as foot positioning. In the current study, subjects were instructed to point the toes towards the floor, potentially increasing anterior leg muscle activity and subsequently decreasing posterior leg muscle activity. Although not specified by Ekstrom et al., the figure used to demonstrate the exercise demonstrates the use of ankle plantarflexion during the Bird Dog Pose, potentially increasing activity of posterior lower extremity muscles including the gluteus maximus.

LIMITATIONS AND FUTURE RESEARCH

In the current study, the order of yoga poses was randomized, and both the researchers and subjects were blinded when possible, yet limitations remain. It is possible that subjects did not generate a true MVIC of each muscle tested due to lack of effort or suboptimal positioning. Attempts were made to minimize these potential limitations by standardizing instructions to subjects, standardizing pose positioning methods, and using MVIC testing methods consistent with previous studies.

The most effective method for instructing yoga poses has not yet been examined. The use of standardized instruction to subjects instead of individualized instruction may have limited gluteal activation in the current study. Gluteal muscle activity during yoga poses was not studied in subjects with pathology, so generalizing results to an injured population should be avoided. Future research should examine the effects of strength training using the Half Moon Pose and Warrior Three Pose. Examination of their effects on pathology and performance is also warranted.

CONCLUSION

The results of the current study indicate that the Half Moon Pose and Warrior Three Pose had the highest activation for the gluteal muscles studied in healthy young adults with variable yoga experience. The high to very high activation levels found indicates that both of these poses have the potential to provide strengthening stimuli. Higher gluteus medius activation was demonstrated by males compared to females, and by inexperienced subjects compared to experienced subjects. The information from this study can help coaches, athletes, yoga instructors, and clinicians determine which yoga poses to consider for gluteal strengthening or endurance exercises.

CONFLICT OF INTEREST

There are no potential conflicts of interests, including financial arrangements, organizational affiliations, or other relationships that may constitute a conflict of interest regarding the submitted work.
REFERENCES


Original Research

Biomechanical Changes During a 90º Cut in Collegiate Female Soccer Players With Participation in the 11+

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Keywords: injury, knee, training

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Background

Valgus collapse and high knee abduction moments have been identified as biomechanical risk factors for ACL injury. It is unknown if participation in the 11+, a previously established, dynamic warm-up that emphasizes biomechanical technique and reduces ACL injury rates, reduces components of valgus collapse during a 90º cut.

Hypothesis/Purpose

To determine whether participation in the 11+ during a single soccer season reduced peak knee abduction moment and components of valgus collapse during a 90º cut in collegiate female soccer players.

Study Design

Prospective cohort study

Methods

Forty-six participants completed preseason and postseason motion analysis of a 90º cut. During the season, 31 players completed the 11+ and 15 players completed their typical warm-up (control group). Peak knee abduction moment, components of valgus collapse (hip adduction, internal rotation, and knee abduction angles), and a novel measure of knee valgus collapse were analyzed with repeated-measures ANOVAs to determine differences between preseason and postseason. Smallest detectable change (SDC) and minimal important difference (MID) values were applied to contextualize results.

Results

There was a significant main effect of time for non-dominant knee valgus collapse (p=0.03), but decreases in non-dominant knee valgus collapse only exceeded the SDC in the intervention team.

Conclusions

Clinically meaningful decreases in knee valgus collapse may indicate a beneficial biomechanical effect of the 11+. Participation in the 11+ may lower ACL injury risk by reducing valgus collapse during a 90º cut.

Level of Evidence

2b
INTRODUCTION

Nearly 30 million women play soccer worldwide\(^1\), while approximately 27,000 women play collegiate soccer in the United States.\(^2\) Collegiate female soccer players incur anterior cruciate ligament (ACL) injuries at more than double the rate of men.\(^3–5\) Of these injuries, most occur via a non-contact mechanism.\(^6\) Landing with the knee extended and in dynamic valgus during an abrupt or unexpected pivoting or cutting maneuver have been cited as frequent components of non-contact ACL injuries.\(^6–9\) Poor neuromuscular control, including dynamic knee valgus, is also believed to be a modifiable risk factor contributing to the increased incidence of non-contact ACL injuries in female soccer players.\(^10\)

A variety of neuromuscular training programs have been designed to address strength and neuromuscular control deficiencies and reduce injury risk in female athletes.\(^11–13\) Common components of effective neuromuscular training programs include high intensity plyometrics, strength training, and an emphasis on exercise technique.\(^12,14\) A systematic review of the efficacy of neuromuscular training programs on the rate of ACL injuries by Sugimoto et al. reported a 73.4% relative risk reduction for non-contact ACL injuries in female athletes participating in neuromuscular training programs.\(^15\) The 11+ (previously known as the FIFA11+) is a program designed to be a comprehensive, time effective, warm-up program for soccer players that addresses key components of neuromuscular training including lower extremity strengthening and dynamic balance exercises.\(^15\) Furthermore, the 11+ emphasizes soft landings with plyometrics and maintaining proper lower extremity alignment throughout the program, but can be implemented by coaches with minimal training.\(^15\) The 11+ has also been established as an effective program for reducing ACL injuries in soccer players.\(^16,17\) An initial randomized control trial of the 11+ demonstrated a reduction of severe lower-extremity injury by 50% in female athletes, and additional studies have demonstrated a decrease in ACL injuries among male soccer players.\(^16,17\) Although the 11+ is effective in reducing non-contact ACL injury rates, the mechanism by which participation in the program reduces injury, and whether participation alters a player’s movement patterns on the field, is unclear.

Previous studies have sought to examine biomechanical changes following participation in the 11+ using a vertical drop jump. Collegiate female soccer players performing the 11+ for two consecutive seasons demonstrated greater knee flexion angle with drop jump landings compared to players completing a standard warm-up. However, players demonstrated no changes in kinematics related to lower extremity valgus.\(^18\) Pre-adolescent soccer players performing the 11+ for a single season demonstrated significant decreases in knee abduction moment during a double legged landing task when compared to control subjects completing a standard warm-up.\(^19\) Although bilateral tasks like the drop jump have been used in several studies as a biomechanical screening tool, it has also been suggested that a more sport-specific or challenging task may be needed to screen for ACL injury risk.\(^20\)

Cutting is a movement pattern that soccer players frequently execute, and is the second most common mechanism of non-contact ACL injury among female soccer players.\(^21\) An epidemiological study of players in the German women’s national league reported that 22% of traumatic, noncontact injuries were the result of cutting. Furthermore, 7 of 11 total ACL injuries recorded in this epidemiological study were the result of a change in direction.\(^22\) Female soccer players who underwent ACL reconstruction (ACLR) have been shown to have significantly higher knee abduction angles and knee abduction moments than uninjured players while completing an anticipated cut to 45°.\(^23\) Although no normative values have been established for what constitutes a high knee abduction load during a cutting maneuver, it has been established that increased knee valgus may indicate increased risk for ACL injury and decreased neuromuscular control.\(^24\) It has also been determined that sharper cutting angles (>45°) result in greater knee abduction angles and moments than more shallow cutting angles.\(^25\) Therefore, the purpose of this study was to determine whether participation in the 11+ led to changes in hip and knee biomechanics during a soccer-specific 90° cut. Specifically, the aims were to determine whether participation led to changes in peak knee abduction moment, and the components of valgus collapse: hip adduction angle, hip internal rotation angle, and knee abduction angle. The authors’ hypotheses were that collegiate female soccer players participating in the 11+ for one season would demonstrate a greater decrease than control team players in peak hip adduction angles, hip internal rotation angles, knee abduction angles, knee abduction moments, and knee valgus collapse.

MATERIALS AND METHODS

PROCEDURES

Sixty-nine athletes from three National Collegiate Athletic Association (NCAA) Division 1 and Division 2 women’s soccer teams participated in this study (Table 1). Teams were recruited based on proximity to the testing site and willingness to participate in motion analysis testing and the 11+ intervention. All participants signed informed consent documents prior to participation, and all study procedures were approved by the University of Delaware Institutional Review Board. Players were included, regardless of injury history, if they could complete a unilateral cutting task. Two teams completed the 11+ as a warm-up before team practices and games and served as the intervention cohort (Figure 1). Execution of the 11+ was supervised by the teams’ coach and athletic trainers. The coach from each intervention team completed a digital contract at the beginning of the season to acknowledge compliance to completing the 11+ throughout the 12 week season. Further description of the 11+ can be found on the FIFA Medical Network website.\(^26\) Compliance was also verified by a study investigator at the conclusion of the season. Intervention teams completed the 11+ at least three times a week for the duration of preseason and throughout the NCAA soccer season. The third team agreed to participate in preseason and postseason motion analysis testing, but was not willing to implement the 11+. Therefore, the third team served as a control team and continued to complete their standard warm-up before practices and
Table 1: Pre-Season Demographic Variables Between Groups. Presented as mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Intervention</th>
<th>Control</th>
<th>p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>1.68 (0.1)</td>
<td>1.65 (0.1)</td>
<td>0.12</td>
</tr>
<tr>
<td>Age (years)</td>
<td>19.1 (1.3)</td>
<td>19.3 (1.1)</td>
<td>0.43</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>63.5 (5.1)</td>
<td>60.7 (6.2)</td>
<td>0.12</td>
</tr>
<tr>
<td>Time Between Testing (Days)</td>
<td>92.6 (14.4)</td>
<td>96.3 (5.5)</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Figure 1: Consort Diagram of Study Design and Participant Follow-Up.

Games. The control team’s warm-up consisted of running, dynamic stretching, and passing the ball. Each team’s respective athletic trainer kept a log of all injuries sustained by players throughout the season, which was then sent to the study investigators.

Players completed pre and postseason motion analysis of a unilateral 90° cutting task (Figure 1). Kinematic and kinetic data were recorded simultaneously using an 8 camera motion system (VICON, Oxford Metrics Ltd, London, England) sampling at 240Hz and three embedded force plates sampling at 1080Hz (Bertec, Worthington, OH, USA). Twenty-two retroreflective markers were placed on bony landmarks by one investigator (AA) with excellent inter-rater and intra-rater reliability (ICC>0.95) (Appendix 1). A static calibration trial was then taken to create a model. For the 90° cut, participants planted their foot on the force plate and turned 90° to the contralateral side. Players were given a demonstration of the task and verbal instructions to, ‘Run forward, plant your foot forward, turn 90°, and keep running.’ Only trials with an entire foot strike on the force plate were accepted for data analysis. Foot angle at initial contact varied some between players. To ensure that players completed a 90° cut, trials were rejected if the foot was in greater than 45° of internal rotation. The mean number of trials rejected per participant for these errors was <1 trial. Approach velocity was not controlled for at the time of data collection. Instantaneous approach velocity was calculated in a retrospective manner by taking the first derivative of the position of the bottom pelvis marker at initial contact (defined as vertical ground reaction force >50N) on the closest of two preceding force plates; initial contact on the preceding force plates varied between individuals secondary to stride length. Three trials without errors were collected on both the right and left limbs, but only the second and third trials were analyzed secondary to higher reliability.27 Limb dominance was defined as the self-reported preferred kicking leg.

DATA ANALYSIS

Markers for motion analysis data were labelled with Vicon Nexus (v 1.85 VICON, Oxford Metrics Ltd, London, England), and gaps in the markers were filled using Nexus’s spline based algorithm if gaps were less than five frames. Trials with gaps greater than five frames were excluded from the final statistical analysis. Inverse dynamics and rigid body analysis of motion analysis data was performed in Visual 3D using custom written scripts (C-Motion Inc., Germantown, MD, USA). Kinematic and kinetic data were low pass filtered at 6Hz and 40Hz respectively with a fourth order Butterworth filter.28,29 Peak hip adduction and internal rotation angles and peak knee abduction angles and ex-
Table 2: Instantaneous Approach Velocity.

<table>
<thead>
<tr>
<th>Cut Trial</th>
<th>Intervention Mean (m/s)</th>
<th>Control Mean (m/s)</th>
<th>Time x Group Interaction</th>
<th>Main effect: Time</th>
<th>Main Effect: Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Preseason</td>
<td>3.15 (0.41)</td>
<td>2.82 (0.20)</td>
<td>0.68</td>
<td>0.44</td>
<td>0.005</td>
</tr>
<tr>
<td>Dominant Postseason</td>
<td>3.18 (0.46)</td>
<td>2.92 (0.30)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-dominant Preseason</td>
<td>3.13 (0.43)</td>
<td>2.93 (0.34)</td>
<td>0.28</td>
<td>0.73</td>
<td>0.003</td>
</tr>
<tr>
<td>Non-dominant Postseason</td>
<td>3.19 (0.34)</td>
<td>2.82 (0.21)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results

Approach Velocity

Forty-six participants (15 control, 31 intervention) had complete motion analysis data at the pre and postseason time points after accounting for unusable data due to marker dropout >five frames and subject dropout due to injury (Figure 1). There were no significant differences between groups for demographic variables (Table 1). Forty-three participants (15 control, 30 intervention) had instantaneous approach velocity data and instantaneous approach velocity data was not present for three participants since they did not contact either preceding force plate. There were no significant interactions between group and time point for instantaneous approach velocity. There was a significant main effect of group for approach velocity of the dominant and non-dominant 90° cut; the control group was 0.3–0.4m/s slower than the intervention group at both time points (Table 2).

Hip Kinematics

There was a significant interaction effect for non-dominant hip adduction angle (p<0.05) (Table 3), but changes in non-dominant hip adduction angle did not exceed the SDC. There was a main effect of time for dominant hip internal rotation angle (p<0.01). Dominant hip internal rotation angle decreased from preseason to postseason, and this change exceeded the SDC in both groups. There was a main effect of time for non-dominant hip internal rotation angle (p<0.01). Non-dominant hip internal rotation angle decreased from preseason to postseason, and this change exceeded the SDC in both groups. There were no other significant interactions or main effects that exceeded the SDC or MID for hip frontal and transverse plane variables.

Knee Kinematics and Kinetics

There was a time main effect (p<0.01) for dominant knee abduction angle. Dominant knee abduction angle increased from preseason to postseason, and this change exceeded the SDC in both groups. There were no other significant interactions or main effects that exceeded the SDC or MID for knee sagittal or frontal plane variables.

Valgus Collapse

There was a main effect of time for dominant knee valgus collapse (p<0.01), but changes in dominant knee valgus collapse did not exceed the SDC for either group. There was a main effect of time for non-dominant knee valgus collapse (p<0.05). Non-dominant knee valgus collapse decreased from preseason to postseason, but only exceeded the SDC in the intervention group (Figure 2).
Table 3: Hip and Knee Kinematic and Kinetic Results

<table>
<thead>
<tr>
<th>Variable, Time</th>
<th>Dominant</th>
<th>ANOVA</th>
<th>Main Effect</th>
<th>Non-Dominant</th>
<th>ANOVA</th>
<th>Main Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intervention</td>
<td>Control</td>
<td></td>
<td>Intervention</td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Hip Adduction Angle (°) Pre-Season</td>
<td>-5.97 (5.20) [-8.17, -3.76]</td>
<td>-2.87 (7.67) [-6.05, 0.30]</td>
<td></td>
<td>-5.77 (5.12) [-7.54, -4.00]</td>
<td>-6.24 (4.37) [-8.79, -3.70]</td>
<td>0.411</td>
</tr>
<tr>
<td>Hip Adduction Angle (°) Post-Season</td>
<td>-5.31 (6.55) [-7.58, -3.04]</td>
<td>-3.61 (5.58) [-6.87, -0.35]</td>
<td>0.011</td>
<td>-7.92 (5.72) [-9.88, -5.97]</td>
<td>-5.14 (4.67) [-7.95, -2.32]</td>
<td>0.003</td>
</tr>
<tr>
<td>Hip Internal Rotation Angle (°) Pre-Season</td>
<td>13.94 (5.09) [11.7, 16.1]</td>
<td>8.11 (7.81) [4.94, 11.3]</td>
<td>0.001</td>
<td>11.39 (7.86) [8.58, 14.2]</td>
<td>7.58 (7.56) [3.54, 11.6]</td>
<td>0.071</td>
</tr>
<tr>
<td>Hip Internal Rotation Angle (°) Post-Season</td>
<td>9.31 (5.08) [7.64, 11.0]</td>
<td>3.21 (3.46) [0.80, 5.62]</td>
<td>0.892</td>
<td>7.61 (6.23) [5.33, 9.88]</td>
<td>4.65 (6.39) [1.39, 7.92]</td>
<td>0.705</td>
</tr>
<tr>
<td>Knee Abduction Angle (°) Pre-Season</td>
<td>-3.90 (3.09) [-5.23, -2.57]</td>
<td>-6.59 (4.69) [-8.50, -4.67]</td>
<td>0.892</td>
<td>7.61 (6.23) [5.33, 9.88]</td>
<td>4.65 (6.39) [1.39, 7.92]</td>
<td>0.705</td>
</tr>
<tr>
<td>Knee Abduction Angle (°) Post-Season</td>
<td>-5.56 (4.21) [0.82, -7.22]</td>
<td>-8.00 (5.24) [-10.4, -5.62]</td>
<td>0.820</td>
<td>4.29 (3.88) [-5.81, -2.77]</td>
<td>6.49 (4.80) [-8.67, -4.31]</td>
<td>0.633</td>
</tr>
<tr>
<td>Knee Abduction Moment (N*m/kgm) Pre-Season</td>
<td>0.24 (0.12) [0.20, 0.28]</td>
<td>0.26 (0.09) [0.20, 0.02]</td>
<td>0.15</td>
<td>11.36 (7.93) [8.56, 14.2]</td>
<td>7.38 (7.30) [3.36, 11.4]</td>
<td>0.11</td>
</tr>
<tr>
<td>Knee Abduction Moment (N*m/kgm) Post-Season</td>
<td>0.25 (0.12) [0.21, 0.29]</td>
<td>0.23 (0.11) [0.17, 0.29]</td>
<td>0.15</td>
<td>0.23 (0.07) [0.21, 0.26]</td>
<td>0.21 (0.08) [0.17, 0.25]</td>
<td>0.11</td>
</tr>
<tr>
<td>Knee Valgus Collapse (°) Pre-Season</td>
<td>-4.58 (9.98) [-8.16, -1.00]</td>
<td>-2.63 (9.72) [-7.78, 2.52]</td>
<td>0.15</td>
<td>-8.91 (11.37) [-13.33, -4.49]</td>
<td>-9.04 (13.85) [-15.4, -2.68]</td>
<td>0.07</td>
</tr>
<tr>
<td>Knee Valgus Collapse (°) Post-Season</td>
<td>-6.57 (8.75) [-10.1, -3.07]</td>
<td>-8.89 (11.4) [-13.9, -3.86]</td>
<td>0.15</td>
<td>-15.98 (11.93) [-20.32, -11.63]</td>
<td>-9.60 (12.19) [-15.85, -3.53]</td>
<td>0.07</td>
</tr>
</tbody>
</table>
DISCUSSION

The primary aim of this study was to determine whether the 11+ would reduce components of valgus collapse in female collegiate soccer players. The hypothesis was partly supported by the data. The intervention group demonstrated a statistically significant reduction in non-dominant hip abduction angle, a component of valgus collapse, and a clinically meaningful decrease in knee valgus on the non-dominant limb. Reductions in dominant and non-dominant hip internal rotation angle that exceeded the SDC were also observed. However, these changes were seen in both the intervention and control group participants so they cannot be attributed to participation in the 11+.

Knee valgus during a vertical drop jump has been cited as a risk factor for non-contact ACL injuries and has been used as a biomechanical measure of neuromuscular control.\(^2^4\) The soccer specific task of cutting has been used less frequently to identify whether biomechanical changes have taken place after implementation of an established injury prevention program.\(^2^1,3^0,3^1\) In this study, the intervention group demonstrated a 7.1° decrease in knee valgus collapse.\(^2^7\) Although this change did not reach statistical significance, it did exceed the SDC of 6.4°, indicating this is likely a true biomechanical change. So, this decrease in valgus collapse in the non-dominant limb may indicate a positive biomechanical effect of the 11+. This biomechanical change is especially interesting in the context of a sport-specific task like cutting. Video analysis of ACL injuries in male soccer players has demonstrated that players who tore their ACL while cutting were typically in knee valgus at the time of injury, suggesting that this is a hazardous posture for cutting maneuvers.\(^3^2\) Additionally, comparisons of the kinematics and kinetics of male and female athletes during a cutting task have indicated that female athletes tended to have greater knee valgus while cutting than male athletes.\(^3^3,3^4\) Previous literature has also demonstrated that sharper cutting angles lead to greater loads at the knee joint.\(^2^5\) So, a reduction in valgus collapse at a higher cutting angle, such as a 90° cut, may be especially advantageous for reducing ACL injuries. Further research is needed, however, to determine whether this change in biomechanics also corresponds with a reduced rate of ACL injury.

Discrete these promising results, changes in valgus collapse exceeded the SDC but did not reach statistical significance and were only seen in the non-dominant limb. The lack of statistical change in valgus collapse may indicate that the 11+ does not equally address movements in all planes of motion. Valgus collapse is a combination of frontal and transverse plane motions, but the majority of dynamic running exercises in the 11+ focus on sagittal plane motions. The balance and plyometric elements of the 11+ do address frontal plane knee control, however, these exercises may not represent typical injury scenarios. Minimal statistical changes in hip frontal and transverse plane biomechanics may indicate that players could benefit from additional dynamic neuromuscular training in the frontal and transverse planes of motion. Additionally, a low volume of unilateral exercises in the 11+ may be a shortcoming of the program and could help explain why biomechanical changes were not observed consistently in the dominant and non-dominant limbs. Since a 90° cut is a unilateral task with frontal and transverse plane biomechanical demands, there may not be a great enough volume of neuromuscular training specific to cutting in the 11+ to alter well-established playing biomechanics. Given the prevalence of cutting in a typical soccer match, it may also be valuable to implement cutting drills at a variety of angles with an emphasis on knee alignment during the cut.

High peak knee abduction moments have previously been identified as a risk for non-contact ACL injury.\(^2^4\) The intervention group participants in this study did not demonstrate significant changes in peak knee abduction moments despite demonstrating decreases in non-dominant knee valgus collapse. Intervention group participants also demonstrated a statistically significant decrease in non-dominant hip adduction angle during the 90° cut. Since hip adduction angle is a component of knee valgus collapse, this may indicate that biomechanical changes at the hip are driving changes in valgus collapse versus changes at the knee. Consequently, this may help explain why postseason changes in knee abduction moments were not observed in this study.

Although there is strong evidence that the 11+ is effective in reducing ACL injury rates, there has been low implementation of it.\(^1^6,1^7,3^5\) Time and adherence are two highly ranked barriers to long-term implementation of injury prevention programs such as the 11+.\(^3^6,3^8\) High player adherence has also been linked to a greater reduction in injuries.\(^1^4,3^9\) The coaches for the intervention teams in the current study completed a digital contract and agreed to complete the 11+ three times a week. However, individual player exposure and program progressions were not recorded, which is a limitation of this study. Access to individual player compliance information may have allowed for more detailed statistical analysis on how individual exposures to the 11+ affects player biomechanics. Future research should examine whether individual player exposure to an intervention like the 11+effects magnitude of biomechanical changes, as previous research examining individual and team compliance to an intervention has demonstrated a greater reduction in knee injuries.\(^4^0\) However, monitoring individual player compliance and progressions can be difficult to implement, especially across multiple
teams. Therefore, interpretation of the current results is limited by a lack of data to confirm a connection between adherence, biomechanical change, and ultimately reduction in ACL injuries. Establishing this connection may help improve the perceived time investment of an injury prevention program such as the 11+ and ultimately increase implementation.

A limitation of this study was not controlling for approach velocity of the 90° cut. Although there was a significant main effect of group, there was not a significant time x group interaction or main effect of time for instantaneous approach velocity. This suggests that biomechanical changes across the season were likely beyond noise of the signal and not the result of changes in cut velocity between time points. Analysis of a pre-planned cut may also be a limitation of this study as there is evidence that unanticipated cutting has been associated with higher loads on the knee joint than anticipated cutting. It is possible that the results of this study may also have been different in a younger age group. The mean age of the intervention group participants was 19.1 years due to inclusion of collegiate soccer teams. There is evidence that neuromuscular training programs are most effective in reducing injuries in females younger than 18 years-old. Regarding biomechanics, Thompson-Kolesar et al determined that pre-adolescent girls participating in the 11+ for eight weeks demonstrated greater improvements in biomechanical, especially in knee abduction angle, than adolescent girls. The slightly older age (college) of the participants may have limited the biomechanical changes observed across the season. However, it is unknown if age of the study’s participants impacted biomechanical change. Limited information about individual player exposure to and progression of the 11+ throughout the season, was an additional limitation. In future studies, the authors would collect individual player compliance information.

One of the strengths of this study was that it investigated the biomechanical effects of the 11+ on a sport-specific task. The results of this study indicate that the 11+ may have the potential to positively impact players’ movement strategies in the context of a task that is regularly performed on the field and carries a risk for ACL injury. Another strength of this study was the comparison of biomechanical changes to SDC and MID values. These values allowed for deeper understanding of the clinical impact biomechanical changes with this task may have.

CONCLUSION

The principal finding of this study was that participation in the 11+ led to a clinically meaningful, although not statistically significant, decrease in knee valgus collapse in the non-dominant limb. There is a preponderance of evidence supporting the implementation of a neuromuscular training program, such as the 11+, in female athletes. This study adds to the existing evidence that neuromuscular training programs are beneficial to female soccer players as it suggests that the 11+ may have the potential to reduce risky biomechanical patterns during the sport-specific task of cutting. Regardless, there is overwhelming evidence that female soccer players should be consistently participating in some form of neuromuscular training, that includes strength training and plyometric components, to reduce the risk of injury.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST

All authors declare no conflicts of interests.

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REFERENCES


Background
Restoration of quadriceps strength following anterior cruciate ligament reconstruction (ACL-R) continues to challenge both patients and clinicians. Failure to adequately restore quadriceps strength has been linked to decreased patients' self-reported outcomes and an increased risk for re-injury. Early identification of quadriceps strength deficits may assist in tailoring early interventions to better address impairments.

Purpose
The purpose of this study was to assess the relationship between early (12 weeks following ACL-R) isokinetic peak torque and isokinetic peak torque at time of return to sport (RTS) testing.

Study Design
Cohort Study

Methods
A total of 120 participants (males = 55; females =65) were enrolled in the study (age = 16.1±1.4 yrs; height = 1.72±10.5 m; mass = 70.7±16.3 kg). All participants were level 1 or 2 cutting and pivoting sport athletes who underwent a primary bone-patellar tendon-bone autograft ACL-R. Participants were tested at two time points: 12 weeks following surgery and again at time of RTS testing. A linear regression model was carried out to investigate the relationship between age, sex, and isokinetic peak torque at 12 weeks following ACL-R and isokinetic peak torque at time of RTS testing.

Results
When 12-week isokinetic peak torque was entered first for the hierarchy regression analysis, this factor was predictive of the peak torque at the time of RTS testing, $F(1, 118) = 105.6, p < 0.001, R^2 = 0.472$, indicating that the 12-week quadriceps strength accounted for 47% of the variance in the quadriceps strength at the time of RTS testing. When age and sex were added in the regression analysis, both factors only added 0.8% of variance for the quadriceps strength at the time of RTS testing.

Conclusion
Isokinetic peak torque at 12 weeks following surgery was shown to be a significantly strong predictor (47%) for isokinetic quadriceps strength recovery at time of RTS. This
INTRODUCTION

Restoration of quadriceps strength following anterior cruciate ligament reconstruction (ACL-R) continues to challenge both patients and clinicians.1-4 Quadriceps weakness following ACL-R, particularly with bone-patellar tendon-bone (BPTB) autograft, has been linked to poor self-reported outcomes,4-6 altered biomechanics,1,7 and increased risk of second injury.8 These deficits in quadriceps strength following ACL-R seem to be more pronounced in those individuals undergoing BPTB autografts versus other graft types (i.e. hamstring autograft).4 Conversely, restoration of quadriceps strength has been shown to be protective against second ACL injury.9-11 Additionally, this prolonged and persistent quadriceps weakness has been theorized to contribute to the early posttraumatic osteoarthritis seen after ACL-R.12,13 Thus, restoring quadriceps strength is crucial for the short-term and long-term health of individuals following ACL-R.

The development of early objective criteria that can identify patients who have restored sufficient quadriceps strength can assist clinicians in appropriately tailoring early interventions. In the changing healthcare environment, many patients have limited access to physical therapy and the ability to identify patients who are on, ahead, or behind schedule early in the rehabilitation process may allow the clinician to direct care based upon objective data with the goal of improved patient outcomes. Several such early measures have been established for other impairments for patients after ACL-R. For example, Garrison et al.14 found a significantly positive relationship between the Y-Balance Test-Lower Quarter (YBT-LQ) at 12-weeks post-operatively and jump performance at time of return to sport (RTS). Participants who demonstrated a greater than 4 cm YBT-LQ anterior reach difference between sides at 12-weeks did not meet criteria (more than 10% difference) at time of RTS testing for the single and triple hop testing.14 Lablanca et al.15 found that ground reaction force symmetry during a squat at one-month post-operation was an independent predictor ($\Delta R^2 = 0.14$, $p < 0.01$) of ground reaction force symmetry during a landing task at the time of RTS. Sigward et al. found that knee moments during gait at four weeks were significantly related to knee moments during running at four months.16 These studies highlight the importance of how an early objective measurement of an impairment can be related to the outcome of a similar impairment domain in a later stage of recovery and ultimately influence criteria used to determine when an athlete is ready to return to play.3,4,17,18

While numerous studies have found correlations between late-stage isokinetic quadriceps strength and other objective measures (patient reported outcomes, hop testing, balance testing), little focus has been given to early quadriceps strength, such as that at 12 weeks.1,5,9,11,19 However, previous data suggests that isometric quadriceps strength increases longitudinally at 4, 8, and 12 weeks following ACL-R.20,21 This early time frame is important in rehabilitation as this is when patients are beginning to transition to running- and plyometric based training.22,23 Additionally, it has been well documented that a significant deficit in quadriceps strength is still present at this time;23 however, no studies have quantified this deficit or correlated this early deficit with late stage impairment. At 12-weeks after ACL-R many patients are still under the direct care of their rehab specialist and early identification of quadriceps strength deficits may allow modification to the treatment plan to address said deficit. Furthermore, utilizing these early quadriceps strength measures to help predict late stage strength impairments can assist in clinical decision making.

Therefore, the purpose of this study was to examine the relationship between isokinetic peak torque of individuals at 12-weeks following ACL-R and isokinetic peak torque of the same individuals at time of RTS testing. In addition, the secondary purpose of the study was to determine if isokinetic knee extension peak torque at 12 weeks would predict quadriceps strength recovery at the time of RTS testing. It was hypothesized that isokinetic peak torque at 12 weeks would be highly predictive to isokinetic peak torque at time of RTS testing.

METHODS

A total of 120 participants who met the inclusion criteria were enrolled in the study. Table 1 displays the characteristics of the participants. All participants were screened by the study staff prior to enrollment. Participants were considered eligible if they injured their ACL for the first time, were level 1 or 2 athletes who planned on returning to competitive sport and did not have any full thickness chondral injuries or grade II or III medial collateral ligament (MCL), lateral collateral ligament (LCL) or posterior collateral ligament (PCL) injuries. All participants gave informed consent to participate and the rights of each person were protected. If the participant was a minor, parental consent and child consent were attained. The Institutional Review Board of Texas Health Resources approved this research study.

All participants completed two testing sessions with the first session occurring at 12 weeks following ACL-R. The second testing session was at the time of RTS testing which was an average of 7.2 ± 1.3 months following surgery. Decision to complete RTS testing was based on input from the surgeon and physical therapist based on the participant’s clinical presentation. Both testing sessions consisted of isokinetic isometric peak torque testing on the Biodex Multi-Joint Testing and Rehabilitation System (Biodex Medical Systems, Shirley, NY). Isokinetic peak torque was assessed bilaterally. The femoral condyle of the tested limb was

Level of Evidence

3
Table 1: Characteristics of the participants (n = 120)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>172.0 ± 10.5</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>70.7 ± 16.3</td>
</tr>
<tr>
<td>Age (years)</td>
<td>16.1 ± 1.4</td>
</tr>
<tr>
<td>Gender</td>
<td>M= 55, F= 65</td>
</tr>
<tr>
<td>Mechanism of injury (contact/indirect/non-contact)</td>
<td>23/24/73</td>
</tr>
<tr>
<td>Time from surgery to RTS testing (months)</td>
<td>7.3 ± 1.3</td>
</tr>
</tbody>
</table>

RTS = return to sport

Table 2: Descriptive statistics (means ± SD) of clinical tests and knee extensor peak torques of all participants at 12 weeks following ACL-R and at the time of return-to-sport (RTS) (n = 120)

<table>
<thead>
<tr>
<th></th>
<th>12 weeks</th>
<th>RTS</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKDC Score (%)</td>
<td>66.86 ± 10.77</td>
<td>90.52 ± 11.25</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Knee Extension ROM (°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved</td>
<td>1.73 ± 2.34</td>
<td>2.38 ± 2.33</td>
<td>0.045</td>
</tr>
<tr>
<td>Uninvolved</td>
<td>4.37 ± 1.22</td>
<td>3.29 ± 2.22</td>
<td>0.320</td>
</tr>
<tr>
<td>Knee Flexion ROM (°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved</td>
<td>139.60 ± 9.38</td>
<td>140.73 ± 12.03</td>
<td>0.258</td>
</tr>
<tr>
<td>Uninvolved</td>
<td>143.27 ± 14.86</td>
<td>143.22 ± 7.30</td>
<td>0.703</td>
</tr>
<tr>
<td>Single hop distance LSI (%)</td>
<td>N/A</td>
<td>95.80 ± 5.73</td>
<td>N/A</td>
</tr>
<tr>
<td>Triple Hop Distance LSI (%)</td>
<td>N/A</td>
<td>95.95 ± 11.99</td>
<td>N/A</td>
</tr>
<tr>
<td>Y-Balance Test composite score (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved</td>
<td>91.51 ± 6.92</td>
<td>95.71 ± 9.00</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Uninvolved</td>
<td>96.54 ± 6.76</td>
<td>99.62 ± 5.39</td>
<td>0.334</td>
</tr>
<tr>
<td>Knee Extensor Peak Torque (Nm/Kg)</td>
<td>1.13 ± 0.40</td>
<td>1.55 ± 0.45</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

IKDC = International Knee Documentation Committee Questionnaire, ROM= range of motion; LSI= limb symmetry index.

aligned with the Biodex axis of rotation following the manufacturer's instructions. Participants performed five repetitions of submaximal knee extension/flexion to familiarize themselves with the testing motion. To determine isokinetic peak torque, participants performed five consecutive concentric contractions at 60°/sec on each limb. The uninvolved limb of participants was tested prior to testing the involved limb. The average of the five trials was normalized to each participant’s body weight and used for analysis. Any testing that resulted in a coefficient of variance of greater than 15% was discarded and the quadriceps strength test was repeated following an appropriate rest interval. Additional clinical test results, including the International Knee Documentation Committee Questionnaire (IKDC) scores, range of motion (ROM) of knee extension and flexion, limb symmetry indices (LSI) of single hop distance, triple hop distance, YBT-LQ composite scores, collected at 12 weeks following ACL-R and at the time of RTS testing, were used to describe the participants of the study, and were not used for statistical analysis (Table 2).

STATISTICAL ANALYSIS

Descriptive statistics were calculated for participant characteristics and normalized quadriceps strength of all participants. All statistical analyses were performed using SPSS version 23 (IBM, Armonk, NY). First, a Pearson-Product-Moment correlation coefficient was calculated between isokinetic peak torque at 12 weeks following ACL-R and isokinetic peak torque at time of RTS testing. Next, a regression was conducted to determine the influence of quadriceps strength at time of RTS testing in addition to age and sex which have been shown to be significant predictors of quadriceps strength.25,26 The alpha level was set at 0.05 for all statistical analyses.

RESULTS

The correlation showed a significant strong positive relationship (Figure 1) between quadriceps strength at 12 weeks after ACL-R and quadriceps strength at the time of RTS (r = 0.687; p < 0.001). Prior to the regression analysis, data were checked for violations of the assumptions for regression
Table 3: Hierarchical regression analysis results of 12-week extensor peak torque, age and sex on extensor peak torque at time of return-to-sport (RTS) testing (n = 120)

<table>
<thead>
<tr>
<th>Step 1</th>
<th>B</th>
<th>R²</th>
<th>ΔR²</th>
<th>B</th>
<th>β</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-week Extensor Peak Torque</td>
<td>0.472</td>
<td>0.781</td>
<td>0.687</td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>B</td>
<td>R²</td>
<td>ΔR²</td>
<td>B</td>
<td>β</td>
<td>p</td>
</tr>
<tr>
<td>12-week Extensor Peak Torque</td>
<td>0.480</td>
<td>0.008</td>
<td>0.744</td>
<td>0.655</td>
<td>&lt;0.001*</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.013</td>
<td>-0.042</td>
<td>0.545</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (0=male, 1=female)</td>
<td>-0.084</td>
<td>-0.093</td>
<td>0.210</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B: constant; ΔR²: R² change; B = unstandardized coefficients; β = standardized coefficients.

Figure 1: Scatter plot of knee extensor peak torque (Nm/Kg) of the quadriceps muscle at 12 weeks and at the time of return-to-sport (RTS) (n = 120)

DISCUSSION

The purpose of this study was to examine the relationship between isokinetic peak torque at an early stage (i.e., 12 weeks) of recovery from ACL-R and at the time of RTS testing (i.e., 7-9 months after ACL-R). The 12-week quadriceps strength was shown to be a strong predictor, and that 47% of isokinetic peak torque at the time of RTS testing was explained by the isokinetic peak torque at 12-weeks after ACL-R. The identification of isokinetic peak torque deficits at this early stage of ACL-R recovery can further provide clinicians with an understanding of quadriceps strength recovery progression during the rehabilitation process. As restoring quadriceps strength continues to challenge surgeons, clinicians, and patients, the short- and long-term consequences of not restoring quadriceps strength can be significant, including re-injury and potentially life-style altering post-traumatic osteoarthritis. Numerous studies have demonstrated that at the time of RTS testing, many individuals continue to demonstrate deficits in quadriceps strength. While this is certainly problematic, for many clinicians and patients the identification of these deficits at this point may be too late for effective intervention. In most cases by six months post-operation, patients have typically transitioned out of structured care; therefore, early identification of these strength deficits may assist clinicians in better tailoring early interventions for quadriceps strength deficits. When available, the use isokinetic testing at 12 weeks and the regression equation provided in this manuscript can help to provide clinicians an indication of how a patients quadriiceps is progressing. Contrary to other reports in the literature,25,26 age and gender were found to be weak predictors for quadriceps strength recovery at the time of RTS. As the majority of our study participants were high school and freshmen/sophomore college athletes, the narrow age range could have contributed to the non-significant finding. Recently, Kuenze
et al.\textsuperscript{25} found that female athletes had slower quadriceps strength recovery at the time of RTS after ACL-R than male athletes. However, in this present study no difference was found between female and male athletes. The difference between the studies could in part be explained by the inclusion of all graft types (BPTB, hamstrings and allograft) in the study by Kuenze et al. In addition, only 10\% of Kuenze et al.'s male participants had a BPTB graft with their ACL-R, whereas 59\% of their female participants had a BPTB graft. This disproportionate percentage of participants with BPTB grafts, also may have influenced the sex-difference results of their study.

Few studies have examined isokinetic peak torque in the early stage of recovery (i.e., 12 weeks or earlier) following ACL-R. Harput et al. reported on 24 subjects following ACL-R who completed isometric quadriceps strength testing at 4,8, and 12 weeks following surgery.\textsuperscript{21} As expected, they found a longitudinal increase in quadriceps strength across time points. Similarly, as part of studies examining early neuromuscular rehabilitation, Dreschler et al. and Fitzgerald et al. reported on isometrics quadriceps strength at 90 and 60 degrees of knee flexion respectively. Dreschler et al.\textsuperscript{20} tested subjects at 4- and 12-weeks following ACL-R, and Fitzgerald et al.\textsuperscript{28} completed testing at 12-weeks and 16-weeks post ACL-R. Both studies also showed an increase in strength across time. These studies help to support the notion of early isokinetic peak torque testing and that strength generally increases across time in these early phases following ACL-R. Furthermore, Hartigan et al. previously demonstrated that pre-operative quadriceps strength, along with patient age, correctly predicted 82\% of subjects who did not pass RTS criteria at time of RTS testing. Interestingly, Hallagin et al. compared pre-operative quadriceps strength to strength at 12-weeks post ACL-R, and found a 44\% decrease in quadriceps strength between these two time points.\textsuperscript{25} These findings together seem to suggest that the additional trauma of surgery has a significant deleterious effect on early quadriceps strength and that while pre-operative strength strongly influences strength at time of RTS, the progression of strength is not linear in nature.\textsuperscript{29} Comparison across these studies is difficult, as some studies were intervention studies and utilized isometric testing at 60, 70, and 90 degrees of knee flexion, while the study by Hallagin et al.\textsuperscript{25} utilized isokinetic testing.

A limitation of these studies examining the quadriceps strength in the early stage of rehabilitation is that there is limited follow-up after ACL-R. It is well accepted that with the appropriate treatment approaches, strength will increase in the early phases after surgery. However, given the significant quadriceps strength deficits that are reported at 6, 12 and 24 months after ACL-R the progression of strength is slow and clearly not linear. Thus, how these early strength measures predict long term (greater than six months post-surgery) outcomes is relatively unknown. Pua et al.\textsuperscript{18} reported on a cohort of 70 patients who completed isometric quadriceps strength testing at 70 degrees of knee flexion at 6 weeks following ACL-R. In their multivariate regression model, quadriceps strength at six weeks was a significant predictor of six-month single-leg hop for distance and single leg vertical countermovement jump.\textsuperscript{18} Similarly, Beischer et al. found that 40\% of the athletes in their study who had a limb symmetry indices of 80\% or higher at four months following ACL-R achieved symmetrical muscle function at 12 months compared with fewer than 10\% of the athletes who had an limb symmetry index (LSI) lower than 80\%.\textsuperscript{30} The findings from Pua et al. and Beischer et al. support the findings from our study that quadriceps strength in the early stage of post-operative ACL-R has significant implications on late stage objective measures.

Early objective strength values have the potential to be invaluable to patients and clinicians. In the changing healthcare landscape with many patients facing high co-payments and limited approved physical therapy visits, access to long-term physical therapy following ACL-R is becoming increasingly limited. The ability to identify patients who are on, ahead, or behind schedule early in the process will allow more directed early treatment and hopefully improved patient outcomes. The results of this study indicated that 48\% of isokinetic quadriceps strengths at time of RTS testing was explained by 12-weeks quadriceps strength, age and sex. There are likely many factors that help explain the remaining 52\% of strength at RTS including pain, inflammation, swelling, fear, atrophy, and decreased neural drive.\textsuperscript{31} Identification of the additional factors that contribute to quadriceps strength at time of RTS is the obvious next step to allow for more directed treatment strategies.

This study is not without limitations. The primary limitation of this study is that individuals were not assessed for meeting RTS criteria at time of RTS testing. This study is part of a larger ongoing ACL outcomes study and the purpose of this sub investigation was to assess for the specific relationship between 12-week and RTS isokinetic peak torque values, not to assess if 12-week strength values could differentiate those who returned or did not return to sport. Additionally, there was no follow up beyond RTS in this cohort and so there is currently not a definitive way to determine if/when these athletes returned to sport following testing. There is also a limitation in the generalizability of this study as only those athletes following primary ACL-R with PBTB graft type were included and these findings likely change when other graft types are included. Thirdly, no measurement of central activation ratio (a ratio that measures maximum voluntary force produced divided by the force produced following a superimposed burst during a maximal voluntary contraction) was taken and this has been shown to be diminished following ACL-R and play a major role in quadriceps strength.\textsuperscript{5} Lastly, there are some inherent limitations with using isokinetic dynamometry when considering clinical applicability; however, it remains the gold standard for measurement of strength following ACL-R.

CONCLUSIONS

In conclusion, quadriceps strength at 12 weeks following surgery was shown to be a significantly strong predictor (47\%) for isokinetic quadriceps strength recovery at time of RTS. This finding underscores the importance of early restoration of quadriceps strength and that while non-modifiable factors such as sex and age are important, early restoration of quadriceps strength most strongly influences late stage quadriceps strength.
CONFLICT OF INTERESTS

The authors have no conflicts of interest to declare.
REFERENCES


The Effects of Soft Tissue Flossing on Hamstring Range of Motion and Lower Extremity Power

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1 University of Lynchburg

Keywords: blood flow, fascial shearing, hamstring flexibility, voodoo bands

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Background
Flossing includes wrapping a specialized latex band around a muscle group providing compression, partially occluding blood flow, followed by performing exercises. This is hypothesized to improve flexibility by dissipating myofascial adhesions; however, research is lacking.

Objective
To determine the effect of the application of a floss band to the thigh on hamstring flexibility and lower extremity power.

Design
Crossover Study

Setting
Exercise Physiology Laboratory

Participants
Twenty-one recreationally active individuals (8 male, 13 female; age = 22.62±2.99 years; height = 171.52±9.08 cm; mass = 73.57±11.37 kg).

Methods
Three counterbalanced interventions were studied during body weight squats, lunges, and hamstring curls (without resistance): floss, sham, and control. The floss treatment included wrapping the Rogue Wide Voodoo Floss Band™ from the proximal knee to the gluteal fold at a pressure of 140 to 200 mmHg. The sham treatment included wrapping the same band in the same location with less pressure (10 to 40 mmHg) while the control treatment did not include floss band application. Hip flexion range of motion, via the straight leg raise, and power (single-leg vertical jump) were compared from pre-test to post-test using a 3x2 repeated measures ANOVA.

Results
There was a significant interaction between time and session for hamstring flexibility (F(2,40)=17.54, p<0.001, η²=0.47). Post hoc tests showed significant differences between pre- (86.14±8.06 degrees) and post-test (90.81±7.69 degrees) for the floss session (p<0.001, Mean Difference=4.67, CI95=3.35-5.98) and between pre- (87.67±7.51 degrees) and post-test (89.86±7.88 degrees) for the sham session (p=0.001, Mean Difference=2.19, CI95=0.98-3.40). There were no significant interactions for jump power (F(2,40)=1.82, P=0.18, η²=0.08, 1- β=0.56).
Conclusions

Flossing treatment increased hamstring flexibility more than the sham session without affecting lower body power. Flossing could be beneficial when treatment or performance preparation goals are increased flexibility without decreased power. Future studies should continue to examine the clinical effectiveness of flossing on an injured population.

INTRODUCTION

Tissue flossing using floss bands, or "Voodoo bands™," is becoming increasingly popular throughout the world of athletics and strength and conditioning.1 The application of a floss band includes wrapping a large specialized latex rubber band around a joint or muscle group to provide compression, partially occluding blood flow, and then performing a range of motion exercise for a short period of time, approximately one to three minutes.1 This form of therapy is hypothesized to improve flexibility by dissipating myofascial adhesions across the muscle belly;2 however, few research studies have been conducted to support this proposed benefit.

Currently, there have only been three studies examining the effectiveness of flossing.1,3,4 Flossing across the talocrural joint has been shown to improve peak muscular dorsiflexion torque, both dorsiflexion and plantarflexion range of motion (ROM), and power during ankle movements.1,5 The hypothesized benefit of increased ROM by applying a floss band across the talocrural joint has been evaluated previously,1,5 but a study investigating the efficacy of flossing solely soft tissue, such as the hamstrings, has yet to be completed. Adequate flexibility are essential to the performance of athletes and are commonly a target for improvement as athletes with hypomobility are at a higher risk for injury in sport.5

Many traditional warm-up methods such as proprioceptive neuromuscular facilitation (PNF), static stretching, and deep tissue foam rolling (DTFR) have been shown to improve range of motion.5–8 However, these techniques have also been shown to have some negative effects such as decreased power immediately after stretching.6–8 A second limitation to a method such as static stretching is that there is an extended amount of time required to see ROM benefits from baseline.6 Flossing is hypothesized to immediately increase ROM while potentially leaving power unaltered. The effects of flossing have been researched across joints in multiple studies but is yet to be studied across the belly of targeted muscles.1,3,4 Therefore, the purpose of this study was to determine the effect of the application of a floss band to the thigh on hamstring flexibility and lower extremity power.

METHODS

A 3x2 repeated measures crossover study design included two within factors, intervention (floss, sham, control) and time (pre-test, post-test). Participants completed three different sessions occurring approximately two to four days apart where they received one of the three interventions in a counterbalanced order. For the purposes of this study, ROM was defined as movement coming from a joint while flexibility involves optimization of a muscle or muscle group.

PARTICIPANTS

A convenience sample of 21 recreationally active university students (8 male, 13 female; age = 22.62±2.99 years; height = 171.52±9.08 cm; mass = 73.57±11.37 kg) were recruited to participate in this study after obtaining approval by the University of Lynchburg IRB. Recreationally active was defined as exercising for at least 30 minutes per day, three times per week at moderate intensity.9 Exclusion criteria included a history of chronic hamstring strains, recent surgery to the lower extremity that would alter his or her ability to complete the study, pregnancy, and age under 18 years.

PROCEDURES

Emails were sent to prospective participants seeking to recruit volunteers. Those who responded scheduled a meeting with the lead author to sign an informed consent form and provide demographic information. A counterbalanced approach was used when assigning participants to an intervention order in an effort to reduce any potential learning effects. Once treatment order was determined, the participants warmed-up on a stationary bike (Monark Ergomedic 828E, Vansbro Sweden) for five minutes with no resistance and a constant cadence of 50–60 RPM.10 The warm-up was the same prior to each session. After warm-up, three trials of hip flexion ROM,10 via the straight-leg raise, were measured on the dominant leg with a digital inclinometer on a smartphone app (iHandy level, reliability=0.97, validity=0.99, SEM=1.35º).11 The dominant leg was determined by asking the participants which leg would be used to kick a ball. The researcher observed participants for proper positioning, keeping the knee extended, contralateral thigh remaining against the table, neutral pelvic position, and no external rotation of the contralateral hip (Figure 1). If participants performed any of these deviations, corrections were cued by the researcher and measurement was reassessed. The best of the three trials was recorded for analysis.10,12

The participants completed three trials of a single-leg vertical jump with countermovement and an arm swing using his/her dominant leg on the Just Jump mat (Probiotics Inc, Huntsville, AL, reliability=0.96, validity=0.97).10,13 The best of the three trials was recorded for analysis.10 Each intervention group performed pre-testing the same way and each session took less than 20 minutes.

Intervention. The floss treatment involved applying a 4” elastic band to the dominant upper leg (Figure 2). The thigh was wrapped, starting at the superior pole of the patella overlapping by 50% and moving proximally up the thigh, ending at the gluteal fold.2 The desired pressure of this wrap was between 140 and 200 mmHg2 as measured by a
sub-bandage pressure sensor (Tekscan, South Boston, MA, reliability=0.97, validity=0.98) placed over the belly of the rectus femoris (Figure 3).14

The sham treatment involved the exact same 4" elastic band with very light pressure. The floss band was applied the same way as the floss treatment while reducing the pressure so that the band was just tight enough to not fall off. Pressure was measured between 10 and 40 mmHg of pressure on the thigh. The control treatment involved no application of a band and the participants only warmed-up on the stationary bike, performed the pre-test, performed active movements as described below without a band, and then completed post-test measurements.

Exercise Protocol. The participants were instructed to perform one set of 10 bodyweight squats so the quadriceps were parallel to the floor, 10 lunges on each leg, and 20 standing hamstring curls with no resistance. The researcher demonstrated the proper technique first in order to show the participants how to correctly perform the exercises. The protocol took approximately two minutes to complete and was designed to target the muscles tested in the straight leg raise through complex multi-joint dynamic movements. After participants completed all of the exercises, the wrap was removed and the participants were instructed to walk for one minute. The ROM and power measurements were repeated in the same manner as during the pre-test. The cool-down consisted of five minutes on the stationary bike at the same speed and resistance as the warm-up. There were two to four days between each of the three research sessions.

STATISTICAL ANALYSIS

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, version 25.0) using two separate 3x2 repeated measures ANOVAs to compare the effects of intervention (floss, sham, control) and time (pre-test, post-test), one for each of the two dependent variables (ROM and power). Post-hoc analysis was performed with Bonferroni correction when main effects were found to be significant. We set the alpha level at 0.05 a priori.

RESULTS

For flexibility, the interaction between time and session was significant ($F_{2,40}=17.54$, $p<0.001$, $\eta^2=0.47$; Table 1). Figure 4 illustrates the means for each group at pre-test and post-test. Post hoc tests for flexibility showed significant differences between pre- (86.14±8.06 degrees) and post-test (90.81±7.69 degrees) for the floss session ($p<0.001$, Mean Difference=4.67 degrees, CI$_{95}$=5.55-5.98). In addition, post hoc tests revealed significant differences between pre- (87.67±7.51 degrees) and post-test (89.86±7.88 degrees) for the sham session ($p=0.001$, Mean Difference=2.19 degrees, CI$_{95}$=0.98-3.40). For jump power, the interaction between time and session was not statistically significant ($F_{2,40}=1.82$, $p=0.18$, $\eta^2=0.08$, 1- $\beta$=0.56; Table 2).

DISCUSSION

This study was the first to investigate the application of floss bands to the muscles of the thigh and measure subsequent flexibility improvements and single-leg vertical jump performance. The main clinical finding was that flossing improved flexibility by an average of 4.68 degrees without hindering power in the lower extremity. Based on the validity and reliability research by Vohralik et al.,11 the criterion validity of the inclinometer tool was based upon a device with ±0.5º margin of error and was found to have a SEM of 1.55º, indicating that the differences found in the current study were also clinically significant. The researchers hypothesize that tissue flossing caused dissipation of myofascial adhesions along the hamstrings without affecting actual tissue length or negatively affecting the priming of Golgi tendon organs (GTOs) and muscle spindles.2 There have been multiple research studies using several different techniques proposed to improve flexibility in the hamstrings, such as static and PNF stretching.6,7 Physiologically for these stretching techniques, hamstring flexibility improvement is accomplished by stimulating GTOs.
and muscle spindles to allow the muscle fibers to lengthen.\(^2\)

The difference between static and PNF stretching techniques and flossing is that flossing is proposed to break up tissue adhesions that limit flexibility, which may cause some irritation of the underlying tissue allowing maintenance of flexibility over time.\(^2\) Traditional stretching techniques target the length or extensibility of the muscle, but this lengthening mechanism has been shown to decrease strength, power output, and muscle activation by affecting the GTOs and muscle spindles.\(^15\) Research has also shown that 30 minutes of static stretching must be performed twice per week for at least five weeks to improve baseline flexibility.\(^16\) In this study, flexibility was increased immediately while power remained unaffected. These findings may have significant value in a variety of settings that may include injury prevention, rehabilitation, and increased athletic performance due to maintaining ROM of the hamstrings.

Another common mechanism for increasing flexibility is deep tissue foam rolling (DTFR). DTFR has been reported to improve hamstring flexibility similarly to a PNF stretching routine.\(^8\) The hypothesis behind the benefits of DTFR includes the stimulation of GTOs.\(^8\) This stimulation is believed to decrease athletic performance by negatively affecting the priming of the GTOs.\(^8\) When GTOs in the muscle are rolled over, they become less sensitive resulting in a decrease in the amount of power the muscle is able to produce. DTFR should be used with caution prior to physical activity as this may decrease performance by reducing power.\(^8\)

Even though this study is the first to the authors' knowledge to examine the effects of flossing over muscle bellies, other researchers have examined the effects of tissue flossing on joints, specifically the ankle and the shoulder.\(^1, 3, 4\) These studies have all found clinically relevant improvement in ROM of the ankle and shoulder after the application of a floss band. Researchers have claimed that occlusion and reintroduction of blood flow helps to improve ROM.\(^2\) Clinically, this theory supports the use of floss bands not only across a joint but also over the muscle bellies for increased

---

**Table 1: Range of Motion (ROM) Measurements in Degrees**

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Mean Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floss</td>
<td>86.14±8.06º</td>
<td>90.81±7.69º</td>
<td>4.67º (3.35, 5.98)*</td>
</tr>
<tr>
<td>Sham</td>
<td>87.67±7.51º</td>
<td>89.86±7.88º</td>
<td>2.19º (0.98, 3.40)*</td>
</tr>
<tr>
<td>Control</td>
<td>87.95±10.75º</td>
<td>88.14±9.93º</td>
<td>0.19º (-0.63, 1.01)</td>
</tr>
</tbody>
</table>

\(^*\) p<0.05 for intervention compared to control; CI = confidence interval

**Table 2: Power Measurements in Watts**

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Mean Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floss</td>
<td>3078.73±767.97 W</td>
<td>3120.58±823.16 W</td>
<td>41.85 W (-5.66, 89.35)</td>
</tr>
<tr>
<td>Sham</td>
<td>3130.86±817.71 W</td>
<td>3116.91±865.23 W</td>
<td>-13.95 W (-76.56, 48.66)</td>
</tr>
<tr>
<td>Control</td>
<td>3101.49±817.64 W</td>
<td>3117.64±810.74 W</td>
<td>16.15 W (-26.51, 58.81)</td>
</tr>
</tbody>
</table>

CI = confidence interval

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**Figure 3: TekScan Pressure Sensor**

**Figure 4: Group Means for Flexibility Across Testing Session**

\(^*\) p<0.05 for intervention compared to control
ROM as these same claims may be supported when flossing the muscle.

This study was not without limitations. The population was composed solely of healthy, college-aged individuals. With positive outcomes in a healthy population, future studies should continue to examine the clinical effectiveness of flossing on an injured population. While flossing has been shown to be effective with healthy individuals, these benefits may be compounded when being used for recovery and rehabilitation from injury. Another limitation was that there was low statistical power for the analysis of vertical jump which increases the odds of a Type II error. Increasing the sample size may produce different results for the effects of tissue flossing on lower extremity power. Further research should be conducted to determine what band pressure provides optimal benefits. Future research should also aim to determine a timeline for flexibility improvements after flossing. Determining the effects of flossing on more functional exercises could aid in identifying potential improvement carryover to sport specific activities. Lastly, the variability in days between the trials (2-4) could also be a limitation and should be examined in future studies.

CONCLUSION

While there are many mechanisms to increase flexibility, these results support that flossing may not only immediately improve flexibility, but achieve this without hindering power. Therefore, flossing may be an appropriate treatment when ROM needs to be increased without altering power output. With positive outcomes in a healthy population, future studies should continue to examine the clinical effectiveness of flossing on an injured population.

CONFLICTS OF INTEREST

Authors report no Conflicts of Interest.

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REFERENCES


Female Adolescent Soccer Players Utilize Different Neuromuscular Strategies Between Limbs During the Propulsion Phase of a Lateral Vertical Jump

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1 Right to Dream Academy, 2 Texas Health Sports Medicine, 3 Northwestern University

Keywords: limb dominance, vertical jump, between-limb

Background
Multiplanar dynamic stability is an important unilateral function in soccer performance but has been scarcely examined in female soccer players. The lateral vertical jump task assesses unilateral functional performance, and energy generation contribution examines how each joint (hip, knee, ankle) contributes to the vertical component of the vertical jump phase to measure inter- and intra-limb differences.

Purpose
To examine dominant versus non-dominant limb performance using energy generation contribution of the hip, knee, and ankle during the vertical jump component of the lateral vertical jump.

Study Design
Cross-sectional observational study.

Methods
Seventeen healthy, adolescent female soccer players (age 13.4±1.7 years; height 160.6±6.0 cm; mass 53.1±8.2 kg) participated. Quadriceps strength was measured via isokinetic dynamometry. Energy generation contribution (measured from maximal knee flexion to toe off) and vertical jump height were measured during the vertical component of the lateral vertical jump.

Results
There was no significant difference between limbs for quadriceps strength (p=0.64), jump height (p=0.59), or ankle energy generation contribution (p=0.38). Energy generation contribution was significantly greater in the dominant hip (dominant 29.7±8.6%, non-dominant 18.4±6.3%, p<0.001) and non-dominant knee (dominant 22.8±6.8%, non-dominant 36.2±8.5%, p<0.001).

Conclusion
High demand on coordination and motor control during the lateral vertical jump and inherent limb dominance may explain different intra-limb strategies for task performance despite jump height symmetry. Non-dominant affinity for stability and dominant compensatory performance may neutralize potential asymmetries. Implications for symmetry in observable outcomes such as jump height must consider underlying internal asymmetries.

Levels of Evidence
3B

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Clinical Relevance

Symmetrical findings on functional tasks have underlying internal asymmetries observed here in female adolescent soccer players. The lateral vertical jump may highlight these internal asymmetries (hip- versus knee-dominant movement strategies) due to the high coordinative demand to perform the task. Clinicians should be cognizant of underlying, potentially inherent, asymmetries even when observing functional symmetry in a task.

What is known about the subject

Female adolescent soccer players are a high-risk cohort for sustaining anterior cruciate ligament injuries. Limb dominance may play a role in the performance of functional tasks, and limb dominance in soccer players is quite specialized: the dominant limb is the preferred kicking limb, while the non-dominant limb is the preferred stabilizing limb (plant leg). Functional performance in female soccer players has been studied in kicking, dribbling, sprinting, change of direction, and jumping – however, these tasks were measured independent of limb dominance. It remains to be seen how unilateral functional tasks may be affected by limb dominance in female adolescent soccer players.

What this study adds to existing knowledge

This study provides data on functional performance relative to limb dominance in female adolescent soccer players, and captures the lateral vertical jump task in both inter- and intra-limb measures. This highlights that intra-limb strategies to perform a coordinated motor task may be different between limbs, herein attributed to limb dominance. Even if gross motor outputs between limbs are symmetrical (i.e. jump height), the underlying movement strategies to achieve that output may be different (hip- versus knee-dominant movement strategies). These findings are important to research on functional performance measures related to attaining between-limb symmetry, as measures of energy generation contribution open the door for a more thorough understanding of joint-by-joint intra-limb contributions during a functional task.

INTRODUCTION

Female soccer has grown to include over 30 million worldwide participants. Between 2013 and 2017, youth female soccer participation has increased by 70%. This impressive growth has not been equaled by corresponding scientific literature, where a dearth of research exists in the women’s game, especially when compared to their male counterparts. Soccer has a large focus on tactics and strategy. On-field tactical decisions regularly come down to player positioning and the capabilities of those players, often with consideration for limb dominance. Limb dominance specific to soccer is often dichotomized into a dominant kicking limb and a non-dominant support limb, which is determined by asking the question: “which is your preferred foot to kick the ball?” In sport-specific functional tasks, the dominant limb in male soccer players produces greater ball velocity during maximal instep kicks, performs quicker changes of direction, and has better intersegmental patterning than the non-dominant limb. In contrast, limb dominance comparisons relative to functional testing in female soccer players have been scarcely reported. Limb dominance during functional testing has previously been reported in a group of healthy female soccer players, with no significant differences between dominant and non-dominant limb for the drop vertical jump in knee motion or knee abduction moments. In a sample of first-team Swedish female players, Östenberg et al. reported no between-limb differences in a series of functional jump and hop test distances when comparing right versus left or the dominant versus non-dominant limbs.

Functional testing methods in athletes should ideally replicate the demands of a particular sport. Soccer is embodied by multidirectional and multiplanar movements with variable locomotor demands involving running backwards and sideways and a change in locomotor activity every four seconds in elite women’s competition. Previous research examining functional testing in female soccer players includes studies of kicking and dribbling, sprinting, changing directions, and an array of jumping tasks, all of which were assessed independent of limb dominance. The jumping tasks reported in the literature are often unidirectional and uniplanar (i.e. vertical jump, single leg hop, triple hop, drop jump, broad jump), although a recent study by Bishop et al. suggests the multiplanar nature of soccer warrants multiple jump tests to be used to classify interlimb asymmetries. The lateral vertical jump task is a performance measure that can be used to assess multiplanar dynamic stability. It has previously been studied at time of return to sport in female athletes following anterior cruciate ligament (ACL) reconstruction and compared to age- and activity-matched healthy female controls. Females in the ACL reconstruction group utilized a greater energy absorption contribution (measure of contributions of the hip, knee, and ankle during the landing phase of the lateral vertical jump) through both the involved and unininvolved hips than females in the healthy group. While these findings demonstrate altered energy absorption strategies utilized during the lateral vertical jump, the focus was on how the individual loaded the limb during the landing portion of the task. This study rather will focus on the energy generation performed during the propulsion.
phase of the lateral vertical jump. As such, the aim of the current study was to examine dominant versus non-dominant limb performance using energy generation contribution of the hip, knee, and ankle during the vertical jump component of the lateral vertical jump. With side-to-side differences demonstrated in single leg countermovement jump in a similar population, we hypothesized that female adolescent soccer players will produce greater total energy generation, demonstrated by vertical jump height, in the dominant limb than the non-dominant limb. We also hypothesized that the dominant limb would demonstrate greater energy generation contribution in the hip and knee and similar energy generation contribution in the ankle when compared to the non-dominant limb.

MATERIALS AND METHODS

This study investigated the differences between dominant and non-dominant limb performance using a novel lateral hop to vertical jump measure of dynamic stability. A cross-sectional design was implemented following the STROBE (Strengthening the Reporting of Observational studies in Epidemiology) statement. The dominant limb was determined by self-report, defined as the limb that the participant reported she would choose to kick a ball. The lateral vertical jump task was divided into energy generation contributions of the hip, knee, and ankle joints to assess if within-limb strategies differed between the dominant and non-dominant limb.

PARTICIPANTS

A total of 17 healthy female soccer players (Table 1) volunteered to participate in this study. These adolescent soccer players (age 13.4 ± 1.7 years) were a subset of a larger cohort study with inclusion criteria: between the ages of 13 and 25 years and involved in a level 1 sport (involving cutting, planting, pivoting, jumping, and landing) for at least 50 hours/year. A power analysis was calculated to estimate sample size using energy generation contribution as the variable of interest and it was determined that seventeen participants were needed to detect statistical significance (80% power at p < 0.05). Participants were considered for study inclusion if they scored ≥ 95% on the International Knee Documentation Committee (IKDC) subjective form and did not experience any lower extremity orthopedic injuries within 3 months before testing. After the screening process, eligible participants were invited to take part in the study. Since participants were minors, parental permission and child assent were obtained and the rights of each person were protected. The institutional review board of Texas Health Resources approved all research procedures. After enrollment in the study, information regarding injury history and athletic involvement was collected from each participant. Height and body mass were measured for each participant using an eye-level weigh beam scale (Detecto, Webb City, MO, USA).

<table>
<thead>
<tr>
<th>Table 1: Participant demographics (n= 17).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Soccer Participation (hours/week)</td>
</tr>
<tr>
<td>Season Duration (months)</td>
</tr>
<tr>
<td>IKDC Score</td>
</tr>
</tbody>
</table>

IKDC= International Knee Documentation Committee

PROCEDURES

3-DIMENSIONAL MOTION ANALYSIS

Retroreflective marker placement was consistent with a previously published protocol and attached to the participant with double-sided tape. Marker placement included the spinous process of the seventh cervical vertebra, twelfth thoracic vertebra, between the fourth and fifth lumbar vertebrae, sternum, bilateral acromion process, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, anterior thigh, medial and lateral epicondyles of the femur, anterior shank, medial and lateral malleoli, calcaneus, and first and fifth metatarsal heads. Three additional retroreflective markers were attached on the sacrum as a cluster. Qualisys motion capture system with 10 Oqus cameras (Qualysis, Göteborg, Sweden) were used to collect three-dimensional coordinates of reflected markers attached to the participant at a sampling rate of 120 Hz. Two force plates (AMTI, Watertown, MA, USA) were used to collect ground-reaction forces at a sampling rate of 1200 Hz, and kinematic and force plate data were time synchronized. After completion of the static trial, markers of the medial femoral epicondyle, medial malleolus, and bilateral anterior superior iliac spine were removed, and participants performed the lateral vertical jump.

LATERAL VERTICAL JUMP

Participants began this unilateral jump task by standing to the side of the force plate at a distance equal to 50% of their height with the testing limb closest to the force plate. The dominant limb was tested first. Fifty percent of the participant’s height was used to ensure that participants are challenged with the task while also normalizing for individual height differences. Participants were asked to hop onto the force plate by pushing off the ground with their non-testing limb, land with the testing limb on the force plate, and then immediately perform a maximal single leg vertical jump and land back onto the force plate with their testing limb (Figure 1). Immediately after landing on the force plate, the participants were required to stabilize themselves on the force plate for approximately two seconds. Unilateral vertical jump height was captured in centimeters extrapolated from flight time. Participants warmed up on an exercise bike before performing three trials on each limb. Trials were excluded and repeated if the participant’s entire foot did not contact the force plate, if the non-testing limb con-
tacted the ground or force plate upon landing or immediately after, or if the participant did not maintain balance.

**DATA PROCESSING AND REDUCTION**

Three-dimensional joint coordinates were estimated from the trajectories of the reflective markers. All kinematic and kinetic data were exported into Visual3D software (C-Motion) to process and reduce data. The kinematic and force data were filtered via a fourth-order low-pass Butterworth filter with a zero-phase lag at 10 Hz. The lower extremity joint angles were calculated using an inverse kinematic approach, and the lower extremity internal moment was calculated using an inverse dynamic approach. The energy generation contribution was calculated by integrating the positive part of the power curve where joint angular velocity and net joint moment are in opposite directions, indicating concentric loading during the vertical jump takeoff phase from maximal knee flexion to toe-off. The energy generation contribution for each joint was normalized to the product of height and weight and averaged across three trials.

**ISOKINETIC DYNAMOMETRY**

The Multi-Joint Testing and Rehabilitation System (Biodex Medical Systems) was used for testing isokinetic quadriceps muscle strength. Participants were seated on the Biodex system and secured with padded straps around the thigh, pelvis, and torso to minimize accessory and compensatory movements during testing. The femoral condyle of the testing limb was aligned with the dynamometer axis of rotation following the manufacturer’s instructions. A warmup consisting of five submaximal knee extension/flexion contractions (60 degrees/second) was provided to familiarize each participant with the testing motion. Next participants performed five maximum effort trials. The average of the five trials was normalized to body mass (Nm/kg) and used for data analysis.

**STATISTICAL ANALYSES**

All data analyses were performed using SPSS version 23 (International Business Machines Corporation, Armonk, NY). Multiple paired t-tests were used to assess between-limb differences in energy generation contribution at the hip, knee, and ankle and quadriceps strength. A Bonferroni correction was applied to account for multiple comparisons and the alpha level was set at P < .01. Effect sizes were estimated for each variable of interest using Cohen’s $d$ formula.

**RESULTS**

Table 2 demonstrates the between limb differences for outcome variables including vertical jump height, quadriceps strength, and energy generation contribution at the hip, knee, and ankle. The dominant limb demonstrated significantly greater hip energy generation contribution (29.7±8.6%) than the non-dominant limb (18.4±6.3%, p < 0.001). At the knee, the dominant limb produced significantly less energy generation contribution than the non-dominant limb (dominant 22.8±6.8%, non-dominant 36.2±8.5%, p < 0.001). There were no other significant differences between the dominant and non-dominant limbs for ankle energy generation contribution (p = 0.38), jump height (p = 0.59), or quadriceps strength (p = 0.64). Effect sizes using Cohen’s $d$ are also reported in Table 2.

**DISCUSSION**

This study aimed to examine dominant versus non-dominant limb performance using energy generation contribution of the hip, knee, and ankle during the vertical jump component of the lateral vertical jump. Isokinetic quadriceps strength and vertical jump height were not significantly different between limbs and each had small effect sizes. The dominant limb indicated greater hip energy generation contribution and lesser knee energy generation contribution when compared to the non-dominant limb, with no between-limb differences in ankle energy generation contribution.

We hypothesized female adolescent soccer players would produce greater total energy generation in the dominant limb, indicated by greater vertical jump height. The lateral vertical jump adds frontal plane demand and increased task complexity, leading to our expectation of between-limb differences. However, vertical jump height was not signifi-
Table 2: Dominant versus non-dominant limb comparisons.

<table>
<thead>
<tr>
<th></th>
<th>Dominant</th>
<th>Non-Dominant</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (m)</td>
<td>0.12</td>
<td>0.13</td>
<td>0.59</td>
<td>0.33</td>
</tr>
<tr>
<td>Knee extension peak torque 60°/s (Nm/kg)</td>
<td>1.79</td>
<td>1.82</td>
<td>0.64</td>
<td>0.06</td>
</tr>
<tr>
<td>Hip energy generation contribution (%)</td>
<td>29.7</td>
<td>18.4</td>
<td>&lt;0.001</td>
<td>1.51</td>
</tr>
<tr>
<td>Knee energy generation contribution (%)</td>
<td>22.8</td>
<td>36.2</td>
<td>&lt;0.001</td>
<td>1.74</td>
</tr>
<tr>
<td>Ankle energy generation contribution (%)</td>
<td>47.5</td>
<td>45.4</td>
<td>0.38</td>
<td>0.25</td>
</tr>
</tbody>
</table>

SD= standard deviation

Significantly different between limbs. We also expected greater energy generation contribution in both the hip and knee on the dominant limb to comprise the hypothesized greater vertical jump height. Knee energy generation contribution was significantly lower on the dominant side, and there were no notable differences in vertical jump height between limbs. These findings did not align with our hypothesis.

In countermovement jump and drop jump tasks, performance is hip and knee dependent while the ankle has lesser contribution. These results are in contradiction with the findings of the current study in that the overall percentage of contribution of the ankle in both limbs (dominant 47.5±7.7%, non-dominant 45.4±8.9%) was higher than the contribution percentages of the hip and knee in either limb. While the current study focuses on between-limb differences rather than the percent of contribution from each individual joint, the fact that females relied on more of an “ankle strategy” during take-off does highlight task specific contributions of the ankle during the lateral vertical jump. Previous data demonstrates similar ankle contribution during the landing portion of the lateral vertical jump in healthy female adolescent athletes. While the current study was examining the percent contribution of each joint’s ability to generate power, the former studied the ability to absorb forces or energy absorption contribution when landing from a jump. Nevertheless, young female athletes appear to rely on an ankle strategy during performance of a lateral vertical jump.

In the absence of observed power (vertical jump height) and strength (quadriceps strength) differences between limbs, energy generation contribution differences point to motor patterning. In general, hip, knee, and ankle muscle strength capacity are primary indicators of jump height, although motor control influences the extent with which that muscle capacity can be activated. Previous evidence indicates the role of dynamic stabilization and neuromuscular control in the landing phase of a single leg hop, with a balance training group demonstrating significantly reduced impact landing forces following training interventions. The motion in traditional countermovement jumps occur in the sagittal plane, aligned with the upcoming jump. In the lateral vertical jump, the preceding lateral hop phase adds a multiplanar component, necessitating frontal plane landing control. Neuromuscular control strategies from a lateral hop differ from landing in an anterior-posterior direction, requiring greater mechanical loading for lateral braking, and inducing greater demands on dynamic postural stability. As the end of the lateral hop phase of the lateral vertical jump occurs, frontal plane motion must be immediately transferred to the sagittal plane to perform the vertical jump. Jump performance is dependent on peak power development in the direction of the jump. For effective energy generation for the vertical jump phase, frontal plane deviations must be minimized. As such, the lateral vertical jump may be a good indicator of motor control as evidenced by energy generation contribution differences between limbs despite symmetrical jump heights.

Theorizing that the non-dominant limb better positions itself at the moment of energy transfer from the lateral hop into the vertical jump is feasible, highlighting the importance of coordination to perform the lateral vertical jump. Previous studies indicate the non-dominant limb functions in stability to allow the dominant limb to perform a manipulative task, and the repetition of these unilateral actions may result in neuroplastic adaptations creating better proprioception and stabilization in the non-dominant limb. In soccer, the dominant limb functions to kick the ball while the non-dominant limb is necessary for stability. The non-dominant limb in soccer players has demonstrated greater dynamic stability during single leg drop jumps as evidenced by knee valgus moment. It is reasonable that the non-dominant limb performs this type of task more efficiently. On the contrary, with reversed roles, the dominant limb functioning as the landing “supporting” leg may have less neuromuscular control, driving a more hip-centric pattern to operate in the frontal plane to produce the vertical jump outcome. Perhaps clinicians should consider potential differences in strategies used to jump during this task in the current population. As such, interventions might include a greater focus on hip exercises in the non-dominant limb with more intention on knee or quadriceps exercises in the dominant limb.

LIMITATIONS

Generalizability of these results is limited to the cohort observed. These adolescent athletes are still developing, likely both in physical maturation and skill acquisition. It remains to be seen how more adult athletes, who might be more mature movers, might have different neuromuscular patterning and coordination. Differences in between-limb EGC may be attributed to coordination and motor control under the...
assumption that between-limb muscle strength is similar. Symmetry was observed in quadriceps muscle strength, but between-limb hip strength was not assessed to further examine this finding. The authors also assume that between-limb jump height can be attributed to power, strength, and coordination of the lower extremities. Other variables, such as intermuscular coordination using surface electromyography, or accounting for trunk and upper extremity positioning, may be useful in future studies.

**PRACTICAL APPLICATIONS**

Female adolescents in sport are a high-risk group for ACL injury, also demonstrating alarmingly high re-injury rates. Recent studies have reported the dominant limb in soccer players is more likely to sustain an ACL injury. Establishing outcomes for sport-specific tasks will help bridge the gap between traditional hop tests and full return-to-sport. Young females demonstrate movement patterns characterized by neuromuscular deficits that can be attributed to lacking strength and power, but also motor control and coordination. Continuing to study motor patterns in adolescent females may further elucidate the higher-level functional importance of the lateral vertical jump as a measure of dynamic stability. It is clear that different strategies for producing power are employed between the dominant and non-dominant limbs during the lateral vertical jump. Likewise, asymmetries in energy generation contribution at the hip and knee are apparent, but the clinical relevance of this finding remains difficult to ascertain. If the observable outcome (jump height) is symmetrical, but technique and patterning to achieve it (energy generation contribution) is asymmetrical, how should the task be classified?

For functional testing outcomes, attaining symmetry should be the standard. While arbitrary goals set at 90% of the contralateral limb or deeming a 15% difference as abnormal are common, meeting those cutoffs alone may not be sufficient. Grindem et al. reported that each percentage point closer to 100% symmetry in quadriceps strength resulted in a 5% decrease in re-injury rate in post-ACL reconstruction athletes. Functional tests should have some degree of sport-specificity if they intend to replicate on-field demands, and the lateral vertical jump appears applicable to numerous soccer-specific movement patterns. It is common for a soccer player to transition from a lateral movement into sagittal plane movement, all while negotiating space and potentially contacting an opponent. The present study sought to identify initial values for this novel task in vertical jump height. Independent of the aforementioned between-limb differences in EGC at the hip and knee, jump height was similar between limbs, indicating this cohort of healthy female adolescent soccer players is symmetrical in that regard. This preliminary data suggests the lateral vertical jump task can be used as an additional tool in rehabilitation and strength and conditioning, beyond traditional bilateral jumping tasks and unilateral but uniplanar tasks.

Symmetry normalization is a milestone in rehabilitation following injury but not the final goal. At some point, the intrinsic between-limb differences driven by inherent lateral dominance provide a ceiling. Even upon achieving symmetrical observable outcomes in between-limb vertical jump height, clinicians must recognize inherent "unseen" asymmetries and consider the intra-limb motor pattern alterations that may be used to achieve symmetry. While the results of the current study demonstrate similar power (vertical height) between limbs, the strategies used to achieve the outcome varied (i.e., greater hip, less knee energy generation contribution on the dominant limb versus less hip, greater knee energy generation contribution on the non-dominant limb). The takeaways from the present study are that functional performance measures and striving for symmetry are not "black and white" – symmetry on the surface may not tell the underlying story. Symmetrical performance observed for jump height may be achieved via different underlying movement strategies.

**CONCLUSION**

The lateral vertical jump task is a novel measure of unilateral, multiplanar dynamic stability. The findings demonstrate interlimb symmetry in jump height during the lateral vertical jump task when comparing the dominant and non-dominant limbs. However, different internal strategies were employed to achieve this outcome, demonstrated by higher knee energy generation contribution in the non-dominant limb and higher hip energy generation contribution in the dominant limb. Intra-limb symmetry must be considered within the context of the desired outcome, with the understanding that underlying joint-by-joint energy generation contribution differences may not coincide with overall outcomes.

**CONFLICTS OF INTEREST**

None declared.

**FUNDING**

None to report.

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REFERENCES


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Medio-Lateral Hamstring Muscle Activity in Unilateral vs. Bilateral Strength Exercises in Female Team Handball Players – A Cross-Sectional Study

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Keywords: emg, exercise, hamstrings, medio-lateral activation, strength

Background
Reduced activation of the hamstring muscles and specifically the medial semitendinosus muscle (ST) has been shown to be a risk factor for non-contact anterior cruciate ligament (ACL) injury. Specific hamstring strength exercises may show high ST activity, however the effect of unilateral vs. bilateral exercise execution on ST activation remains unknown.

Purpose
To investigate selected lower limb strengthening exercises performed either unilaterally or bilaterally to identify 1) which exercise elicited the highest hamstring activation, 2) which exercise elicited the highest ST activation, and 3) to examine if unilateral exercise execution altered the medio-lateral hamstring activation pattern. Furthermore, the kinematic characteristics of each specific exercise and execution modality were determined to reveal possible causes for differences in medio-lateral hamstring activation between the different exercise conditions.

Study design
Cross-sectional study.

Methods
Single-session repeated measures were obtained in a randomized manner. Twenty-three female elite team handball players were recruited. Hamstring electromyographic (EMG) activity and 3D kinematics were obtained during selected lower limb exercises (hip thrust, kettlebell swing, Romanian deadlift). Hamstring EMG activity, normalized to maximal voluntary contraction (MVC) (nEMG), and inter-muscular activation difference between the ST and lateral hamstring biceps femoris (BF) were compared across exercises using two-way repeated measures ANOVA.

Results
Bilateral hip thrust demonstrated highest overall hamstring activity (68.9±16.6 %). Kettlebell swing (Δ13%-point, p<0.01) and Romanian deadlift (Δ20-24%-point, p<0.01) demonstrated greater ST-BF activation differences (Δ=ST-BF) in favor of ST compared to hip thrust (Δ2-7%). Positive correlations were observed between knee joint angle and ST activity in kettlebell swing and deadlift.
Conclusion
Kettlebell swing, deadlift and hip thrust all produced high activation of the hamstring muscles. Kettlebell swing and both deadlift exercises were superior in activating ST over BF, favoring these exercises in the prevention of non-contact ACL injury in female athletes, which should be evaluated in future intervention studies.

Level of evidence

INTRODUCTION

Acute knee injuries, especially to the ACL, often result in functional instability.\(^1\) Consequently, ACL injury can have a number of negative consequences on both the short- and long-term functioning of the knee joint.\(^2\)\(^-\)\(^4\)

ACL injuries occur three to seven times more frequently in athletes compared to non-athletes, and represents a substantial problem in ball sports such as team handball and football,\(^2\)\(^-\)\(^8\) which involve sudden stops and side-cutting maneuvers. In 80 % of the cases, the ACL injury happens in non-contact situations.\(^9\) Further, the incidence of non-contact ACL injury is reported to be three to six times higher for women than men.\(^5\)\(^-\)\(^9\)\(^-\)\(^13\) Proper neuromuscular control is imperative for stabilization of the knee joint during athletic movements with injury risk. Especially, adequate hamstring activation before or during the landing phase is considered important to control excessive rotations and protect e.g. the ACL.\(^11\)\(^,\)\(^12\)\(^,\)\(^14\)

Compared to male athletes, female athletes exhibit greater quadriceps EMG activity during vertical stop-jump tasks\(^14\) and side-cutting maneuvers,\(^15\)\(^,\)\(^16\) while male athletes often display higher hamstring activation in these situations with high risk of ACL injury.\(^14\)\(^-\)\(^22\) Moreover, reduced strength and recruitment of the hamstring muscles are considered significant risk factors in relation to non-contact ACL-rupture.\(^23\)\(^-\)\(^25\) Introducing preventive training programs have shown positive effects on the muscle-strength relationship between quadriceps and the hamstrings,\(^22\)\(^,\)\(^24\) as well as on the neuromuscular activation pattern in selected landing and side-cutting situations.\(^22\) The medial hamstring muscle(s) seem particularly important in this context, as a reduced medial (semitendinosus) electromyographic (EMG) activity during side-cutting in combination with a high activity in the lateral quadriceps (vastus lateralis) have been shown to be related to an elevated risk of non-contact ACL injury.\(^25\) Previous research has identified dynamic valgus of the knee as a predisposing factor for ACL injury in female athletes.\(^26\) The balance between medial-lateral hamstring recruitment seems highly important for the control of dynamic valgus.\(^27\) Female athletes appear to have disproportionately greater EMG activity in their lateral biceps femoris muscle than male athletes when landing from a jump.\(^28\) Increased lateral hamstring recruitment potentially could lead to a more open medial joint space and thereby contributing to increased dynamic valgus, and hence contribute to increase the risk of non-contact ACL injury.\(^28\)

Strengthening exercises for the hamstring muscles such as hip extension and isolated knee flexion (i.e. leg curl) typically show high levels of muscle activity in the lateral biceps femoris compared to the medial semitendinosus.\(^29\)\(^-\)\(^33\) From an ACL injury prevention perspective, it thus becomes relevant to examine the relative balance between semitendinosus and biceps femoris muscle activity during commonly used training exercises, in order to identify or develop exercises with high medial vs lateral hamstring muscle activity. Recent research has identified the Kettlebell swing and Romanian deadlift to be associated with a preferential activity in the semitendinosus vs. biceps femoris muscle,\(^33\)\(^,\)\(^34\) and as a common characteristic both exercises are performed with nearly straight knees and a forceful hip extension with the peak load at the most flexed hip joint angle. However, these exercises may vary in the technique, load and intensity of the movement, which may affect the activity of the muscles. Furthermore, progression in these exercises are frequently achieved by using a single stance leg, typically in a common belief that the preventive exercise effect is improved when the exercise involves an increased need for dynamic joint stabilization. However, the effect of this assumption on hamstring muscle activation levels has never been tested in controlled experimental settings.

The purpose of this study, therefore, was to investigate selected lower limb strengthening exercises performed either unilaterally or bilaterally to identify 1) which exercise elicited the highest hamstring activation, 2) which exercise elicited the highest ST activation, and 3) to examine if unilateral exercise execution altered the medio-lateral hamstring activation pattern. Furthermore, the kinematic characteristics of each specific exercise and execution modality were determined to reveal possible causes for differences in medio-lateral hamstring activation between the different exercise conditions.

METHODS

SUBJECTS

Female team handball players from the three highest Danish team handball divisions were invited to participate in the study. Twenty-three players (mean age: 20.7±2.9 year; mean height: 176.0±5.7 cm; mean weight: 73.1±7.3 kg; mean handball training frequency: 3.2±0.9 sessions/week; mean strength training frequency: 2.8±0.8 sessions/week) with no previous history of ACL injury or hamstring injury volunteered to participate in the study.

The study was approved by the local Ethics Committee (H-18063645). All participants received written information about the study and each participant confirmed their participation by signing a written declaration of consent. All participants were informed about the protection of subject rights.

International Journal of Sports Physical Therapy
TEST PROCEDURES

A pretest familiarization session was carried out on a separate day prior to the first test day. In this session, all experimental exercises were demonstrated for the participant by an experienced test instructor. Afterwards the participant executed the exercises with guidance from the test instructor to ensure that the exercise was correctly executed. When correct technique and movement execution were achieved, the individual load for the testing day was established for each exercise. The kettlebell weight corresponded to a 20RM load, whereas an 8RM load was chosen for the bilateral Romanian deadlift and hip thrust exercises. During all unilateral exercise conditions, the exercise load/weight corresponded to half of the load used in the corresponding bilateral exercise condition.

On the day of testing, all participants performed a standardized warm-up program that involved five stretching exercises for the larger muscle groups (quadriceps, hamstrings, chest, shoulders, back) followed by a number of low-load strength training exercises (squats, lunges, hip bridge, back extensions, crunches, push-ups) performed in 3 sets of 10 repetitions for each exercise with 30-45 s rest between sets. After warm-up, participants performed three maximal voluntary isometric knee flexor contractions (MVC) of five seconds duration (30-s pause between successive MVC trials) were performed to determine maximal volitional EMG activity in the lateral and medial hamstring muscles (more details provided below). Finally, for familiarization ten repetitions were performed for each exercise using a 16RM load (40RM in kettlebell swing) altogether followed by three minutes of rest. Subsequently, five test repetitions using an 8RM load (20RM load in kettlebell swing) were performed and sampled for later off-line analysis. A total of six exercises were performed in a cluster randomized order using lottery notes with numbers from 1 to 6.

The unilateral exercises were performed on both legs (and data averaged between the two limbs), in the order of dominant non-dominant leg. Approximately three minutes of rest were prescribed between exercises to avoid fatigue.

EXERCISE PROTOCOL

The exercise protocol involved three distinct lower limb strengthening exercises (kettlebell swing, Romanian deadlift and hip thrust). The exercises were selected based on their regular involvement in clinical practice and athlete physical conditioning, as well as being inspired by previous ACL injury prevention programs.29,35–41 As a common characteristic, all selected exercises involved a large degree of hip flexion and -extension.

KETTLEBELL SWINGS (KS)

Participants were standing with their feet positioned in parallel (shoulder width distance between right and left foot). The exercise was always performed bilaterally (no unilateral variant) using an explosive (i.e. maximally accelerated) hip extension to swing the kettlebell up (chest level) using straight arms continuing into a down-ward swing between the legs, while in all swing phases maintaining a knee joint angle close to full extension (Figure 2A).

The kettlebell weight corresponded to a 20RM load i.e. the maximal weight the subject could swing 20 times without loss of correct technique. The subject performed a single set of ten swings using this load.

ROMANIAN DEADLIFT (DL)

Bilateral DL: Participants lifted the barbell (load corresponding to 8RM) with the feet parallel and shoulder-width apart. The barbell was lifted from hanging right below the knees with an explosive extension of the hips until standing upright (Figure 2B). The knees were maintained at an angle near full extension.

Unilateral DL: Participants performed the exact same movement as described for the bilateral DL, except standing
on one leg. The subject performed a single set of five repetitions with a load corresponding to half of the two-legs load (Figure 2C).

HIP THRUSTS (HT)

Bilateral HT: Participants were positioned supine with the upper part of the back supported on a bench and starting with flexed hips and knees. A barbell was placed on the upper part of the thigh (weight corresponding to 8RM) and was lifted as fast as possible by extending the hips. The exercise was performed using two different feet positions that resulted in different knee joint angles at full hip extension; first, a set of five repetitions with an ~90° knee angle (Figure 2D) and afterwards a set with ~110° knee angle (180° = full extension).

Unilateral HT: This exercise was performed as described above for bilateral HT testing, except using a single leg only. The subject performed a single set of five repetitions with a weight corresponding to half of the load used in the two-legs HT (Figure 2E). Unilateral HT was only performed as the 90° knee flexion end-position exercise.

ELECTROMYOGRAPHY (EMG) RECORDINGS

The skin of the subject was shaved with a hand razor and carefully cleaned with ethanol before electrode placement on both legs. Bipolar surface EMG electrodes (2-cm inter electrode distance, Myon Aktos, prophysics SOL AB, Höör, Sweden) were placed at the BF and ST muscles according to standard recommendations. Raw EMG signals were pre-amplified, band-pass filtered (20-450 Hz) and sampled with a frequency of 1000 Hz. The EMG recordings were high-pass filtered using a 4th order Butterworth filter with a cut-off frequency of 10 Hz and subsequently smoothed by a symmetrical moving root-mean-square filter (RMS) with a window size of 50 ms and 29 ms running overlap.

Before exercise testing, the maximal EMG activity was obtained during maximal voluntary isometric hamstring muscle contraction (MVC), as described in detail elsewhere. Three maximal isometric MVC's were performed for the knee flexors (hamstrings) of each leg separated by 30-s rest and the peak EMG amplitude of the three trials was used for later EMG normalization.

All dynamic EMG data were normalized to the maximal EMG amplitude recorded during MVC testing. The peak EMG amplitude for each repetition was obtained, and the mean of five repetitions for DL and HT exercises and ten repetitions in KS for each participant were used.

BIOMECHANICAL ANALYSIS

All tests were performed in a biomechanical motion analysis laboratory with eight infrared cameras (Vicon T40 cameras, Vicon Motion Systems Ltd, Oxford, UK) with a frame capture frequency of 100Hz. Data were collected using inherent software, (Nexus 2, Vicon Motion Systems Ltd, Oxford, UK).

3D BIOMECHANICAL MODEL

To obtain hip and knee joint kinematic data, a total of 22 reflective markers were placed over anatomical landmarks according to a modified Helen Hayes marker setup, except
Table 1: Descriptive characteristics of participants

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y):</td>
<td>23</td>
<td>18</td>
<td>28</td>
<td>20.7 ± 2.9</td>
</tr>
<tr>
<td>Height (cm):</td>
<td>23</td>
<td>165.7</td>
<td>190.8</td>
<td>176.0 ± 5.7</td>
</tr>
<tr>
<td>Weight (kg):</td>
<td>23</td>
<td>62.0</td>
<td>91.2</td>
<td>73.1 ± 7.3</td>
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<tr>
<td>Active handball years:</td>
<td>23</td>
<td>5</td>
<td>21</td>
<td>12.2 ± 3.9</td>
</tr>
<tr>
<td>Handball training sessions per week:</td>
<td>23</td>
<td>2</td>
<td>5</td>
<td>3.2 ± 0.9</td>
</tr>
<tr>
<td>Strength training sessions per week:</td>
<td>23</td>
<td>2</td>
<td>5</td>
<td>2.8 ± 0.8</td>
</tr>
</tbody>
</table>

for the thigh markers, which were substituted by markers attached over the patella, to reduce the effect of wobbling masses.45

STATISTICAL ANALYSIS

Shapiro-Wilk testing was performed to check for normality. Subsequently, a two-way analysis of variance (ANOVA) was performed in SPSS (Version 22, IBM SPSS Statistics) using a repeated measures procedure with Bonferroni corrections to determine whether differences existed in peak nEMG between exercise type and medial vs lateral hamstring muscles, respectively. Factors included in the model were muscles (ST and BF) and exercises (six exercises), as well as the interaction between these. Pearson correlation analysis was performed to examine the potential relationship between hip- and knee joint range of motion and muscle activity, respectively.

p-values of ≤0.05 were considered statistically significant.

A statistical power of 80 % to detect a difference of p=0.05 with a standard deviation of 20 in nEMG (expressed in % of peak EMG at MVC) and a between-exercise difference of 15 % points of peak nEMG was calculated to require a total of 16 participants.33

RESULTS

Data were excluded from two participants, due to undetected loss of markers during the test exercises. Thus, the present results contain data from 21 participants. Subject characteristics are presented in Table 1 with participant flow illustrated in Figure 1.

HAMSTRING MUSCLE ACTIVATION

Total hamstring muscle activity (mean (ST+BF)) expressed as peak normalized EMG amplitude (nEMG) varied between the different test exercises (Figure 3). The HT exercise performed at 110° knee angle (HT 110°) showed the highest activity level of 68.9±16.6 % (mean ±SD). Hamstring activity levels for the other tested exercises were: Two-legs DL (DL-2legs) (68.0±18.8 %), Single-leg HT (HT-1leg) (67.4±18.3 %), Single-leg DL (DL-1leg) (63.6±16.7 %), KS (53.0±15.0 %), HT performed at 90° knee angle (HT 90°) (50.4±15.9 %).

![Figure 3: Mean hamstring activity (% of peak nEMG) shown as group mean +/- SEM.](image)

*Significantly different from KS and HT 90° (p< 0.02), **Significantly different from HT 90° (p< 0.02).

Table 2: Peak normalized EMG (nEMG) activity of ST and BF. Expressed as mean (±SD).

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Peak nEMG (% of max)</th>
<th>ST</th>
<th>BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL-2legs</td>
<td>80 (17)</td>
<td>57 (20)**</td>
<td></td>
</tr>
<tr>
<td>DL-1leg</td>
<td>74 (16)</td>
<td>54 (18)**</td>
<td></td>
</tr>
<tr>
<td>KS</td>
<td>59 (14)</td>
<td>47 (16)**</td>
<td></td>
</tr>
<tr>
<td>HT 90°</td>
<td>54 (17)</td>
<td>47 (15)*</td>
<td></td>
</tr>
<tr>
<td>HT 110°</td>
<td>71 (18)</td>
<td>65 (16)</td>
<td></td>
</tr>
<tr>
<td>HT-1leg</td>
<td>69 (18)</td>
<td>66 (18)</td>
<td></td>
</tr>
</tbody>
</table>

nEMG= normalized EMG, ST= semitendinosus, BF= biceps femoris, DL-2legs= two-legged deadlift, DL-1leg= single leg dead lift, KS= kettlebell swing, HT= hip thrust

*Significant difference between ST and BF (p=0.038).

MEDIAL LATERAL ACTIVATION BALANCE

Within-exercise analysis of the medial-lateral hamstring activation balance (Δ = difference between ST and BF, ±SD)
showed a preferential activation of ST over BF during DL-2legs (Δ23.8±2.4 %, p<0.0001), DL-1leg (Δ20.0±2.2 %, p<0.0001), KS (Δ12.8±2.1 %, p<0.0001) and HT 110° (Δ6.5±2.1 %, p<0.05), whereas no difference was found for HT 90° (Δ6.3±2.3 %) and HT-1leg (Δ2.1±1.0 %) (Figure 4, bar graphs).

Between exercise analysis of the medial-lateral activation balance (Figure 4, arrows) revealed elevated muscle activity difference in favor of ST during DL-2legs compared to KS (~Δ11 %), HT 110° (~Δ17.3 %), HT 90° (~Δ17.5 %) and HT-1leg (~Δ21.7 %) (p<0.0001). Likewise, DL-1leg evoked greater ST-BF activity difference than HT 110° (~Δ13.5 %), HT 90° (~Δ13.7 %) and HT-1leg (~Δ17.9 %) (p<0.001). ST-BF muscle activity difference was also greater during the KS compared to HT-1leg (~Δ10.7 %) (p<0.01).

RELATIONSHIPS BETWEEN HAMSTRING MUSCLE ACTIVITY AND KNEE JOINT ROM

For the HT exercises, HT 110° demonstrated a knee range of motion (ROM) between 79.9±9.2° and 56.8±9.7° flexion. HT 90° had a knee ROM between 102.2±9.9° and 76.1±10.2° flexion. A correlation analysis revealed a positive correlation (r=0.515, p<0.035) between more extended knee joint angles and increased ST and BF muscle activity.

The KS exercise was characterized by a hip ROM ranging from 2.4±8.2° to 96.5±8.0° of flexion whereas knee ROM was 9.5±5.5° to 48.2±11.5° flexion (0° = full extension). A positive correlation was revealed (r=0.456, p<0.024) between more extended knee joint angles and increased ST muscle activity during the ECC phase.

The DL exercises demonstrated a hip ROM between 9.7±5.9° and 100.2±7.5° flexion, and a knee ROM between 8.4±6.2° and 34.8±9.7° flexion. No correlation was observed between DL kinematics versus ST or BF muscle activity.

RELATIONSHIP BETWEEN HAMSTRING MUSCLE ACTIVITY AND HIP EXTENSION ANGULAR VELOCITY

The KS exercise demonstrated a mean hip extension angular velocity (HAV) of 312.2±58.1° s⁻¹ and 204.2±40.2° s⁻¹ in the CON- and ECC phase, respectively. A positive correlation was revealed (r=0.459, p<0.05) between increased HAV and elevated ST muscle activity.

The DL exercises performed on either two legs or a single leg demonstrated a mean HAV of 244.8±57.1° s⁻¹ and 203.8±32.3° s⁻¹, respectively, in the CON phase. Velocity in the ECC phase was 101.2±56.2° s⁻¹ when performed on two legs and 71.6±21.9° s⁻¹ on a single leg. No relationships were observed between HAV in both DL exercises and hamstring activity.

The HT exercises demonstrated a mean HAV of 222.7±54.8° s⁻¹, 201.3±49.8° s⁻¹ and 157.3±39.7° s⁻¹ in HT 90°, HT 110° and HT-1leg, respectively. The ECC phase demonstrated a mean HAV of 95.2±39.0° s⁻¹, 89.9±27.9° s⁻¹ and 81.2±20.5° s⁻¹ in HT 90°, HT 110° and HT-1leg, respectively. No relationships were observed between HAV in all HT exercises and hamstring activity.

A comparison analysis between exercises showed higher CON HAV in KS compared to both DL exercises and the three HT exercises (p<0.035). Likewise, DL-2legs showed higher HAV compared to DL-1leg, HT 110° and HT-1leg (p<0.025). Finally, DL-1leg, HT 90° and HT 110° showed higher HAV compared to HT-1leg (p<0.045). KS showed higher HAV compared to all the other exercises in the ECC phase (p<0.054).

DISCUSSION

The main finding of the present study was that all examined lower limb exercises elicited a minimum of 50 % muscle activity in the hamstring muscles, which identified these exercises to be suitable for hamstring muscle strengthening. Further, the majority of the exercises were ST dominant, as evident by elevated ST compared to BF muscle activity. HT and KS displayed a positive correlation between more extended knee joint angles and elevated ST muscle activity. Likewise, KS revealed a positive correlation between increased HAV and an increase in ST muscle activity.

HAMSTRING MUSCLE ACTIVATION

All exercises involved high levels of muscle activity in the hamstring muscles, especially when knee joint angles were near full extension (180° = full extension). In the HT exercise, a positive correlation also was found between reaching more extended knee joint angles and elevated ST and BF activity. Similar observations have been reported by Collazo Garcia et al., who tested four variations of the HT exercise, two of those similar to the HT 90° and HT 110° in the present study. Their study revealed high levels of ST and BF activity when HT exercise was performed with a more extended knee joint angle (ST: 70±17 % vs 71±18 % in the present study) compared to a 90° knee joint angle (ST: 32±8 % vs 54±17 % in the present study). The architecture of the ST muscle with long fiber lengths gives it excellent potential to contract at long muscle lengths. This could at least in part explain the lower muscle activation differences between ST and BF at more extended knee joint angles observed in both the Collazo Garcia and the present study.

Together with HT 90°, the KS exercise demonstrated the...
lowest levels of hamstring muscle activity. Previous studies have reported similar magnitudes of normalized muscle activity in the KS exercise.\textsuperscript{46–48} In contrast, a single previous study observed hamstring activity levels in KS reaching 90% of nEMG, which was recorded at 78±8° knee joint flexion.\textsuperscript{53} This is in contrast to the present study, which demonstrated a mean knee joint ROM between 10.7±4.1° and 48.2±11.2° flexion (mean for KS: 30.9±6.7°). Furthermore, the present study revealed a positive correlation between more extended knee joint angles and increased hamstring muscle activity in the KS exercise. Even though Zebis and coworkers used a similar setup and study population, the more extended knee joint angles in their study could possibly explain the high hamstring activity values observed in their study.\textsuperscript{50}

ST-DOMINANT EXERCISES

The present study revealed that DL and KS exercises preferentially activated ST over BF, and at intensity levels sufficient to stimulate muscle strength gains. Likewise, Zebis and coworkers reported DL-2legs and KS to be highly ST dominant exercises.\textsuperscript{53} During KS and DL, the hamstring muscles are extensively stretched with the highest load at the greatest hip flexion angles. Thus, the ST dominance may partly be explained by the fact that ST, in contrast to BF, are parallel fibered and characterized by long fiber lengths and a high number of sarcomeres in-series.\textsuperscript{49} This arrangement results in a large total shortening capacity (i.e. ensures large joint ROM) along with a high maximum velocity of contraction.\textsuperscript{50,51} Even though the KS may be superior to DL in reflecting real life sports activities due to its functional execution, our study clearly demonstrates that when DL is performed explosively using either a single leg or two legs, it evokes high preferential activation of the ST muscle.

UNILATERAL EXERCISES

Although the present study did not find a difference in the medial-lateral hamstring activation levels between bilateral and unilateral DL exercises, as a novel observation the present data indicated unilateral DL to involve high ST muscle activity while incorporating an important element of postural balance control. This may be relevant to consider in rehabilitative and prophylactic hip and knee stability training planning.

To the authors’ best knowledge only two studies have previously examined hamstring muscle activity during single-leg DL exercise.\textsuperscript{48,52} Examining female athletes, Tsaklis and coworkers reported higher ST muscle activity compared to BF during DL-1leg.\textsuperscript{48} Even though muscle activity levels per se were lower compared to the present study. The fact that DL-1leg is a ST dominant exercise, despite low exercise loads,\textsuperscript{48} indicates that it may be relevant to implement this exercise in early rehabilitation after ACL reconstruction, where high exercise loads are contraindicated.

No previous studies have examined hamstring muscle activity during unilateral HT, however, neuromuscular activity has been assessed in various lower limb muscles including the hamstrings during different bridge exercises using a single leg.\textsuperscript{53–55} The bridge exercise is comparable to the HT, but the shoulders are supported on the floor instead of a bench, while still involving extension of the hip. When ST muscle activity was examined during single-leg bridge exercise performed with different knee joint angles, higher ST muscle activity was noted between 90° (57±51 %) and 60° (79±52 %) compared to the 120° (19±12 %) knee joint flexion.\textsuperscript{54} Similar activity levels were noted in the Lehecka study for the BF muscle (69±18 %), which more or less is comparable to the results from the present study (ST: 69±18 % and BF: 66±18 %).

Unilateral HT exercise revealed significantly lower HAV compared to bilateral HT, KS and DL exercises. Furthermore, unilateral HT demonstrated the smallest medial-lateral hamstring activation difference. In the execution of this exercise, stability around the hip and core is essential for ensuring a stable (i.e. non-tilting) pelvis. This weight shifting caused by the unilateral execution of the exercise might have caused a more equal medial to lateral activation. Notably, unilateral HT did not seem to be effective of elevating ST muscle activity over BF. However, this exercise could be preferable when focusing on improving hip and core stability, as well as eliciting high overall hamstring muscle activity, without increasing direct load on the knee joint.

LIMITATIONS

During the process of off-line data analysis, a number of participants demonstrated knee joint flexion angles in the KS that were more flexed (~25-50°) than the target position of 15°, which were not readily apparent during the time of testing. Furthermore, as this study evaluated selected lower limb training exercises among female athletes, the present findings and conclusions may not be readily transferable to male athletes or untrained persons.

CONCLUSIONS

In conclusion, the present study identified a number of lower limb strength exercises with high levels of neuromuscular activity in the hamstring muscles. As the main study finding, all these exercises involved higher ST activity over BF. Equally important, unilateral as well as bilateral DL exercises showed the greatest medial-lateral activation difference favoring ST activation compared to all other exercises. The kinematic data furthermore illustrate that ensuring extended knee joint angles and increasing HAV may be key focus areas for health care professionals and physical conditioning coaches, and these aspects may be more challenging to achieve during explosive-type exercise such as the KS.

CONFLICTS OF INTEREST AND SOURCE OF FUNDING

The authors report no conflicts of interest and no source of funding.

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Differences in Muscle Activities and Kinematics between Forefoot Strike and Rearfoot Strike in the Lower Limb during 180° Turns

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Keywords: anterior cruciate ligament, forefoot strike, landing technique, movement system, rearfoot strike

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Background
A forefoot strike (FFS) could be a safer landing technique than a rearfoot strike (RFS) during a cutting motion to prevent anterior cruciate ligament (ACL) injury.

Purpose
This study aimed to determine the joint angles, ground reaction force (GRF), and muscle activity levels associated with FFS and RFS landings during 180° turns.

Study design
Cross-sectional study

Methods
Fourteen male soccer players from the University of Tsukuba football (soccer) club participated in this study. The FFS consisted of initial contact with the toes on the force plates followed by the rearfoot; meanwhile, the initial contact was performed with the heels on the force plates followed by the forefoot for the RFS. Ankle, knee, and hip joint angles were recorded using a three-dimensional motion capture system. GRFs were measured using a force plate. Gluteus medius (GM), rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), biceps femoris (BF), tibialis anterior (TA), and lateral gastrocnemius (GL) activities were measured by electromyography.

Results
The activities of GM, GL, and ST from initial contact to early periods during landing into the ground with the FFS are larger than those with RFS. In addition, the results showed significant differences in lower-limb angles and GRFs between the FFS and RFS.

Conclusion
These results suggest that there might be differences in ACL injury risk during a 180° turn between the FFS and the RFS pattern. An investigation into the grounding method that prevents injury is necessary in future studies.

Levels of Evidence
Level 3b

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries can be broadly divided into two types: contact, which involves physical contact, and non-contact, which does not involve physical contact with another person. Non-contact types account for approximately 70–80% of all ACL injuries, and they often occur with motions that induce a change in direction, sudden deceleration, and valgus of the knee joint with internal rotation of the tibia. ACL injuries occur 17–50 msec after landing and have shown to be associated with an increase in the ground reaction force (GRF), valgus knee angle, and torque within 40 msec of landing. Moreover, ACL injuries occur when individuals land with the rearfoot or soles horizontal to the ground during deceleration.

The knee valgus angle—a risk factor for non-contact ACL injury—increases when the change-in-direction angle increases, during internally rotated foot landing positions, when the vertical component of the GRF increases, and with greater levels of quadriceps activity. Several studies have examined cutting motions in the diagonal-forward direction. With large changes in direction, such as 180° turns, the direction of movement of the center of gravity is reversed during the deceleration and acceleration phases. In fact, a 180° turn produces a high risk of injury, similar to a 45° cut, if performed at the same approach velocity. Scheurs et al. found similarities in knee abduction moments between 90° and 180° turns; however, these joint loads were greater than those produced by 45° cuts, while Cortes et al. found greater joint loading with 180° turns compared to 45° cuts. Moreover, there are only a few studies that have examined this issue. In particular, few studies have examined 180° turns in detail, and differences in how foot landings affect joint angles, GRFs, and muscle activity have been poorly investigated. Yoshida et al. reported that the forefoot strike (FFS) is less likely to damage the ACL than the rearfoot strike (RFS) during a 60° cutting motion. Similarly, Donnelly also reported that a RF fall pattern during unplanned sidestepping places a large mechanical demand on the knee joint, which is associated with an elevated ACL injury risk. This study aimed to determine the joint angles, ground reaction force (GRF), and muscle activity levels associated with FFS and RFS landings during 180° turns. Therefore, the authors hypothesize that the FFS reduces the stress on the knee compared with the RFS even during a 180° turn.

METHODS

DESIGN

This cross-sectional study was approved by the Teikyo, Heisei University Ethical Committee (task number 29-022). All procedures were performed in accordance with the Declaration of Helsinki.

PARTICIPANTS

Participants included 14 male soccer players who were members of the university football club (mean height, 169.3 ± 5.4 cm; weight, 66.3 ± 4.6 kg; age, 20.8 ± 1.0 years). Players were excluded if they had any injury-related pain or disorder and a history of ACL injury, lower-limb surgery, or severe locomotive organ disease within the prior three months. Each participant provided written or oral consent after receiving a thorough explanation of the study.

PROCEDURES

The task motion began with the participants standing in the anatomical position with their hip and knee joints slightly flexed and the right leg pulled one foot-length back. Three steps were taken to reach a force platform, approximately 150 cm away. During landing, the right foot was uniformly placed approximately 90° in the progress direction to perform a 180° turn (Figure 1). Landing was performed with an FFS, in which the anterior portion of the foot strikes the platform first, and also in a RFS, in which the posterior portion of the foot strikes the platform first (Figure 2). In other words, the FFS consisted of initial contact with the toes on the force plates followed by the rearfoot; meanwhile, the initial contact of RFS was performed with the heels on the force plates followed by the forefoot like the methods of Cortes. The participants performed the FFS and RFS, in that order, three times each after being allowed to practice the motions until they were accustomed to them. Failed attempts, described as a landing that was not performed according to the prescribed conditions, were confirmed by foot markers and were discarded.

The participants wore suitable sized motion capture suits, which are suitable clothing for the markers to be placed on the body, with 49 markers attached to the body surface (Appendix 1). The measurements were performed using 12 infrared cameras (OptiTrack, Acuity Inc., Tokyo) and a three-dimensional motion tracking system (Motive Tracker, OptiTrack). The 12 infrared cameras were placed around the force platform to surround the participants while performing each task. Calibration was performed to determine each camera’s relative position and the origin and axes of the fixed coordinate system. A calibration wand (CW-500, OptiTrack) was used to obtain a high-quality level of calibration precision. The origin and axes of the fixed co-
ordinate system were determined using a calibration square (CS-100, OptiTrak), which was placed in the right anterior corner of the force platform from the participants’ viewpoint. The right anterior corner of the force platform was the origin. The Z-axis was vertical to the platform (+), the X-axis was toward the left (+), and the Y-axis was in the posterior direction (+) (right-handed coordinate system). During the task motion, each marker’s coordinates were measured using a sampling frequency of 100 Hz and were then used to calculate the angles of the ankle, knee, and hip using a motion analysis system (Frame-DIASV system, DKH, Tokyo Japan).

The myoelectric potential of the lower extremity musculature was measured using surface electromyography (K800, Biometrics, Newport, UK). Electromyography amplifiers (SX230-1000, Biometrics; inter-electrode distance: 2 cm), which function as combined surface electrodes and amplifiers, were placed parallel to the direction of the muscle fibers and fixed above with elastic tape. A grounding electrode was placed on the left wrist. Surface electrodes and fixed from above with elastic tape. A grounding electrode was placed on the left wrist. The induced myoelectric potentials were A/D converted at a 1,000-Hz sampling frequency and saved on a personal computer using the TRAIS system, a data capturing and general-purpose analysis program. Activities of the following muscles were evaluated: gluteus medius (GM), rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), biceps femoris (BF), lateral head of the gastrocnemius (GL), and tibialis anterior (TA). Before the task, 5-s data of maximum voluntary isometric contraction (MVIC) for each muscle against manual resistance was measured three times. The greatest value achieved was used as the MVIC in this study. The tasks were performed three times each in the FFS and RFS conditions. The acquired myoelectric potentials were filtered using a band-pass filter (at 20 and 400 Hz), and subsequently, a full-wave was rectified. The maximum values of the 3 timed MVICs were averaged, and the myoelectric potentials measured during the tasks were divided by the MVIC to obtain the %MVIC.

Vertical (Z-axis) and anterior-posterior (Y-axis: corresponding to the X-axis on the motion analysis coordination system) components of the GRF values during the task motion were measured using a force platform (9286BA, Kistler, Kanagawa, Japan) at a 1,000-Hz sampling frequency and saved on a personal computer using the TRAIS system. Participants’ GRF values were standardized by dividing them by the body weight. The data were filtered using a low-pass filter at 6 Hz. The point of ground initial contact (IC) was obtained when the vertical component of the GRF reached 10 N. The point at which the GRF was 10 N or less was defined as take-off. The anterior/posterior component and the lateral component of the GRF were determined by the direction of the body in the landing position. In other words, a starting position to the left was considered to be the same as the forward landing position.

In this study, the joint angle, muscle activity, and GRF values during the FFS and RFS tasks were normalized by the stance phase. The stance phase was defined as that from the IC (0%) to the foot-off (100%) phase. Reports indicate that ACL damage occurs 40 msec after the IC landing, and the ACL is most loaded at 160 msec. This study, therefore, defined the early phase as up to 50% from the IC landing.

![Figure 2: Foot strike landing](image)

(a) Forefoot strike (FFS), and (b) Rearfoot strike (RFS).

**RESULTS**

The vertical component of the GRF was significantly larger from 9–20% and at 99% with the RFS compared to the FFS (p<0.05) (Figure 3a). The posterior component of the GRF was significantly larger from the IC to 16% and from 92–100% with the FFS compared to the RFS (p<0.05) (Figure 3b). The anterior component of the GRF was significantly larger, from 72–81% with the FFS compared to the RFS (p<0.05).

GM activity was significantly larger with the FFS than with the RFS from IC to 5% (p<0.05) (Figure 4a). ST activity was significantly larger with the FFS than with the RFS from IC to 5% (p<0.05) (Figure 4b). GM activity was significantly larger with the FFS than with the RFS from IC to 14% (p<0.05) (Figure 4c). There were no significant differences in the activity of the other muscles between the FFS and RFS (Figure 4d-h).

The hip flexion angle was significantly larger from 18–70% with the RFS compared to the FFS (p<0.05) (Figure 5a). The hip abduction angle was significantly larger from 86–100% with the RFS compared to the FFS (p<0.05) (Figure 5b). The hip external rotation was significantly larger at 95% with the RFS compared to the FFS (p<0.05) (Figure 5c).

The knee valgus angle was significantly smaller from 18–34% with the RFS compared to the FFS (p<0.05) (Figure 6a). The knee internal rotation angle was significantly
larger from 14–30% with the RFS compared to the FFS (p<0.05) (Figure 6b). The knee external rotation angle was significantly larger from 86–100% with the RFS compared to the FFS (p<0.05) (Figure 6b). The plantar flexion angle was significantly larger from the IC to 26% with the FFS compared to the RFS (p<0.05) (Figure 7a). The ankle supination angle was significantly larger from the IC to 35% and from 67–91% with the FFS compared to the RFS (p<0.05) (Figure 7b). There were no significant differences in the other hip, knee, and ankle angles between the FFS and RFS (Figures 6c and 7c).

**DISCUSSION**

The results of this study indicate that significant differences in the lower-limb angles, muscle activities, and GRFs exist between the FFS and RFS, in varied portions of the stance phase. The larger ankle plantar flexion angle of the FFS demonstrated that the task motion was performed as instructed under the conditions used. ACL injuries occur in the very early phase after landing; therefore, this study considered the different variables produced by the FFS and RFS in the early landing stages. There were significant differences in the vertical and posterior components of the GRFs as well as GM, RF, GL, and ST muscle activation during the early phase as up to 50% from the IC landing between the FFS and RFS.

The vertical component of the GRF has been shown to be larger with a FFS than with a FFS during two-leg drop jumps.11 ACL strain begins to increase during the flight phase before landing and reaches a peak that corresponds to the peak GRF.13 Lin used a computer simulation to compare lower extremity kinematics and kinetics between experimental conditions with and without non-contact ACL injuries.16 The authors reported that athletes had significantly greater normalized peak posterior and vertical GRF in the simulated injury trials. In addition, Yu reported that the peak vertical ground reaction force significantly correlated with the peak proximal tibia anterior shear force and peak knee extension moment during the landing.17 Additionally, compared to a non-injured group, an ACL injury group exhibited larger knee valgus angles, with a vertical GRF component of approximately 20% larger.2 Therefore, the higher vertical component of the GRF observed with an RFS could increase the risk of ACL injury by placing greater tension on the ACL. The vertical component with the FFS was lower than that with an RFS; therefore, a FFS might reduce the risk of ACL injury.

Increased GL activity before landing, which causes plantar flexion of the ankle during the FFS, buffers the impact of landing through eccentric contractions of the GL. Because the plantar flexion angle was significantly larger with the FFS than with the RFS, a FFS might reduce the risk of ACL injury. The hamstrings functions to prevent anterior displacement of the tibia.18–21 Because anterior displacement of the tibia increases ACL tension, the current study’s results indicate that increased GL and ST activity during the FFS may prevent large amounts of tension from being placed on the ACL, thereby reducing the risk of ACL injury. Activity of the gluteal muscles during landing motions buffers the load on the leg joints in the flexion direction, helps maintain posture in the sagittal plane, and keeps the pelvis horizontal. These functions stabilize movements of the hip and knee joints, which reduces tension on the ACL.22–25 Results of the current study revealed that GM activity increased during the FFS from IC to 5%. Considering that the GM is the primary abductor of the hip joint, this could help maintain the posture in the coronal plane and reduce the risk of ACL injury during 180° turns.

The knee internal rotation angle increased from 14–30% with a RFS, which might indicate that the FFS could reduce the risk of ACL injury compared to the RFS. The supination angle of the ankle was larger with a FFS, which may help
prevent ACL injury, but the risk of ankle sprain should also be considered. The current results also demonstrated that the hip flexion angle was larger, and the knee valgus angle and posterior GRF were smaller with a RFS than an FFS. These results are similar to findings from Cortes et al. stating that the RF landing technique resulted in decreased knee valgus angles, knee flexion, knee adductor moment, posterior GRF, and an increased hip flexion angle at IC. Jones et al. indicated that the penultimate contact during pre-planned changes in direction helps reduce loading on the turning leg where there is a greater risk of injury to knee ligaments. Regarding knee valgus, the current study found that the FFS approached the neutral position, and the RFS headed toward the varus direction. The knee valgus angle observed in the current study was small, and there is a possibility that the risk of ACL damage related to the valgus angle has little effect on the RFS and FFS. However, as a proposition to the field, there is a possibility that the RFS is better for actions with a large valgus angle such as the pivot task, similar to findings from Cortes et al. As for the posterior component of the GRF, even if the anterior component appears in the RFS, if the GRF passes posterior to the center of the knee joint, the tibia receives the anterior pulling force, increasing the risk of ACL damage. On the other hand, even if the rear component is high in the FFS, if the GRF passes anterior to the knee, ACL stress may not increase. However, in the current study, the positions of the penultimate (left) foot and the landing (right) foot were not the same in all trials. Therefore, it is possible to increase the posterior component of the GRF by landing anterior to the body’s gravitational center in the FFS; however, the results of the current study do not clarify the reason for the difference in the GRF.

The differences in the hip abduction, hip external rotation, and knee external rotation angles were in the later phase; therefore, it is considered that they would likely have a weak association with the occurrence of ACL injuries.

This study has some limitations. First, examining the biomechanical risk factors cannot precisely reproduce the conditions during which ACL rupture occurs, and rely on analyzing a sham movement during the experiment. Although the authors believe that the sham movement/experimental conditions were similar to actual sports activity, there may be some differences in the experimental condition and ACL rupture. Second, the trunk and pelvis should be studied further, because the current study did not measure the angles of trunk side bending and pelvic leaning. Finally, there were only 14 male soccer-playing participants in this study; therefore, there may be errors due to the small sample size. It is also unclear whether the results of this study can apply to female athletes and whether they can be applied to athletes who specialize in sports other than soccer. The difference between the hip joint flexion angle and the posterior component of the GRF may also have been influenced by the lack of evaluation of the penultimate contact. In the future, increasing the number of participants and including athletes of other sports, and including women, will lead to a broader application of the results.

Figure 5: Joint angles of the hip
(a) Hip flexion angle (p<0.05), (b) hip abduction angle (p<0.05), and (c) hip external rotation (p<0.05). Each part of the figure includes a hypothesis test. Black line indicates forefoot, red line indicates rearfoot, and shaded areas indicate standard deviation (SD).

Figure 6: Joint angles of the knee
(a) Knee valgus angle (p<0.05), (b) knee internal rotation angle (p<0.05), and (c) knee flexion/extension. Each part of the figure includes a hypothesis test. Black line indicates forefoot, red line indicates rearfoot, and shaded areas indicate standard deviation (SD).

SPM, statistical parametric mapping.
CONCLUSION

The present study investigated the difference between the FFS and RFS during 180° turns. The FFS consisted of initial contact with the toes on the force plates followed by the rearfoot. For the RFS, the initial contact was performed with the heels on the force plates followed by the forefoot. The results of this study indicate that the FFS pattern, when compared to the RFS, produces decreased vertical and GRF components and increased ST muscle activity, implying the potential for reduction in the risk of ACL injury during a 180°-turn movement. Because these results helped clarify that the difference that foot strike has on kinematics and kinetics, it is necessary to further investigate if a type of foot strike can affect injury prevention.

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest for all authors.

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Figure 7: Joint angles of the ankle

(a) The plantar flexion angle (p<0.05), (b) the ankle supination angle (p<0.05), and (c) adduction/abduction. Each part of the figure includes a hypothesis test. Black line indicates forefoot, red line indicates rearfoot, and shaded areas indicate standard deviation (SD).

SPM, statistical parametric mapping.
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

The Test Re-Test Reliability of A Novel Single Leg Hop Test (T-Drill Hop Test)

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Background
Functional training and testing are an important part of a comprehensive rehabilitation program stressing the neuromuscular system in ways that simulate athletic performance to help determine criteria for return to sport. There are numerous single leg hop tests that have been used for these purposes, however, the validity and clinical relevance has been questioned. Many of the functional performance tests assess only the sagittal plane or forward direction and may only partially assess a person’s athletic abilities. There is a need for reliable and valid functional tests to assess in a multi-directional manner.

Purpose/Hypothesis
The purpose of this study is to determine the test re-test reliability of a novel multi-directional timed single leg hop test (T-Drill Hop Test) for use in rehabilitation and performance assessments.

Study Design
Cross-sectional reliability study.

Methods
Fifty healthy recreationally active college age subjects, (23 males and 27 females) between the ages of 18 and 35, (mean age 23.48 with SD 3.82) consented to perform the test. The subjects hopped along a 10ft. x 10ft. “T” shaped course. Subjects performed two timed maximum effort trials of the T-Drill Hop Test on each leg with an interval of 3-7 days between the two testing days. Intraclass Correlation Coefficients (ICC) were calculated to determine intersession reliability.

Results
The inter-rater reliability (ICC’s) for the entire group of 50 subjects ranged between .98 and 1.00 suggesting excellent reliability. The bilateral comparison, utilizing paired t-tests, of the T-Drill Hop Test demonstrated no significant differences between the time scores for the dominant and non-dominant legs for either males or females (p>.05).

Conclusion
This study demonstrates the T-Drill Hop Test has excellent test re-test reliability. These results are important prior to validation and utilization as a clinical functional performance test.

Levels of Evidence
Level 2
INTRODUCTION

Fifty-seven to seventy percent of injuries that occur during high school and collegiate sport participation involve the lower extremity (LE). The risk of lower extremity re-injury is also relatively high. Up to 25% of athletes experience an ACL graft re-rupture or a contralateral tear upon return to unrestricted physical activity. Twelve to forty-seven percent of those people who sprain their ankle will suffer from recurrent ankle sprains, with 24% re-spraining within 3 months of initial injury.

Given these high rates of LE injuries, rehabilitation specialists must explore ways to prevent re-injury and eliminate any persistent functional deficits to enable an effective and safe return to sport activity. Time from surgery is often the only variable considered in return to sport decision-making; therefore, many patients may return to sport with persistent strength and performance impairments which increase their risk of re-injury. Functional performance tests are meant to simulate, in a controlled fashion, sport-like movement patterns and stress the strength, power, and agility characteristics that are present in sport competition. Functional performance tests range from general lower extremity power and agility tests to unilateral hopping tests. Functional performance tests have been developed to assess rehabilitative progression and as part of a battery of tests helping to determine discharge criteria.

Hop tests are easy to administer and require little space and technology to perform. Hop tests are the preferred type of functional test due to the utilization of the uninjured limb as a control for between limb comparisons and as a reference for which discharge from rehabilitation and return to sport may be determined. Single leg hop tests like the hop for distance, triple hop for distance, 6-meter timed hop and triple cross-over hop have extensive research support and retest reliability and discriminative ability of forward, medial, and rotational hop tests. They also reported that the medial and rotational hop tests were more likely to show limb asymmetries in ACL-reconstructed participants compared to forward sagittal plane hop tests.

There is a need for functional performance tests to evolve to better assess athletic characteristics and help determine the ability to return to unrestricted physical activity and aid in finding those at-risk patients in order to better determine return to sport criteria. It has been recommended that hop tests that assess different planes of motion may give greater information about the function of the knee. Hardesty et al. assessed frontal plane hop tests in women's basketball and soccer players finding the medial triple hop for distance may be effective at identifying side-to-side asymmetries in these athletes.

Given the number of functional performance tests and the conflicting results demonstrated in the literature, it is important to continue to investigate new tests that may add to or replace existing tests to aid in return to play decisions. Clinicians must choose tests that are objective, reliable, and valid and that preferably test in multiple planes of movement. Therefore, the purpose of this study is to determine the test re-test reliability of a novel multi-directional timed single leg hop test (T-Drill Hop Test) for use in rehabilitation and performance assessments.

METHODS

PARTICIPANTS

Fifty subjects (27 females and 23 males; mean age 23.48 years with SD 3.82) were recruited to participate in the study. The males' average height and weight were 71.55 inches (SD 3.083) and 190.87 pounds (SD 30.87). The females' average height and weight were 65.52 inches (SD 2.38) and 149.04 pounds (SD 18.38). Subjects were recreationally active as per American College of Sports Medicine guidelines. All subjects participated in moderate intensity aerobic physical activity for a minimum of 30 minutes 5
days a week or vigorous intensity aerobic physical activity for a minimum of 20 minutes on 3 days a week. None of the participants were competitive athletes. Subjects also completed a demographic form and the PAR-Q\textsuperscript{25} to identify any other contraindications for participation in the study. Subjects were included in the study if they did not have any orthopedic disorders, injuries, fractures or surgeries to the lumbar spine or lower extremities within the past year. Potential participants were excluded if they were outside the age range of 18-35 years, unable to complete the test as prescribed, or were unable to read, write, and communicate in English. Subjects were excluded if they had a history of orthopedic disorders or surgeries to the lumbar spine or lower extremities within the past year prior to data collection. If the subjects met the inclusion criteria, they read and signed an informed consent form approved by the Institutional Review Board. All testing was performed in the Biodynamics and Human Performance Center.

**PROCEDURES**

Subjects performed a lower extremity bicycle ergometer warm-up for 5 minutes at a self-selected Borg’s rating of perceived exertion of 12-14. They then stretched the gastrocnemius-soleus complex, quadriceps and hamstring muscles for 30 seconds each. The T-Drill Hop Test is designed to be 10 feet long and then 5 feet wide on each side of the center line of the T (Figure 1). Subjects watched a video of the performance of the T-Drill Hop Test. Following the video, the subjects were shown a live demonstration of the T-Drill Hop Test by one of the researchers. Subjects then completed one sub-maximal warmup of the test with their hands on their hips hopping on the specified leg, prior to the 2 maximal trials per leg. A jump is performed with two legs simultaneously, whereas, a hop is taking off and landing on the same single leg.

The testing protocol is detailed in the following paragraph. The starting extremity was identified by using a computer random number generator. If the right extremity was selected, then the subject would perform the test using a maximal effort in an anterior direction down the center of the “T” and at the intersection of the “T”, they would do the lateral hops toward the selected leg’s side, i.e., if they started with the right leg, they would hop toward the right side of the “T” first, and then toward the left side of the “T”. The subjects then returned back to the center of the “T” and did retro-hopping back to the starting position. A 60-120 second rest was permitted between the first and the second test on each limb. The subjects performed a sub-maximal warmup and 2 maximal test trials and the scores from the maximal test trials were averaged. Then the opposite leg was tested using the same testing protocol and scoring (Figure 1).

If the subject performed any qualitative “faults” during the performance of the test, then the subjects were required to repeat the test. Examples of faults would include: separating the hands from the hips, touching the non-hopping foot to the ground, not hopping directly behind the targets during the test, or not staying in a relatively straight line on the “T”. Two researchers stood on opposite sides of the testing area and timed the test by using their iPhone (Apple, CA.) stop watches. The times from each researcher were averaged for each repetition, and then the times were averaged for the 2 repetitions to calculate the final score for the subject for each test leg.

Subjects returned between 3-7 days for the second battery of tests. Subjects were encouraged to not do anything differently and to maintain their usual and customary activities between the test sessions. Additionally, subjects were asked to have similar eating and sleeping habits, wore similar shoes and clothing, and were tested at approximately the same time of day for both sessions. The second testing session protocol was performed in the same manner as the first test to determine reliability of the T-Drill Hop Test.
The Test Re-Test Reliability of A Novel Single Leg Hop Test (T-Drill Hop Test)

Table 1: Test–retest reliability intraclass correlation coefficients ICC (2,k)

<table>
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<tr>
<th>Test</th>
<th>ICC</th>
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<th>95% CI Upper</th>
<th>SD</th>
<th>SEM</th>
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DL1=dominant leg trial one
DL2=dominant leg trial two
NDL1= non dominant leg trial 1
NDL2= non dominant leg trial 2
T1= time for tester one
T2= time for tester two
D2 = day 2

STATISTICAL ANALYSIS

SPSS Version 25 software (IBM SPSS Inc., Armonk, NY) was used for data analysis. Two-way random Intraclass Correlation Coefficients (ICCs) (2,k 95%CI) were used to determine the reliability of the tests from the first to the second testing sessions.26 The Minimal Detectable Change (MDC) was calculated for the interrater measurements using the following formula: \( MDC_{95} = SEM \times 2.77(\sqrt{2} \times 1.96) \) to determine the magnitude of change that would exceed the threshold of measurement error at the 95% confidence level.26 Paired t-tests were utilized to determine if there was a significant difference in the time score between the dominant and non-dominant lower extremities with an Alpha level of \( p<0.05 \).

RESULTS

The Intraclass Correlation Coefficient (ICC) 2,k (95% CI), Standard error of measure and MDC (95% CI) are shown on Table 1. The ICC’s with combined male and female subjects (n=50) ranged between .98 and 1.00, demonstrating excellent reliability. Koo and Ma described ICC values above .90 are indicative of excellent reliability.27 The mean time for the females’ dominant leg was 9.58 seconds and the standard deviation was 2.57. The mean time for the females’ non-dominant leg was 9.40 seconds with a standard deviation of 2.39. The mean times for the males’ dominant and non-dominant legs were 7.22 seconds and 7.37 seconds, respectively, with standard deviations of 1.16 and 1.10, respectively. The bilateral comparison, utilizing paired dependent t-tests, of the T-Drill Hop Test demonstrated no difference between time scores for dominant and non-dominant legs (\( p>0.05 \)). (Table 2)

DISCUSSION

The current study demonstrated excellent test re-test reliability of the T-Drill Hop Test. Due to the excellent reproducibility in normal recreationally active subjects, this test could be utilized to compare lower extremity function between the limbs. This is in line with other hop tests assessing frontal and transverse planes of movement.10–12,25,28 Dingegen hypothesized that medial and rotational single-leg-hop tests could be used to compliment evaluations focusing on movements in the forward direction to track progress during injury recovery or optimization of performance.23 Clinicians must consider that sport activity involves movements in all planes of motion. The current multidirectional hop test can be an important assessment to help determine progression during rehabilitation, physical performance training, and determining readiness to return to sport.

Docherty and Sharma both showed a significant relationship between functional ankle instability and performance deficits in the side hop and figure-of-8 hop tests.29,30 Functional performance tests should assess athletic characteristics of strength, power, agility, change-of-direction, and balance. Recent studies reported only 30% of post-operative ACL-reconstructed patients perform change-of-direction and agility training as part of their rehabilitation progression.31,32 Edwards et al. concluded that patients who completed 6 months of rehabilitation incorporating jumping and agility tasks had a higher rate of return to sport, suggesting that postoperative rehabilitation is important in predicting return to sport.33 They went on to recommend evaluating biomechanical symmetry in addition to performance symmetry in regard to the functional performance testing.33 The results of these studies demonstrate the need for evaluating an individual’s ability with multi-directional
**Table 2: Paired t-test results**

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movement testing prior to return to sport activity. Functional testing batteries need to quickly provide clinicians the information, both qualitative and quantitative, that they need to help determine readiness to progress through a comprehensive rehabilitation program. Having many hop tests that are tested in a similar plane of motion may be counter-productive and not give the best representation of the patient’s willingness and ability to move in
other planes of movement. The functional testing battery should comprise a short list of tests that evaluate multiple planes of movement. The information from the tests will provide a more comprehensive picture of the patient to aid in determining their readiness to return to activity and sport. Having one simple reliable test that can evaluate multiple directions (forward, side-to-side and backwards) and several athletic characteristics (speed, power, change-of-direction and agility) would be more efficient for clinicians to use in a limited space. Change-of-direction and agility are two important and specific skills that can be assessed for side-to-side asymmetry using this test.

Areas for future research would be to determine the validity of the T-Drill Hop Test and further develop the qualitative information to base successful test performance. Research to develop a normative data base for males and females over a variety of age groups and sport participation would be helpful. A direct comparison of the T-Drill Hop Test to some of the other existing single leg hop tests to determine which is more sensitive at detecting limb asymmetries.

LIMITATIONS

There are several limitations to this study. First, the sample had an uneven mix between men and women. Munro demonstrated differences between genders with hop testing, therefore, this limitation should be taken into consideration. The second limitation concerns the sample of convenience because all the subjects in this study were a healthy non-patient college-aged population, creating limited external validity. These limitations provide opportunities for future research.

CONCLUSION

The results of the current study suggest that the T-Drill Hop Test has excellent test re-test reliability. These results are important prior to validation and utilization as a clinical functional performance test. Based on the results of this study, limb symmetry index should be equal in healthy normals, as there was no statistical difference between the dominant and non-dominant legs. The current study may assist in the development of a serial testing paradigm for use during the training and rehabilitation of patients or clients with lower extremity pathology.

CONFLICT OF INTEREST

The author has no conflict of interest to report.

ACKNOWLEDGEMENTS

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REFERENCES


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Background
Calf muscle strain injuries are a common running injury affecting male runners and are known to have high recurrence rates. Currently, limited evidence exists investigating factors associated with this injury with no previous study investigating the running kinematics of male runners with a history of repeat calf muscle strain injuries.

Purpose
To investigate whether male runners with a history of repeat calf muscle strain injury demonstrate differences in stance phase running kinematics when compared to healthy controls.

Study Design
Case-control investigation

Level of Evidence
3b

Methods
Stance phase kinematics were compared between 15 male runners with a history of calf muscle strain injury and 15 male control participants during treadmill running at 3.2m/s. Independent t-tests were used to compare differences in stance phase kinematic parameters between groups and effect sizes were calculated using Cohen’s d.

Results
The group with a history of calf muscle strain injury demonstrated a significant $2.1^\circ$ and $3.1^\circ$ increase in contralateral pelvic drop and anterior pelvic tilt during mid stance. In addition, this group exhibited longer stance times and a more anterior tilted pelvis, flexed hip and a greater distance between the heel and centre of mass at initial contact. Large effect sizes, greater than 0.8, were observed for all differences. No significant differences were observed for ankle and knee joint kinematics between the groups.

Conclusion
This is the first study to identify kinematic characteristics associated with recurrent calf muscle strain injury. While it is not possible to determine causality, the observed kinematic differences may contribute to recurrent nature of this injury. Specifically, it is possible that neuromuscular deficits of the hip and calf muscle complex may lead to increased strain on the calf complex. Rehabilitation interventions which focus on addressing pelvis and hip kinematics may reduce the demands placed upon the calf complex and could prove clinically effective.

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INTRODUCTION

Running is an increasingly popular method of physical activity; however it also poses a considerable risk of injury with an estimated one in three runners being injured in their lifetime.\(^1\) Of all running injuries, the majority are thought to occur to the knee and lower limb, accounting for 7 to 50% and 9 to 32% of all running injuries respectively.\(^2\)

One lower limb injury commonly experienced by runners is calf muscle strain injury (CMSI). CMSIs can occur to either the soleus or the gastrocnemius muscles and often present as sudden onset of pain localised to the calf muscle belly, with an inability to continue activity.\(^3\) Amongst running populations, previous literature has reported prevalence rates of CMSI to range from 12 to 23.3\(^\pm\)4.5 and incidence rates ranging between 4.5% and 53\(^\pm\)7. CMSIs are also known to have recurrence rates as high as 38\%,\(^8\) suggesting that underlying contributors to CMSI remain unaddressed following return to running.

Currently there are only a limited number of studies investigating factors associated with CMSIs. Of the available literature, studies have identified male gender,\(^7\) greater age, higher body mass index (BMI) and having suffered a previous CMSI\(^6\) as the main risk factors for CMSI. It is hypothesised that these risk factors may contribute to biomechanical and neuromuscular maladaptation resulting in increased vulnerability of the calf complex to further injury.\(^9\) Although this highlights at-risk populations, many of the identified risk factors are non-modifiable and consequently cannot be targeted within the rehabilitation process. Therefore, there is a need for greater understanding of modifiable risk factors for CMSIs, as this may help inform rehabilitation programs and reduce the high recurrence rates of CMSI amongst runners.

During the stance phase of running, the soleus acts to control both ankle dorsiflexion and knee flexion, decelerating the downward movement of the body's mass.\(^10\) At mid to late stance both the gastrocnemius and soleus then act to plantarflex the ankle, facilitating the vertical and forward propulsion of the body.\(^10,11\) During early stance, the calf muscle contracts isometrically while the muscle tendon unit elongates,\(^12,13\) with peak muscle forces reported to reach upwards of 1.9 and 6.7 times body weight for the gastrocnemius and soleus respectively.\(^14\) It is perhaps this period of time where the calf complex is most vulnerable to injury.

Muscle strain injuries are thought to occur as tissues lengthen while exposed to high external forces.\(^15,16\) For example, hamstring strain injuries have been most frequently reported to occur during late swing phase of sprinting or during kicking actions, as the hamstrings lengthen under high forces.\(^17\) With reference to the calf complex, it has been proposed that increased ankle dorsiflexion and knee flexion during stance phase could contribute to injury development;\(^18\) with the calf exposed to elevated muscle forces whilst musculotendinous structures are in a lengthened position.\(^15,14,18,19\) However, although a feasible explanation for CMSI, there has been minimal biomechanical research to explore this mechanism.

Currently the only available evidence investigating whether biomechanics play a role in CMSIs are limited to two case reports,\(^20,21\) with only one study reporting an injury during running.\(^21\) Specifically, Orchard et al\(^20\) reported the incidence of an acute CMSI in a cricket player, while Kong et al\(^21\) reported the onset of a CMSI in a runner. Both authors reported the onset of injury to occur around the point of peak muscle lengthening during early stance, suggesting the biomechanical loads associated with high external forces as the tissues lengthen may result in elevated tissue strain and injury.\(^20,21\) Although these studies provide insight into the mechanics occurring at the moment of injury, they are limited to only one participant and therefore may not be generalisable to wider populations.

Understanding potential kinematic differences between runners with a history of repeat CMSI and injury free controls may provide information to direct future rehabilitation and preventative strategies for this injury. Therefore, the aim of this study was to investigate whether male runners with a history of repeat calf muscle strain injury demonstrate differences in stance phase running kinematics when compared to healthy controls. It was hypothesised that runners with a history of recurrent calf muscle injury would demonstrate either increased peak ankle dorsiflexion or knee flexion angles during the stance phase of running. These kinematic patterns could increase the strain placed upon the calf muscle complex which may contribute to repeat CMSI.

METHODS

A total of 30 rearfoot strike male runners were enrolled in this study, including 15 runners with a history of repeat calf muscle strain injury and 15 controls (\textit{Table 1}). Participants were assessed by the lead clinician to confirm injury history and diagnosis prior to participation. All participants provided written informed consent prior to being enrolled in this study and ethical approval was obtained from the local ethics committee.

All participants were injury free at the time of testing and therefore we were unable to distinguish whether the original injuries occurred to the gastrocnemius or soleus muscle. As such, these injuries were classified more broadly as calf muscle strain injury (CMSI). Participants were included within the CMSI group providing they reported a history of two or more CMSIs within the last 12 months. A history of unilateral injuries was reported in six participants and bilateral injuries in nine participants. One participant reported their most recent CMSI to have occurred within the prior six months, 10 reported sustaining a CMSI within the prior three months, one within the prior two months and a further two participants reported experiencing their most recent injury within the prior month. Symptoms were described as a sudden onset of pain localised to the calf muscle resulting in an inability to continue running. Participants were excluded if they reported any prior injury to the lower back, previous lower limb surgery, neurological impairment or any previous traumatic injury to the lower limb. Participants were included within the control group providing they were running a minimum of 20km per week over two or more days and reported no history of common overuse running related injuries over an 18-month period.

Kinematic data were collected from all participants while
running on a treadmill at 3.2m/s wearing their own running shoes. After a five-minute warm up period, 30 seconds of kinematic data were collected using a 12 camera Qualysis Oqus (Göteborg, Sweden) system (240Hz). Treadmill running has been reported to produce kinematics comparable to over-ground running and therefore can be considered representative of participants natural running gait. Additionally, all participants reported being comfortable with treadmill running. A standardised running speed of 3.2m/s was selected to avoid between participant variability in running kinematics due to speed, with this speed considered similar to average training paces commonly encountered by recreational runners and used in prior biomechanical studies.

A total of nine anatomical segments were tracked following a previously published protocol. Segments included the thorax, pelvis and bilateral thigh, shank and foot segments. Further details of the markers used to track each segment and the precise definition of the anatomical coordinate systems are provided in previous publications.

Raw kinematic data were low pass filtered at 10Hz. Inter-segmental kinematics, along with the motions of the pelvis and thorax with respect to the laboratory system, were calculated using a six degrees of freedom model using the Visual 3d (C-Motion) software. Gait events were defined using a previously validated kinematic algorithm, in which initial contact was defined as the first peak in vertical acceleration of either the heel or metatarsal markers. Toe-off was identified as the vertical jerk peak of the 2nd metatarsal marker. Gait events were used to segment each kinematic signal into a minimum of 10 consecutive gait cycles. An ensemble average for each signal was created and selected kinematic parameters derived from the ensemble average curves. This latter processing was carried out using a custom Matlab script.

Several kinematic parameters were selected for data analysis. Kinematic parameters included sagittal and frontal plane joint angles at initial contact, peak joint angles during stance, joint excursion of the ankle and knee and spatiotemporal parameters. Peak angles during stance were defined as the maximum joint angle between initial contact and toe off. Joint excursion was calculated as the range of movement from initial contact to the peak angle at mid stance. Spatiotemporal parameters included stride length, step rate, stance time, flight time as well as the horizontal distance between the heel marker and centre of mass at initial contact. Center of mass was calculated using a nine segment model comprised of bilateral feet, shank and thigh segments, as well as the pelvis, lumbar and thoracic spine. A recent study identified a link between a range of lower limb running injuries and kinematics of the pelvis and trunk. Therefore, kinematic parameters of the trunk, pelvis and lower limbs were included in the analysis. Independent t-tests were used to compare differences between groups and effect sizes calculated using Cohen’s d. A critical alpha of .05 was set and effect sizes of 0.2, 0.5 and 0.8 were interpreted as small, medium and large respectively.

### RESULTS

When compared to the control group the previously injured group were found to have a significantly longer stance time (p < 0.01) and greater distance between heel and center of mass at initial contact (p < 0.01), characteristic of an over-stride running gait (Table 2). No other significant differences were observed between the groups for any spatiotemporal parameters. There were several differences found at the hip and pelvis kinematics between the previously injured and control groups (Table 3). At initial contact the previously injured group landed with a significant 4.4° increase in hip flexion (p ≤0.01) and a significant 3.7° increase in anterior pelvic tilt (p ≤0.01). At mid stance the previously injured group demonstrated a significant 2.1° increase in peak contralateral pelvic drop (p ≤0.01) and 3.1° greater anterior pelvic tilt (p = .05) when compared to the control group. These differences demonstrated large effect sizes ranging from 0.8 to 1.2 (Table 3). Interestingly, there were no significant differences observed in any of the kinematic parameters related to the knee or ankle (p > .05) (Figures 2 and 3).

### DISCUSSION

The aim of the present study was to identify whether male runners with a history of recurrent calf muscle strain injuries demonstrate differences in running kinematics when compared to healthy controls. It was hypothesised that the CMSI group would demonstrate greater peak ankle dorsiflexion and knee flexion angles during the stance phase of running. This hypothesis was based on the premise that excessive ankle dorsiflexion and knee flexion angles would increase the eccentric load placed on the calf complex, leading to tissue damage and injury. Contrary to this

### Table 1: Participant characteristics, Mean (standard deviation).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Controls (n = 15)</th>
<th>CMSI (n = 15)</th>
<th>P - Value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>42.4 (7.2)</td>
<td>47.8 (9.1)</td>
<td>0.09</td>
<td>0.66</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.2 (4.9)</td>
<td>179.4 (4.5)</td>
<td>0.25</td>
<td>0.47</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.8 (1.7)</td>
<td>23.6 (2.6)</td>
<td>0.12</td>
<td>0.36</td>
</tr>
<tr>
<td>Run Frequency* (runs per week)</td>
<td>4.7 (2.0)</td>
<td>3.2 (0.9)</td>
<td>0.02</td>
<td>0.97</td>
</tr>
<tr>
<td>Weekly Running Volume* (miles)</td>
<td>30.1 (14.6)</td>
<td>19.8 (7.4)</td>
<td>0.03</td>
<td>0.89</td>
</tr>
</tbody>
</table>

* indicates statistically significant difference.
Table 2: Spatiotemporal parameters, mean (standard deviation).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Controls</th>
<th>CMSI</th>
<th>P - Value</th>
<th>Effect Size</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight Time (sec)</td>
<td>0.204 (0.04)</td>
<td>0.181 (0.05)</td>
<td>0.17</td>
<td>0.51</td>
<td>-0.059 - 0.011</td>
</tr>
<tr>
<td>Stance time (sec)*</td>
<td>0.523 (0.03)</td>
<td>0.562 (0.04)</td>
<td>≤0.01</td>
<td>1.10</td>
<td>0.014 - 0.063</td>
</tr>
<tr>
<td>Stride Length (meters)</td>
<td>2.23 (0.09)</td>
<td>2.27 (0.14)</td>
<td>0.31</td>
<td>0.34</td>
<td>-0.043 - 0.133</td>
</tr>
<tr>
<td>Stride Rate (Steps per minute)</td>
<td>164.9 (6.7)</td>
<td>162.3 (10.3)</td>
<td>0.41</td>
<td>0.30</td>
<td>-9.118 - 3.838</td>
</tr>
<tr>
<td>CoM Vertical Excursion (cm)</td>
<td>9.3 (1.0)</td>
<td>9.3 (1.5)</td>
<td>0.88</td>
<td>0.05</td>
<td>-0.896 - 1.040</td>
</tr>
<tr>
<td>Heel to CoM distance at contact (cm)*</td>
<td>13.3 (2.8)</td>
<td>15.8 (2.5)</td>
<td>≤0.01</td>
<td>0.94</td>
<td>0.44 - 4.38</td>
</tr>
</tbody>
</table>

* indicates statistically significant difference. CoM = centre of mass.

Table 3: Kinematic characteristics mean (standard deviation).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Controls</th>
<th>CMSI</th>
<th>P - Value</th>
<th>Effect Size</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Angles at Initial contact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis anterior tilt* (°)</td>
<td>6.2 (3.5)</td>
<td>9.9 (3.7)</td>
<td>≤0.01</td>
<td>1.04</td>
<td>1.01 - 6.44</td>
</tr>
<tr>
<td>Hip Flexion* (°)</td>
<td>21.8 (3.5)</td>
<td>26.3 (3.9)</td>
<td>≤0.01</td>
<td>1.20</td>
<td>1.66 - 7.23</td>
</tr>
<tr>
<td>Knee flexion (°)</td>
<td>6.3 (5.4)</td>
<td>5.4 (5.2)</td>
<td>0.64</td>
<td>0.17</td>
<td>-4.88 - 3.06</td>
</tr>
<tr>
<td>Ankle dorsiflexion (°)</td>
<td>9.6 (4.5)</td>
<td>11.3 (6.6)</td>
<td>0.42</td>
<td>0.29</td>
<td>-2.53 - 5.89</td>
</tr>
<tr>
<td>Foot Inclination (°)</td>
<td>20.4 (6.0)</td>
<td>23.8 (6.8)</td>
<td>0.16</td>
<td>0.53</td>
<td>-1.42 - 8.20</td>
</tr>
<tr>
<td>Joint Angles at mid stance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contralateral Pelvic Drop* (°)</td>
<td>3.5 (2.6)</td>
<td>5.7 (1.9)</td>
<td>≤0.01</td>
<td>0.94</td>
<td>0.45 - 3.83</td>
</tr>
<tr>
<td>Pelvis anterior tilt* (°)</td>
<td>6.0 (3.8)</td>
<td>9.1 (3.8)</td>
<td>0.03</td>
<td>0.80</td>
<td>0.21 - 5.88</td>
</tr>
<tr>
<td>Hip Adduction (°)</td>
<td>9.2 (2.2)</td>
<td>11.3 (3.1)</td>
<td>0.07</td>
<td>0.68</td>
<td>-0.19 - 4.05</td>
</tr>
<tr>
<td>Knee flexion (°)</td>
<td>33.0 (2.8)</td>
<td>33.4 (5.1)</td>
<td>0.81</td>
<td>0.09</td>
<td>-2.72 - 3.46</td>
</tr>
<tr>
<td>Ankle Dorsiflexion (°)</td>
<td>23.4 (2.2)</td>
<td>24.3 (3.4)</td>
<td>0.37</td>
<td>0.33</td>
<td>-1.21 - 3.08</td>
</tr>
<tr>
<td>Rearfoot eversion (°)</td>
<td>4.0 (2.6)</td>
<td>3.1 (5.1)</td>
<td>0.53</td>
<td>0.23</td>
<td>-2.08 - 3.96</td>
</tr>
</tbody>
</table>

All values are presented as degrees of movement (°). * indicates statistically significant difference.

hypothesis, there were no differences in peak ankle or knee joint angles (Figures 2 and 3), however there were differences between groups for pelvis and hip kinematics as well as longer stance times. Therefore, it appears that there are stronger associations between proximal rather than distal kinematics and CMSIs.

In the present study, an increase in contralateral pelvic drop and anterior pelvic tilt were observed in runners with a history of calf muscle strain injury. Peak contralateral pelvic drop has previously been reported to be associated with multiple different running injuries, including iliotibial band syndrome, patellofemoral pain, medial tibial stress syndrome and Achilles tendinopathy,24 however this is the first study to identify similar associations amongst runners with CMSI. It is possible that this observation indicates potential deficits in the neuromuscular function of the gluteal muscles during the stance phase of gait. The gluteus medius is considered one of the primary stabilizers of the hip and pelvis in the frontal plane, while the gluteus maximus assists in control of anterior pelvic tilt.30 Delayed onset of these muscles has previously been reported to result in a loss of neuromuscular stiffness around the hip and pelvis, subsequently leading to altered kinematic patterns.31 Therefore, the observation of increased contralateral pelvic drop and anterior pelvic tilt in the CMSI group, could indicate neuromuscular deficits of the gluteal muscles which may have implications for calf muscle function during running.
The gluteal muscles play a key role in vertical support and propulsion during the stance phase of gait through synergy with the gastrocnemius, soleus and quadriceps.\(^1\) Modelling studies have reported the gluteal muscles to provide up to half the total vertical support during running.\(^1\) Similarly, along with the soleus muscle, the gluteus maximus and posterior fibres of the gluteus medius play a role in the control of knee flexion velocity,\(^2\) generating a hip extension moment during early stance which accelerates the knee into extension. It is possible that deficits of the gluteal muscle group may reduce the hip muscle contribution to knee extension, vertical support and propulsion. This, in turn, could lead to an increase in muscular demand at the calf muscle complex and subsequent tissue overload and injury.\(^3\) If such a mechanism does play a role in the aetiology of CMSI, then rehabilitation approaches may need to focus on correcting proximal dysfunctions in order to reduce the mechanical demand on the calf muscle complex during running. However, EMG studies are now required to investigate this idea further.

The CMSI group were also observed to land with significantly greater hip flexion and distance between the heel and center of mass at initial contact, characteristic of an over-stride running gait.\(^4\) This may explain the longer stance times observed amongst the CMSI group and could have implications for calf muscle function. In a previous study by Napier et al.\(^5\) hip flexion and heel to center of mass distance at initial contact were correlated with peak horizontal breaking force, which will slow the forward momentum of the centre of mass during early stance. Additionally, without compensatory knee and ankle kinematics, an over-stride running gait will result in a posterior shift in the centre of pressure under the foot\(^6\) which may reduce the capacity for storage of elastic energy within the calf complex. Consequently, in order to reaccelerate the centre of mass at toe off, there may be a need to increase ankle power generation from mid to late stance.\(^7,8\) It is conceivable that such biomechanical compensation could increase the demand on the calf complex and may subsequently lead to repeated muscle overload and greater musculotendinous strains, increasing the risk of tissue failure and injury.

It is also possible that neuromuscular deficits of the calf complex may underlie the observation of an increase in stance time and that such deficits may play the calf complex at risk of injury. During the early stance phase of running, the calf muscle complex contracts isometrically, while the muscle tendon unit elongates.\(^9,10\) This interaction, between isometric muscle contraction and elongation of the elastic components of the muscle tendon unit, acts to store elastic energy which is later returned during the propulsion phase, accelerating the body’s mass vertically.\(^9,10,11\) It is conceivable that such biomechanical compensation could increase the demand on the calf complex and may subsequently lead to repeated muscle overload and greater musculotendinous strains, increasing the risk of tissue failure and injury.

Figure 1: Frontal plane pelvis ensemble average kinematic waveform across the gait cycle. Positive y-axis values represent the contralateral side of the pelvis dropping away from the side of the standing leg, negative represent the contralateral side of the pelvis elevating relative to the side of the standing leg. CMSI= calf muscle strain injury.

Figure 2: Sagittal plane knee ensemble average kinematic waveform across the gait cycle. Positive y-axis values represent flexion, negative represent extension. CMSI= calf muscle strain injury.

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The results from this current study highlight an association between specific kinematic characteristics and a history of CMSI. Although it is not possible to infer causation from these data, the study provides new insight into potential mechanisms for recurrent CMSIs. Therefore, these findings could be used to inform future research and rehabilitation strategies. Firstly, considering the finding of altered kinematics at the hip and pelvis, rehabilitation interventions focusing on hip muscle function may serve to increase proximal contributions to vertical support and propulsion during running, reducing the work required of the ankle plantarflexors. Second, gait retraining interventions may be a useful intervention, targeting many of the observed kinematic deficits. Specifically, increasing step rate has been shown to improve kinematics at the hip and pelvis,\(^12\) reduce over-stride,\(^13\) increase gluteal and calf muscle activation...
Kinematic Characteristics of Male Runners With a History of Recurrent Calf Muscle Strain Injury

prior to foot contact and reduce force requirements at the ankle joint. Therefore, gait retraining may prove beneficial in the management of runners with recurrent CSMI through the restoration of mechanical deficits. Finally, future studies should consider formalised assessment of muscle activation patterns and plantarflexor muscle strength, as deficits in peak muscle force or rate of force development can be addressed within the rehabilitation process and could play a role in the recurrent nature of this injury.

There are some limitations which must be acknowledged. Due to the retrospective nature of this study it cannot be confirmed whether the observed kinematics are the cause or effect of injury. The CSMI group did demonstrate a significantly lower weekly training volume and running frequency when compared to the control group (Table 1). Therefore, it is possible that repeated interruption to training exposure due to injury, could have a negative impact on both tissue and biomechanical function. However, considering the recurrent nature of CSMIs, it is possible that the observed kinematics represent ongoing neuromuscular and functional deficits which may contribute to the persistence of this injury.

An additional limitation is that all participants were required to run at the same testing speed of 3.2m/s. Consequently, some participants may have been running at a speed slightly faster or slower than preferred. However, a prior publication investigating biomechanical differences between high-performance and recreational runners across a range of testing speeds, suggested between-group biomechanical differences may occur irrespective of testing speed. Therefore, subtle variations in running speed are unlikely to have influenced the between group kinematic findings of the present study. Finally, the current study was restricted to a male population of rearfoot strikers. Therefore, further work is required to understand if the observed kinematic patterns are characteristic of other populations, such as forefoot strikers and female runners.

CONCLUSION

This study is the first to identify that male runners with a history of recurrent calf muscle strain injury demonstrate altered stance phase running kinematics. In contrast to the original hypothesis, the data suggest a strong link between pelvic-hip kinematics and the presence of CSMI injury. These findings may be the result of underlying neuromuscular deficits which are consistent with the recurrent nature of this injury. Based on these findings further research should consider assessment of muscle activation patterns as well as the force generating capacity of the calf and hip complex, as this may explain the observed kinematic patterns and can be targeted within the rehabilitation process. Gait retraining interventions may also prove useful as a short-term intervention, addressing the observed proximal kinematic deficits which may have positive implications for the function of the calf complex.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST

The authors report no conflicts of interest.
REFERENCES


Kinematic Characteristics of Male Runners With a History of Recurrent Calf Muscle Strain Injury
Original Research

Lumbopelvic Stability and Trunk Muscle Contractility of Individuals with Chronic Ankle Instability

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¹ School of Rehabilitation Sciences, Old Dominion University

Keywords: ankle sprain, core endurance, diagnostic ultrasound, lumbopelvic stability, self-reported function, transversus abdominis

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Background
Chronic ankle instability (CAI) results in hip neuromuscular impairments that can perpetuate dysfunction through reduced lumbopelvic stability and subsequent malpositioning of the lower body during functional movement. Lumbopelvic stability might be further impaired through changes in trunk muscular contractility. However, lumbopelvic stability and trunk muscle morphology have not been compared between individuals with and without CAI.

Purpose
To compare lumbopelvic stability and trunk muscle contractility between individuals with and without chronic ankle instability (CAI) and determine if lumbopelvic stability and trunk muscle contractility are associated with self-reported function.

Study Design
Case-control study.

Methods
Ten individuals with CAI, 10 ankle sprain copers (COP), and 10 healthy controls (CON) participated. Diagnostic ultrasound imaging was used to assess transversus abdominis (TrA) and lumbar multifidus (LM) muscle contractility. A percent change in contraction thickness from rested to contracted conditions was calculated for each muscle. Lumbopelvic stability was assessed using unilateral hip bridge, trunk flexion endurance, Biering-Sorensen, and side plank tests. Self-reported function was measured with the Foot and Ankle Ability Measure Activity of Daily Living (FAAM-ADL) and Sport (FAAM-S) subscales. One-way ANOVAs and Cohen’s d effect sizes compared scores on clinician and patient-reported outcomes between groups. Pearson product moment correlations analyzed associations between self-reported function and trunk muscle contractility and lumbopelvic stability. Significance was set a priori at P<0.05

Results
COP had significantly greater TrA contractility than CAI (P<0.01, $d=2.65[1.45,3.85]$) and CON (P=0.03, $d=1.05[0.08,1.94]$). Although not statistically significant, a large effect size suggest that CAI had lower TrA contractility than CON (P=0.12, $d=0.92[-0.03,1.80]$). No differences existed for LM contractility or lumbopelvic stability tests. A moderate direct correlation ($r=0.65$, P=0.04) existed between CON’s TrA contractility and FAAM-ADL scores.

Conclusion
Deficits in TrA contractility are a novel finding among individuals with CAI. While LM contractility and lumbopelvic stability did not differ between groups, future research should continue to examine their relevance to CAI.
Lumbopelvic Stability and Trunk Muscle Contractility of Individuals with Chronic Ankle Instability

3b

INTRODUCTION

Chronic ankle instability (CAI) is a significant musculoskeletal condition that affects up to 70% of the estimated 23,000 individuals that sustain an ankle sprain in the United States daily.\(^1,2\) CAI is associated with various impairments that promote frequent ankle sprain recurrences, episodes of “giving way,” and feelings of instability.\(^3,4\) In addition to being highly common, CAI is associated with decreased levels of physical activity and quality of life throughout the lifespan and increased risk for joint osteoarthritis.\(^5\) Conversely, a portion of individuals with a history of ankle sprain, deemed copers, respond more favorably by avoiding these long-term consequences.\(^5\)

Copers and individuals with CAI are distinguishable through surveys of self-reported function (i.e. ability to complete activities of daily living and sport)\(^6\) as well as tests of neuromuscular control.\(^5,7\) Such comparisons are valuable to clinicians designing and evaluating therapeutic interventions intended to eliminate characteristics of CAI and foster those of copers. Most of the comparisons between individuals with CAI and copers have examined residual impairments in the ankle joint, and thus, most rehabilitation protocols focus exclusively on restoring function of the ankle.\(^8\) Increasingly, individuals with CAI are reported to have hip muscular impairments,\(^9,10\) which can perpetuate CAI through reduced stability of the trunk and pelvis (lumbopelvic stability) and resultant malpositioning of the lower body.\(^11,12\)

Although CAI is potentially exacerbated by reduced lumbopelvic stability, this association remains predominantly theoretical. Lumbopelvic stability can be evaluated through tests that challenge an individual’s ability to maintain trunk and hip alignment, but to date, no studies have compared performance between individuals with and without CAI. Furthermore, while lumbopelvic stability is likely affected by hip muscular impairments, it is also highly influenced by the trunk musculature. However, minimal research exists regarding trunk muscle morphology in individuals with CAI. Previous studies have reported that individuals with CAI have greater rates of low back pain,\(^13\) delays in trunk muscle activation,\(^14\) and reduced contractility of the diaphragm muscle.\(^15\) Trunk muscle contractility is important for lumbopelvic stability, but contractility of essential stabilizers, such as the transversus abdominis and lumbar multifidus, has not been examined in individuals with CAI.

Therefore, the purpose of this study was to compare lumbopelvic stability and trunk muscle contractility between individuals with and without CAI. The authors hypothesized that individuals with CAI would have reduced lumbopelvic stability and trunk muscle contractility compared to copers and healthy controls. Identification of deficits in lumbopelvic stability and trunk muscle contractility would direct clinicians to new rehabilitation strategies that could contribute to comprehensive care for individuals with CAI. Additionally, the authors intend to determine if deficits in lumbopelvic stability and trunk muscle contractility were associated with reduced self-reported function. The authors hypothesized that greater lumbopelvic stability and trunk muscle contractility would be associated with better self-reported function in individuals with CAI, copers, and healthy controls. With this analysis, the authors will elucidate how new interventions that target the lumbopelvic region might influence patients’ perceived abilities to engage in activities of daily living and sport.

METHODS

PARTICIPANTS

Using a case-control study design, 30 participants were separated into CAI, coper (COP), and control (CON) groups, using criteria established by the International Ankle Consortium.\(^4,5\) Inclusionary criteria for all groups consisted of being between ages 18 and 40 and completing at least 30 minutes of physical activity three times per week. Exclusion criteria consisted of a history of balance or vestibular disorders, previous spine or lower extremity fracture or surgery, low back pain in the previous six months, concussion in the previous 6 months, and spine and lower extremity musculoskeletal and neurovascular disorders (besides ankle sprain) in the previous two years. All participants read and signed an informed consent document approved by the university’s Institutional Review Board prior to beginning any study procedures.

PROCEDURES

Each participant reported to the Athletic Training Education Laboratory for a single session and completed the study procedure in the following order: 1) self-reported function, 2) trunk muscle contractility, 3) lumbopelvic stability. The two muscle contractility tests and four lumbopelvic stability tests (unilateral hip bridge endurance, trunk flexion endurance, Biering-Sorensen, and side plank) were completed in an order determined by a random number generator. One trial of each lumbopelvic stability test was completed with 1-minute rest intervals between trials. Tests were conducted on the involved side for CAI and COP groups, and a randomly selected side for the CON group. In the case a member of the CAI group had bilateral CAI, the side with the most episode of giving way was tested. Participants reported their level of ankle-specific function with the Foot and Ankle Ability Measure (FAAM) subscale.\(^6\) Participants completed both Activity of Daily Living (FAAM-ADL) and Sport (FAAM-S) subscales. Calculated scores for each subscale ranged from 0 (complete loss of function) to 100 (no loss of function).

Diagnostic ultrasound imaging was used to analyze contractility of the transversus abdominis (TrA) and lumbar multifidus (LM) muscles in the trunk. A portable ultrasound unit (LOGIQ e 2008; GE Healthcare, Wauwatosa, WI) and a linear-array transducer (12L-RS, GE Healthcare, Wauwatosa, WI) visualized and recorded images of each muscle. Thickness of both muscles were measured using...
images taken at rest and while contracted using procedures described previously. An average of three measurements for each muscle in rested and contracted conditions was calculated. A percent change in contraction thickness from rested to contracted conditions was calculated for each muscle using the following formula:

\[
\text{Percent Change} = \frac{\text{mean}_{\text{contrated}} - \text{mean}_{\text{tested}}}{\text{mean}_{\text{tested}}} \times 100
\]

The unilateral hip bridge endurance test was performed on the floor with the participant supine and arms across their chest. The participant performed a double-leg bridge maneuver until a neutral spine and pelvis were achieved. To maintain a neutral spine, the examiner aligned a target with the anterior superior iliac spine of the participant’s non-test limb. Once a neutral position was established, the participant extended the knee of the non-test limb. Once a neutral position was established, the participant extended the knee of the non-test limb so that their thighs remained parallel. While their hips were supported by the test limb, the participant held this position for maximum time.

The trunk flexion endurance test required the participant to sit against a plank with the trunk in 60° of flexion relative to the floor. The participant’s knees and hips were flexed to 90° and hands were folded across their chest. The examiner removed the plank away from the participant’s back, and the participant was instructed to maintain 60° of flexion for maximum time.

The Biering-Sorensen test required the participant to lay prone on a treatment table with their trunk unsupported. The participant was secured with straps across their waist and the anterior superior iliac spine of the participant’s non-test limb. To maintain a neutral spine, the examiner aligned a target with the participant’s trunk in a neutral position for maximum time.

The side plank test required participants to assume a side-lying position with their involved side down. The participant raised their hips and trunk off the table, supporting their body in a neutral position through their feet and elbow, and maintained that position for maximum time.

**STATISTICAL ANALYSIS**

Shapiro-Wilk tests were used to examine normality of demographics and primary outcomes of each group. Since data were found to be normally distributed (P > 0.05), separate one-way ANOVAs were used to compare demographics, self-reported function, trunk muscle contractility, and lumbopelvic stability between groups. For significant main effects, Tukey post-hoc tests examined pairwise comparisons. Cohen’s d effect sizes (small = 0.2-0.49, moderate = 0.5-0.79, large > 0.8) and 95% confidence intervals examined the magnitude of significant pairwise differences. Pearson product moment correlations (negligible < 0.3, low = 0.3-0.49, moderate = 0.5-0.69, high = 0.7-0.89, very high = 0.9-1.0) analyzed associations between self-reported function and trunk muscle contractility and lumbopelvic stability. Significance was set *a priori* at P<0.05. All statistical analyses were conducted using IBM SPSS Statistics, version 24 (IBM Corporation, Armonk, NY).

**RESULTS**

Between groups comparisons of demographics and primary outcomes are presented in Table 1. No significant differences in demographics were present. Significant main effects were present for TrA contractility, unilateral hip bridge, and scores on both FAAM subscales. Pairwise comparisons revealed that COP had significantly greater TrA contractility than CAI (p < 0.01, d = 2.65[1.45, 3.85]) and CON (p = 0.03, d = 1.05[0.08, 1.94]). No statistically significant difference in TrA contractility was present between CAI and CON (p = 0.12, d = 0.92[-0.03, 1.80]). No significant pairwise comparisons were present for the unilateral hip bridge test. CAI had significantly lower FAAM-ADL scores than COP (p = 0.02, d = -1.07[-1.96, -0.10]) and CON (p = 0.01, d = -1.15[-2.05, -0.16]) and significantly lower FAAM-S scores than COP (p = 0.04, d = -0.94[-1.82, 0.02]) and CON (p < 0.01, d = -1.45[-2.36, -0.41]).

**DISCUSSION**

The primary finding of this study is that COP exhibited significantly greater TrA contractility compared to CAI and CON. The reason for COP’s superior TrA contractility is beyond the intent of this study, but potential contributors include elevated pre-injury TrA contractility, inherent resis-

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**Table 1: Between-group comparisons of demographics**

<table>
<thead>
<tr>
<th></th>
<th>CAI (n=10)</th>
<th>COP (n=10)</th>
<th>CON (n=10)</th>
<th>ANOVA (F)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs.)</td>
<td>23.9 ± 4.4</td>
<td>23.0 ± 3.0</td>
<td>23.2 ± 3.3</td>
<td>0.20</td>
<td>0.82</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.6 ± 9.8</td>
<td>173.0 ± 6.5</td>
<td>166.6 ± 6.1</td>
<td>1.82</td>
<td>0.18</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>81.5 ± 19.1</td>
<td>76.0 ± 13.4</td>
<td>68.7 ± 16.3</td>
<td>1.54</td>
<td>0.23</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>5 M/ 5 F</td>
<td>5 M/ 5 F</td>
<td>3 M/ 7 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Ankle Sprains (#)</td>
<td>2.9 ± 1.8*</td>
<td>1.7 ± 0.7*</td>
<td>0.0 ± 0.0</td>
<td>17.37</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Time Since Most Recent Ankle Sprain (months)</td>
<td>41.3 ± 33.3*</td>
<td>62.4 ± 35.1*</td>
<td>0.0 ± 0.0</td>
<td>12.91</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

*Statistically different from the CON group (p<0.05)

Abbreviation: CAI, chronic ankle instability; COP, coper; CON, control
Table 2: Between-group comparisons of primary outcomes

<table>
<thead>
<tr>
<th></th>
<th>CAI (n=10)</th>
<th>COP (n=10)</th>
<th>CON (n=10)</th>
<th>ANOVA (F)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM (% change)</td>
<td>13.5 ± 9.2</td>
<td>14.9 ± 7.5</td>
<td>16.4 ± 10.9</td>
<td>0.26</td>
<td>0.77</td>
</tr>
<tr>
<td>TrA (% change)</td>
<td>32.6 ± 17.9†</td>
<td>114.0 ± 37.6*</td>
<td>67.4 ± 50.2</td>
<td>11.73</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Unilateral Hip Bridge Test (s)</td>
<td>29.5 ± 21.3</td>
<td>54.6 ± 33.4</td>
<td>28.6 ± 13.8</td>
<td>3.71</td>
<td>0.04</td>
</tr>
<tr>
<td>Beiring-Sorensen Test (s)</td>
<td>101.5 ± 44.5</td>
<td>144.0 ± 77.6</td>
<td>139.2 ± 62.6</td>
<td>1.37</td>
<td>0.27</td>
</tr>
<tr>
<td>Side Plank Test (s)</td>
<td>68.4 ± 67.2</td>
<td>84.6 ± 36.6</td>
<td>62.7 ± 29.6</td>
<td>0.58</td>
<td>0.57</td>
</tr>
<tr>
<td>Trunk Flexion Endurance Test (s)</td>
<td>219.4 ± 103.2</td>
<td>188.5 ± 91.4</td>
<td>178.3 ± 91.5</td>
<td>0.50</td>
<td>0.61</td>
</tr>
<tr>
<td>FAAM-ADL (%)</td>
<td>89.4 ± 11.9*†</td>
<td>98.6 ± 2.3</td>
<td>99.2 ± 1.6</td>
<td>6.00</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>FAAM-S (%)</td>
<td>81.8 ± 16.2*†</td>
<td>94.3 ± 9.5</td>
<td>98.6 ± 2.5</td>
<td>6.34</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

*Statistically different from the CON group (p<0.05)
†Statistically different from the COP group (p<0.05)

Table 3: Pearson Product Moment Correlations between FAAM scores and clinical outcomes.

<table>
<thead>
<tr>
<th></th>
<th>FAAM-ADL (%)</th>
<th>FAAM-S (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>P</td>
</tr>
<tr>
<td>LM (% change)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>-0.16</td>
<td>0.66</td>
</tr>
<tr>
<td>COP</td>
<td>0.07</td>
<td>0.84</td>
</tr>
<tr>
<td>CON</td>
<td>0.19</td>
<td>0.60</td>
</tr>
<tr>
<td>TrA (% change)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>0.28</td>
<td>0.44</td>
</tr>
<tr>
<td>COP</td>
<td>-0.55</td>
<td>0.10</td>
</tr>
<tr>
<td>CON</td>
<td>0.65</td>
<td>0.04*</td>
</tr>
<tr>
<td>Unilateral Hip Bridge Test (s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>0.50</td>
<td>0.14</td>
</tr>
<tr>
<td>COP</td>
<td>0.08</td>
<td>0.82</td>
</tr>
<tr>
<td>CON</td>
<td>0.14</td>
<td>0.71</td>
</tr>
<tr>
<td>Beiring-Sorensen Test (s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>0.44</td>
<td>0.20</td>
</tr>
<tr>
<td>COP</td>
<td>0.35</td>
<td>0.33</td>
</tr>
<tr>
<td>CON</td>
<td>0.50</td>
<td>0.14</td>
</tr>
<tr>
<td>Side Plank Test (s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>0.48</td>
<td>0.15</td>
</tr>
<tr>
<td>COP</td>
<td>-0.18</td>
<td>0.62</td>
</tr>
<tr>
<td>CON</td>
<td>0.30</td>
<td>0.41</td>
</tr>
<tr>
<td>Trunk Flexion Endurance Test (s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>0.01</td>
<td>0.98</td>
</tr>
<tr>
<td>COP</td>
<td>0.10</td>
<td>0.79</td>
</tr>
<tr>
<td>CON</td>
<td>0.16</td>
<td>0.66</td>
</tr>
</tbody>
</table>

*Statistically significant correlation (p<0.05)

Abbreviation: CAI, chronic ankle instability; COP, coper; CON, control; LM, lumbar multifidus; TrA, transversus abdominis; FAAM-ADL, Foot and Ankle Ability Measure Activity of Daily Living subscale; FAAM-S, Foot and Ankle Ability Measure Sport subscale

Table: Lumbar and trunk muscle contractility of individuals with chronic ankle instability

The identification of enhanced TrA contractility in copers suggests that targeting it during ankle sprain rehabilitation might contribute to avoidance of CAI, however, this remains unconfirmed.

While there was not a significant difference between CAI and CON, large effect sizes suggest that CAI might have had clinically meaningful reductions in TrA contractility compared to COP and CON. The TrA primarily acts as a spinal stabilizer by increasing intra-abdominal pressure and is an important part of feedforward motor control when anticipating an external perturbation or preparing for move-
The ability of the TrA to increase intra-abdominal pressure is contingent upon the diaphragm’s ability to contract and maintain the position of the abdominal contents. Terada et al. previously reported that individuals with CAI had reduced left hemidiaphragm contractility, which might further impair trunk stability when combined with reduced TrA contractility. Gong provided evidence of the TrA’s contribution to postural control performance in a study that reported a low, significant correlation between TrA thickness and static balance performance in healthy females. Another study reported that increasing postural demand during static stance resulted in increased TrA activation of healthy males. Collectively, these studies suggest that balance impairments, which are commonly identified among individuals with CAI, might be partially attributable to dysfunction of the TrA. However, since postural control was not evaluated in the current study, the link between TrA contractility and balance deficits of individuals with CAI could not be determined by this study. While contractile impairments of the TrA appear to exist among individuals with CAI, the etiology of this alteration cannot be determined through the current retrospective study design. Evidence exists for neuromuscular impairments being precursos to and results of CAI, so more work is needed to identify the course of TrA contractility deficits.

Converse to the TrA, no differences in LM contractility were present between groups. While the LM also has a part in feedforward activation when preparing for lower extremity movement, its contraction does not occur as early as the TrA, potentially indicating a lesser role in initiating lumbopelvic stability. Despite its later activation, the role of the LM in spinal stabilization is well documented; of note, reduced cross sectional area of LM is implicated in low back pain. Limited evidence exists linking LM contractility, low back pain, and CAI. Nadler et al. reported that collegiate athletes with lower extremity injuries, including CAI, required more treatment for low back pain compared to those without lower extremity injuries. While it is conceivable that dysfunction of the LM could be more prominent among individuals with CAI, these data do not support this association. A potential reason for the lack of differences in LM contractility is the exclusionary criteria, which eliminated individuals with low back pain. Future studies should examine alterations in LM contractility among multiple groups with concurrent and asynchronous presentations of CAI and low back pain.

In addition to LM contractility, none of the lumbopelvic stability tests differed between groups. Lumbopelvic stability is widely considered a requisite to neuromuscular control of the lower extremity by providing a stable foundation upon which to generate motion and transmit force. Increased gluteal muscle activation latencies and decreased hip strength previously reported in individuals with CAI signify that deficits commonly exist in stabilizers of the lumbopelvic complex. Thus, the authors hypothesized that among individuals with CAI, reduced lumbopelvic stability would be present and potentially contribute to reduced neuromuscular control of the lower extremity. Others have attempted to, but were unsuccessful in determining if reduced baseline scores on trunk flexion endurance, Biering-Sorensen, and side plank tests increase risk of lower extremity injuries. The trunk flexion endurance test had some mixed findings, but the lumbopelvic stability tests did not demonstrate predictive value for injury. Although the ability of these tests to predict ankle sprains specifically has not been explored, the findings of the current and previous studies suggest that lumbopelvic stability might have limited relevance to CAI. However, it is also possible that the static endurance tests were simply not representative of lumbopelvic stability deficits of individuals with CAI. A previous study of individuals with functional ankle instability demonstrated increased latency times of the erector spinae and rectus abdominis muscles during a trunk unloading task compared to healthy controls. Additionally, increased trunk extensor latency was associated with greater time required to stabilize following a jump landing. A similar laboratory test identified increased sagittal and frontal plane displacements of the trunk after sudden unloading as significant risk factors for knee injuries in female collegiate athletes. The unanticipated nature of the unloading tasks in the previous studies provided unique challenges not present in the stability tests that incorporated no unanticipated perturbations. Unanticipated landing tasks have previously resulted in increased lower extremity muscle activation latency, and thus reduced preparation of the sensorimotor system, compared to anticipated landing tasks. If unanticipated perturbations are needed to detect lumbopelvic stability deficits of individuals with CAI, then it is unlikely that the selected tests would do so. Although the selected lumbopelvic stability tests failed to differentiate individuals with and without CAI, the authors recommend that the efficacy of other lumbopelvic stability measures should be explored. Tests that involve assessment of dynamic lumbopelvic stability will likely be more applicable to the functional demands of physically active individuals.

Only one statistically significant correlation was found, in which the CON group’s TrA contractility was moderately associated with FAAM-ADL scores. This finding indicates that healthy individuals with greater TrA contractility had greater self-reported physical function during ADLs. Thus, in the CON group, the TrA likely serves as a rigid support to generate proximal stability and better contribute to neuromuscular control during functional tasks. While this association was expected, the authors anticipated lumbopelvic stability tests and LM contractility would have additional relationships with self-reported function. It is unclear why no other meaningful correlations were discovered, but as discussed earlier, the selected lumbopelvic stability tests might not have been truly representative of lumbopelvic stability of copers or individuals with CAI, and thus, demonstrate minimal influence over self-reported function. Additionally, it is possible that participants with a previous ankle sprain experienced central nervous system reorganization that limited the influence of the LM and TrA on self-reported function.

Limitations must be acknowledged in the present in this study. First, the retrospective study design limits the authors’ ability to determine if TrA contractility deficits originated before or after the onset of CAI. While participants were required to maintain a minimum level of physical activity, further variations in exercise mode, intensity, fre-
quency, and duration that were not accounted for might have influenced the study results. Additionally, variations in physical activity might have affected the participants’ group placement; those that avoid certain physical activities might be less likely to sprain their ankle or experience other symptoms of CAI. The lack of examiner blinding could have influenced observations when conducting clinical tests. The authors attempted to evaluate lumbopelvic stability with multiple clinically applicable tests, but as explained earlier, the tests might not have sufficiently challenged the sensorimotor system of the participants enough to detect between-group differences.

CONCLUSION

Copers exhibited superior TrA contractility compared to individuals with CAI and healthy controls. This finding is potentially indicative of a positive neuromuscular adaptation in copers that provides protection against the onset of CAI. Conversely, individuals with CAI might be less able to develop this adaptation, which could contribute to the persistence of CAI. There is no distinct reason that the CAI population lacks this adaptation, but inherent resistance or insufficient rehabilitation are potential contributors. While TrA contractility was not influential to self-reported function of copers or individuals with CAI, further research should examine the value of enhancing this outcome during rehabilitation of patients with CAI. While no group differences in lumbopelvic stability were present, future studies should continue to explore the importance of lumbopelvic stability in CAI rehabilitation.

CONFLICTS OF INTEREST

The authors of this manuscript have no conflicts of interest to disclose.

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REFERENCES


The Effects of Whole Body Vibration on the Limits of Stability in Adults With Subacute Ankle Injury

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Keywords: ankle sprain, balance, limits of stability, subacute, whole body vibration, movement system

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Background

Limited research exists on the effects of both high and low frequency whole body vibration (WBV) on individuals with subacute lateral ankle sprains.

Hypothesis/Purpose

To examine the difference in the effects of high and low frequency WBV on limits of stability (LOS) in adults with a subacute ankle sprain. It was hypothesized that WBV would improve effects on outcome variables for LOS as a component of dynamic balance.

Study Design

Quasi-experimental, pretest-posttest design.

Methods

Fifteen participants ages 19-27 years (Mean age 22±2.36) with either a Grade I or Grade II lateral ankle sprain received WBV in bilateral stance under three randomized conditions (high frequency-25 Hz, low frequency-6 Hz, and control, which consisted of bilateral stance with machine off) for six minutes over three sessions (one time per week). The LOS test, consisting of 5 variables, were assessed using the NeuroCom® Balance Manager-SMART EquiTest® (Natus Medical Incorporated, Pleasanton, CA) at baseline and after the intervention period. The participants completed a practice LOS test and then had a six-minute standing rest break. After the rest break, they completed the pre-LOS (baseline) test. Intervention was administered using the Galileo® Med L Chip Research (Novotec Medical GmbH, Pforzheim, Germany) for six minutes for the appropriate condition of either high or low frequency WBV or control. Data analysis was performed using 2-Way (2x3) Repeated Measures ANOVAs with additional post hoc testing as needed.

Results

Significant interactions were found for reaction time (RT), movement velocity (MVL), and maximal excursion (MXE) composite scores with a decrease in RT of 0.117 seconds (p=0.022) between control and high frequency conditions during the post LOS. For composite MVL, an increase of 0.547 degrees/second (p=0.002) between pre- and post-high frequency WBV occurred. For composite MXE, an increase of 2.13% (p=0.031) when comparing pre- and post-high frequency WBV.

Conclusion

Findings suggest that a single session of high frequency WBV in individuals with a subacute lateral ankle sprain may result in improvement in several components of...
postural stability. WBV is a quick intervention that could be implemented in physical therapy clinics, athletic training rooms, and workout facilities to improve an individual’s LOS as a component of dynamic balance one to eight weeks post lateral ankle sprain.

Level of Evidence

2b

INTRODUCTION

Ankle sprains are a common sports related injury with about 23,000 occurring daily in the United States.\textsuperscript{1,2} Although ankle sprains occur in many types of sports, the most common sports are basketball, football, and soccer. There are three types of ankle sprains: medial (involves the deltoid ligament), lateral (involves the anterior talofibular ligament, calcaneofibular, and posterior talofibular), and syndesmotic, also called a high ankle sprain (involves the interosseous ligament between the distal tibia and fibula). Lateral ankle sprains, being the most common type of sprain, occur from either an uncontrolled force or from excessive supination and adduction when the ankle is plantar-flexed.\textsuperscript{1} Ankle injuries are also defined along a continuum of acute (immediately post injury to 4 days post), subacute (1 to 8 weeks post injury), and chronic (greater than 8 weeks post).\textsuperscript{3} The severity of ankle sprains are defined by Grades I through III which note the percentage of tissue that is torn or disrupted. Grade I is defined by less than 25% of ligament fibers torn, Grade II is defined as 25% to 75% of ligament fibers torn, and Grade III is defined as greater than 75% of the ligament being non-contiguous.\textsuperscript{4,5}

This study focused on the subacute phase of an ankle sprain which is defined as one to eight weeks after the initial injury.\textsuperscript{3} Certain special tests can be performed clinically to determine the grade of ankle sprain. The most common special tests used are the anterior drawer test and the talar tilt test.\textsuperscript{4-6} A Grade I sprain is classified by a positive scoring on the anterior drawer test and a negative scoring on the talar tilt test, which means there is damage to the anterior talofibular ligament. A Grade II is classified by a positive scoring on both the anterior drawer test and the talar tilt test, which means there is damage to both the anterior talofibular ligament and calcaneofibular ligament.\textsuperscript{4,6-8} Ankle sprains may impact various components of the movement system, namely the musculoskeletal and nervous systems. Not only do ankle sprains damage ligaments, but they also damage mechanoreceptors and the joint capsule, which can then potentially adversely affect joint proprioception and balance. Most common treatments for ankle sprains initially involve the following: taping, bracing, protection, rest, ice, compression, and elevation. General rehabilitation typically involves the use of range of motion (ROM), strength training, and balance/proprioception training in order to progress the individual. Another rehabilitation technique includes the use of whole body vibration (WBV). Previous research has been conducted on the effects of WBV as a rehabilitation intervention on chronic ankle instability (CAI); however, there is limited research on the effects of WBV as a rehabilitation intervention on subacute ankle sprains.\textsuperscript{1}

WBV is a modality that is recognized for improving neurovascular and neuromuscular performance and balance through vertical sinusoidal oscillations.\textsuperscript{9} The vibration moves from the foot throughout the rest of the body.\textsuperscript{9} There are several different vibrations that can be utilized, such as an alternating, simultaneous, and multidirectional.\textsuperscript{9} The frequencies range from low to high depending on the type of vibration administered. For alternating side-to-side vertical WBV, low frequency is between 5-12 hertz (Hz) and high frequency is between 20-30 Hz.\textsuperscript{10} For simultaneous vertical WBV, low frequency is at 20-30 Hz and high frequency is 35-50 Hz.\textsuperscript{9} Frequencies below 12 Hz cause muscle contraction without triggering the stretch reflex resulting in a conscious compensation of movement, whereas high frequencies focus on training muscle power and force through the rapid contraction and partial relaxation of the muscle.\textsuperscript{10} WBV has been shown to improve performance and balance in sub-populations such as the elderly and individuals with motor impairments like Parkinson Disease, stroke, and multiple sclerosis.\textsuperscript{11} However, Ritzmann et al. have recently suggested that WBV can enhance balance control in young healthy individuals.\textsuperscript{11} Research has also shown that WBV can lead to physiological changes in muscle spindles, joint mechanoreceptors, strength, and power resulting in enhanced proprioception and balance in individuals with CAI.\textsuperscript{12} Although high frequencies have been shown to increase neurovascular and neuromuscular performance and balance, there has been insufficient research that examines the effects of low frequency WBV on the limits of stability (LOS) as a component of dynamic balance of young, healthy or injured adults, particularly examining the effects of WBV on subjects who have sustained Grade I and II ankle injuries, subacutely.

Postural stability is the ability to maintain one’s center of gravity (COG) within the base of support (BOS); the maximum range in which the COG can be displaced without loss of balance or changing the BOS is referred to as the LOS.\textsuperscript{13,14} The LOS test measures a person’s reaction time (RT), movement velocity (MVL), endpoint excursion (EPE), maximal excursion (MXE), and directional control (DCL) when shifting their COG in eight different directions.\textsuperscript{14,15} At the two ends of the lifespan, young children and older adults, postural stability is at its lowest.\textsuperscript{16} Young adults, however, have a larger amount of postural stability and are able to expand their LOS, which decreases their risk of falls. Young adults that participate in athletics depend on their postural stability to maintain their balance while performing dynamic movements such as: throwing, catching, kicking, and blocking. Injury to ankle ligaments will decrease an individual’s LOS due to swelling, pain, and instability. Previous research has used the LOS test to determine its effects on balance in individuals who have sustained ankle sprains.\textsuperscript{17}

The purpose of this study was to examine the difference in the effects of high and low frequency WBV on LOS in adults with a subacute ankle sprain. It was hypothesized that WBV would improve effects on outcome variables for
LOS as a component of dynamic balance.

METHODS

RESEARCH DESIGN

Quasi-experimental pretest-posttest design.

PARTICIPANTS

Fifteen participants, aged 19-27 years (Mean age 22±2.36) years were recruited through posted flyers on a University campus and through school-wide emails. All 15 participants had sustained a lateral ankle sprain (Grade I Sprain - n=12; Grade II Sprain – n=3). Those that participated in the study were rewarded a $25 gift card after completion of all three sessions through an internal university grant. The inclusion criteria included the following: between the ages of 18 and 29, having sustained a Grade I or II ankle sprain in the prior one to five weeks, and able to speak and read English. While the subacute phase was recognized as occurring between one to eight weeks post ankle injury, the inclusion criteria was for the prior one to five weeks to ensure data collection could be completed within the subacute timeframe. The exclusion criteria included the following: sustained an ankle injury in the prior six days or longer than eight weeks, had sustained a Grade III ankle sprain, were on medications that affected balance, and/or were currently pregnant. The participants were informed of all the study risks and benefits of receiving WBV prior to filling out a pre-screening questionnaire and then were instructed on how to perform the LOS Test. All participants were required to sign an informed consent prior to participation. The study received university institutional review board approval prior to screening or data collection.

INSTRUMENTATION AND OUTCOME MEASURES

The Galileo® Med L Chip Research (Galileo) (Novotec Medical GmbH, Pforzheim, Germany), was used to provide the WBV intervention. The Galileo is a guided therapy machine, which provides an alternating side-to-side WBV while stimulating the normal gait pattern. There is a separate control panel that allows the researcher to control the frequency and duration of the intervention and a handrail available for additional participant safety. The vertical lines on the base of the machine allow for consistency of foot placement. High and low frequency WBV were delivered at 25 Hz and 6 Hz, respectively.

The NeuroCom® Balance Manager system (NeuroCom) (SMART EquiTest, Natus Medical Incorporated, Pleasanton, CA) was used to assess balance by the administration of the LOS test to assess the participants’ RT, MVL, EPE, MXE, and DCL when shifting their COG in eight different directions. This device also is accompanied with a harness for participant safety. The participants have eight seconds to shift their COG in an effort to move the cursor to its appropriate destination. The eight directions include the following: forward, forward right, right, backward right, backward, backward left, left, and forward left. A composite score was then generated as a compilation of the average of each direction for each variable.

Data collected as a component of dynamic balance.

RESULTS

Significant interactions for composite scores for the LOS variables of RT, MVL, and MXE were found. For composite RT, a significant two-way interaction was noted between condition and time F(2,28)=5.505, p=0.044.
Post hoc analysis for simple main effects for condition revealed significant differences among the three post-conditions of LOS (high frequency, low frequency, control) F(2,28)=3.754, p=0.036 (Figure 2).

Pairwise comparisons revealed a significant decrease in composite RT of 0.117 seconds (95% CI, .019 to .214, p=0.022) between control and high frequency conditions during the post LOS. For composite MVL, a significant two-way interaction was noted between condition and time F(2,28)=3.394, p=0.048 (Table 1). Post hoc investigation for simple main effects for time revealed a significant increase in composite MVL of 0.547 degrees/second F(1,14)=13.771, p=0.002 (95% CI, .231 to .863) between pre- and post-high frequency WBV. For composite MXE, a significant two-way interaction was noted between condition and time F(2,28)=4.271, p=0.024 (Table 1). Post hoc investigation for simple main effects for time revealed a significant increase in composite MXE of 2.13% F(1,14)=5.767, p=0.031 (95% CI, .228 to 4.039) when comparing pre- and post-high frequency WBV.

DISCUSSION

The purpose of this study was to examine the difference in the effects of high and low frequency WBV on LOS in adults with a subacute ankle sprain. It was hypothesized that WBV would improve effects on outcome variables for LOS as a component of dynamic balance. Out of the five LOS composite scores assessed, only three of them were statistically significant between interventions. Although low frequency WBV was examined in this study, the results indicate that only high frequency WBV may impact the movement system and lead to improvements in some of the fundamental variables required for postural stability. Regarding clinical meaningfulness, while the current study found statistically significant change occurring in RT (decrease of .117 seconds), MVL (increase of .547 deg/sec), and MXE (increase of 2.13%), true, clinically meaningful, change appears to be questionable based on previous research. Alsalaheen et al. examined LOS test composite scores as well as the individual LOS components in healthy adolescents and found a MDC95 of 0.13 seconds for RT, 1.55 deg/second for MVL, and 5.9% for MXE in order for true change to occur.18 Although these results cannot be generalized to the current study population of those with subacute lateral ankle sprains, it may indicate that clinically meaningful changes did not occur.

HIGH FREQUENCY WBV

To the authors’ knowledge, there are no other current research studies that have examined the effects of WBV on the LOS as a component of dynamic balance in individuals with a lateral ankle sprain. However, several authors have examined the effects of WBV on balance in a variety of populations. According to Ritzmann et al., high frequency alternating side-to-side vertical WBV, administered through the Galileo Sport, improved balance control as noted by center of pressure movement during one-leg stance for 38 physically fit adult students who trained for four weeks.11

This is consistent with the results of the current study in that high frequency (25 Hz) WBV delivered in an alternating side-to-side device improved RT, MVL, MXE of the LOS Test that correlate with improved balance in a similar age population. However, the Ritzmann, et al. study looked at a healthy adult population as compared to the current subacute ankle sprain group. The current study is also in agree-

<table>
<thead>
<tr>
<th>Variable</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>F(2,28)=3.505, p=0.044*</td>
</tr>
<tr>
<td>MVL</td>
<td>F(2,28)=3.394, p=0.048*</td>
</tr>
<tr>
<td>EPE</td>
<td>F(2,28)=2.016, p=0.153</td>
</tr>
<tr>
<td>MXE</td>
<td>F(2,28)=4.271, p=0.024*</td>
</tr>
<tr>
<td>DCL</td>
<td>F(2,28)=1.835, p=0.178</td>
</tr>
</tbody>
</table>

RT = Reaction Time, MVL = Movement Velocity, EPE = End Point Excursion, MXE = Maximum Excursion, DCL = Directional Control, *p<0.05
ment with Sierra-Guzman et al., who found improvements in balance using the Biodex Balance System after high frequency simultaneous vertical WBV (30-40 Hz) utilizing the Excel Pro vibration platform in 50 recreational athletes with CAI who were randomized to three groups: vibration, non-vibration, or control. The intervention occurred one time per week for three consecutive weeks. Again, while not addressing subacute ankle injuries and with using simultaneous vertical rather than alternating side-to-side WBV, those authors found that elements of balance also improved in CAI when utilizing high frequency WBV.

Additionally, while not addressing balance specifically, other studies have examined the impact of WBV on individuals with CAI and found high frequency WBV to improve outcomes related to range of motion, strength, and proprioception. One such study had 39 participants with CAI randomized to three groups: normative, static stretch, and static stretch with WBV (simultaneous vertical) at 34 Hz. The study was conducted four days per week for three weeks. The static stretching with high frequency WBV group saw increases with dorsiflexion ROM that were better than with static stretching alone. While that study investigated individuals with chronic conditions and not subacute ankle injuries, it is interesting to note that high frequency WBV was beneficial to treatment in a CAI population. Likewise, the present study found that high frequency WBV may be beneficial to the subacute ankle injury population. The reasons for this benefit may be two-fold. As previously mentioned, previous researchers have found that WBV produces physiological changes in muscle spindles, joint mechanoreceptors, strength, and power resulting in enhanced proprioception and balance. As such, one reason may involve lowering the threshold for activation of these receptors. Additionally, high frequency WBV may produce a summative effect of the stimulus required to produce activation in these structures.

LOW FREQUENCY VIBRATION

Low frequency (6 Hz) alternating side-to-side WBV was not found to have a significant impact on balance in an adult population with subacute ankle sprains in the current study. Additionally, there are no studies to date showing that low frequency WBV has a favorable impact on dynamic balance for a population suffering from subacute lateral ankle sprains.

However, the results of the current study are in line with the results of a study by Rendos et al. in which 19 active adults were studied in a control group and a group with CAI. The participants received low frequency (30 Hz) simultaneous vertical WBV and sham interventions on 3 different testing days in a random order. Results indicated that the low frequency WBV did not improve static or dynamic balance in either group.

LIMITATIONS

Limitations in the present study were noted. For one, spontaneous healing over time may have been a factor. All participants completed three sessions over the course of three weeks. Although all participants remained in the subacute phase of injury during their participation in this study, the healing process for their ankle injury was continuous, and likely variable among subjects. Thus, it is possible that spontaneous healing over the study period could have enhanced the effects of the intervention, and occurred differently among subjects.

Second, a learning effect could have influenced the results. All participants were required to perform a practice LOS Test to allow each participant to acclimate to the test. Therefore, as participants continued through the sessions, they may have demonstrated improvements in their pre- and post-LOS testing secondary to this effect.

Finally, participants may not have maintained a consistent knee position during the intervention. Knee flexion was measured using a goniometer once every session, as the participant mounted the Galileo, to ensure a standardization of each participant’s stance during the randomized condition portion of the session. Every participant was then verbally instructed to maintain this set degree of knee flexion throughout receiving the random condition. However, knee flexion was never re-assessed throughout the session and may have changed, potentially altering the effects of WBV.
CONCLUSIONS

The results of the current study suggest that a single session of high frequency WBV for individuals with a sub-acute ankle sprain resulted in statistically significantly improved RT, MVL, and MXE during the post-LOS test performance. There were no significant findings associated with either the low frequency WBV condition or the control condition. Further research is required to determine the clinical significance of these results and to investigate the long-term effects of a single session of high frequency WBV, since this study focused mainly on the immediate effects. Additional research should also be performed to determine if multiple sessions of high frequency WBV over the course of several weeks would be more beneficial in improving additional variables of an individual's LOS. Moreover, a comparison between the effects of alternative side-to-side delivery of WBV and simultaneous vertical WBV on individuals with subacute ankle injuries would be beneficial.

CONFLICT OF INTEREST

The authors report none.

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REFERENCES


Original Research

Concentric and Eccentric Force Changes with Elastic Band and Isotonic Heavy Resistance Training: A Randomized Controlled Trial

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Keywords: elbow, hip, isokinetic, shoulder, movement system, resistance training

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Background
Inclusion of resistance training as part of a general fitness program to improve health, and lower risk of disease and injury is well established. Two common options to improve strength are elastic bands and weights. Comparison between elastic bands (as the sole resistance) to isotonic strengthening for concentric and eccentric strength outcomes following the use of low repetitions/heavy resistance has not been reported.

Hypothesis/Purpose
The purpose was to examine the effects of a four-week isotonic low repetitions/heavy resistance strengthening program compared to a low repetitions/heavy resistance elastic band strengthening program on shoulder external rotation, hip abduction, and elbow flexion concentric and eccentric isokinetic force production in college aged untrained females.

Study Design
Randomized Trial

Methods
Twenty healthy females performed pre-and-post isokinetic (60 degrees/second) concentric/eccentric testing of the elbow flexors, shoulder external rotators, and hip abductors. Participants were randomly assigned to a four-week independent low repetitions/heavy resistance strengthening program performed with either elastic bands or isotonic exercises.

Results
A significant (p < 0.05) effect of time was found for eccentric elbow flexor and concentric and eccentric hip abduction force production in the elastic band group with post-test values greater than pre-test values. A significant (p < 0.05) effect of time was found for elbow flexor concentric and eccentric force production in the isotonic group with post-test values greater then pre-test values. No significant (p>0.05) effect of time was found for shoulder external rotator concentric and eccentric forces for both groups, the isotonic group's hip abduction concentric and eccentric force production and elastic band group's elbow flexion concentric force production. No significant effect of intervention (p >0.05) on concentric or eccentric elbow flexors, shoulder external rotators, or hip abductors force production was found, with pre-test and post-test values being similar between groups.

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Concentric and Eccentric Force Changes with Elastic Band and Isotonic Heavy Resistance Training: A Randomized Controlled...

Conclusion
Health care practitioners and coaches can consider the prescription of a heavy resistance training program with elastic bands or isotonic exercises for an independent exercise program and expect similar concentric and eccentric muscle force changes.

Level of Evidence
Level 2b

INTRODUCTION
The benefits of resistance training as part of a general fitness program and to improve health is well established and is recommended by the American College of Sports Medicine (ACSM). Improved muscular strength lowers cardiovascular disease, decreases risk of acquiring physical functional limitations, and improves bone mass and composition. Concentric (muscle shortening), eccentric (muscle lengthening) and isometric (no change in muscle length) muscle contractions are various ways to measure strength. Elastic, concentric, and isometric strength capabilities are all important for performing well in sport activities, injury prevention, and affect rehabilitation at the knee, hip and elbow.

Health care professionals, such as physical therapists and personal trainers, commonly prescribe strengthening with elastic bands and/or weights to improve muscular strength, health, and for injury prevention and rehabilitation. Weights provide a constant external load and therefore are considered an isotonic form of strengthening exercise. Elastic bands, in contrast, provide linear variable resistance; meaning as range of motion increases and the band becomes more taut, resistance increases. Elastic bands have the benefit of being highly portable and are frequently used for independent exercise programs. Knowing which strengthening method (band vs. weights) may be superior for affecting eccentric, concentric and isometric strength is important for optimal outcomes.

Both isotonic and elastic band strengthening appear to result in similar concentric and isometric upper extremity and lower extremity strength gains. Prior research on the effects of strengthening comparing elastic bands to isotonic exercises has utilized males, adolescents and athletic college aged females. Previous research indicates significant increases in shoulder eccentric force using elastic bands and the combination of elastic bands with isotonic exercises compared to controls with no strengthening. However, research has not compared the effect on eccentric strength solely with the use of elastic bands compared to isotonic strengthening methods. Additionally, there is no research comparing elastic bands to isotonic strengthening in sedentary college aged females. Health care professionals would benefit from knowing if untrained healthy females have similar outcomes as males and athletic females, as well as comparing isotonic exercise to solely elastic band exercise strengthening outcomes. Gaining this information will provide healthcare professionals guidance regarding which method of strengthening to prescribe for each patient populations.

High load, low repetition or low-moderate load, high repetition exercise are two different parameters to improve muscular performance. ACSM considers three or more sets of four to six repetitions at 85% or greater of a one repetition maximum a high load, low repetition program intended to target improving strength. A low-moderate load, high repetition routine entails two or more sets of greater than six repetitions at less than 85% of one repetition maximum (1RM) intended to target hypertrophy and muscular endurance development. Males, adolescents, and trained females demonstrated similar isometric and concentric strength gains with either isotonic or variable resistance strengthening that utilized hypertrophy and muscular endurance strengthening parameters of low-moderate load, high repetition (> eight repetitions). Prior research has not investigated whether similar concentric and eccentric strength outcomes can be achieved with a high load, low repetition elastic band versus a high load, low repetition isotonic resistance program.

Short term strength gains are important because health care professionals such as physical therapists are often expected to demonstrate improvement in four to six weeks for reimbursement and continuation of care. The ACSM recommends initial use of low-moderate load, high repetition for untrained persons to increase endurance and learn proper form. However, untrained lifters demonstrated a significant increase in concentric strength with a high load, low repetition isotonic exercise routine compared to low-moderate load, high repetition following eight-weeks of lifting. Therefore, if the goal of an exercise program is to achieve the greatest short-term concentric and eccentric strength gains, and a client demonstrates proper form, a high load, low repetition program may be indicated. Knowledge of strength outcomes utilizing high load, low repetition program with elastic bands compared to isotonic exercises would be valuable for health care professionals to understand strength outcomes that may occur over a four-week period.

The purpose of this research was to examine the effects of a four-week isotonic low repetitions/heavy resistance strengthening program compared to a low repetitions/heavy resistance elastic band strengthening program on shoulder external rotation (ER), hip abduction and elbow flexion concentric and eccentric isokinetic force production in college aged untrained females.

The null hypothesis was that there would be no difference in concentric or eccentric muscle force changes found due to isotonic strengthening as compared to elastic band strengthening after a four-week training program.

METHODS
An a priori power analysis determined a sample size of twenty (10 in each group) based on a 5% margin of error...
with a 95% confidence interval using variance determination calculated from previous studies.\textsuperscript{15,21} Twenty-four healthy females age 20-30 were recruited through word of mouth, personal contact and flyers between February and April of 2015 based on an expected 15% drop-out rate. Researchers terminated recruitment following enrollment of 24 qualified participants. Inclusion criteria included healthy college aged females. Exclusion criteria included a current injury, current participation in a regular strength-training program or no access to a gym with weights.

The University of the Sciences Institutional Review Board approved this study prior to enrollment of participants (Protocol: 639927-4). Participants gave written informed consent prior to participation. The study was not a registered clinical trial.

**STUDY DESIGN**

The study was a randomized controlled trial of healthy females. Researchers blinded testers to group assignment for both pre- and post-testing. Participants completed identical pre- and post-test strength testing on the Baltimore Therapeutic Equipment (BTE) Primus RS at University of the Sciences to record force and determine correct resistance for isotonic or elastic training. Post testing occurred two to seven days following the last exercise session, which occurred over four weeks. Participants performed concentric and eccentric isokinetic testing at 60 degrees/second of the shoulder external rotators, elbow flexors, and hip abductors. The testing velocity of 60 degrees/second was previously reported to be a good representation of both concentric and eccentric force production.\textsuperscript{8} Testing parameters followed instructions as described in the BTE manual (Figure 1).\textsuperscript{22} Participant testing position for elbow flexion was in standing, feet shoulder width apart, humerus adducted to side, neutral shoulder rotation with forearm supinated. Testing position for shoulder ER was in standing, feet flat on the floor, shoulder abducted 45 degrees, elbow flexed 45 degrees and forearm in neutral position. Testing position for hip abduction was in side lying on contralateral side of hip being tested, pad placed immediately proximal to knee and hip in neutral flexion/extension. Researchers did not allow participants to use any substitution patterns during testing. All participants completed the testing protocol on the PrimusRS for the right elbow flexors, shoulder external rotators, and hip abductors through their full active range of motion.

The PrimusRS has previously demonstrated excellent test-retest reliability [ICC\textsubscript{2,1} = 0.99 (95% CI 0.96-0.99)] for isokinetic concentric elbow flexion peak torque at 60 degrees/second.\textsuperscript{23} The same study reported excellent test-retest reliability with a range of ICC\textsubscript{2,1} values between 0.95-0.98 for concentric isokinetic testing at 60 degrees/second for elbow extension, knee flexion and knee extension. Additional studies have reported excellent (ICC range 0.844-0.99) test-retest reliability for concentric power of the ankle, hip force, isotonic functional tasks and static isotonic upper limb strength testing.\textsuperscript{24-26} The factory calibrated the PrimusRS prior to delivery and researchers calibrated the PrimusRS prior to each testing session to ensure accurate measurement.\textsuperscript{22}

![Figure 1: Isokinetic test position for shoulder external rotation, elbow flexion and hip abduction. Concentric and eccentric testing at 60 degrees per second through participants full ROM.](image)

Participants performed a five-minute warm-up on a stationary bicycle prior to a warm-up of three submaximal concentric/eccentric (at 50% perceived effort) repetitions and one maximal repetition to familiarize participants with the movement. They then received a one-minute rest followed by testing of five maximal reciprocal repetitions on the right side. Researchers documented the average maximal concentric and eccentric peak force of the five repetitions. The average of the five test contractions was previously utilized for isokinetic testing of the shoulder.\textsuperscript{14} Individuals received a five-minute rest between testing motions. Following testing an independent researcher, blinded to test results, randomly assigned participants to either a strength training program with Theraband\textsuperscript{®} elastic band (EB) or isotonic exercises (IS) using Microsoft Excel (2013).

Investigators converted average maximal peak force (N) of the five concentric contractions to kilograms. The independent exercise prescription included three sets (one-minute rest between sets), of four to six repetitions, performed three times per week (minimum 48 hours rest between sessions) for four weeks. Final data inclusion required participants complete eight sessions over four weeks, as previous studies demonstrated strength and functional improvement in as little as four weeks in healthy populations and three to four weeks in persons with lumbar and shoulder pathology.\textsuperscript{14,27,28} A National Strength and Conditioning Association Certified Strength and Conditioning Specialist supervised instruction of subjects in their independent exercise training sessions. Participants returned one week after initial training to ensure they were performing the exercises correctly.
The IS group attended the university gym and independently completed dumbbell elbow flexion (bicep curls) and dumbbell side-lying shoulder ER with shoulder adducted to side (Figure 2). Researchers prescribed the appropriate weight to achieve 85% of the calculated kilograms of maximum concentric peak isokinetic force that was produced during testing. The IS group performed hip abduction strengthening on the Life Fitness Optima Series Hip Abductor/Adductor secondary to the use of cuff weights did not achieve required resistance (Figure 2). The EB group performed standing elbow flexion (bicep curl), standing shoulder ER with shoulder adducted to side and hip abduction in side-lying with bands around knees (Figure 3). Researchers prescribed the appropriate color of Theraband® Resistance Bands (https://www.theraband.com) and percent stretch to achieve 85% of maximum concentric peak torque peak isokinetic force that was produced during testing as previously published. Participants performed four to six repetitions at a rate of one repetition per six seconds (three seconds concentric and three seconds eccentric contraction) in a controlled motion. Participants kept a self-reported log of the days, sets, repetitions and resistance of exercises completed. Participants performed the exercises at the same prescribed resistance during the four-week training period.

STATISTICAL ANALYSIS

Statistical analysis was conducted with SPSS (IBM SPSS Statistics 25, Armonk, NY, USA). Descriptive statistics were calculated. Independent t-tests were performed to compare any differences in age and compliance between the two groups. Preliminary data screening procedures were performed to assess the basic assumptions of ANOVA. Data were normally distributed except for elbow flexion post concentric results. A 2x2 mixed factorial ANOVA assessed whether differences existed in concentric and eccentric isokinetic forces in response to an EB and IS strengthening program. Homogeneity of the variance assumption was assessed with Levene’s test and demonstrated a significant p-value for elbow concentric pre- and post-testing (p = 0.001) and hip abduction eccentric pre-testing (p = 0.021). Levene’s test for all other variables were non-significant (p > 0.05). The Mann-Whitney U non-parametric statistical analysis was used for elbow flexion concentric and hip abduction eccentric results.

RESULTS

There was no significant difference (t (1.85) = 18, p = 0.08) in age between the isotonic (M=23.90, SD=2.23, N=10) and elastic band (M=22.30, SD=1.57, N=10) groups. Two of the initial 12 subjects recruited in each of the IS group and EB groups did not complete the required minimum eight exercise sessions over four weeks and therefore twenty participants (10 per group) were included in final data analysis. None of the participants reported an adverse event.

There was no significant difference (t (0.16) = 18, p = 0.87) in compliance (sessions completed) between the IS (M=11.30, SD=0.95) and EB (M=11.20, SD=1.69) groups. There was no significant difference in pre-test and post-test
Table 1: Mann Whitney U test for pre-and post-testing between groups for concentric elbow flexion concentric and eccentric hip abduction force production.

<table>
<thead>
<tr>
<th>Testing</th>
<th>Isotonic (n=10)</th>
<th>Elastic band (n=10)</th>
<th>U</th>
<th>Z</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexion concentric (N)</td>
<td>Pre-testing</td>
<td>8.80</td>
<td>12.20</td>
<td>30.0</td>
<td>-1.285</td>
<td>.199</td>
</tr>
<tr>
<td></td>
<td>Post-testing</td>
<td>11.10</td>
<td>9.90</td>
<td>44.0</td>
<td>.454</td>
<td>.650</td>
</tr>
<tr>
<td>Hip abduction eccentric (N)</td>
<td>Pre-testing</td>
<td>9.25</td>
<td>11.75</td>
<td>37.5</td>
<td>.454</td>
<td>.345</td>
</tr>
<tr>
<td></td>
<td>Post-testing</td>
<td>8.85</td>
<td>12.15</td>
<td>33.5</td>
<td>.125</td>
<td>.650</td>
</tr>
</tbody>
</table>

Table 2: Pre-testing and Post-testing descriptive data (N) and percent change within each group between testing sessions.

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-Testing (n=10)</th>
<th>Post-testing (n=10)</th>
<th>95% CI</th>
<th>p-value</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flex Conc</td>
<td>Isotonic</td>
<td>70.5(11.55)</td>
<td>91.28(20.75)</td>
<td>(-35.78, -6.41)</td>
<td>†</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td>88.65(25.05)</td>
<td>100.12(46.35)</td>
<td>(-37.99,3.30)</td>
<td>†</td>
</tr>
<tr>
<td>Elbow flex Ecc</td>
<td>Isotonic</td>
<td>99.28(22.65)</td>
<td>130.32(33.35)</td>
<td>(-57.82,4.24)</td>
<td>.03*</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td>112.86(41.72)</td>
<td>140.48(70.75)</td>
<td>(-61.19,-1.77)</td>
<td>.04*</td>
</tr>
<tr>
<td>Shoulder ER Conc</td>
<td>Isotonic</td>
<td>54.06(11.19)</td>
<td>61.84(17.75)</td>
<td>(-19.91,4.35)</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td>57.29(19.15)</td>
<td>68.82(14.81)</td>
<td>(-25.58,1.73)</td>
<td>.08</td>
</tr>
<tr>
<td>Shoulder ER Ecc</td>
<td>Isotonic</td>
<td>64.21(12.99)</td>
<td>69.81(14.93)</td>
<td>(-19.3,8.1)</td>
<td>.38</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td>69.19(20.22)</td>
<td>75.50(14.72)</td>
<td>(-24.61,9.18)</td>
<td>.32</td>
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<tr>
<td>Hip Abd Conc</td>
<td>Isotonic</td>
<td>229.87(66.51)</td>
<td>253.24(79.29)</td>
<td>(-59.93,13.23)</td>
<td>.18</td>
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<tr>
<td></td>
<td>Elastic</td>
<td>259.92(113.52)</td>
<td>296.87(90.81)</td>
<td>(-69.89,-3.6)</td>
<td>.03*</td>
</tr>
<tr>
<td>Hip Abd Ecc</td>
<td>Isotonic</td>
<td>259.59(48.79)</td>
<td>277.90(69.94)</td>
<td>(-53.52,16.89)</td>
<td>†</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td>299.01(93.53)</td>
<td>332.84(70.53)</td>
<td>(-63.15,-13.82)</td>
<td>†</td>
</tr>
</tbody>
</table>

N = Newtons; flex= flexion; ER= external rotation; ABD= abduction; Ecc= Eccentric; Conc= concentric
* Within group significant difference (p<.05); †- Non-parametric statistics reported in Table 3

values for concentric elbow flexor (p=0.199 and p=0.650 respectively) and eccentric hip abductor forces (p=0.35 and p=0.65 respectively) between the two groups. (Table 1).

The results showed no significant main effect of intervention (F (1,18) =.406 p=0.532, η² =.022) for eccentric elbow flexors, (F (1,18) =.715, p=0.409, η² =.038) concentric shoulder external rotators, (F (1,18) =.946 p=0.344, η² =.05) eccentric shoulder external rotators, and (F (1,18) =.913 p=0.352, η² =.048) concentric hip abductor force production with pre-test and post-test values being similar between groups (Figure 4). Percent change in force within each group ranged from 7-30% (Table 2).

The results demonstrated a significant main effect of time for both groups between pre- and post-test (F (1,18) =11.94, p=0.003, η² =.399) on eccentric elbow flexors, (F (1,18) =6.55, p=0.02, η² =.267), concentric shoulder external rotators (F (1,18) =8.52, p=0.009, η² =.321), and concentric hip abductor forces with post-intervention force greater than pre-intervention force (Table 2). There was no significant main effect for change in force between pre-and post-test (F (1,18) =1.74, p=0.204, η² =.088) for eccentric ER. Means and SD are located in Figure 4 and Table 2. The EB group had a significant increase in concentric hip abductor force (p=0.03) whereas the IS group demonstrated no significant increase (p>0.05) (Table 2).

Concentric elbow flexor and eccentric hip abductor forces did not have normal distribution. Therefore, non-parametric statistics (Wilcoxon signed rank) compared pre-test and
Table 3: Wilcoxon-signed rank results for comparing pre-and post-testing forces within each group for elbow flexion concentric and hip abduction eccentric

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-Testing (n=10)</th>
<th>Post-testing (n=10)</th>
<th>Z</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexion concentric (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isotonic</td>
<td>70.5</td>
<td>91.28</td>
<td>-2.50</td>
<td>.013*</td>
<td>0.33</td>
</tr>
<tr>
<td>Elastic band</td>
<td>83.79</td>
<td>73.15</td>
<td>-0.866</td>
<td>.386</td>
<td>0.04</td>
</tr>
<tr>
<td>Hip abduction eccentric (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isotonic</td>
<td>256.28</td>
<td>298.10</td>
<td>-0.866</td>
<td>.386</td>
<td>0.04</td>
</tr>
<tr>
<td>Elastic band</td>
<td>314.93</td>
<td>338.60</td>
<td>-2.40</td>
<td>.017*</td>
<td>0.30</td>
</tr>
</tbody>
</table>

N = Newtons, * - significantly different (p < 0.05) between pre-and-post testing

post-test values within each group for these outcomes. The IS group had a significant (p=0.013) increase in concentric elbow flexor force but there was not a significant (p=0.386) change in eccentric hip abduction force between pre- and post testing (Table 3). The EB group had a significant (p=0.017) increase in eccentric hip abductor force but not a significant (p=0.386) change in concentric elbow flexor force between pre- and post-testing (Table 3).

DISCUSSION
ELASTIC TUBING VS. ISOTONIC EXERCISE

The present study demonstrated that a four-week heavy resistance (85% 1RM) program with isotonic exercises was comparable to elastic band exercises for concentric and eccentric force outcomes in healthy untrained females for hip abduction, elbow flexion and shoulder ER. The isokinetic concentric force production in untrained females following either an IS or EB program is in agreement with a previous study on isotonic strength outcomes of untrained middle aged men with cardiovascular disease following either an IS or EB program. Turban et al. reported no difference in 1RM isotonic concentric strength (on a weight machine) for elbow and knee extension following five weeks of resistance training using elastic bands or a weight machine. They reported concentric strength increases between 15% and 24% for knee and elbow extensor. The untrained female participants in the current study demonstrated similar isokinetic concentric force increases between 10% and 30% for elbow flexors, external rotators and hip abductors. The large 30% increase in the IS group for the elbow flexors may be due to one participant having a low initial bicep force, therefore decreasing the pre-testing group mean force score resulting in a larger increase in post-testing force. Non-parametric testing accounted for data not being normally distributed and resulted in no significant difference in post-test scores for the elbow flexors. This study is the first to demonstrate comparable eccentric force changes with IS and EB exercises. The eccentric force changes were slightly less (7%-14%) than concentric force changes. The current study adds additional evidence to indicate that isotonic strengthening is comparable to elastic band strengthening for both concentric and eccentric force in a healthy female population with no previous strength training experience.

Colado et al. reported equivalent functional isometric strength for vertical rowing, squat and back extension increases in young (mean 21.79 years) physically fit females that completed a resistance program with elastic tubing or with weight machines/free weights. Their functional isometric results were similar to the current isokinetic force results in an untrained population of the same age and sex. The current four week results are also in agreement with the results by Lima et al. following a 12-week exercise program in middle aged males and females (age range 54-62). They reported similar positive isometric strength gains between IS and EB training at six and 12 weeks and also comparable functional exercise capacity. These previous studies comparing elastic tubing to isotonic exercises utilized multi-joint and functional task measurements of strength.
Therefore, it remains unclear if different muscles or groups of muscles respond similarly to elastic bands and isotonic strengthening.

The use of both upper extremity and lower extremity isolated muscle group testing positions in this study demonstrated that the hip abductors (gluteus medius), shoulder external rotators (teres minor, infraspinatus), and elbow flexors (biceps) responded similarly to elastic band and isotonic strengthening programs. Strength increases in the first four-weeks are predominately from neural adaptations such as improved neural recruitment, central nervous activation, improved motor unit firing and inhibitory mechanisms.² The comparable outcomes in this study may result in similar neural adaptations regardless if IS or EB resistances is utilized. Therefore, not surprisingly, specific upper and lower extremity muscles demonstrate similar strength changes. The isolated muscle group strength increase in four weeks is important information for rehabilitation professionals. Rehabilitation professional target individual muscle groups early in injury recovery and progress to functional activities. Campos et al. demonstrated greater concentric strength gains in eight weeks with a low repetition/high load resistance program compared to a high repetition/low load resistance program.²⁰ The increase in both concentric and eccentric force in four weeks demonstrated in the current study and results from the previous study provide evidence that both IS and EB resistance utilizing low repetitions/high load resistance can be effectively utilized as an alternative for patients that may not tolerate high repetitions due to pain.²⁰ Strength of these specific muscle groups are all important for performing sport activities, injury prevention and rehabilitation at the knee, hip and elbow.⁵⁻⁷,⁹ Health care professionals can utilize either strength training method to similarly increase functional, isometric and isolated concentric and eccentric isokinetic muscle group force.

**PARAMETERS**

Although previous studies used higher repetitions than the current study, the current study demonstrated similar increases in concentric shoulder ER (14%, 20%) force and less eccentric shoulder ER (8%, 9%) force at four weeks compared to five and 12 week programs.¹¹⁻¹⁴,¹⁷ Two studies of isokinetic shoulder strength changes compared elastic tubing programs to elastic tubing combined with free weights and to controls.¹¹,¹³ The strengthening protocol by Turban et al. included four sets of 12 contractions for five weeks at a perceived exertion of 15-15 on the 6-20 Borg scale.¹³ Lima et al. in contrast had a longer training program of 12-weeks and implemented a progressive design with 2x15 (weeks 1-3), 3x15 (weeks 4-6), 3x10 (weeks 7-9) and 4x6 (weeks 10-12).¹¹ Resistance in the study by Lima et al. increased if a participant could perform more than two of the prescribed repetitions at a given resistance. Two different studies reported a 17.0% increase in peak torque and no significant increase respectively in collegiate tennis players following four to five weeks of 15-20 repetitions of band exercises 3-4x/week.¹⁴,¹⁷ Similar concentric and eccentric strength results are achieved regardless of mode of resistance (isometric or elastic band), intensity (percentage of maximal force or perceived exertion) or number of repetitions performed between four and 12 weeks.

Key components of resistance training are prescription of appropriate resistance and corresponding repetitions to induce a moderate to hard effort irrespective of mode of resistance. There are various proposed methods to determine the appropriate amount of resistance when training with elastic bands/tubing. Isokinetic force results, used to determine resistance, as utilized in this study, reflect the use of the gold standard of force measurement. However, an isokinetic device is costly and not readily available to all healthcare professionals. Resistance correlating to isotonic resistance of Theraband® elastic bands, tubing and CLX™ bands has been previously reported for each color.²⁹,³⁰ Clinicians can use these or other documented values of variable resistance to determine a 1RM and then choose appropriate training loads. Calculation of a 1RM from a 50% perceived effort maximum repetitions test using the CLX™ bands found almost perfect agreement (R² = 0.98) with a 1RM test.³¹ A benefit of a 50% maximum repetition test is utilization with injured or untrained individuals to reduce risk of injury that may come from a 1RM test. Michelitti et al. also calculated estimated intensity of workload based on number of repetitions performed with the CLX™ bands for training purposes.³¹ The Borg scale from 6-20 and the OMNI-Resistance scale (0 “Extremely easy” – 10 Extremely hard) demonstrated a significant positive correlation with force applied during variable resistance exercises.¹₃,³² These rate of perceived exertion methods are easy to administer and available to anyone, but less accurate than previously described methods. A health care professional can utilize one of these reliable proven methods of exercise prescription with elastic bands to achieve comparable strength benefits to isotonic resistance training.

Limitations of the study should be considered when comparing current results to previous research and alternative populations. This study was limited to inclusion criteria of untrained females between 20-30 years of age. A health care practitioner should be cautious in outcome expectations with males, different age groups and active persons, as these populations have not been fully studied. Larger sample sizes (> 10 in each group) and longer training studies of eight or more weeks may concur with the current findings or have different results. The short duration (four weeks) of the study may not have allowed adequate time for muscle hypertrophy to occur, however this parameter was not measured. A study greater than eight weeks in duration is recommended to determine if long term comparison of strength gains between modes of resistance is a result of hypertrophy or solely neuromuscular changes.¹⁸ There may have been differences in participants’ intensity and compliance due to reliance on participants’ self-reports. Attempts to control for intensity and compliance were made by researchers initially training subjects and performing a one-week follow-up to ensure correct intensity and exercise form. Additionally, researchers may add a rate of perceived exertion scale to increase the likelihood participants are exercising at the correct intensity. The current study duration, untrained population and independent exercise program are common parameters encountered by healthcare professionals.
practitioners and therefore clinically relevant.

CONCLUSION

The results of the current study indicate comparable isokinetic concentric and eccentric force outcomes in untrained females following an independent four-week low repetition/high load IS or EB resistance program. Practitioners can confidently prescribe and expect positive concentric and eccentric strength changes with either mode of resistance based on equipment availability and a person’s comfort level. The portability of elastic bands allows athletes and clients to continue strength training programs during travel and vacations with continued improvement. The use of EBs and weights can be utilized in an independent home exercise program to increase strength as long as adequate resistance, repetitions, intensity and instruction are utilized.

CONFLICT OF INTEREST

The Theraband Academy supplied Theraband® resistance bands for this research, however, no authors have a financial interest.

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REFERENCES


Mechanical Percussion Devices: A Survey of Practice Patterns Among Healthcare Professionals

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Keywords: massage, muscle soreness, perceived pain, recovery, tapotement

Background
Mechanical percussion devices have become popular among sports medicine professionals. These devices provide a similar effect as manual percussion or tapotement used in therapeutic massage. To date, there are few published studies or evidence-based guidelines for these devices. There is a need to understand what professionals believe about this technology and how they use these devices in clinical practice.

Purpose
To survey and document the knowledge, clinical application methods, and use of mechanical percussion devices among healthcare professionals in the United States.

Design
Cross-sectional survey study.

Methods
A 25 question online survey was emailed to members of the National Athletic Trainers Association, Academy of Orthopedic Physical Therapy, and American Academy of Sports Physical Therapy.

Results
Four hundred twenty-five professionals completed the survey. Most professionals (92%, n=391) used devices from two manufacturers: Hyperice® and Theragun®. Seventy-seven percent directed clients to manufacturer and generic websites (n=329) to purchase devices. Most respondents used a medium and low device speed setting for pre- and post-exercise (62%, n=185), pain modulation (59%, n=253), and myofascial mobility (52%, n=222). A large proportion of respondents preferred a total treatment time between 30 seconds and three minutes (36-48%, n=153-204) or three to five minutes (18-22%, n=76-93). Most respondents (54-69%, n=229-293) believed that mechanical percussion increases local blood flow, modulates pain, enhances myofascial mobility, and reduces myofascial restrictions. Most respondents (72%, n=305) were influenced by other colleagues to use these devices. Sixty-six percent used patient reported outcomes (n=280) to document treatment efficacy. Live instruction was the most common mode of education (79%, n=334).

Conclusion
These results are a starting point for future research and provide insight into how professionals use mechanical percussion devices. This survey also highlights the existing gap between research and practice. Future research should examine the efficacy of this technology and determine consensus-based guidelines.

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INTRODUCTION

Mechanical percussion devices have become common myofascial interventions used among sports medicine professionals. Mechanical percussion is often applied with electric or battery powered devices that utilize differently shaped tips to provide a rapid compression force to the myofascia (e.g., similar to a small jackhammer used to break up cement). Currently, several commercial manufacturers, such as Hypervolt® or TheraGun®, manufacture different mechanical percussion devices (Figure 1). Many manufacturers have a variety of models with various settings that may include different speeds/frequencies (i.e., 17-53 Hz), amplitudes, and applicator tips (e.g., large and small ball, flat tip, bullet/pointy tip, fork) (Figure 2). Device percussion settings are often within the range of frequencies and amplitudes (e.g., 5 to 300Hz) found to produce positive myofascial outcomes. Mechanical percussion therapy devices are marketed in different healthcare and fitness settings to be used as part of a pre-activity warm-up, post-activity recovery, or part of a myofascial treatment.1

The mechanical and vibrational action of these devices is similar to manual percussion or tapotement which is a specific technique in therapeutic massage. Manual percussion requires the clinician to apply a rapid, compressive striking of the myofascia with the edge of the hands (e.g. chop), tips of fingers, or a cupped hand. Manual percussion may create vibration throughout the myofascial tissues being treated. This technique has been found to reduce spinal reflex excitability in muscles without affecting their contractile properties and increasing ankle flexibility while not affecting muscle power. Mechanical percussion devices may produce similar or greater effects as manual percussion by impacting the myofascia at a different frequency, amplitude, and force with higher friction, reduced therapist upper extremity stress, and larger areas covered in shorter treatment periods. The mechanical percussion devices also allow for longer treatment durations with reduced clinician upper extremity stress with varied frequencies and amplitudes which may influence outcomes differently than other application methods.1

The application of mechanical vibration stimulus using specific treatment parameters may produce different mechanical and neurophysiological effects by targeting afferent receptors through the myofascial tissue vibration. For example, targeted local muscle vibration may provide a more cost-effective alternative to whole body vibration because targeted vibration is less likely to stimulate both agonist and antagonist tissue.1 Mechanical percussion devices may also effect cutaneous and myofascial mechanoreceptors, such as the Ruffini receptors and Pacinian corpuscles, differently than clinical applied manual percussion therapy. For instance, receptors with a greater response to high frequency vibration or low amplitude frequencies for longer durations (i.e., 15-60 minutes) may be more stimulated by the devices to inhibit sympathetic activity or produce positive clinical outcomes.1,10 Other receptors, however, such as the Merkel receptors, Meissner corpuscles, Ruffini cylinders, and Pacinian corpuscles possess a spectrum of receptor field areas and may respond better to other interventions (e.g., myofascial rolling) or different vibrational parameters.11,12 This technique has been found to reduce spinal reflex excitability in muscles without affecting their contractile properties and increasing ankle flexibility while not affecting muscle power. Mechanical percussion devices may produce similar or greater effects as manual percussion by impacting the myofascia at a different frequency, amplitude, and force with higher friction, reduced therapist upper extremity stress, and larger areas covered in shorter treatment periods. The mechanical percussion devices also allow for longer treatment durations with reduced clinician upper extremity stress with varied frequencies and amplitudes which may influence outcomes differently than other application methods.1

The market and utilization of local mechanical percussion devices has grown despite the paucity of studies on exploring the mechanism of action or clinical outcomes. Mechanical percussion devices have been marketed in different healthcare and fitness settings to be used as part of a pre-activity warm-up, post-activity recovery, or part of a myofascial treatment.1

The application of mechanical vibration stimulus using specific treatment parameters may produce different mechanical and neurophysiological effects by targeting afferent receptors through the myofascial tissue vibration. For example, targeted local muscle vibration may provide a more cost-effective alternative to whole body vibration because targeted vibration is less likely to stimulate both agonist and antagonist tissue.1 Mechanical percussion devices may also effect cutaneous and myofascial mechanoreceptors, such as the Ruffini receptors and Pacinian corpuscles, differently than clinical applied manual percussion therapy. For instance, receptors with a greater response to high frequency vibration or low amplitude frequencies for longer durations (i.e., 15-60 minutes) may be more stimulated by the devices to inhibit sympathetic activity or produce positive clinical outcomes.1,10 Other receptors, however, such as the Merkel receptors, Meissner corpuscles, Ruffini cylinders, and Pacinian corpuscles possess a spectrum of receptor field areas and may respond better to other interventions (e.g., myofascial rolling) or different vibrational parameters.11,12 This technique has been found to reduce spinal reflex excitability in muscles without affecting their contractile properties and increasing ankle flexibility while not affecting muscle power. Mechanical percussion devices may produce similar or greater effects as manual percussion by impacting the myofascia at a different frequency, amplitude, and force with higher friction, reduced therapist upper extremity stress, and larger areas covered in shorter treatment periods. The mechanical percussion devices also allow for longer treatment durations with reduced clinician upper extremity stress with varied frequencies and amplitudes which may influence outcomes differently than other application methods.1

The marketing and utilization of local mechanical percussion devices has grown despite the paucity of studies on exploring the mechanism of action or clinical outcomes. To date, there is currently one published peer reviewed study on mechanical percussion devices. The researchers measured the acute post-treatment effects of a five minute mechanical percussion session on calf muscle range of motion (ROM) and plantar flexor maximal voluntary contractions (MVC). The researchers found acute in-
Mechanical Percussion Devices: A Survey of Practice Patterns Among Healthcare Professionals

creases in ROM but no changes in plantar flexor MVC. This research is similar to other myofascial interventions such as vibrating foam rollers. Researchers have reported similar post-treatment acute increases in ROM but insignificant changes in muscle performance after the vibrating roller intervention. Other research on local vibration therapy has reported improvements in maximum isometric forces, ROM, and muscle performance when used as part of a traditional training program. Peer et al. reported local vibration therapy produced acute improvements in ROM and muscle stiffness compared to ice, compression and elevation following a hamstring or ankle soft tissue injury. The research on mechanical percussion devices is still emerging with only one study currently published. Future studies are needed to further validate mechanical percussion when compared to other local vibration therapy and myofascial interventions.

Currently there are no evidence based clinical guidelines for the use of mechanical percussion devices. Further laboratory-based and clinical outcomes studies are needed to best guide clinical practice regarding these devices; however, research should also be informed based on how the devices are utilized by clinicians when providing care to patients. Understanding the knowledge and current trends in the use of mechanical percussion devices among healthcare professionals may help guide researchers in developing guidelines for research and/or practice. Thus, the purpose of this study was to survey and document the knowledge, clinical application methods, and use of mechanical percussion devices among healthcare professionals in the United States.

METHODS
STUDY TYPE AND PARTICIPANTS
This cross-sectional survey study was approved by Institutional Review Board at California State University Dominguez Hills (# 20-065). Healthcare professionals were recruited via convenience sampling for this study. Participants of three professional organizations were sent a group email requesting participation in an online survey between the months of September to November 2019. A random sample of members from the National Athletic Trainers Association (N=3,000) and all members of the Academy of Orthopedic Physical Therapy (N=17,811) and American Academy of Sports Physical Therapy (N=6,597) were contacted.

SURVEY DESIGN
The online survey (SurveyMonkey® www.surveymonkey.com) included 25 questions that represented three distinct areas: 1) demographics and percussion device information, 2) clinical application methods, and 3) beliefs, clinical measures, and education. For respondent demographics, the goal was to document age, credentials, practice setting/s, and experience. For mechanical percussion device information, the goal was to document the types of commercial devices, applicator tips used by professionals, and common places clients may be directed to purchase such devices. For clinical application methods, the goal was to document how professionals used the devices in three practice scenarios: 1) pre- and post-exercise, 2) pain modulation, and 3) to enhance myofascial mobility. Respondents were also asked questions regarding preferred device speed, treatment time, and movement rate for the device. For beliefs, the goal was to document respondent beliefs on using the devices in practice: choosing percussion devices as an intervention, therapeutic effects, variables that influence treatment, preferred clinical measures, and preferred modes of education. Appendix A provides a summary of survey questions.

After initial survey development was completed, the first survey draft underwent two rounds of pilot testing with five independent athletic training and physical therapy professionals to establish face validity. Based upon reviewer feedback, revisions were made, and a final set of survey items was identified. The final survey was further tested for readability using the Flesch reading-ease test and Flesch-Kincaid grade level test. The survey’s 25 questions scored 70.0 on the Flesch Ease of Reading Test and 6.0 on the Flesch-Kincaid Grade level test which indicated the English used in the survey was fairly easy to read and at the 6th grade level. These methods have been used in prior myofascial intervention survey research.

DATA ANALYSIS
Data were downloaded from SurveyMonkey for analysis. Statistical analysis was performed using SPSS version 25.0 (IBM SPSS, Armonk, NY, USA). Descriptive data including total responses, frequency count, and percentages were calculated. Data were treated conservatively, and any respondent who failed to answer an item, excluding demographic items, was removed from the data set.

RESULTS
A total of 27,408 healthcare professionals were recruited. Five hundred and ten professionals began the survey for a 1.9% overall response rate (510/27,408). A total of 425 respondents completed the survey (83.3% completion rate) which were included in the data analysis. Incomplete surveys were eliminated. This section discusses the majority of respondent answers for each question within the three distinct survey areas using rounded values for ease of interpretation. A more detailed description of respondent answers can be found in Tables 1-4.

RESPONDENT DEMOGRAPHICS AND MECHANICAL PERCUSSION DEVICES
Fifty-nine percent (n=251) of respondents were men and 41% (n=172) were women. Fifty-two percent (n=222) reported being a certified athletic trainer, 40% (n=170) a physical therapist, 3% a chiropractor, 1% a personal trainer, and 4% reported having a medical degree or other credential such as massage therapist. A substantial proportion of respondents reported working in an outpatient facility (56%, n=152) or university setting (31%, n=133). The reported average years in practice was approximately 16 years (Table 1).
Table 1: Demographics and devices (N=425)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>59.06% (251)</td>
</tr>
<tr>
<td>Female</td>
<td>40.47% (172)</td>
</tr>
<tr>
<td>Prefer not to answer</td>
<td>00.47% (002)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary Profession</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Therapist</td>
<td>40.00% (170)</td>
</tr>
<tr>
<td>Chiropractor</td>
<td>3.05% (13)</td>
</tr>
<tr>
<td>Certified Athletic Trainer</td>
<td>52.24% (222)</td>
</tr>
<tr>
<td>Occupational Therapist</td>
<td>0.00% (000)</td>
</tr>
<tr>
<td>Massage Therapist</td>
<td>0.71% (003)</td>
</tr>
<tr>
<td>Certified Personal Trainer</td>
<td>1.41% (6)</td>
</tr>
<tr>
<td>MD, DPM, DO</td>
<td>0.24% (1)</td>
</tr>
<tr>
<td>Other</td>
<td>2.35% (10)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary practice setting</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outpatient facility</td>
<td>35.76% (152)</td>
</tr>
<tr>
<td>Hospital based facility</td>
<td>4.24% (18)</td>
</tr>
<tr>
<td>University sports medicine</td>
<td>31.29% (133)</td>
</tr>
<tr>
<td>Athletic training facility</td>
<td>15.76% (67)</td>
</tr>
<tr>
<td>High school athletic training facility</td>
<td>3.53% (15)</td>
</tr>
<tr>
<td>Fitness or wellness facility</td>
<td>9.41% (40)</td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years in practice</th>
<th>Average years in professional practice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15.60 ±11.78 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of commercial brands devices used in practice</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperice® Hypervolt</td>
<td>54.12% (230)</td>
</tr>
<tr>
<td>Theragun® original/GS Pro/G3</td>
<td>37.88% (161)</td>
</tr>
<tr>
<td>TimTam Power Massager™</td>
<td>2.59% (11)</td>
</tr>
<tr>
<td>KraftGun</td>
<td>0.24% (1)</td>
</tr>
<tr>
<td>Other commercial devices</td>
<td>5.17% (22)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preferred mechanical percussion applicator tips</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large round ball</td>
<td>33.88% (144)</td>
</tr>
<tr>
<td>Small round ball</td>
<td>43.53% (185)</td>
</tr>
<tr>
<td>Flat tip</td>
<td>14.12% (60)</td>
</tr>
<tr>
<td>Bullet or cone tip (pointy)</td>
<td>3.06% (13)</td>
</tr>
<tr>
<td>Fork</td>
<td>0.47% (2)</td>
</tr>
<tr>
<td>Other tips</td>
<td>4.95% (21)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Place where clients are directed to purchase devices</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer website</td>
<td>39.06% (166)</td>
</tr>
<tr>
<td>Generic website (e.g. Amazon)</td>
<td>38.35% (163)</td>
</tr>
<tr>
<td>Store (brick and mortar)</td>
<td>3.29% (14)</td>
</tr>
<tr>
<td>Sell in my facility</td>
<td>3.29% (14)</td>
</tr>
<tr>
<td>I don't recommend</td>
<td>16.01% (68)</td>
</tr>
</tbody>
</table>

* Respondents chose all options that applied to them; M.D= Medical Doctor; D.O= Doctor of Osteopathy; D.P.M= Doctor of Podiatric Medicine

Most respondents reported using mechanical percussion devices from the manufacturers Hyperice® (54%, n=230) and Theragun® (38%, n=161). The most popular applicator tips used were the small round ball (44%, n=185) and large round ball (34%, n=144 tips). Respondents most often directed clients to manufacturers websites (39%, n=166) or generic websites (38%, n=163) to purchase devices for self-care (Table 1).
Table 2: Clinical application: pre and post-exercise intervention (N=425)

<table>
<thead>
<tr>
<th>Which percussion speed level is preferred for post-exercise (based upon specific brand models)</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed (level 3) (range: 47-53Hz)</td>
<td>09.65% (41)</td>
</tr>
<tr>
<td>Medium speed (level 2) (range: 33-40 Hz)</td>
<td>37.65% (160)</td>
</tr>
<tr>
<td>Low speed (level 1) (range: 17-29 Hz)</td>
<td>23.52% (100)</td>
</tr>
<tr>
<td>I don’t use a specific speed</td>
<td>20.00% (85)</td>
</tr>
<tr>
<td>I don’t use percussion for a pre-intervention treatment</td>
<td>09.18% (39)</td>
</tr>
<tr>
<td>Which percussion time is preferred for post-exercise</td>
<td></td>
</tr>
<tr>
<td>5 to 30 seconds</td>
<td>05.65% (24)</td>
</tr>
<tr>
<td>30 seconds to 3 minutes</td>
<td>21.88% (93)</td>
</tr>
<tr>
<td>5 minutes or greater</td>
<td>05.65% (24)</td>
</tr>
<tr>
<td>I don’t use a specific treatment time</td>
<td>22.59% (96)</td>
</tr>
<tr>
<td>I don’t use percussion for a pre-intervention treatment</td>
<td>08.47% (36)</td>
</tr>
<tr>
<td>How fast does the device move for post-exercise</td>
<td></td>
</tr>
<tr>
<td>1 to 2 seconds along the body region (up and down)</td>
<td>06.12% (26)</td>
</tr>
<tr>
<td>2 to 5 seconds along the body region (up and down)</td>
<td>28.94% (123)</td>
</tr>
<tr>
<td>5 to 10 seconds along the body region (up and down)</td>
<td>26.82% (114)</td>
</tr>
<tr>
<td>10 seconds or greater along the body region (up and down)</td>
<td>09.42% (40)</td>
</tr>
<tr>
<td>I don’t use a specific cadence (speed)</td>
<td>20.23% (86)</td>
</tr>
<tr>
<td>I don’t use percussion for a pre-intervention treatment</td>
<td>08.47% (36)</td>
</tr>
</tbody>
</table>

*Respondents chose all options that applied to them

CLINICAL APPLICATION: PRE- AND POST-EXERCISE INTERVENTION

For pre-exercise treatment, most respondents used a medium (38%, N=160) or low device speed (24%, n=100), while 20% (n=85) reported not using a specific speed setting. A portion of respondents preferred a treatment time of 30 seconds to three minutes (48%, n=202); a relatively equal amount of respondents reported using a treatment time of three to five minutes (18%, n=76) or reported not using a specific amount of time for treatment (17%; n=73). Most respondents indicated they moved the device at a rate ranging between two to 10 seconds (54%, n=230) along the treatment region during a treatment session (Table 2).

For post-exercise treatment, the majority of respondents also used a medium (33%, N=139) or low device speed (28%,
Clinical Application: Pain Modulation and Myofascial Mobility

For pain modulation, the majority of respondents reported using a medium (23%, N=98) or low device speed (36%, n=155); however, a portion of respondents (21%; n=89) reported not using a specific speed setting. A subset of respondents preferred a treatment time of 30 seconds to three minutes (35%, n=151), but a treatment time of three to five minutes (21%, n=88) was also common. A number of respondents (17%; n=71) indicated they did not use a specific treatment time for pain modulation. A large portion of respondents moved the device at a rate ranging between two to 10 seconds (56%, n=230) along the treatment region for pain modulation.

For myofascial mobility, a medium speed device setting was used by the largest subset (34%, N=145) of respondents. Substantial portions of respondents, however, reported using either a high device speed (n=77), a low device speed (n=69), or non-specific device speed (24%; n=103) setting during treatment. A portion of respondents preferred a total treatment time of 30 seconds to three minutes (36%, n=152), but using a three to five-minute (22%; n=93) time was also common. A portion of respondents (23%; n=100) reported not using a specific treatment time for myofascial mobility. A large portion of respondents (54-56%, n=230) moved the device at a rate ranging between two to 10 seconds (54%, n=229) along the treatment region to improve myofascial mobility.

Beliefs, Clinical Measures, and Education

For beliefs about percussion devices, most respondents indicated using the devices for therapeutic treatment (86%, n=565). The respondents indicated they chose to utilize the devices pre-exercise (46%, n=194) and post-exercise (43%, n=182) with their clients. Most respondents believed that mechanical percussion increases local blood flow (69%, n=293), modulates pain (65%, n=276), enhances myofascial mobility (62%, n=262), and reduces myofascial restrictions (54%, n=229). A portion of respondents indicated the percussion devices could enhance post-exercise recovery (32%, n=165), enhance pre-exercise neuromyofascial excitation (37%, n=156), and increase joint ROM (31%, n=153) (Table 4).

Most respondents reported that collaboration with other professionals (72%, n=305) and their prior empirical experience using the devices (48%, n=202) were substantial influencers of their use of mechanical percussion devices in practice. Other cited factors included social media (22%, n=97), manufacturer instructions (24%, n=100), and continuing education (23%, n=99). The clinical measures most often used by respondents to assess the effectiveness of mechanical percussion devices were patient reported outcomes (66%, n=280) and joint ROM (54%, n=144); however, 17% (n=71) of the respondents indicated not using any clinical measures to assess treatment efficacy. The most common mode of client education was live instruction (79%, n=334) and a smaller portion of respondents recommended a self-guided program (13%, n=56) (Table 4).

Discussion

Mechanical percussion devices are an emerging type of myofascial intervention used by sports medicine professionals. Despite their popularity, there is little published peer-reviewed research on these devices which creates a gap between the evidence and clinical practice. Clinical practice recommendations or evidence-based reviews to guide clinical practice are lacking and little is known regarding the utilization of these devices by practicing healthcare professionals. This survey was the first study to document healthcare professionals’ beliefs and clinical application of mechanical percussion devices which might guide future research. The subsequent sections will further discuss the survey responses.

Respondent Demographics and Mechanical Percussion Devices

A substantial proportion of respondents (67%) reported working in an outpatient facility or university setting. The most utilized percussion devices (92%) reported were from two manufacturers: Hyperice® and Theragun®. The most popular applicator tips used were the small round ball (44%) and large round ball (34%) tips. These findings are similar to self-myofascial rolling surveys which revealed similar respondent demographics and clinical use of the devices. Prior research revealed that professionals tend to follow recommendations supported by research in their clinical practice when using self-myofascial rollers; however, clinicians do not have a similar body of knowledge to follow evidence-based clinical application of mechanical percussion devices. The majority of local muscle vibration therapy research has been focused on resistance training outcomes and the inconsistencies in utilized parameters in outcomes prevents the creation of evidence-based guidelines or an understanding of potential mechanisms of muscle response post-treatment. Mechanical percussion researchers may want to utilize a similar research strategy to self-myofascial rolling research, which attempts to connect clinical practice and research. Researchers should consider the clinical setting, preferred devices, and applicator tips revealed in this survey when designing future studies. Replication of commonly utilized clinical parameters would provide a more representative sample of treatment effect that reflects current clinical practice and application of these devices. Similarly, more standardized approaches to laboratory-based research would better inform our knowledge of how musculoskeletal structures respond to local vibration therapy.
Table 3: Clinical application: pain modulation and myofascial mobility (N=425)

<table>
<thead>
<tr>
<th>Which percussion speed level is preferred for pain modulation (based upon specific brand models)</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed (level 3) (range: 47-53Hz)</td>
<td>09.41% (40)</td>
</tr>
<tr>
<td>Medium speed (level 2) (range: 33-40 Hz)</td>
<td>23.06% (98)</td>
</tr>
<tr>
<td>Low speed (level 1) (range: 17-29 Hz)</td>
<td>36.47% (155)</td>
</tr>
<tr>
<td>I don't use a specific speed</td>
<td>20.94% (89)</td>
</tr>
<tr>
<td>I don't use percussion for a pain modulation treatment</td>
<td>10.12% (43)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Which percussion time is preferred for pain modulation</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 30 seconds</td>
<td>08.24% (35)</td>
</tr>
<tr>
<td>30 seconds to 3 minutes</td>
<td>35.53% (151)</td>
</tr>
<tr>
<td>3 to 5 minutes</td>
<td>20.71% (88)</td>
</tr>
<tr>
<td>5 minutes or greater</td>
<td>06.59% (28)</td>
</tr>
<tr>
<td>I don't use a specific treatment time</td>
<td>18.81% (80)</td>
</tr>
<tr>
<td>I don't use percussion for a pain modulation treatment</td>
<td>10.12% (43)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How fast is the device moved for pain modulation</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 2 seconds along the body region (up and down)</td>
<td>10.82% (46)</td>
</tr>
<tr>
<td>2 to 5 seconds along the body region (up and down)</td>
<td>32.00% (136)</td>
</tr>
<tr>
<td>5 to 10 seconds along the body region (up and down)</td>
<td>23.29% (99)</td>
</tr>
<tr>
<td>10 seconds or greater along the body region (up and down)</td>
<td>07.06% (30)</td>
</tr>
<tr>
<td>I don't use a specific cadence (speed)</td>
<td>16.71% (71)</td>
</tr>
<tr>
<td>I don't use percussion for a pain modulation treatment</td>
<td>10.12% (43)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Which percussion speed level is preferred for myofascial mobility (based upon specific brand models)</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed (level 3) (range: 47-53Hz)</td>
<td>18.12% (77)</td>
</tr>
<tr>
<td>Medium speed (level 2) (range: 33-40 Hz)</td>
<td>34.12% (145)</td>
</tr>
<tr>
<td>Low speed (level 1) (range: 17-29 Hz)</td>
<td>16.24% (69)</td>
</tr>
<tr>
<td>I don't use a specific speed</td>
<td>24.24% (103)</td>
</tr>
<tr>
<td>I don't use percussion for a myofascial mobility treatment</td>
<td>07.29% (31)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Which percussion time is preferred for myofascial mobility</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 30 seconds</td>
<td>05.65% (24)</td>
</tr>
<tr>
<td>30 seconds to 3 minutes</td>
<td>35.77% (152)</td>
</tr>
<tr>
<td>3 to 5 minutes</td>
<td>21.88% (93)</td>
</tr>
<tr>
<td>5 minutes or greater</td>
<td>05.88% (25)</td>
</tr>
<tr>
<td>I don't use a specific treatment time</td>
<td>23.53% (100)</td>
</tr>
<tr>
<td>I don't use percussion for a myofascial mobility treatment</td>
<td>07.29% (31)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How is the device moved for myofascial mobility</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 2 seconds along the body region (up and down)</td>
<td>06.59% (28)</td>
</tr>
<tr>
<td>2 to 5 seconds along the body region (up and down)</td>
<td>26.82% (114)</td>
</tr>
<tr>
<td>5 to 10 seconds along the body region (up and down)</td>
<td>27.29% (116)</td>
</tr>
<tr>
<td>10 seconds or greater along the body region (up and down)</td>
<td>05.42% (23)</td>
</tr>
<tr>
<td>I don't use a specific cadence (speed)</td>
<td>26.59% (113)</td>
</tr>
<tr>
<td>I don't use percussion for a myofascial mobility treatment</td>
<td>07.29% (31)</td>
</tr>
</tbody>
</table>

*Respondents chose all options that applied to them

DEVICE CLINICAL APPLICATION

The initial data regarding the clinical application of these devices among healthcare professionals can be used to help inform future laboratory studies. These results revealed that most respondents (52-62%) used a medium and low device speed setting for pre-exercise, post exercise, pain modulation, and myofascial mobility treatment. Most respondents preferred a total treatment range between 30 seconds and three minutes (36-48%) followed by three to five minutes (18-22%) for all four conditions. A large portion of respondents (54%) moved the device at a rate ranging between two to 10 seconds for all four conditions. Interestingly, twenty to twenty-two percent of respondents did not use a specific device speed setting, treatment time, or moving speed for all four conditions. The results suggest...
that clinicians may be non-specific or inconsistent with the utilized treatment parameters when providing local mechanical percussion therapy.

Inconsistent treatment parameters have also been reported across the literature examining the effectiveness of local muscle vibration therapy with vibration frequencies ranging from 5-300Hz and treatment duration ranging from six seconds to 60 minutes. Researchers examining strength training protocols and local vibration therapy have reported that lower frequencies (i.e., 65Hz) were not as effective as higher frequencies (e.g., 100Hz, 300Hz) for improving muscle performance. Other researchers have also reported that low frequencies (i.e., 5-50Hz) can be effective for improving muscular performance with short treatment durations (i.e., 1-2 minutes). This has led some researchers to suggest that a relationship between frequency and treatment duration (i.e., high frequency and long treatment duration or low frequency and short treatment duration) may exist which could guide clinicians in setting treatment parameters in an attempt to maximize treatment effectiveness. Before using the literature to guide clinical practice, clinicians and researchers should consider three questions: 1) Are training protocols utilized in studies examining vibrational therapy matching similar practices found in clinical rehabilitation or fitness settings? 2) Are treatment duration and vibrational frequency equally weighted variables in determining treatment effect? and 3) Do reported or calculated effect sizes support or refute the potential reported results thought to contrast each other in the literature? Future research should utilize specific treatment parameters to help determine treatment effectiveness and yield greater understanding on potential tissue adaptations and mechanisms of action.

### BELIEFS, CLINICAL MEASURES, AND EDUCATION

Research should also be conducted to assess the effect of mechanical percussion treatment on various clinical outcome measures. Most respondents (54-69%) believed that mechanical percussion increases local blood flow, modu-

<table>
<thead>
<tr>
<th>Table 4: Beliefs, clinical measures, and education (N=425)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reasons for choosing mechanical percussion devices for their clients</strong></td>
</tr>
<tr>
<td>Injury prevention</td>
</tr>
<tr>
<td>Performance enhancement</td>
</tr>
<tr>
<td>Therapeutic treatment (e.g. pain modulation)</td>
</tr>
<tr>
<td>Pre-exercise warm-up</td>
</tr>
<tr>
<td>Post-exercise treatment</td>
</tr>
<tr>
<td>Other (please specify)</td>
</tr>
<tr>
<td><strong>Therapeutic effects respondents believe occur with mechanical percussion</strong></td>
</tr>
<tr>
<td>Enhanced myofascial pain modulation</td>
</tr>
<tr>
<td>Increased joint range of motion</td>
</tr>
<tr>
<td>Enhanced post-exercise recovery</td>
</tr>
<tr>
<td>Enhanced pre-exercise neuromyofascial excitation</td>
</tr>
<tr>
<td>Increase in local blood flow</td>
</tr>
<tr>
<td>Breaking up scar adhesions</td>
</tr>
<tr>
<td>Breaking up myofascial trigger points</td>
</tr>
<tr>
<td><strong>Variables that influenced philosophy for using percussion treatment devices</strong></td>
</tr>
<tr>
<td>Peer reviewed research articles</td>
</tr>
<tr>
<td>Continuing education courses and conference</td>
</tr>
<tr>
<td>Manufacturer instructions</td>
</tr>
<tr>
<td>Social medial posts or videos (e.g. YouTube)</td>
</tr>
<tr>
<td>Collaboration with other professionals</td>
</tr>
<tr>
<td>My prior empirical experience</td>
</tr>
<tr>
<td>Other (please specify)</td>
</tr>
<tr>
<td><strong>Clinical measures used to assess the effects of percussion treatment</strong></td>
</tr>
<tr>
<td>Joint range of motion</td>
</tr>
<tr>
<td>Pressure pain threshold (e.g. algometer)</td>
</tr>
<tr>
<td>Patient reported outcomes (e.g. NPRS, VAS pain scales)</td>
</tr>
<tr>
<td>Movement based testing (e.g. FMS®, SFMA)</td>
</tr>
<tr>
<td>Muscle performance (strength testing)</td>
</tr>
<tr>
<td>No, I do not evaluate</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td><strong>Common modes of educating clients about mechanical percussion</strong></td>
</tr>
<tr>
<td>Live instruction</td>
</tr>
<tr>
<td>Video instruction</td>
</tr>
<tr>
<td>Self-guided program (e.g. client chooses parameters)</td>
</tr>
<tr>
<td>Education materials (e.g. handouts with exercises)</td>
</tr>
</tbody>
</table>

*Respondents chose all options that applied to them
NPRS= Numerical pain rating scale; VAS= Visual analog scale; FMS®= Functional Movement Screen®, SFMA®= Selective Functional Movement Assessment

Before using the literature to guide clinical practice, clinicians and researchers should consider three questions: 1) Are training protocols utilized in studies examining vibrational therapy matching similar practices found in clinical rehabilitation or fitness settings? 2) Are treatment duration and vibrational frequency equally weighted variables in determining treatment effect? and 3) Do reported or calculated effect sizes support or refute the potential reported results thought to contrast each other in the literature? Future research should utilize specific treatment parameters to help determine treatment effectiveness and yield greater understanding on potential tissue adaptations and mechanisms of action.

### BELIEFS, CLINICAL MEASURES, AND EDUCATION

Research should also be conducted to assess the effect of mechanical percussion treatment on various clinical outcome measures. Most respondents (54-69%) believed that mechanical percussion increases local blood flow, modu-
lates pain, enhances myofascial mobility, and reduces myofascial restriction. A smaller portion believed these devices could enhance pre-exercise neuromyofascial excitation (37%) and increase joint range of motion (51%). The only published mechanical percussion study reported acute post-treatment increases in ROM but no changes in plantar flexor MVC. This study provides some initial data supporting the effects of mechanical percussion devices on ROM. Other related research has been focused on muscle performance when combining local vibration therapy with strength training protocols as opposed to clinical outcomes research. The paucity of mechanical percussion research highlights the need for more clinically controlled studies examining clinical outcomes. While research is lacking on mechanical percussions devices, our survey findings of respondent beliefs are not unexpected given the perceived benefits of other myofascial therapies (e.g., self-myofascial rolling, instrument assisted soft-tissue mobilization), which have been purported to produce similar clinical outcomes.

The largest variable (72%) reported to influence respondents’ use of mechanical percussion was collaboration with other professionals. These findings are consistent with other myofascial interventions studies that suggest clinicians will seek out or utilize informal training or peer feedback to guide practice. The majority of professionals (66%) used patient reported outcomes (e.g. VAS, NPRS) to measure the efficacy of their treatment, which is expected given the literature evidence suggesting similar interventions are thought to improve patient reported outcomes such as pain. A smaller portion of respondents (34%) used joint ROM as an outcome which reflects the respondent beliefs and mechanical percussion study discussed in the aforementioned section. The most common mode of client education included live instruction with the devices. The use of patient outcomes and education is consistent with other myofascial interventions such as self-myofascial rolling.

**PRACTICE IMPLICATIONS AND FUTURE RESEARCH**

This descriptive survey documented professional beliefs and clinical application methods that may help guide researchers. The results of this study should be considered a starting point for future research with respect to who is using these devices, settings used, as well as postulated benefits. There is a gap between the research and professional practice that should be used to ignite both scientific and clinical investigation. It is important to develop scientific guidelines to prescribe the most effective program for clients that considers appropriate outcomes that are feasible based on biophysiological processes. Furthermore, clinical studies are needed to determine the efficacy of these interventions regarding both merits and limitations. Future research is needed to study these topics and bring the industry closer to a consensus on optimal programming and application parameters for healthy and injured individuals.

**LIMITATIONS**

Several limitations need to be discussed for this investigation. First, this survey was sent to a sample of healthcare professionals, predominantly in an outpatient setting with a 1.5% response rate. A larger sample with a higher response rate may have produced different results and the current results could be influenced by non-response error. However, this is the first survey study on these devices which currently lack published evidence regarding their use or application parameters. Second, the survey contained a limited number of items. Different questions may have revealed different ideas of how professionals use mechanical percussion devices; for example, the mechanical percussion devices noted in the survey may not have represented all available commercial devices. Also, respondents with different training or practice settings may have interpreted questions differently which could influence responses. Finally, these results can only be generalized to the healthcare professionals surveyed. This survey was sent to members of three professional organizations. The results may not fully represent the perceptions and practices from other non-member healthcare professionals. However, the results do provide insight into responses among different professionals.

**CONCLUSION**

This is the first survey to document mechanical percussion beliefs and clinical application methods of healthcare professionals. The lack of research has forced professionals to use self-preferred treatment methods supported by recommendations from device manufactures, anecdotal evidence, or other informal sources. This is a concern because the clinical efficacy and safety of mechanical percussion is currently unknown. This survey is a starting point to guide future research on this topic.

**CONFLICT OF INTEREST STATEMENT**

The authors have no conflict of interest with this manuscript.

Submitted: July 26, 2020 CDT, Accepted: December 27, 2020 CDT
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A: Survey questions

Background
The existing body of kinesiology tape (KT) research reveals inconsistent results which challenges the efficacy of the intervention. Understanding professional beliefs and KT clinical application might provide insight for future research and development of evidence-based guidelines.

Purpose
The purpose of this study was to survey and document the beliefs and clinical application methods of KT among healthcare professionals in the United States.

Design
Cross-sectional survey study.

Methods
A 30-question online survey was emailed to members of the National Athletic Trainers Association, Academy of Orthopedic Physical Therapy, and American Academy of Sports Physical Therapy. Professionals were also informed through a recruitment post in different private healthcare Facebook groups.

Results
One thousand and eighty-three respondents completed the survey. Most respondents used KT for post-injury treatment (74%), pain modulation (67%), and neuro-sensory feedback (60%). Most believed that KT stimulates skin mechanoreceptors (77%), improve local circulation (69%), and modulates pain (60%). Some respondents believed KT only created a placebo effect (40%) and use it for such therapeutic purposes (58%). Most used a standard uncut roll (67%) in black (71%) or beige (66%). Most respondents did not use any specialty pre-cut tape (83%), infused tape (99.54%), or a topical analgesic with tape (65%). The most common tape tension lengths used by respondents were 50% tension (47%) and 25% (25%) tension. Most respondents provided skin prep (64%) and tape removal (77%) instructions. Some did not provide any skin prep (36%) or tape removal (23%) instruction. The average recommended times to wear KT were two to three days (60%). The maximum times ranged from two to five days (81%).

Conclusion
This survey provides insight into how professionals use KT and highlights the gap between research and practice. Future research should address these gaps to better determine evidence-based guidelines.
Level of Evidence

INTRODUCTION

Dr. Kenso Kase introduced kinesiology tape (KT) in the 1970s and healthcare professionals have since made it a popular intervention across different rehabilitation, fitness, and sports settings.1 The tape is made of a cotton-base, with elastic properties and adhesive which allows it to be applied directly to the skin. KT is available in different sizes, widths, material, lengths (e.g. precut, rolls), and textures. Currently, numerous manufacturers, such as KT Tape®, Kinesio Tape®, and TheraBand® Kinesiology Tape, produce various types of tape to meet different therapeutic needs such as: sports, edema control, and neurosensory effects. Some manufacturers have expanded beyond tape production and provide professional continuing education and certification to practitioners who want to utilize KT in clinical practice.

Despite the popularity, the research regarding KT therapeutic benefits is inconclusive with many studies reporting inconsistent outcomes.2 Since 2010, approximately thirty-eight KT systematic reviews have been published appraising the efficacy for specific conditions. The reviews found inconclusive evidence for shoulder,3,4 knee,5 and elbow disorders,6 as well as spinal pain,7 proprioception,8 brachial plexus injury in children,9 muscle strength,10 and sports performance.11 Researchers also appraised the KT literature on musculoskeletal conditions,2,12–15 chronic musculoskeletal pain,16,17 sports injuries,18 in eight systematic reviews and found inconclusive results. Weak to moderate evidence was found supporting the efficacy of KT for postmastectomy lymphedema,19 children with Cerebral Palsy,20–22 stroke patients,23–26 ankle function,27 athletic performance,28,29 myofascial pain,30 and as an adjunct therapy for shoulder impingement,31 lumbosacral pain,17,32–37 and patellofemoral pain.38

The variable KT research has left many unanswered questions regarding therapeutic efficacy, which is exacerbated by variations in KT application and use, as well as a lack of translation from the research to practice. Currently, little is known regarding the training and practice patterns of professionals who utilize KT and how practice patterns correspond to application methods used in KT research. Professionals may disregard the weak body of KT evidence given individual practice experiences with the technique. Further, evidence-based practice recommendations for application are lacking and clinicians may use their own preferred methods of administering the intervention. Variations from practice to research, or across groups of clinicians with varied training, may result in inconsistencies and limit the ability to create best practice consensus or optimal guidelines for practice and research. Thus, there is a need to survey and document the KT beliefs, training, and clinical practices of healthcare professionals to understand how KT is used for patient care. To our knowledge, KT surveys examining practice patterns, perceptions, and training of professionals utilizing the technique have not been published. Obtaining such information may help guide future studies and the development of evidence-based guidelines. The purpose of this study was to survey and document the beliefs and clinical practices of KT among healthcare professionals in the United States.

METHODS

STUDY TYPE AND PARTICIPANTS

This cross-sectional survey study was approved by the Institutional Review Board at California State University Dominguez Hills (# 20-115). Healthcare professionals were recruited via convenience sampling between March to May 2020. Emails were sent to a random sample of members from the National Athletic Trainers Association (N=3,500) and all members of the Academy of Orthopedic Physical Therapy (N=17,811) and American Academy of Sports Physical Therapy (N=6,597). This sampling technique has been used in prior myofascial intervention survey research.39,40 Healthcare professionals (N=21,775) were also informed through a recruitment post in different private healthcare Facebook groups. Prior research has documented that Facebook is an effective recruitment tool for healthcare research purposes.41

SURVEY DESIGN

The online survey (SurveyMonkey® www.surveymonkey.com) included one respondent consent question and 29 questions that represented seven distinct areas: 1) respondent demographics, 2) clinical perceptions about KT, 3) clinical application of standard, specialty, infused KT, topical, and clinical measures, and 4) KT education, and referral.

The focus of respondent demographic questions was to document participant age, credentials, practice setting/s, and professional experience. The goal of clinical perceptions about KT questions were to document professional beliefs about the use of the tape with clients, KT therapeutic effects, and physiological mechanisms. Also, to document respondent beliefs about KT precautions and contraindications. The focus of the clinic application of KT questions were to document how professionals use different KT tapes, topicals, and clinical measures in their practice. Practice patterns were further assessed by documenting how professionals approached KT education such as skin prep, tape removal, length of time to wear KT, patient education, and referral.

After initial survey development was completed, the first survey draft underwent two rounds of pilot testing with four independent athletic training and physical therapy professionals to establish face validity. Based upon reviewer feedback, revisions were made, and a final set of survey items was identified.39,40 The final survey was further tested for readability using the Flesch reading-ease test and Flesch-Kincaid grade level test. The 30 questions in the final survey scored 55.2 on the Flesch Ease of Reading Test and 7.0 on the Flesch-Kincaid Grade level test, which indicated the
English used in the survey was fairly easy to read at the 7th grade level. These methods have been used in prior myofascial intervention survey research.

DATA ANALYSIS

Data were downloaded from SurveyMonkey for analysis. Statistical analysis was performed using SPSS version 25.0 (IBM SPSS, Armonk, NY, USA). Descriptive data including total responses, frequency count, and percentages were calculated. Data were treated conservatively, any respondent who failed to answer an item was removed from the data set.

RESULTS

A total of 51,000 healthcare professionals were recruited. A total of 1,535 professionals began the survey. Incomplete surveys were eliminated from the data synthesis. A total of 1083 respondents finished the survey resulting in a 2.1% completion rate (1,083/51,000).

This section details most respondent answers for questions within the seven distinct survey areas using rounded values for ease of interpretation. A more detailed description of respondent answers can be found in Tables 1-7.

RESPONDENT DEMOGRAPHICS

Forty-five percent (n=492) of respondents were men and 54% (n=584) were women. Sixty-one percent (n=657) reported being a physical therapist, 30% (n=325) a certified athletic trainer, 4% (n=44) a physical therapist assistant, 2% (n=19) a chiropractor, 1% (n=10) a massage therapist, and 2% reported being a member of another profession. A substantial proportion of respondents reported working in a private outpatient facility (42%, n=152), hospital based facility (18%, n=197), university sports medicine or athletic training facility (12%, n=131), and secondary school setting (11%, n=125). The reported average years in practice was approximately 16 years (Table 1).

Respondent also indicated several factors that influenced how KT was applied in their clinical practice. The most common influential factors were collaboration with other professionals (75%, n=812), continuing education courses or conferences (74%, n=805), prior empirical experience (64%, n=694), and peer review research and textbooks (53%, n=580). Respondents also reported relying on websites, social media, and YouTube (31%, n=358) and manufacturer instructions (29%, n=313) to inform their clinical application of KT (Table 2).

Several potential therapeutic effects of KT were also reported by the respondents. Most respondents believed KT modulates pain (70%, n=756), enhances proprioception and kinesthetic sense (69%, n=748), and increases local circulation (65%, n=709), while a smaller portion reported believing KT enhances myofascial mobility (29%, n=319). A substantial percentage (58%, n=635) of respondents also indicated a belief that KT creates a placebo effect (Table 2).

The reported potential physiological mechanisms that occur with KT application are reported in Table 2. Most respondents believed that KT stimulates skin mechanoreceptors increasing proprioception (77%, n=834), lifts the skin to improve local circulation (69%, n=749), stimulates skin nociceptors resulting in pain modulation (60%, n=652), and creates a placebo effect (74%; n=798). Others indicated that KT application improves muscle activation and motor control (46%, n=501) and inhibits muscle activation (32%, n=345) when used in patient care (Table 2).

Most respondents believed their preferred tension length created a therapeutic effect by enhancing proprioception and kinesthetic sense (59%, n=656), modulating pain (55%, n=599), increasing local circulation (43%, n=469), and enhancing myofascial mobility (23%, n=254). Forty-four percent (n=475) of respondents believed their preferred tension length provided a placebo effect (Table 2).

A large portion of respondents (51%, n=549) considered skin irritation and itching as precautions. Twenty-five percent (n=276) also considered thin skin as a precaution followed by impaired or altered sensation (9%, n=87). Ninety-five percent (n=1028) of respondents reported no other precautions to consider beyond the ones listed in the survey (Table 2).

Regarding KT contraindications, thirty-three percent (n=561) of respondents considered skin allergies (e.g. adhesives, latex) and 33% (n=556) considered open wounds and lesions as contraindications. Thirteen percent (n=146) considered inability to communicate as a contraindication followed by deep vein thrombosis (5%, n=52), undiagnosed rash or skin irritation (4%, n=40), malignancy (active) (3%, n=38), and diabetes (2%, n=26). Eighty-five percent (n=918) of respondents reported no other contraindications to consider beyond the ones listed in the survey (Table 2).

CLINICAL APPLICATION OF STANDARD KT, INFUSED KT, TOPICALS, AND CLINICAL MEASURES

Respondents reported utilizing a variety of tape brands and styles in clinical practice (Table 3). For commercial brand KT, KT Tape® (59%, n=640), RockTape® (50% n=546), Kinesio® tape (33%, n=359), and TheraBand® tape (11%, n=116) were the most commonly reported types of tape used by respondents. The respondents also indicated using a variety of tape colors, with black (71%, n=774) and beige (66%, n=715) being the most common colors used (Table 3).

Most respondents reported using the KT standard uncut roll (2in/5cm x16.4ft/5m) (67%, n=724), while the large standard uncut roll (36%, n=389), standard pre-cut strips (15% n=168), and the wide uncut roll (11%, n=114) were also commonly used by clinicians (Table 3). Only a small portion of respondents reported using the pre-cut fan tape (9%, n=96), pre-cut tape for the lower body (4%, n=43), or pre-cut tape for the upper body (3% n=38); most of the respondents (83%, n=902) reported not using any of the specialty pre-cut tape options available (Table 3).

When applying KT to clients, the most common tension length used by respondents was 50% (47%, n=510) followed by 25% (25%, n=268) and 75% (18%, n=199) tension; seven percent (n=71) of respondents reported using no tension length (Table 3).

Almost all the respondents indicated the commercially manufactured infused tapes (99.54%, n=1078) were not used in their clinical practice (Table 4). Similarly, most re-
<table>
<thead>
<tr>
<th>Please describe your gender.</th>
<th>Frequency % (N)</th>
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</thead>
<tbody>
<tr>
<td>Male</td>
<td>45.43% (492)</td>
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<tr>
<td>Female</td>
<td>53.92% (584)</td>
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<tr>
<td>Other</td>
<td>0.18% (002)</td>
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<tr>
<td>Prefer not to answer</td>
<td>0.47% (005)</td>
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<tr>
<th>Please choose your profession.</th>
<th>Frequency % (N)</th>
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<tbody>
<tr>
<td>Physical Therapist</td>
<td>60.66% (657)</td>
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<tr>
<td>Chiropractor</td>
<td>01.75% (19)</td>
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<tr>
<td>Certified Athletic Trainer</td>
<td>30.00% (325)</td>
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<tr>
<td>Occupational Therapist</td>
<td>0.28% (3)</td>
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<tr>
<td>Acupuncturist</td>
<td>0.00% (0)</td>
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<tr>
<td>Physical Therapist Assistant</td>
<td>4.09% (44)</td>
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<tr>
<td>Occupational Therapist Assistant</td>
<td>0.09% (44)</td>
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<tr>
<td>Massage Therapist</td>
<td>0.92% (10)</td>
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<tr>
<td>Certified Personal Trainer</td>
<td>0.28% (3)</td>
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<tr>
<td>Kinesiotherapist</td>
<td>0.09% (1)</td>
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<td>Exercise Physiologist</td>
<td>0.18% (2)</td>
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<tr>
<td>Educator (secondary schools, collegiate)</td>
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<tr>
<td>Physician Assistant</td>
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<tr>
<td>Medical Doctor, Podiatrist, Doctor of Osteopathy</td>
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<td>0.92% (10)</td>
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<tr>
<th>Please choose your primary practice setting.</th>
<th>Frequency % (N)</th>
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<tr>
<td>Private outpatient facility</td>
<td>42.10% (456)</td>
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<td>Public outpatient facility (e.g. state, county)</td>
<td>1.48% (16)</td>
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<tr>
<td>Hospital based facility</td>
<td>18.19% (197)</td>
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<tr>
<td>University/college sports medicine or athletic training facility</td>
<td>12.09% (131)</td>
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<tr>
<td>Secondary school athletic training facility</td>
<td>11.54% (125)</td>
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<tr>
<td>Academic/research institution</td>
<td>2.22% (24)</td>
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<tr>
<td>Fitness or wellness facility</td>
<td>1.01% (11)</td>
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<tr>
<td>Massage therapy facility</td>
<td>0.28% (3)</td>
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<tr>
<td>Military service facility</td>
<td>1.48% (16)</td>
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<td>In-home services</td>
<td>1.57% (17)</td>
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<td>Professional sports</td>
<td>2.59% (28)</td>
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<tr>
<td>Skilled nursing facility/acute facility</td>
<td>0.74% (8)</td>
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<tr>
<td>Industrial/occupational health services</td>
<td>1.94% (21)</td>
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<tr>
<td>Other setting not listed</td>
<td>2.77% (30)</td>
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How many years have you been in professional practice?
- Average years in professional practice: 16.13 ± 11.11 years

Correspondents (65%, n=704) also indicated not using any topical analgesic in combination with a non-infused KT. The most commonly utilized topical analgesics, however, were Biofreeze® (23%, n=255), RockTape RockSauce® Fire (9%, n=98), RockTape RockSauce® Ice (7%, n=77), Flexall® (6%, n=61), and Voltaren® gel (5%, n=55) with non-infused KT (Table 4).

The most common clinical measures used by respondents to assess the efficacy of KT were patient reported outcomes (80%, n=862), girth measurements (45%, n=463), joint range of motion (40%, n=437), sports specific assessment (40%, n=437), movement-based testing (36%, n=395) and muscle performance (strength) testing (31%, n=337) (Table 4).

**KT EDUCATION AND REFERRAL**

Regarding skin prep before applying KT, sixty-four percent (n=695) of respondents provided client instructions. Common instructions included to clean and dry skin (53%, n=576), avoid lotions, oils, topicals, or gels (37%, n=396), and trim or remove hair on the body region (12%, n=131) being taped. Thirty-six percent (n=388) of respondents did...
Table 2: Clinical perceptions about KT (N=1083)

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<tr>
<th>What are common reasons you use KT on your clients?</th>
<th>20.78% (225)</th>
<th>15.42% (167)</th>
<th>74.24% (804)</th>
<th>66.85% (724)</th>
<th>60.30% (653)</th>
<th>24.01% (260)</th>
<th>45.52% (493)</th>
<th>1.39% (15)</th>
<th>6.00% (65)</th>
<th>40.44% (438)</th>
<th>0.64% (7)</th>
<th>0.74% (8)</th>
<th>7.01% (76)</th>
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<table>
<thead>
<tr>
<th>Which factors have influenced how you apply KT to your clients?</th>
<th>53.55% (580)</th>
<th>74.33% (805)</th>
<th>28.90% (313)</th>
<th>0.83% (9)</th>
<th>31.10% (338)</th>
<th>74.98% (812)</th>
<th>64.08% (694)</th>
<th>1.66% (18)</th>
<th>5.36% (20)</th>
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<tr>
<th>What therapeutic effects do you believe occur with KT?</th>
<th>29.46% (319)</th>
<th>69.80% (756)</th>
<th>15.05% (165)</th>
<th>13.48% (146)</th>
<th>12.56% (136)</th>
<th>13.11% (142)</th>
<th>69.10% (748)</th>
<th>0.64% (7)</th>
<th>0.28% (3)</th>
<th>65.47% (709)</th>
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<th>58.63% (635)</th>
<th>3.23% (35)</th>
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<td>Increases in local circulation (e.g. lymphatic)</td>
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<thead>
<tr>
<th>Which physiological mechanisms do you believe occur with KT?</th>
<th>69.16% (749)</th>
<th>77.00% (834)</th>
<th>60.20% (652)</th>
<th>15.24% (165)</th>
<th>13.85% (150)</th>
<th>46.26% (501)</th>
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<tbody>
<tr>
<td>Tape lifts the skin to allow improved local circulation</td>
<td>Tape lifts the skin to allow improved local circulation</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tape stimulates skin mechanoreceptors increasing proprioception</td>
<td>Tape stimulates skin mechanoreceptors increasing proprioception</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape stimulates skin nociceptors resulting in pain modulation</td>
<td>Tape stimulates skin nociceptors resulting in pain modulation</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Tape help improve joint range of motion</td>
<td>Tape help improve joint range of motion</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape helps improve muscle performance (strength)</td>
<td>Tape helps improve muscle performance (strength)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tape helps improve muscle activation and motor control</td>
<td>Tape helps improve muscle activation and motor control</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Table 2: Clinical perceptions about KT (N=1083)*

*What are common reasons you use KT on your clients?*
- Performance enhancement
- Injury prevention
- Post-injury treatment (e.g. edema, ecchymosis)
- Pain modulation
- Neuro-sensory feedback (e.g. proprioception)
- Myofascial mobility
- Neuromuscular re-education
- Pre-exercise warm-up
- Post-exercise treatment
- Placebo effect
- Posture feedback
- Patient requests KT
- Joint support
- Edema or swelling
- Other

*Which factors have influenced how you apply KT to your clients?*
- Peer reviewed research articles, textbooks
- Continuing education courses or conferences
- Manufacturer instructions
- KT textbooks
- Websites, social media posts, or videos (e.g. YouTube)
- Collaboration with other professionals
- My prior empirical experience
- Patient interest
- Other variables not listed

*What therapeutic effects do you believe occur with KT?*
- Enhanced myofascial mobility
- Pain modulation
- Increased joint ROM
- Enhanced stretch tolerance of muscles
- Enhanced post-exercise recovery
- Enhanced pre-exercise neuromyofascial excitation
- Enhanced proprioception and kinesthetic sense
- Enhance muscle activation/motor control
- Inhibit muscle activation/motor control
- Increases in local circulation (e.g. lymphatic)
- Decreased edema, swelling, and/or effusion
- Postural awareness
- Placebo effect
- Other effects not listed

*Which physiological mechanisms do you believe occur with KT?*
- Tape lifts the skin to allow improved local circulation
- Tape stimulates skin mechanoreceptors increasing proprioception
- Tape stimulates skin nociceptors resulting in pain modulation
- Tape help improve joint range of motion
- Tape helps improve muscle performance (strength)
- Tape helps improve muscle activation and motor control

*Table 2: Clinical perceptions about KT (N=1083)*

*What are common reasons you use KT on your clients?*
- Performance enhancement: 20.78% (225)
- Injury prevention: 15.42% (167)
- Post-injury treatment (e.g. edema, ecchymosis): 74.24% (804)
- Pain modulation: 66.85% (724)
- Neuro-sensory feedback (e.g. proprioception): 60.30% (653)
- Myofascial mobility: 24.01% (260)
- Neuromuscular re-education: 45.52% (493)
- Pre-exercise warm-up: 1.39% (15)
- Post-exercise treatment: 6.00% (65)
- Placebo effect: 40.44% (438)
- Posture feedback: 0.64% (7)
- Patient requests KT: 1.38% (15)
- Joint support: 0.46% (5)
- Edema or swelling: 0.74% (8)
- Other: 7.01% (76)

*Which factors have influenced how you apply KT to your clients?*
- Peer reviewed research articles, textbooks: 53.55% (580)
- Continuing education courses or conferences: 74.33% (805)
- Manufacturer instructions: 28.90% (313)
- KT textbooks: 0.83% (9)
- Websites, social media posts, or videos (e.g. YouTube): 31.10% (338)
- Collaboration with other professionals: 74.98% (812)
- My prior empirical experience: 64.08% (694)
- Patient interest: 1.66% (18)
- Other variables not listed: 5.36% (20)

*What therapeutic effects do you believe occur with KT?*
- Enhanced myofascial mobility: 29.46% (319)
- Pain modulation: 69.80% (756)
- Increased joint ROM: 15.05% (163)
- Enhanced stretch tolerance of muscles: 13.48% (146)
- Enhanced post-exercise recovery: 12.56% (136)
- Enhanced pre-exercise neuromyofascial excitation: 13.11% (142)
- Enhanced proprioception and kinesthetic sense: 69.10% (748)
- Enhance muscle activation/motor control: 0.64% (7)
- Inhibit muscle activation/motor control: 0.28% (3)
- Increases in local circulation (e.g. lymphatic): 65.47% (709)
- Decreased edema, swelling, and/or effusion: 0.28% (3)
- Postural awareness: 0.18% (2)
- Placebo effect: 58.63% (635)
- Other effects not listed: 3.23% (35)

*Which physiological mechanisms do you believe occur with KT?*
- Tape lifts the skin to allow improved local circulation: 69.16% (749)
- Tape stimulates skin mechanoreceptors increasing proprioception: 77.00% (834)
- Tape stimulates skin nociceptors resulting in pain modulation: 60.20% (652)
- Tape help improve joint range of motion: 15.24% (165)
- Tape helps improve muscle performance (strength): 13.85% (150)
- Tape helps improve muscle activation and motor control: 46.26% (501)
**What therapeutic effects do you believe occur with your preferred KT tension length you use with clients?**

- Tape can inhibit muscle activation: 31.86% (345)
- Tape can create a placebo effect: 73.68% (798)
- Other physiological mechanisms not listed: 1.38% (15)

**Which general precautions do you believe are most important with kinesiology tape?**

- Skin reaction/allergy (e.g. irritation, itching): 50.69% (549)
- Thin skin (e.g. common in elderly): 25.48% (276)
- Lymph node removal: 2.86% (31)
- Connective tissue disorder (e.g. Marfan syndrome): 3.79% (41)
- Medications that alter sensation: 1.57% (17)
- Pregnancy: 1.39% (15)
- Impaired or altered sensation: 9.08% (87)
- Unusual pain or discomfort: 6.19% (67)

**What other precautions should professionals consider with kinesiology tape?**

- No other precautions: 94.92% (1,028)
- Prior skin reaction to KT: 0.74% (8)
- Allergy to adhesives or latex: 0.74% (8)
- Patient understanding, compliance, and self-efficacy: 1.01% (11)
- Patient ability to self-apply tape: 0.37% (4)
- Patients with impaired judgement/cognition: 0.65% (7)
- Other reason not listed above: 1.57% (17)

**Which contraindications do you believe are most important with kinesiology tape?**

- Diabetes: 2.40% (26)
- Peripheral neuropathy: 1.39% (15)
- Acute injury: 1.57% (17)
- Skin with open wounds or lesions: 32.87% (356)
- Allergy to adhesives, latex, or synthetic tapes: 33.33% (361)
- Deep vein thrombosis: 4.80% (52)
- Congestive heart failure: 1.66% (18)
- Malignancy (active): 3.51% (38)
- Renal insufficiency: 0.28% (3)
- Infection or fever: 1.85% (20)
- Undiagnosed rash or skin irritation: 3.69% (40)
- Inability to communicate: 13.48% (146)
- Lymph edema: 0.55% (6)

**What other contraindications should professionals consider with kinesiology tape?**

- No other contraindications: 84.76% (918)
not provide any skin prep instruction (Table 5).

Most respondents (77%, n=837) provided tape removal instructions to the clients. Common instructions included slowly removing tape (44%, n=474), applying oil (mineral, baby) to tape or use of adhesive remover (18%, n=191), wetting tape before removal (10%, n=115), and do not rip off tape (7%, n=67). Twenty-three percent (n=246) did not provide any tape removal instructions (Table 5).

The average time respondents recommended clients to wear KT was two (32%, n=544) and three days (58%, n=406). The maximum time respondents recommended clients to wear KT was for five days (33%, n=357), three days (24%, n=259), four days (13%, n=140), and two days (11%, n=114) (Table 5).

The most common type of client education was live instruction (89%, n=960), and most respondents referred clients to generic websites (65%, n=704), retail stores (43%, n=469), or manufacturer websites (26%, n=277) to purchase KT. Twenty-four percent (n=258) of respondents did not provide recommendations to clients on KT purchases (Table 5).

DISCUSSION

This cross-sectional study was the first survey to document healthcare professionals’ beliefs and clinical practices for KT. We attempted to provide insight into the practices of clinicians using KT and to answer clinical questions that have been unanswered in the body of KT evidence to inform future research. The results of our study, combined with the immense body of research, may help discern why inconsistencies may be found in the literature, while also providing awareness of common clinical KT practices to guide future research efforts.

RESPONDENT CLINICAL PERCEPTIONS OF KT

Professionals reported using KT for pain modulation (60-70%), neuro-sensory feedback (e.g. proprioception) (60-77%), neuromuscular re-education (45-46%), post-injury treatment (e.g. increase local circulation; 65-74%), myofascial mobility (24-29%), and placebo effect (40-74%). The respondents, however, reported using continuing education (74%), professional collaboration (75%), and prior experience (64%) to inform their clinical application of KT with clients. Interestingly, these sources were noted more often than peer reviewed research (53%). The current results are similar to prior myofascial intervention survey research examining clinician perceptions of IASTM; clinicians often sought out informal sources of information and utilize personal experience to guide their clinical practice.44 The varied sources of information and training may also help explain the variations in KT use in clinical practice and research, while also potentially explaining respondent beliefs about the clinical use, therapeutic benefits, and physiological effects of KT. Thus, clinician beliefs may be influenced by peer-reviewed research; however, it is also possible clinician beliefs may be more influenced by informal educational sources, as part of KT training provided by a commercial entity, or by their own clinical experiences than by the research evidence (Table 2).

For pain modulation, the research is inconclusive with some studies reporting poor efficacy when using KT for pain related to musculoskeletal injury2 and chronic musculoskeletal pain.16,17 While some researchers report weak to moderate evidence for myofascial30 and low back pain,32–34 For post-exercise soreness, several researchers have documented that KT may diminish the effects of delayed onset of muscle soreness (DOMS) after intense exercise.45–48 For neuro-sensory feedback and muscle re-education, there are mixed results in the literature. Two studies compared KT versus placebo on knee joint position sense in healthy subjects;49,50 a significant group differences was not found in either study, questioning the efficacy of KT for this type of intervention. Other researchers, however, have reported KT improved proprioception in post-ACL repair individuals51 and elderly individuals when the tape was combined with exercise (Table 2).52

For increasing circulation post injury/surgery, several studies suggest KT may increase local microcirculation53–55 and skin temperature,53–55 while decreasing tissue edema.56 Other researchers, however, did not find any significant changes in local microcirculation after KT was applied.57 Respondents also use KT to enhance myofascial mobility, which has some evidence in the literature for causing deformation of the different skin and myofascial layers locally58,59 and distally59 which supports the mechanical effects of the tape.

A substantial portion of respondents also believed KT only creates a physiological placebo (40%), and a large portion of respondents indicated using it for such therapeutic placebo effects (58%) with their clients (Table 2). Several studies have investigated the placebo effects of facilitatory and inhibitory KT taping techniques. One study found that KT promoted increased grip strength among healthy individuals but did not find any electromyography (EMG) changes in the forearm muscles, which suggests some type of indirect placebo effect.60 Others have not found any differences between KT facilitation, inhibition, sham taping, or no taping for muscle activity, strength, power, or per-

### Table 2

| Patient willingness, mental status, or dependence | 1.11% (12) |
| Inability to reach a body region | 0.74% (8) |
| Skin sensitivity or tolerance | 1.66% (18) |
| Fragile or thin skin | 1.94% (21) |
| Other contraindications not listed | 9.79 (106) |

* Respondents chose all options that applied to them; **Respondents ranked their answers; ***Respondents provided answers in a comment section; KT= kinesiology tape; ROM=range of motion
Table 3: Clinical application of standard and specialty KT (N=1083)

<table>
<thead>
<tr>
<th>*Which commercial brand KT do you commonly use in your practice?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KT Tape</td>
<td>59.10% (640)</td>
</tr>
<tr>
<td>RockTape</td>
<td>50.41% (546)</td>
</tr>
<tr>
<td>Kinesio Tex</td>
<td>33.15% (359)</td>
</tr>
<tr>
<td>P-Tex</td>
<td>0.37% (4)</td>
</tr>
<tr>
<td>TheraBand</td>
<td>10.71% (116)</td>
</tr>
<tr>
<td>Spider Tech</td>
<td>3.42% (37)</td>
</tr>
<tr>
<td>Strength Tape</td>
<td>1.02% (11)</td>
</tr>
<tr>
<td>Mueller</td>
<td>7.39% (80)</td>
</tr>
<tr>
<td>Dynamic</td>
<td>3.41% (37)</td>
</tr>
<tr>
<td>Levotape</td>
<td>0.83% (9)</td>
</tr>
<tr>
<td>Leukotape</td>
<td>0.18% (2)</td>
</tr>
<tr>
<td>Other brands not listed</td>
<td>9.04% (98)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Which color/s of KT do you use most often with your clients? (colors without specialty designs)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>71.47% (774)</td>
</tr>
<tr>
<td>Beige</td>
<td>65.83% (713)</td>
</tr>
<tr>
<td>Blue</td>
<td>30.66% (332)</td>
</tr>
<tr>
<td>Pink</td>
<td>17.63% (191)</td>
</tr>
<tr>
<td>Green</td>
<td>2.68% (29)</td>
</tr>
<tr>
<td>Purple</td>
<td>4.80% (52)</td>
</tr>
<tr>
<td>Red</td>
<td>7.94% (86)</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.46% (5)</td>
</tr>
<tr>
<td>Orange</td>
<td>0.37% (4)</td>
</tr>
<tr>
<td>Skin tone</td>
<td>0.46% (5)</td>
</tr>
<tr>
<td>White</td>
<td>0.27% (3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Which types of standard KT do you use most often on your clients? (standard roll and pre-cut tape)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-cut strips (2 in x 10 in) (5 cm x 25 cm)</td>
<td>15.51% (168)</td>
</tr>
<tr>
<td>Pre-cut strips (4 in x 10 in) (10 cm x 25 cm)</td>
<td>3.05% (33)</td>
</tr>
<tr>
<td>Pre-cut strips for digits (1 in x 10 in) (2.54 cm x 25 cm)</td>
<td>0.37% (4)</td>
</tr>
<tr>
<td>Uncut roll (2 in x 16.4 ft) (5 cm x 5 m)</td>
<td>66.85% (724)</td>
</tr>
<tr>
<td>Uncut roll (3 in x 16.4 ft) (7.5 cm x 5 m)</td>
<td>10.53% (114)</td>
</tr>
<tr>
<td>Uncut roll (4 in x 16.4 ft) (10 cm x 5 m)</td>
<td>6.19% (67)</td>
</tr>
<tr>
<td>Uncut roll for digits (1 in x 16.4 ft) (2.5 cm x 5 m)</td>
<td>0.74% (8)</td>
</tr>
<tr>
<td>Uncut large roll (2 in x 105 ft) (5 cm x 32 m)</td>
<td>35.92% (389)</td>
</tr>
<tr>
<td>Uncut large roll (4 in x 105 ft) (10 cm x 32 m)</td>
<td>4.71% (51)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Which types of specialty pre-cut KT do you most often use in your practice?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Blister prevention tape</td>
<td>0.92% (10)</td>
</tr>
<tr>
<td>Pre-cut fan tape (e.g. edema, bruising, lymphatic drainage)</td>
<td>8.86% (96)</td>
</tr>
<tr>
<td>Pre-cut X tape</td>
<td>2.03% (22)</td>
</tr>
<tr>
<td>Pre-cut tape for the upper body regions</td>
<td>3.51% (38)</td>
</tr>
<tr>
<td>Pre-cut tape for the lower body regions</td>
<td>3.97% (43)</td>
</tr>
<tr>
<td>I do not use specialty pre-cut tape</td>
<td>83.28% (902)</td>
</tr>
<tr>
<td>I cut my own tape</td>
<td>0.37% (4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>When applying the KT, what is the most common tension length percentage you use for your clients?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25% tension</td>
<td>24.75% (268)</td>
</tr>
<tr>
<td>50% tension</td>
<td>47.09% (510)</td>
</tr>
<tr>
<td>75% tension</td>
<td>18.37% (199)</td>
</tr>
<tr>
<td>100% tension</td>
<td>2.12% (23)</td>
</tr>
</tbody>
</table>
received maximum strength for the forearm muscles,\textsuperscript{61–63} quadriceps,\textsuperscript{64–67} and calf muscles.\textsuperscript{57} Researchers have also reported no therapeutic differences between KT, sham tape, and control group for individuals with lateral epicondylitis\textsuperscript{68–70} and chronic low back pain.\textsuperscript{71} Professionals should consider that these results are limited to the study methods (e.g. placebo) and study populations; further research is needed to confirm or refute the placebo effects for different populations.

For KT tension length, most of the respondents believed their preferred tape tension length enhanced proprioception and kinesthetic sense (59%) and modulated pain (55%), while a substantial portion felt it increased local circulation (43%), enhanced myofascial mobility (23%), and provided a placebo effect (40%) (Table 2). The research on the efficacy of tape length tension will be further discussed in the next section on clinical application of KT.

For precautions, most respondents considered skin reaction (51%), thin skin (25%), and impaired or altered sensation (e.g. diabetes neuropathy) as the most important to consider for potential KT application adverse events (Table 2). There is a small body of research that has directly studied the side effects and tolerability of KT among individuals with neurological disorders,\textsuperscript{72,73} cancer related lymphoedema,\textsuperscript{74,75} and healthy individuals.\textsuperscript{76} The incidences of side effects (e.g. skin reaction) or intolerance reported among these studies ranged between 4% to 33%.\textsuperscript{72–77} Unfortunately, the research on KT side effects is sparse. The existing data may not represent the actual number of occurrences among different client populations such as athletes and individuals with musculoskeletal disorders.\textsuperscript{77} These two populations may use KT the most and may not be well represented in the current literature. Sports medicine professionals could benefit from knowing the incident rates of KT side effects in this population to improve clinical decision making and inform their practice patterns.

For KT contraindications, most respondents considered skin allergies (33%), open wounds and lesions (33%), and inability to communicate (13%) as the most important (Table 2). Some researchers suggest using a small piece of KT on the forearm to check for a skin reaction to the tape (e.g. redness, itching, etc) noted within 15 minutes.\textsuperscript{78} These precautions and contraindication align with recommendations in the literature but may not represent all possible conditions.\textsuperscript{77,79–81} Professionals should consider that these conditions have not been fully investigated and should properly screen each client prior to administering KT as an intervention.

**CLINICAL APPLICATION OF KT**

Most respondents (47%) purchased tape from three manufacturers, but our results also indicate that clinicians utilize KT from a variety of manufacturers. Clinicians reported using a variety of popular KT colors with clients: black (71%), beige (66%), blue (31%), and pink (18%) (Table 3). Researchers have previously examined the influence of KT color on athletic performance, quadriceps strength, and neuromuscular function among healthy individuals.\textsuperscript{82} Five conditions were measured: no tape, KT beige sham, beige KT with 50% tension, red KT with 50% tension, and blue KT with 50% tension.\textsuperscript{82} The researchers found that KT, regardless of color or condition, did not alter athletic performance, lower leg strength, or neuromuscular function.\textsuperscript{82} The current evidence suggests clinicians may utilize the KT colors preferred by their clients without concerns for it detrimentally affecting athletic performance.

Respondents most often used the KT standard uncut rolls (67%), followed by the large standard uncut roll (36%) then standard pre-cut strips (15%). These respondents did not indicate the use of any specialty pre-cut strips (83%), commercially infused tape (99%), or a combination of a topical analgesic and non-infused tape (65%) in clinical practice; however, a small portion of respondents (23%) did report combining Biofreeze with non-infused tape (Table 3 and 4). While previous research on KT practice patterns was not identified in the literature, the current findings are not unexpected. Clinicians have reported using a variety of IASTM instruments and utilizing instruments from numerous manufactures\textsuperscript{84}; thus, it is not surprising to have similar practice patterns arise with KT. Research regarding the therapeutic effects of different infused KT or the effects of a non-infused KT with a topical analgesic was also not identified in the literature. Due to this lack of evidence, professionals will need to rely on the assessment of patient outcomes and good clinical judgement when matching a specific tape to their clients.

Respondents reported commonly used a KT tension length range of 25-75%, with 50% tension (47%) being the most used among respondents (Table 3). While the actual tension force being used was not validated with the survey responses and the current results do not elucidate whether or how clinicians adjust the tension length based on pathology or patient need; however, the respondent choices for tension length are consistent with general KT recommendations in the literature. A 25% to 50% tape tension length has been recommended for treatment of fascia and circulatory conditions, stimulating, and inhibiting muscle activity.\textsuperscript{85} A tension length range of 75 to 100% has been recommended for treatment of tendons and ligaments.\textsuperscript{85} These recommendations are often shared among professionals, but are not necessarily evidence based.

Different KT tensions were not found to have positive effects among healthy individuals for quadriceps

| 125% tension | 0.74% (8) |
| 150% tension | 0.28% (3) |
| 175% tension | 0.09% (1) |
| No tension | 6.56% (71) |

* Respondents chose all options that applied to them; KT= kinesiology tape
Table 4: Clinical application of Infused KT, topicals, and clinical measures (N=1083)

<table>
<thead>
<tr>
<th>*Which type/s of commercial infused KT do you use with your clients?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tape infused with CBD (Hemp)</td>
<td>0.18% (2)</td>
</tr>
<tr>
<td>Tape infused with Menthol</td>
<td>0.28% (3)</td>
</tr>
<tr>
<td>Tape infused with Copper</td>
<td>0.18% (2)</td>
</tr>
<tr>
<td>Tape infused with Tourmaline</td>
<td>0.09% (1)</td>
</tr>
<tr>
<td>I do not use infused tape</td>
<td>99.54% (1078)</td>
</tr>
</tbody>
</table>

*Which commercially available topical analgesic/s due you use in combination with non-infused KT? (most common brands or types)

<table>
<thead>
<tr>
<th>Topical Analgesic</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofreeze</td>
<td>23.55% (255)</td>
</tr>
<tr>
<td>Tiger Balm</td>
<td>3.51% (38)</td>
</tr>
<tr>
<td>Flexall</td>
<td>5.63% (61)</td>
</tr>
<tr>
<td>RockSauce Fire</td>
<td>9.05% (98)</td>
</tr>
<tr>
<td>RockSauce Ice</td>
<td>7.11% (77)</td>
</tr>
<tr>
<td>Solonpas</td>
<td>1.29% (14)</td>
</tr>
<tr>
<td>IcyHot</td>
<td>1.39% (15)</td>
</tr>
<tr>
<td>Mineral Ice</td>
<td>0.18% (2)</td>
</tr>
<tr>
<td>Ben Gay</td>
<td>0.18% (2)</td>
</tr>
<tr>
<td>CBD Topical</td>
<td>2.22% (24)</td>
</tr>
<tr>
<td>Cramer Atomic Balm</td>
<td>1.75% (19)</td>
</tr>
<tr>
<td>Arnica</td>
<td>3.60% (39)</td>
</tr>
<tr>
<td>Voltaren Gel</td>
<td>5.08% (55)</td>
</tr>
<tr>
<td>Hydrocortisone</td>
<td>0.92% (10)</td>
</tr>
<tr>
<td>Sombra</td>
<td>1.75% (19)</td>
</tr>
<tr>
<td>Other brands not listed</td>
<td>3.51% (38)</td>
</tr>
<tr>
<td>I do not use any topical analgesic</td>
<td>65.00% (704)</td>
</tr>
</tbody>
</table>

*What clinical measures do you use to assess the effects of KT?

<table>
<thead>
<tr>
<th>Clinical Measure</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint range of motion (e.g. goniometer, inclinometer)</td>
<td>40.17% (435)</td>
</tr>
<tr>
<td>Pressure pain threshold (e.g. algometer)</td>
<td>17.08% (185)</td>
</tr>
<tr>
<td>Patient reported outcomes (e.g. NRS, VAS pain scales)</td>
<td>79.59% (862)</td>
</tr>
<tr>
<td>Movement based testing (e.g. FMS, SFMA)</td>
<td>36.29% (393)</td>
</tr>
<tr>
<td>Muscle performance (strength) testing</td>
<td>31.12% (337)</td>
</tr>
<tr>
<td>Activity or sports specific assessment</td>
<td>40.35% (437)</td>
</tr>
<tr>
<td>Girth measurements (e.g. edema)</td>
<td>42.75% (463)</td>
</tr>
<tr>
<td>Gait assessment</td>
<td>0.55% (6)</td>
</tr>
<tr>
<td>Palpation</td>
<td>0.37% (4)</td>
</tr>
<tr>
<td>Observation/visual changes</td>
<td>0.65% (7)</td>
</tr>
<tr>
<td>Other measures not listed</td>
<td>0.92% (10)</td>
</tr>
<tr>
<td>I do not use clinical measures to assess the effects of KT</td>
<td>11.08% (120)</td>
</tr>
</tbody>
</table>

* Respondents chose all options that applied to them; KT= kinesiology tape; CBD= Cannabidiol

strength,84,85 knee joint range of motion,85 lower extremity hop test,84 the gastrocnemius and soleus H-Reflex,86,87 and EMG activity of the quadriceps and hamstrings during a loaded squat exercise.88 However, other researchers have reported that KT does facilitate the H-Reflex89 and shoulder muscle EMG activity90 among healthy individuals. Researchers have also documented that different tape tension lengths (15-50%) did not produce significant changes in EMG paraspinal muscle activity among individuals with chronic low back pain.91,92 The research on KT tension length is inconclusive and has been focused more on healthy versus injured participants, which presents a barrier for interpreting the research. Without sound evidence to guide practice, professional will be forced to rely on their clinical outcomes, personal preferences, or information from informal sources to guide tension length due to the lack of evidence.

For clinical measures, most respondent used patient reported outcomes (80%), girth measurement (43%), joint ROM (40%), movement-based testing sports specific assess-
Table 5: KT education and referral (N=1083)

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes (%)</th>
<th>No (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you instruct your clients to prepare their skin before applying the KT?</td>
<td>64.17%</td>
<td>35.83%</td>
</tr>
<tr>
<td>*If yes to the prior question, what instructions do you provide to your clients?</td>
<td>Clean and dry skin (e.g. soap/water, isopropyl alcohol) 53.18% (576)</td>
<td>Avoid lotions, oils, topicals, or gels 36.56% (396)</td>
</tr>
<tr>
<td>Do you instruct your clients on how to safely remove the KT?</td>
<td>77.29%</td>
<td>22.71%</td>
</tr>
<tr>
<td>*If yes, what instructions do you provide to your clients for removing KT?</td>
<td>Wet tape before removal 10.44% (113)</td>
<td>Remove tape slowly 43.77% (474)</td>
</tr>
<tr>
<td>What is the average time you recommend clients to wear KT?</td>
<td>Less than One Day 2.40% (26)</td>
<td>One Day 8.59% (93)</td>
</tr>
<tr>
<td>What is the maximum time you recommend clients to wear the KT?</td>
<td>Less than One Day 1.11% (12)</td>
<td>One Day 3.14% (34)</td>
</tr>
<tr>
<td>**What are common types of education you use to teach clients about KT?</td>
<td>Live instruction 88.64% (960)</td>
<td>Video instruction 3.14% (34)</td>
</tr>
<tr>
<td>***Where do you direct your clients to purchase KT?</td>
<td>Manufacturer website 25.58% (277)</td>
<td>Generic websites (e.g. Amazon) 65.00% (704)</td>
</tr>
</tbody>
</table>
ments (40%), movement-based testing (36%), and muscle performance (31%) to measure the effects of KT (Table 4). These outcomes are commonly used in the research and are similar to the types of outcome measures used by clinicians when assessing the effectiveness of IASTM.44

KT EDUCATION AND REFERRAL

For skin prep, most respondents (64%) instructed patients to clean and dry skin first, avoid topical lotions, oils, and gels, and to trim or remove hair on the body region being taped. For KT removal, most respondents (77%) instructed their patients to slowly remove the tape, applying oil (mineral, baby) to tape or use of adhesive remover, wet tape before removal, and do not rip off the tape (Table 5). The results of the survey demonstrate some common instructions often taught by tape manufacturers or shared among professionals.77 The most concerning finding was that 36% of respondents did not provide any skin prep instructions and 23% did not provide any tape removal instructions to their clients (Table 5). The current findings are consistent with previous research on IASTM clinician practice patterns for following training recommendations; researchers reported that more than 45% of their respondents indicated failing to following training recommendations from some to all the time.44 The lack of instruction or failure to following training or best practice recommendations may present a risk for injury because the clinician or client may not use the tape correctly. Currently, research is lacking on the best practice recommendations for skin prep and KT removal and little is known about any potential related complications (e.g. allergic reaction, infection, etc.) to KT use in this area.

For length of time wearing tape, most respondents (70%) recommended for clients to wear KT an average of two to three days with a maximum wear time of three to five days (Table 5). These recommendation are consistent with research that has examined the effects of KT wear time of three to seven days on balance and functional performance among healthy individuals,94 among individuals with myofascial pain syndrome and trigger points,95–98 chronic ankle instability,99 subacromial shoulder impingement,100,101 rheumatoid arthritis,102 knee osteoarthritis,103 total knee replacement,104 and lymphedema.105 Studies have also been performed measuring hamstring extensibility,106 increased local tissue temperature,54 and quadriceps strength107 in subjects wearing KT within this time range. Survey respondent recommendations for KT wear time seem to be in line with the research. Professionals should determine KT wear time on an individual basis and always monitor for side effects such as skin irritation or allergy,77 and future research should examine how clinicians adjust wear time based on client need or clinical scenario.

Most respondents used live education (89%) for the clients and referred them to generic websites (65%) and retail stores (43%) to purchase KT. Twenty four percent did not provide recommendations (Table 5). Unfortunately, there is no research measuring the efficacy of different modes or instruction or the influences on professional referral to purchase KT. Only one related myofascial intervention study measured the efficacy of different modes of education for myofascial rolling. The researchers compared a 2-minutes live instruction, video instruction, and a self-administered program for the quadriceps. The study outcomes were passive knee flexion range of motion and pain threshold. The researchers found that all modes produced similar post intervention outcomes for all measures. The researchers concluded that professionals should match the best instructional mode to each patient to provide the best experience.108 Future studies are needed with KT.

PRACTICE IMPLICATIONS AND FUTURE RESEARCH

This survey revealed several trends in the beliefs and clinical application of KT among healthcare professionals: a gap exists between the respondent beliefs, professional practices, and the current evidence. Weaknesses in the research for guiding clinical practice may be caused by two primary issues: tape manufacturing and study method differences. First, the large body of research consists of studies that have used different tape brands. This presents a major issue when comparing study outcomes due to the differences among tape mechanical properties (e.g. tension, strain). Three recent studies measured the material and mechanical properties of 23 different KT brands and found all had different mechanical properties making it difficult for a direct comparison across studies.35,109,110 Second, most of the KT research has variable outcomes due to different study methods and these study methods do not always match common clinical practice. Researchers have used different manufactured tape, taping techniques (e.g. tape elongation length), and outcomes which prevents a direct comparison or reproducibility among studies or direct translation to clinical practice.11,12,18

The KT conflicting evidence creates a gap between professional practice, education, and research. Professionals may rely on their own preferred KT techniques because there are discrepancies between the KT guidelines, techniques taught in professional education courses,77 application in clinical practice, and what is reported in the research. As noted in the introduction, thirty-eight systematic reviews have been published since 2010 with inconclusive results. These issues may reflect the portion of respondents that believe KT only creates a physiological placebo (40%) and use it for such therapeutic placebo effects (59%) with their clients. Future research needs to ad-

<table>
<thead>
<tr>
<th>Table 5</th>
<th>KT removal</th>
<th>I don't recommend</th>
<th>Other recommendations not listed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial distributor/medical supply</td>
<td>0.28% (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I don't recommend</td>
<td>23.82% (258)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other recommendations not listed</td>
<td>5.82% (6)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
dress the issues of variations across tape manufacturing and study methods, while also exploring adverse and long-term effects of KT application. Further, researchers need to establish the most common clinical practice patterns for KT application to inform study methodologies. In addition to examining the effects of KT, researchers also must learn how clinician training influences KT application and patient outcomes, how clinicians determine KT tension and wear time and how these factors influence patient outcomes, and how individual client differences (e.g., age, activity level, pathology, etc.) influence KT application.

LIMITATIONS

Several limitations need to be discussed for this investigation. First, this survey was sent electronically to a cross-sectional sample of healthcare professionals with a 2.1% response rate. A larger sample or a different method for sampling with a higher response rate may have produced different results; the results could be influenced by non-response error. However, to the researcher’s knowledge this is the first KT survey study. Second, the results can only be generalized to the healthcare professionals surveyed. Other healthcare professionals may have provided different responses. Third, the survey contained a limited number of items. Different questions may have revealed different ideas of how professionals use KT. For example, the survey did not ask about respondent preference for KT direction such as the tape is tensioned along muscle origin to insertion for facilitation or opposite for inhibition. The current evidence contradicts these directional techniques. The survey focused on tape tension length only versus directional strategies. Finally, this survey was sent to members of three professional organizations. The results may not fully represent the perceptions and practices from other non-member healthcare professionals. However, the results do provide insight into responses among different healthcare professionals, but further research is needed to determine how respondent demographics may have influenced KT perceptions.

CONCLUSION

This is the first KT survey to document professional beliefs and clinical practices for KT. Professionals use different types and brands of KT. They also apply KT with different lengths and tensions to treat a variety of conditions, including as a placebo by nearly 60% of the respondents. Professionals also believe KT provides numerous positive therapeutic effects for clients, but little is known regarding how the therapeutic effects might be produced with KT application. The KT conflicting results may be caused by two primary issues: tape manufacturing and study method differences. Future research addressing these two issues should be pursued to validate or refute the efficacy of KT.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest with this study.

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REFERENCES


16. Lim ECW, Tay MGX. Kinesio taping in musculoskeletal pain and disability that lasts for more than 4 weeks: Is it time to peel off the tape and throw it out with the sweat? A systematic review with meta-analysis focused on pain and also methods of tape application. Br J Sports Med. 2015;49(24):1558-1566. doi:10.1136/bjsports-2014-094151


59. Pamuk U, Yucesoy CA. MRI analyses show that kinesio taping affects much more than just the targeted superficial tissues and causes heterogeneous deformations within the whole limb. J Biomech. 2015;48(16):4262-4270. doi:10.1016/j.jbiomech.2015.10.056


Identifying Risk Factors of Upper Extremity Injuries in Collegiate Baseball Players: A Pilot Study

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Keywords: acute-to-chronic workload (ACWR), injury prevention, overhead throwing, time loss injury, movement system

Background
Repetitive pitching places tremendous forces on the shoulder and elbow which can lead to upper extremity (UE) or lower extremity (LE) overuse injuries.

Purpose
The purpose of this study was to evaluate pre-season physical measurements in collegiate baseball players and track in-season baseball throwing volume to determine which factors may predict throwing overuse injuries.

Study Design
Retrospective Cohort study.

Methods
Baseline preseason mobility, strength, endurance, and perception of function were measured in 17 collegiate baseball pitchers. Participants were then followed during the course of the season to collect rate of individual exposure, estimated pitch volume, and rating of perceived exertion in order to determine if changes in workload contributed to risk of injury using an Acute-to-Chronic Workload ratio (ACWR).

Results
Participants developing an injury had greater shoulder internal rotator strength (p=0.04) and grip strength in a neutral position (p=0.03). A significant relationship was identified between ACWR and UE injuries (p <0.001). Athletes with an ACWR above or below 33% were 8.3 (CI95 1.8-54.1) times more likely to suffer a throwing overuse injury occurring to the upper or lower extremity in the subsequent week.

Conclusion
ACWR change in a positive or negative direction by 33% was the primary predictor of subsequent injury. This finding may assist sports medicine clinicians by using this threshold when tracking pitch volume to ensure a safe progression in workload during a baseball season to reduce the risk of sustaining overuse upper or lower extremity injuries.

Level of Evidence
3b

INTRODUCTION
Tremendous forces occur on the shoulder and elbow during repetitive pitching that can lead to overuse injuries in collegiate baseball.1,2 The injury incidence rate for shoulder and elbow injuries in the National Collegiate Athletic Association (NCAA) over a 16 year period averages 1.85 and 5.78/1000 practice and game athlete-exposures, respectively.3 Between the NCAA, National Association of Intercollegiate Athletics (NAIA), and National Junior College Athletic Association (NJCAA), there are an estimated 50,000 college
Identifying Risk Factors of Upper Extremity Injuries in Collegiate Baseball Players: A Pilot Study

baseball players. Assuming the injury rate is consistent across an average of a 30-game season and 121 practices in a spring season, this would estimate 20,000 injuries to collegiate baseball players of which 45% occur to the upper extremity (UE).3,4

Research has identified shoulder mobility deficits, shoulder strength deficits, trunk mobility deficits, and kinetic chain considerations as a risk for future injury in baseball players.2,5 Aragon et al6 reported that limited trunk rotation increases the amount of load placed on the shoulder and elbow during a pitching sequence. This limited trunk mobility predisposed an individual to be up to 2.75 times more likely to sustain an injury. Limited shoulder mobility increased the odds of injury by 2.5 in professional pitchers and approximately four times more likely in high school athletes.5,7 Pitching with a fatigued arm was a strong predictor (OR>4) of adolescents reporting shoulder and elbow pain.8 Collegiate baseball pitchers also demonstrated a strong correlation (r=.72) between throwing volume and arm soreness.9 Another overhead sport that is associated with increased risk of upper extremity overuse injuries is cricket.10 Although throwing mechanics differ than baseball, the volume of overs, or throws, is monitored similarly to baseball.10 Cricket bowlers’ injuries were tracked over multiple years and observed 3.3 relative risk of injury associated with increased total number of balls bowled, and 2.1 relative risk when total number of balls bowled decreased from previous workloads.10 It is clear that overuse injuries have several risk factors ranging from mobility deficits to pitch volume to consider when attempting to minimize injuries.2,5–10

Research results suggest that a positive relationship between training load and injury exists.11,12 Monitoring training load throughout a competitive season allows clinicians to objectively measure changes in performance, reveal fatigue, and minimize the risk of non-functional fatigue, illness, and injury.12 Training load is the combination of internal workload (relative biological stressors) and external workload (objective work done during athletic competition or training).11 One method used to analyze training load is the acute-to-chronic workload ratio (ACWR).11 This model describes acute training load (training load of one week) to chronic load (the rolling average of 4 weeks) to determine the preparedness of an athlete.11 Mehta et al13 showed that high school baseball pitchers with an ACWR of 1.27 (the acute workload was 27% greater than the chronic workload) were 14.9 times more likely to sustain an injury.

Pre-season and in-season upper and lower extremity injury risk factors exist in baseball pitchers, that have not been studied specifically in college baseball pitchers. Therefore, the purpose of this study is to evaluate pre-season physical measurements in collegiate baseball pitchers and track in-season baseball throwing volume to determine which factors may predict throwing overuse injuries. The primary hypothesis is that pre-season range of motion (ROM), strength, and patient perception measurements will be diminished in those who develop injuries during the season as compared to those who do not develop injuries. The secondary hypothesis is that in-season workload changes above and below a threshold will predict overuse injuries in the upper or lower extremity. This study will allow clinicians to target efforts to mitigate overuse injuries in the future.

METHODS

This retrospective cohort study has three primary components: pre-season baseline assessment, a daily pitching volume recording to examine pitch volume weekly totals, and a daily tracking of athletic exposure and treatment recording for each pitcher. This data was captured to determine if injury occurrences were associated with baseline measures or in-season throwing volume changes. This study was approved by the university institutional review board.

PARTICIPANTS

A convenience sample of 17 collegiate baseball pitchers from a single Division-I baseball program (mean ± SD age 20.1 ± 0.09 y, height 186.8 ± 26.9 cm, mass 96.5 ± 8.8 kg) participated in this study. Participants included in this study were all pitchers on the team roster in the fall of 2019. Participants were excluded from the study if their position was not solely as a pitcher. Participants were also excluded if they were under the medical care of a physician prior to the start of the study that restricted them from participation in sport. Participants were not excluded for previous injury or surgery to the throwing arm.

MEASUREMENT PROTOCOLS

Range of motion, strength, and endurance measurements were collected in November and December following the conclusion of the fall season. This time point ensured athletes were not fatigued and served as a baseline measurement as the fall season had just been completed. All measurements were collected bilaterally.

Participants were asked to fill out the Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow questionnaire in January, prior to the season. The KJOC Shoulder and Elbow11 evaluates the individual’s perceived level of function in performing overhead sports and is a sensitive measurement tool for detecting subtle changes in upper extremity performance.14

RANGE OF MOTION

All participants had their passive range of motion (PROM) assessed for shoulder external rotation, internal rotation, horizontal adduction, flexion, volar forearm compartment, and trunk rotation. Two trials were averaged to represent each measurement and all measures were taken bilaterally except for trunk rotation where three trials were averaged.2 All measures were captured by two certified athletic trainers working directly with the baseball program and de-identified to protect athletes’ privacy.

Shoulder external rotation and internal rotation were assessed with the participant positioned supine on a table with their arm abducted to 90° and elbow flexed to 90° with a rolled towel placed under the distal humerus.15 One ex-
amined as the athlete to exert maximal force against the dynamometer which was placed 5cm proximal to the proximal wrist extension and wrist flexion crease, respectively. Shoulder elevators in the scapular plane\(^\text{15,18}\) were assessed with the participant seated upright with their back against a wall. The arm was abducted to 90° and horizontally adducted to 45° with the forearm in a neutral “thumbs-up” position. The dynamometer is placed 5cm proximal to the proximal wrist extension crease. The participant is instructed to maximally elevate their arms for two repetitions.

Grip strength was assessed using a Jamar Technologies Hydraulic Hand Dynamometer (Patterson Medical, 50301, Warrenville, IL, USA) in a standard seated position with elbow flexed to 90° and forearm neutral rotation. The participant was instructed to squeeze the hand-held dynamometer with maximal contraction for two seconds following a five second break. Power position grip strength was measured in a similar manner; however, the participant was seated with the arm abducted to 90°, elbow flexed to 90°, and forearm pronated.

Two trials were averaged to represent each measurement and all measures were performed bilaterally.

Posterior shoulder endurance test was assessed as previously described by Evans et al.\(^\text{19}\) First, the participant’s body weight in pounds and arm length in centimeters were measured. Both measurements were entered into an equation to determine a hand-held weight that was used to obtain 20Nm of force. The participant was positioned prone on a table with the arm placed into horizontal abduction and externally rotated with the thumb pointing towards the ceiling while holding the weight. A metal vice grip was attached to a PVC pole to provide feedback. The participant was instructed to hold the position against the metal vice grip until failure. Failure was determined by the participant extending their trunk, not keeping their arm against the metal vice grip after one reminder, rotating the torso, or bending the elbow. The time the participant could hold the position was recorded. The procedure was then repeated on the opposite limb.

IN-SEASON FACTORS

For the secondary purpose of the study, participants were followed during the course of the season to collect rate of individual athletic exposure (Table 1), estimated pitch volume representing the external workloads, and rating of perceived exertion representing the internal workloads in order to determine if changes in workload contributed to risk of injury. Participants were asked to estimate the number of throws they completed on a daily basis in each category defined below. Participants were identified as being injured if they sustained an overuse, upper or lower extremity injury during the season requiring them to miss at least one day of participation. An overuse injury is defined as not traumatic, but rather gradually worsening, injury to the upper or lower extremity. Injuries were categorized as a primary injury if the injury was related to a specific activity (e.g., pitching) and a secondary injury if the injury was related to a different activity (e.g., running).
approximately 70 feet. Long toss was performed at greater intensity at distances ranging from 120-150 feet with the intention of getting the ball to the partner on the fly or on one hop. Flat ground was thrown at 60 feet with varying intensity. Bullpen during practice varied based on the day, athlete, and coaching instructions but was performed on a pitching mound. Game day bullpen followed a similar format but with the intent of preparing the athlete to pitch in a game. Game day pitches was performed on a pitching mound in a game against another team. Other was performed during field work drills during practice with the intent to prepare for different game situations.

After each practice or game, a certified athletic trainer asked the pitchers to estimate their perceived exertion for that day’s exposure and pitch volume for each of the seven categories. The Borg Perceived Exertion Scale ranging from 0 (no exertion at all) to 10 (extremely strong/heavy) was used to represent that day’s internal workload. The same athletic trainer recorded the athlete’s exposure type (Table 1). To expedite data collection, all information was captured using a text messaging system.

### DATA REDUCTION

Each day the pitch volume and RPE data was entered into GideonSoft (Horizon Performance, Raleigh, NC, USA). This software was used to store all the data collected over the course of the season for every pitcher where a spreadsheet was then generated for data analysis. All pitchers were coded to protect their identity. In excel, the daily workload was calculated by multiplying the internal by the external workload to create a unitless measure. Each week these daily workloads were summed to represent weekly totals. The acute-to-chronic workload ratio (ACWR) was the relative change in total workload. The acute workload was represented by the current week’s workload while the chronic workload included the average of the three weeks total workload (current week plus previous two weeks). Unfortunately, the season was cut short due to the COVID-19 virus outbreak; therefore, the data collection ended in the middle of the 9th week of the season. All data was coded to protect their identity. In excel, the daily workload was then generated for data analysis. All pitchers were asked the pitchers to estimate their perceived exertion for that day’s exposure and pitch volume for each of the seven categories. The Borg Perceived Exertion Scale ranging from 0 (no exertion at all) to 10 (extremely strong/heavy) was used to represent that day’s internal workload. The same athletic trainer recorded the athlete’s exposure type (Table 1). To expedite data collection, all information was captured using a text messaging system.

### STATISTICAL METHODS

The frequency counts of athletic exposures were captured daily to identify participation status of a player. This allowed us to compare pre-season measurements between two groups: those that sustained an upper or lower extremity injury, requiring missing participation for at least one day (Injured) to those who did not (Non-Injured).

Preseason descriptive statistics for range of motion, strength, and outcome measures were analyzed for normal distribution using the Shapiro-Wilk test. The data was found to be normally distributed, and the pre-season data was compared between injured and non-injured groups using independent t-test with significance set at $p \leq 0.05$ to determine differences in pre-season measures between the two groups.

The second goal was to investigate whether in-season acute-to-chronic workload changes would precede events of overuse injuries. The initial goal was to use all the total workload values, but due to the large volume of catch throws the RPE ($r=0.73$, $p<0.001$) another approach was taken.

Previous approaches have used only high intensity throws. Therefore acute-to-chronic workload from games, practice and game bullpens pitches were calculated using the same external and internal workload calculation described above. Next, the threshold for percent change was determined to be 33% by examining the absolute values of percent change total workloads and events of injury using a receiver operating characteristics (ROC) curve. The threshold that provided the best balance between sensitivity and specificity was determined using the ROC coordinates. Seventeen pitchers were tracked for six weeks resulting in 101 pitcher-weeks (one pitcher tracked for five weeks) which were reviewed and the ACWR changes greater or less than 33% were identified. A cross tabulation (2x2 contingency table) using a Chi-Square and Fisher Exact test was carried out to determine the relationship between ACWR changes greater or less than 33% and if an overuse injury occurred in the next week. The relative risk ratio was calculated to determine the probability of sustaining an injury along with 95% confidence interval from the contingency table. Statistical analysis of all data was performed using SPSS Statistics version 25 (SPSS Science, Chicago, Illinois). For all statistical analyses, an alpha level of $p < 0.05$ was used. The relative risk ratio was calculated using an online calculator.

### RESULTS

### EXPOSURES

The frequency counts of athletic exposures revealed there...
Table 2: Total Throws During the 2020 Season

<table>
<thead>
<tr>
<th>ID</th>
<th>Role</th>
<th>Catch</th>
<th>Long Toss</th>
<th>Flat Ground</th>
<th>Practice Bullpen</th>
<th>Game Bullpen</th>
<th>Game</th>
<th>Other</th>
<th>Pitch Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSB3</td>
<td>Reliever</td>
<td>1274</td>
<td>145</td>
<td>161</td>
<td>132</td>
<td>87</td>
<td>112</td>
<td>0</td>
<td>1911</td>
</tr>
<tr>
<td>BSB4</td>
<td>Reliever</td>
<td>1660</td>
<td>265</td>
<td>87</td>
<td>190</td>
<td>210</td>
<td>205</td>
<td>0</td>
<td>2617</td>
</tr>
<tr>
<td>BSB5</td>
<td>Reliever</td>
<td>1360</td>
<td>80</td>
<td>70</td>
<td>195</td>
<td>210</td>
<td>189</td>
<td>0</td>
<td>2104</td>
</tr>
<tr>
<td>BSB6</td>
<td>Reliever</td>
<td>1435</td>
<td>90</td>
<td>117</td>
<td>245</td>
<td>157</td>
<td>285</td>
<td>0</td>
<td>2329</td>
</tr>
<tr>
<td>BSB7</td>
<td>Reliever</td>
<td>1115</td>
<td>163</td>
<td>40</td>
<td>235</td>
<td>147</td>
<td>128</td>
<td>0</td>
<td>1828</td>
</tr>
<tr>
<td>BSB8</td>
<td>Reliever</td>
<td>850</td>
<td>480</td>
<td>223</td>
<td>150</td>
<td>232</td>
<td>217</td>
<td>15</td>
<td>2167</td>
</tr>
<tr>
<td>BSB9</td>
<td>Starter</td>
<td>1230</td>
<td>670</td>
<td>0</td>
<td>360</td>
<td>160</td>
<td>485</td>
<td>0</td>
<td>2905</td>
</tr>
<tr>
<td>BSB10</td>
<td>Reliever</td>
<td>840</td>
<td>235</td>
<td>5</td>
<td>225</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1305</td>
</tr>
<tr>
<td>BSB11</td>
<td>Reliever</td>
<td>1700</td>
<td>245</td>
<td>0</td>
<td>240</td>
<td>215</td>
<td>135</td>
<td>0</td>
<td>2535</td>
</tr>
<tr>
<td>BSB12</td>
<td>Starter</td>
<td>1545</td>
<td>765</td>
<td>70</td>
<td>310</td>
<td>190</td>
<td>433</td>
<td>0</td>
<td>3313</td>
</tr>
<tr>
<td>BSB13</td>
<td>Reliever</td>
<td>1336</td>
<td>185</td>
<td>40</td>
<td>368</td>
<td>170</td>
<td>490</td>
<td>0</td>
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</tr>
<tr>
<td>BSB14</td>
<td>Reliever</td>
<td>1445</td>
<td>222</td>
<td>0</td>
<td>210</td>
<td>185</td>
<td>236</td>
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<td>2298</td>
</tr>
<tr>
<td>BSB15</td>
<td>Reliever</td>
<td>960</td>
<td>585</td>
<td>15</td>
<td>230</td>
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<td>160</td>
<td>0</td>
<td>2075</td>
</tr>
<tr>
<td>BSB16</td>
<td>Reliever</td>
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<td>350</td>
<td>382</td>
<td>165</td>
<td>125</td>
<td>296</td>
<td>51</td>
<td>2419</td>
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<tr>
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<td>Reliever</td>
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<td>0</td>
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<td>70</td>
<td>65</td>
<td>30</td>
<td>1503</td>
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<tr>
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<td>Reliever</td>
<td>1330</td>
<td>55</td>
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<td>205</td>
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<td>0</td>
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</tr>
<tr>
<td>BSB19</td>
<td>Reliever</td>
<td>1095</td>
<td>860</td>
<td>215</td>
<td>90</td>
<td>20</td>
<td>14</td>
<td>120</td>
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<td>1470</td>
<td>3850</td>
<td>2478</td>
<td>3785</td>
<td>216</td>
<td>38437</td>
</tr>
<tr>
<td>% Total</td>
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<td>55%</td>
<td>14%</td>
<td>4%</td>
<td>10%</td>
<td>6%</td>
<td>10%</td>
<td>1%</td>
<td>100%</td>
</tr>
</tbody>
</table>

were a total of 1037 exposures in the COVID-19 truncated season with the greatest exposures occurred during practices with 590 (56.9%) exposures and the least exposures observed as being injured out with 26 (2.5%) (Table 3). The frequency counts of pitch types revealed that the most common type of pitches thrown are the catch type accounting for 55% of total pitches (Table 2). Actual game pitches (10%) and bullpen pitches prior to entry into a game (6%) accounted for relatively few number of pitches, which agrees with previous collegiate pitch counts (Table 2). Due to the truncated season, due to the COVID-19 pandemic, 17 pitchers only threw 38,437 pitches averaging to 2,263 pitches per pitcher in 9 weeks of the spring season.

PRE-SEASON MEASUREMENTS

Pre-season descriptive data compared measures collected on the throwing arm to replicate similar studies. Only two measures were found to be significantly different between groups. Players developing an injury were found to have greater shoulder internal rotator strength (p=0.04) and greater grip strength in a neutral position (p=0.03) in the dominant arm (Table 4). No significant differences in the remaining measures were revealed between the pitchers in the injured group compared to those in the non-injured group (Table 4).

IN-SEASON MEASUREMENTS

There were 101 pitcher-weeks exposures for the 17 athletes during the truncated season. As previously described, 12/101 (11.8%) weeks resulted in an overuse injury. It was identified that 10/12 weeks were preceded by an absolute threshold of ACWR>53%. The overuse injuries that were sustained included shoulder internal impingement syndrome, rotator cuff strain, elbow extensor strain (n=2), cubital tunnel neuropathy, bicep muscle strain (n=2), hip flexor strain, and a wrist flexor strain. Due to the low number of events, the Fisher exact test was interpreted to indicate a relationship exists between ACWR>53% and overuse injuries (p=0.001) (Table 5). The relative risk ratio revealed that athletes with an ACWR greater or less than 53% were 8.3 (CI95 1.8-54.1) times more likely to suffer an overuse upper or lower extremity injury in the subsequent week compared to those whose ACWR was within 53% change.

DISCUSSION

The purpose of this study was to examine both pre-season physical measurements and in-season workload factors to identify whether these factors are indicators for increased risk of overuse upper or lower extremity injuries in collegiate baseball pitchers. Our primary hypothesis was not supported as diminished measurement differences between the two groups were not found. Of the 15 pre-season measurements, there was no difference in 13 measurements. Significant differences were found in two strength measurements, although, these differences showed that the injured group was stronger than the non-injured group. This did not agree with the primary hypothesis which stated the in-
Injuries within a collegiate level population. Previous studies have identified that differences in individual mobility and strength measurements lead to increased risk of injury. Others have examined the effect of in-season workload factors and its individual effect on risk of injury in cricket bowlers and in youth, adolescent, and collegiate baseball players. The increased grip strength in the injured groups and the non-injured groups revealed no significant differences in any motion. Our findings do not agree with the findings in the studies by Wilk et al² and Shanley et al. Wilk et al² found that 18% of major and minor league pitchers with a shoulder flexion ROM deficit of 5° in the throwing arm compared to the non-throwing arm were 2.8 times more likely to be placed on the disabled list than those without a deficit. Shanley et al. found that in high school baseball and softball players, decreases in preseason shoulder horizontal adduction (5.2°) and internal rotation (12.1° ± 11.8°) ROM were predictive of who developed an injury. A trend towards statistical significance was noted with reduced shoulder external rotation mobility (p=0.08) in the injured pitcher group which agrees with Camp and colleagues’ findings associated with loss of shoulder external rotation and elbow injuries. The current study findings are in one team over a truncated season likely accounting for different findings.

Results of previous studies suggest that strength deficits have a relationship to upper extremity injuries requiring surgery. Byram et al. identified a trend toward significance (p=0.051) of predicting shoulder injury when examining the prone external rotation strength over prone internal rotation strength ratio. A lower ratio of 0.724 was associated with a 39% increased likelihood of any throwing related injury. This ratio was also lower in those athletes identified in this study who developed a throwing overuse injury (p=0.09). The confounding finding was that the injured group was stronger in shoulder internal rotation than the non-injured group. However, relative to the Byram study, both groups in this study were identified to be weaker than the 5th percentile of professional baseball pitchers. Due to this finding the relative strength balance may be more meaningful than individual strength measures.

The increased grip strength in the injured groups and the nearly significant increased power position grip strength (p=0.13) are interesting findings that are not easily explained. A previous study found a non-significant trend that stronger grip (>25kg) was associated with risk of elbow injuries in youth baseball players. The current study examined all overuse injuries and found that six of the 12 affected the wrist or elbow suggesting that the role that strong grip plays may require future studies on larger number of subjects to determine if there is detrimental effect on

<table>
<thead>
<tr>
<th>ID</th>
<th>Off</th>
<th>Game</th>
<th>Practice</th>
<th>Conditioning</th>
<th>Injured Limited</th>
<th>Injured Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSB3†</td>
<td>14</td>
<td>7</td>
<td>12</td>
<td>8</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>BSB4†¥</td>
<td>11</td>
<td>4</td>
<td>34</td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>BSB5</td>
<td>8</td>
<td>8</td>
<td>38</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB6</td>
<td>6</td>
<td>4</td>
<td>41</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB7</td>
<td>8</td>
<td>5</td>
<td>40</td>
<td>7</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>BSB8†</td>
<td>9</td>
<td>9</td>
<td>29</td>
<td>10</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>BSB9</td>
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<td>4</td>
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<td>9</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>33</td>
<td>0</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB11†</td>
<td>7</td>
<td>4</td>
<td>38</td>
<td>9</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>BSB13</td>
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<td>4</td>
<td>42</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB15</td>
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<td>4</td>
<td>42</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB16†</td>
<td>8</td>
<td>6</td>
<td>32</td>
<td>7</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>BSB18</td>
<td>9</td>
<td>4</td>
<td>38</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB19</td>
<td>9</td>
<td>6</td>
<td>35</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB20†</td>
<td>12</td>
<td>0</td>
<td>39</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB21</td>
<td>6</td>
<td>6</td>
<td>38</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSB22†</td>
<td>10</td>
<td>0</td>
<td>23</td>
<td>5</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>173</td>
<td>75</td>
<td>590</td>
<td>133</td>
<td>40</td>
<td>26</td>
</tr>
<tr>
<td>% Total</td>
<td>16.7%</td>
<td>7.2%</td>
<td>56.9%</td>
<td>12.8%</td>
<td>3.9%</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

* - denotes injury was sustained during the season; † - denotes injury was sustained prior to the start of the season; ¥ - denotes time missed due to illness.
Table 4: Preseason Descriptive Data

<table>
<thead>
<tr>
<th>Range of Motion (degrees)</th>
<th>Injured</th>
<th>Non-Injured</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder Internal Rotation</td>
<td>73</td>
<td>69</td>
<td>0.29</td>
</tr>
<tr>
<td>Shoulder External Rotation</td>
<td>119</td>
<td>124</td>
<td>0.10</td>
</tr>
<tr>
<td>Horizontal Adduction</td>
<td>24</td>
<td>22</td>
<td>0.40</td>
</tr>
<tr>
<td>Shoulder Flexion</td>
<td>187</td>
<td>186</td>
<td>0.90</td>
</tr>
<tr>
<td>Volar Compartment</td>
<td>77</td>
<td>78</td>
<td>0.66</td>
</tr>
<tr>
<td>Left Trunk Rotation</td>
<td>85</td>
<td>83</td>
<td>0.74</td>
</tr>
<tr>
<td>Right Trunk Rotation</td>
<td>87</td>
<td>88</td>
<td>0.96</td>
</tr>
<tr>
<td>Strength (kilograms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder Internal Rotation</td>
<td>19.3</td>
<td>15.1</td>
<td>0.04*</td>
</tr>
<tr>
<td>Shoulder External Rotation</td>
<td>17.1</td>
<td>14.7</td>
<td>0.08</td>
</tr>
<tr>
<td>External Rotation/Internal Rotation Ratio</td>
<td>0.89</td>
<td>1.0</td>
<td>0.09</td>
</tr>
<tr>
<td>Scaption</td>
<td>11.5</td>
<td>11.6</td>
<td>0.92</td>
</tr>
<tr>
<td>Neutral Grip</td>
<td>57.0</td>
<td>51.0</td>
<td>0.03*</td>
</tr>
<tr>
<td>Power Grip</td>
<td>53.9</td>
<td>48.8</td>
<td>0.13</td>
</tr>
<tr>
<td>Posterior Shoulder Endurance Test (s)</td>
<td>79.0</td>
<td>76.0</td>
<td>0.74</td>
</tr>
<tr>
<td>Outcome Measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerlan-Jobe Orthopaedic Clinic</td>
<td>82.7</td>
<td>91.1</td>
<td>0.10</td>
</tr>
</tbody>
</table>

SD = Standard Deviation; * = statistically different at p< 0.05

Table 5: ACWR and Injury contingency table

<table>
<thead>
<tr>
<th>Greater or Less than 33% Change</th>
<th>Injured</th>
<th>Not injured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Within a 33% Change</td>
<td>2</td>
<td>61</td>
</tr>
</tbody>
</table>

The use of patient-reported outcomes at baseline assessment prior to injury is relatively novel but has shown differences between those who did not have an injury history and those with an injury history that may have some underlying issues. Franz et al.14 established normative data for KJOC scores using 203 major and minor league players. This study demonstrated differences in scores between players with a history of shoulder or elbow injury (86.7 ± 14.5) compared to players with no history of injury (96.9 ± 5.0) (p < 0.001). A similar trend was noticed with KJOC scores in the current study. The injured group’s KJOC scores (82 ± 11) were lower than the non-injured group (91 ± 8) which was trending towards significance (p = 0.10). The limited sample limits interpretation of these findings but it appears worth further investigation to assess the ability of the player to tell whether they are likely to develop a future injury.

Collecting data throughout the season using acute to chronic workload ratio to examine changes in training volume has recently become a popular measure to predict injuries.9,10,13,21,22,24 Previous research in baseball is limited but has identified a potential relationship between arm soreness and workload changes in a group of 7 collegiate pitchers.9 This current study expanded with more pitchers and now tracking injuries not just arm soreness. Previous research has used threshold scores ranging from 25%-200% ACWR.10,13,21 The ROC curve analysis from the current study determined that a 33% threshold would be an appropriate threshold to use. This threshold is consistent with previous baseball workload research that showed that changes of 27% revealed that baseball players were 14.9 times more likely to sustain an injury when this amount of change occurred.13 The previous findings are consistent with the current study identifying an eight-fold increased likelihood of injury in baseball pitchers when workload was greater or less than 33%. The current study purposefully examined both increases and decreases in workload ratios as the literature has indicated that both a positive and neg-
ative training spike may predispose athletes to developing musculoskeletal injuries. This study observed 12 pitcher-weeks with injury and an even split of six were due to negative training and six were due to increased stress that preceded injury. The results indicate that changes in pitch volume were seen to have a greater influence regarding ACWR in the time leading to injury. It appears that changes in both directions can alter tissue’s ability to adapt to workloads placed on the upper and lower extremity in pitchers and should be considered in restarting activity following long layoffs.

LIMITATIONS

The primary limitation of this study was that large number of subjects and injuries are often needed to see differences which did not occur in this study. Baseline data was only collected once prior to the start of the season. Collecting measurements throughout the season may have identified if changes in measurements could have influenced the risk of sustaining an injury. Pitch counts were recorded estimates instead of actual pitch counts due to limited resources to capture every pitch. The risk of in-season injury was only examined during a singular season which resulted in a truncated season of only 9 weeks due to COVID-19. This study only examined chronic, overuse injuries and could have included acute, traumatic injuries as well. More weekly exposures are needed as the confidence interval suggest that our estimates may be more by chance than reality. Future studies should consider collecting preseason measurements and in-season factors over multiple years with the hopes of analyzing larger data sets to further examine results.

CONCLUSION

The findings of this research suggest that ACWR change in a positive or negative direction by at least 33% was the primary predictor of subsequent injury. The authors believe that this finding may assist sports medicine clinicians by using this threshold when tracking pitch volume to ensure a safe progression in workload during a baseball season in order to reduce the risk of sustaining overuse upper or lower extremity injuries, however, this should not be the only intervention strategy utilized. Significant differences including increased shoulder internal rotation strength and grip strength in the injured group were identified in this pilot study. The current study findings do not agree with previous literature, so caution with interpretation should be taken. This study serves as pilot data that suggest further acquisition of prospective data across more years may provide collegiate baseball teams with information to reduce injury risk to the upper or lower extremity as they progressively increase or decrease training volumes.

CONFLICT OF INTEREST

No conflicts of interest to report.

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REFERENCES


Original Research

Youth Baseball Caregiver Understanding of Safe Pitching Guidelines and Player Injury

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Background

As more athletes participate in youth baseball, there has been an associated increase in upper extremity injuries. Knowledge of baseball injury prevention guidelines continues to be developed and defined as throwing-related injuries rise. The purpose of this study was to evaluate how knowledgeable youth baseball caregivers were about safe pitching guidelines and secondarily determine pitching practices which may be associated with increased risk of player injury.

Methods

A twenty-two question survey comprised of demographic data, knowledge of overhead throwing guidelines, pitching history, presence of risk factors associated with overhead throwing and pitching habits was distributed to the caregivers of youth baseball pitchers in North Central Florida.

Results

Eighty-three percent (81/98) of those polled were unaware of the existence of safe pitching guidelines, regardless of the pitcher’s playing experience (p > 0.05). Those who pitched more than six months out of the year were significantly more prone to experience throwing arm pain after a performance (p < 0.05). Fifty-two percent (51/98) of the caregivers recalled their child having throwing arm pain as a direct result of pitching, with twenty-six percent (25/98) of pitchers having to miss either a game or a pitching appearance. Twenty-seven percent (26/98) of all players went on to seek medical evaluation for arm discomfort due to pitching. Pitchers 13 years of age and older were more likely to throw curveballs and miss games because of throwing arm pain (p < 0.05).

Conclusion

Despite implementation and accessibility of safe pitching guidelines, a large portion of those surveyed were unaware or noncompliant with these established recommendations. Given the results of this study, further measures need to be taken to improve caregivers’ understanding of current guidelines to help increase compliance and protect youth pitchers.

Level of Evidence

Cross-sectional survey study, 3b

INTRODUCTION

Analysis of how to improve the safety of all amateur sports participants is an area of interest for multiple groups including players, coaches, caregivers, and medical care providers. Protecting youth baseball players from preventable injuries is imperative considering there are over 200,000 youth baseball teams in the United States.1 Systems to reduce the incidence of overuse injuries include
limiting pitch counts (during games, weeks, seasons), allowing for periods of time (months) without pitching, limiting participation in multiple leagues, regulating pitch type, and learning appropriate throwing mechanics.2–6 There are a number of sources that baseball players, caregivers, and coaches can use to learn about safe pitching practices, a majority of which can be found online (Table 1 and Table 2). Despite the accessibility of information regarding safe pitching practices, little league pitchers continue to experience overuse injuries.

A study performed by Fazarale et al. provided a questionnaire to youth baseball coaches in their region concerning the USA Baseball Medical and Safety Advisory Committee (USA BMSAC) pitching guidelines.3 Seventy-three percent of the coaches reported compliance with the recommendations, yet only 45% of the questions regarding pitch count and rest periods were answered correctly. The coaches surveyed believed that only 53% of other coaches in their league followed the guidelines. Furthermore, 19% of these coaches knew that at least one of their players pitched in a game with a sore or fatigued arm. This is of particular concern because many sports medicine experts see shoulder and elbow pain not as an innocent symptom, but rather a warning sign of an acute or developing overuse injury.1

Caregivers and youth baseball players often rely on coaches to enforce safe pitching practices, however previous data has demonstrated that this may not always be consistent.3,6 Petty et al. evaluated risk factors for ulnar collateral ligament (UCL) injury in high school pitchers. In their patient population only 13 of 25 pitchers (52%) believed their coaches were proactive about preventing throwing injuries. They also reported situations where they believed they were overthrowing, including pitching during playoff games, tournaments, and showcase tryouts.6 Additionally, youth pitchers themselves have demonstrated a substantial lack of comprehension of appropriate pitching practices, with as many as 85% reporting never having heard of USA BMSAC guidelines and 57% indicating that they would not seek medical help if they had throwing arm pain after a game.2

The failure of appropriate education can occur at many levels, including ignorance that guidelines exist, lack of awareness of where to learn about guidelines, inaccurate provision of information by coaches, and failure to understand the overall importance of guidelines. To date, no study has evaluated the knowledge that each child's caregiver possesses. The primary purpose of this study was to evaluate how knowledgeable youth baseball caregivers were about safe pitching guidelines and secondarily determine pitching practices which may be associated with increased risk of player injury.

**MATERIALS AND METHODS**

This cross-sectional survey study was approved by the University of Florida Institutional Review Board. A twenty-two question survey was distributed to the caregivers of youth baseball pitchers between the ages of 7 and 18 years old across North Central Florida. Locations utilized for distribution included regional baseball fields during practices and games, the Orthopaedics and Sports Medicine Institute clinics, and affiliated physical therapy/rehabilitation centers in order to reduce bias. The survey was constructed to capture questions on caregiver demographic data, knowledge of throwing guidelines, athlete pitching background and throwing habits based on recommendations provided by the USA Baseball and Medical Safety Advisory Committee, Little League Baseball, and the American Sports Medicine Institute (Appendix 1). The caregivers of the youth pitchers were asked to complete and return the survey. The results of each survey were then placed into a deidentified database using the Research Electronic Data Capture (REDCap) application at the University of Florida. Chi-square
analysis was used to evaluate the categorical variables with the level of significance set a-priori at \( p \leq 0.05 \). As guidelines stratify recommendations based on specific age brackets, a separate subgroup analysis was performed between pitchers less than 13 years old and those 13 years or older to represent youth athletes and those in adolescence. 

RESULTS

POPULATION CHARACTERISTICS

The survey resulted in 102 responses, 98 of which were used for analysis. One survey was excluded because it pertained to a baseball player who was not a pitcher and three others were completed by someone who was not the child’s primary caregiver. Fifty-two percent (51/98) identified themselves as the child’s mother. Ninety-one percent (89/98) of the respondents were Caucasian, and forty percent (39/98) of respondents fell within the 41 to 50 year-old age group. Of those surveyed, thirty-eight percent (37/98) were the caregivers of a pitcher between the ages of 13 and 16. With regards to education, seventy-six percent (74/98) had an associate’s degree, bachelor’s degree, or advanced degree (Table 3).

SURVEY RESULTS

Eighty-three percent (81/98) of those polled were unaware of the existence of safe pitching guidelines. Fifty-three percent (52/98) of the surveyed population did not actively participate in monitoring their child’s pitch count. Seventeen percent (17/98) of the caregivers were unaware of how many pitches their children throw in a typical game. In children 13 years and older, if their caregiver was aware of pitching guidelines, they were more likely to estimate their child threw less than 85 pitches per game (\( p < 0.05 \)).

Forty-four percent (43/98) of the pitchers threw in more than one league at a time while eighteen percent (18/98) pitched at least nine months out of the year. Participation in extra showcase scenarios was reported by fifty-eight percent (57/98) of caregivers and twenty-eight percent (27/98) in four showcase camps or more annually (Table 4). When not pitching, eleven percent (11/98) of the population identified catcher, twenty-six percent (25/98) outfield, and sixty-one percent (60/98) infield as their child’s primary position.

Seventeen percent (17/98) of the caregivers surveyed did not know what kinds of pitches their children throw. Thirty-four percent (34/98) only threw fastballs, change-ups and knuckle balls while fifty-one percent (50/98) also threw breaking pitches (Figure 1). Forty-two percent (41/98) of children were taught pitching technique by their coach, followed by twenty-seven percent (26/98) with a hired instructor, twenty-one percent (21/98) answering “other”, and twelve percent (12/98) taught by a caregiver (either the respondent or their spouse).

Fifty-two percent (51/98) of the caregivers recalled their child having upper extremity pain as a direct result of pitching, which was located twenty-three (45%) times in the shoulder and nine times in the elbow (18%) (Table 5).

Twenty-six percent (25/98) of the pitchers had to miss either a game or a pitching appearance because of their throwing arm pain, and twenty-seven percent (26/98) experienced pain concerning enough to be evaluated by a medical professional (Table 6).
Those pitchers who threw breaking pitches or threw for more than six months out of the year were more likely to experience arm pain after a pitching performance (Figure 2a and Figure 2b, Figure 3; p < 0.05). There was also a general trend toward significance noted in regards to increasing number of months pitching out of the year and arm pain (p = 0.059).

VARIABLE CORRELATIONS

Compared to pitchers younger than 13, players 13 years and older were more likely to throw curveballs (25% compared to 12%; p < 0.05). Additionally, children 13 years of age and older were more likely to miss games because of throwing arm pain (20% compared to 6%; p < 0.05).

Using the same age cutoff of 13 years, there was no statistically significance difference found between awareness of youth pitching guidelines, number of pitches typically thrown in a game, position when not pitching, and who keeps track of pitch count (p > 0.05).

DISCUSSION

Overhead throwing creates an environment of significant mechanical stress. During the pitching motion, the kinetic chain transfers energy from the lower extremity, through the trunk, and finally through the upper extremity. The shoulder and elbow are sensitive to biomechanical stress and prone to pathology because they are inherently less stable joints and near the end of the energy transfer. Individuals who are involved in repetitive events, like pitchers, can be disposed to anatomical and mechanical changes in the throwing arm commonly presenting as overuse injuries.1,10,11

Eighty-three percent of baseball caregivers were unaware of safe pitching guidelines. Given the potential catastrophic complications that can occur from overhead pitching at an early age, the medical community should continue to make data-driven recommendations to best prevent irreparable damage. Many researchers have recognized that prevention of acute and chronic injuries stems from a multidisciplinary approach that includes sports medicine providers, coaches, and caregivers.1,6,12 Limpisvasti et al. recommended that injury prevention in youth baseball begin as early as possible. This is particularly true for those who have the opportunity to play at higher levels, as many of the injuries sustained later in a players’ career are speculated to be the culmination of insults that began at a young age.1

The overall rate of baseball overuse injuries has been estimated at 5% in some studies, with an injury rate of 1.39 per 10,000 athlete-exposures (AEs) for the shoulder and 0.86 per 10,000 AEs for the elbow.13,14 In their patient population, Andrews et al showed that pitchers sustain the majority of shoulder (59.6%) and elbow (56.9%) injuries which were most often caused by overuse. From this same study 10.8% of shoulder injuries and 3.6% of elbow injuries required surgery.14 In this population, 26% of the pitchers had to miss at least one game because of throwing arm pain, and 27% had pain severe enough to require an evaluation by a physician. This number remains unacceptably high and merits further investigation into the failure of preventative measures.

Olsen et al demonstrated that the amount of pitching is the strongest risk factor that correlates with shoulder and elbow pathology. They determined that throwing greater than 80 pitches per appearance and pitching competitively more than eight months per year increased the odds of an injury requiring surgery by 3.83 and 5.05, respectively.15 Despite no statistically significant difference between average number of pitches thrown during a game and throwing arm pain, these findings otherwise support this conclusion with players throwing for greater than six months associated with a significant increase of throwing arm pain. Promisingly, only eighteen percent of participants pitched during nine or more months out of the year. In addition, Zaremski and Farmer demonstrated a highly likelihood of UCL reconstruction in athletes playing in the Southeastern Conference (SEC) compared to more northern conferences. This parallels the playing environment of pitchers from this study as rosters in the SEC consisted of a greater number of players from southern states and were more likely to have grown-up playing baseball year-round.16

There are recommendations to limit the number of different leagues, teams, and showcases in which pitchers participate based on outcomes reported in previous retrospective reviews.17 Seventy-seven percent of players did not participate in other sports beside baseball during the season.
Table 6: Prevalence of throwing arm pain in youth pitchers

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
<th>Don’t Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has your child experienced arm pain in their throwing arm after a pitching performance?</td>
<td>51/97 (52.6%)</td>
<td>40/97 (41.2%)</td>
<td>6/97 (6.2%)</td>
</tr>
<tr>
<td>Has your child ever had to miss a game/practice due to throwing arm pain?</td>
<td>25/96 (26%)</td>
<td>67/96 (69.8%)</td>
<td>4/96 (4.2%)</td>
</tr>
<tr>
<td>Has your child ever been evaluated by medical personnel for arm pain?</td>
<td>26/96 (27.1%)</td>
<td>68/96 (70.8%)</td>
<td>2/96 (2.1%)</td>
</tr>
</tbody>
</table>

and only thirty-nine percent did play another sport outside of the baseball season. Although a growing trend and widely prevalent, early specialization in sports has been demonstrated to lead to higher rates of injury, increased psychological stress and loss of interest in playing. In this sample population forty-four percent of those surveyed reported that their child pitched in more than one league concurrently. Furthermore, while fifty-eight percent of pitchers participated in at least one showcase camp annually, twenty-eight percent participated in four or more. In many circumstances, pitchers have different coaches for each team or showcase. This leads to a lack of continuity in regulating pitch counts and appropriate time off. These situations demonstrate the importance of caregivers becoming both knowledgeable and compliant with safe pitching practices, yet the findings from this study demonstrate that at least fifty-three percent of youth pitchers will not have appropriate oversight.

Overuse injuries of the shoulder and elbow can be exacerbated by other repetitive overhead activities outside of pitching. Data published in 2001 demonstrated that a pitcher who also plays catcher is 2.7 times more likely to sustain a serious throwing arm injury. Additionally, Fleisig and Andrews noted that the shoulder and elbow microtrauma created during pitching may not have adequate time to resolve when pitchers also play catcher. These studies in part form the basis of the recommendation that a pitcher should not also play catcher for their team. Encouragingly, in the population of this survey only eleven percent of the baseball players identified playing catcher as their primary position when not pitching and although sixty-one percent reported playing in the infield secondarily, separate analysis did not find a significant association between alternate field position and throwing arm pain.

The appropriate age at which pitchers should begin to throw specific pitches has gained increasing interest in the sports medicine and baseball communities. Current recommendations from the American Academy of Orthopedic Surgeons (AAOS) are that pitchers should refrain from throwing breaking pitches (curveballs and sliders) until they are skeletally mature. This suggestion is more stringent than previous guidelines which recommended that pitchers not throw breaking pitches until 14 years of age. An article published in AJSM in 2002 investigated if there was a correlation between breaking pitches and injury by prospectively following 476 youth pitchers between the ages of 9 and 14 for a baseball season. They found that the curveball was associated with a 52% increase in shoulder pain while the slider increased elbow pain by 86%. Although questioned by more recent literature which has failed to find an increase in shoulder and elbow forces after breaking pitches compared to other types, in this population of pitchers analysis demonstrated a statistically significant relationship between those players who threw breaking pitches and throwing arm pain (p < 0.05). Nonetheless, 24% of pitchers under 13 years of age were re-
ported to throw curveballs, and 10% in this same age group threw sliders. This result demonstrates that pitchers continue to participate in activities that are contrary to established guidelines. The reason for this may be unfamiliarity with the recommendations from coaches and caregivers or lack of knowledge regarding the association between types of pitches and throwing arm pain.

There are several limitations to this study which encompass the same confounding factors of other cross-sectional surveys. First, a majority of the surveys were administered to caregivers during athletic competition, while only a small amount were provided in a physician’s office or in physical therapy. This may lead to a selection and convenience sample bias, and may not be representative of the population at large. Similarly, this analysis illustrates only a specific geographical region (North Central Florida); therefore, the experiences in this location may not be characteristic of the rest of the country but are likely generalizable to other warm climate areas. More surveys were distributed than the total response of 102, and the nonresponse group may have answered differently which would have altered the results.

Several of the questions in the survey also ask specific details regarding pitch counts and days between performances – the nature of these questions is highly susceptible to recall bias. Although edited and tailored to focus on issues surrounding pitching, the questions may have unintentionally lead individuals or been misinterpreted. Additionally, private pitching lessons were not analyzed, which could have a dramatic effect on overall pitching volume.

Further directions based on the results of this study would include distributing either the same or a similar survey to multiple geographic locations so that all the data could be compiled into one data set for further review. These findings demonstrate a need for better education of youth baseball caregivers. One method of improving their knowledge of guidelines and access to resources would be for healthcare providers to participate in community outreach programs. The efficacy of these outreach programs could be evaluated by prospectively collecting data on shoulder and elbow injuries before and after their implementation.

CONCLUSION

No other study to date has sought to determine caregivers’ knowledge of safe pitching practices. Despite the implementation and accessibility of safe pitching guidelines, a large portion of those surveyed were unaware of or non-compliant with these established recommendations. These findings demonstrated an increase of throwing arm pain in youth baseball players pitching more than six months out of the year, suggesting that annual limitations on pitching performances be considered. Players 13 years and older were more likely to use breaking pitches and miss games due to throwing arm pain, supporting current guidelines from the AAOS that pitchers refrain from throwing breaking pitches until reaching skeletal maturity. Given the results of this study, further measures need to be taken to improve caregivers’ understanding of the guidelines to help increase compliance and protect youth pitchers. Injury prevention should be a multidisciplinary approach that includes educating coaches, caregivers, and youth pitchers. Future directions may include establishing outreach programs for the youth baseball community.

SUPPORT/CONFLICTS OF INTEREST

No sources of support or conflicts of interest to disclose

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REFERENCES


Appendix 1: Caregiver Questionnaire

A Nation-Wide Survey of High School Baseball Coaches’ Perceptions Indicates their Arm Care Programs Play a Role in Injury Prevention

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1 University of Kentucky; University of Evansville, 2 University of Kentucky, 3 Saint Louis Cardinals Baseball Organization

Keywords: arm care, baseball, injury prevention, movement system

Background
Arm care programs consisting of upper extremity strengthening and stretching have been recommended for injury prevention for pitchers of all ages. There has been no investigation into high school baseball coaches’ usage and perceptions of arm care programs to mitigate physical impairments associated with injuries in baseball players.

Hypothesis/Purpose
The purpose of this study was to investigate the current usage of arm care programs by high school baseball coaches. The primary objective was to determine if coaches use group-based or individualized arm care programs. The secondary objective sought to determine if the use of arm care programs is influenced by coaches’ age, education, and experience level. Finally, this study explored the potential barriers to arm care implementation and high school baseball coaches’ current awareness and beliefs of injury prevention.

Study Design
Descriptive cross-sectional survey

Methods
A 29-item online survey was emailed to 18,500 high school baseball coaches throughout the United States. Data were collected for three months, and the response rate was 3.7%.

Results
A total of 87.3% (n=571/654) of responding coaches use arm care programs with their players. Of coaches performing arm care, only 18.5% of 571 individualize their arm care exercises based on specific player needs. However, older and more experienced coaches are more likely to individualize their programs. Among the 12.7% (n=83/654) of coaches who do not use arm care programs, the two most commonly cited reasons for not implementing arm care were lack of observed benefit (41%) and insufficient staff (31%). Although 42% of 654 coaches recognized reduced shoulder mobility as a major contributor to injury, risk factors such as throwing with a fatigued arm, previous injury history, and throwing > 8 months per year were not consistently identified as primary risk factors.

Conclusion
The results of this study suggest that the majority high school baseball coaches implement group-based arm care exercise programs to prevent injury. Lack of confidence in the effectiveness and staffing limitations were major barriers to implementation of arm care programming. However, the responding coaches exhibited inconsistent risk factor
INTRODUCTION

Injuries to the shoulder and elbow are common among high school baseball pitchers. The incidence of experiencing elbow or shoulder pain in high school pitchers is 1.0 per 1000 athletic exposures (AEs) and 1.5 per 1000 AEs, respectively. The shoulder and elbow joint are exposed to tremendous stress during the throwing motion which is typically repeated hundreds of times during competition throughout the season. A number of risk factors, including range of motion (ROM) and strength limitations, high levels of throwing volume, and an increase in acute workload, have been identified as contributing to increased arm soreness and time loss injuries. To combat these risk factors, researchers have focused on investigating compliance with pitch counts, number of rest days in between starts, managing yearly pitching volume, discouraging pitching showcases, and playing catcher as secondary position. As a result, arm care programs, which typically consist of upper extremity strengthening and stretching, core stability, and management of pitching volume have been suggested as necessary components of injury prevention plans for pitchers of all ages.

To reduce the risk of injury to the shoulder and elbow, the USA Baseball Medical & Safety Advisory Committee (USA BMSAC) and Major League Baseball established the Pitch Smart guidelines in 2014. These guidelines proposed age specific throwing limitations in an attempt to manage pitching volume, workload, and fatigue. However, understanding and compliance of these guidelines among baseball coaches have been undermining. In a 2018 survey of 61 baseball coaches, Knapik et al. found that only 56% of coaches kept track of pitch counts routinely and only 45% reported compliance with age specific pitch count recommendations. Considering the poor compliance and knowledge relative to the Pitch Smart guidelines, it is reasonable to suggest that underutilization and awareness deficits regarding arm care programs could also be problematic. Knapik et al. reported that only 8% of the 61 baseball coaches surveyed could correctly identify risk factors that could lead to overuse injury. This lack of knowledge of physical risk factors makes designing effective arm care programs difficult.

When implemented, arm care programs have been shown to be effective at reducing overuse injuries to the elbow and shoulder in overhead athletes. In a randomized controlled trial, Sakata et al. demonstrated a 48.5% reduction in elbow overuse injuries in youth baseball players. Shitara et al. reported that stretching the posterior shoulder muscles lowered the incidence of shoulder and elbow injuries by 36% in high school baseball pitchers. While these two studies showcase the potential effectiveness of arm care programs, there has been no investigation into high school baseball coaches’ current usage and perceptions of arm care programs to improve physical impairments associated with the injury risk factors described above.

To date, the authors are unaware of another study which has explored the application and characteristics of arm care programs from the perspective of the high school baseball coach. Therefore, the purpose of this study was to investigate if high school baseball coaches are using arm care programs to promote shoulder and elbow health for their players. The primary objective was to determine if high school baseball coaches are implementing generalized group-based programs or individualized arm care based on the specific needs of the player. It was hypothesized that less than 50% of high school coaches who implement arm care exercises will use individualized programs. The secondary objective was to investigate if the use of arm care programs is influenced by coaches’ age, education, and experience level. It was hypothesized that older coaches with more education and experience will be more likely to implement individualized arm care exercises. Finally, this study explored potential barriers to arm care implementation and high school baseball coaches’ current awareness and beliefs associated with injury prevention. It was hypothesized that limited time and resources would be identified as common barriers to arm care implementation and that high school coaches would demonstrate limited knowledge of important injury risk factors.

METHODS

SURVEY DEVELOPMENT

This was a descriptive, cross-sectional study which evaluated the current application and characteristics of arm care programs and injury prevention concepts in high school baseball coaches. An electronic survey (Appendix 1) was developed in Qualtrics (electronic data capture tools hosted at the University of Kentucky) based on the current literature involving injury prevention exercise programs in adolescent baseball players. The survey was created by two rehabilitation professionals (KAM and TLU) with multiple years of clinical and research experience in baseball. The survey contained 29-items which were represented in three sections including, 1) demographics/coaching experience, 2) characteristics and application of arm care programs, and 3) knowledge and beliefs of injury prevention measures.

The first section consisted of five questions related to demographic information such as the participant’s age, education level, and coaching experience. Additional questions in this section were related to the age and competition level (school team, recreational league, or traveling team) of the baseball players the participant has coached. Therefore, the purpose of this study was to investigate if the use of arm care programs is influenced by coaches’ age, education, and experience level. It was hypothesized that older coaches with more education and experience will be more likely to implement individualized arm care exercises. Finally, this study explored potential barriers to arm care implementation and high school baseball coaches’ current awareness and beliefs associated with injury prevention. It was hypothesized that limited time and resources would be identified as common barriers to arm care implementation and that high school coaches would demonstrate limited knowledge of important injury risk factors.
grams among high school coaches. The questions in this section were specific to the design of arm care programs and examined the concepts of group versus individualized programs, goals, program components, frequency of performance per week, time allocated to specific exercises and body regions, and barriers to implementation. The third section had seven questions which were designed to determine the high school coaches’ knowledge and current beliefs related to injury prevention. The questions in this section asked about injury risk factors specific to baseball players, effectiveness of arm care programs related to injury incidence reduction, and whether or not risk factors should be monitored throughout the season.

Prior to nationwide distribution, the intra-rater reliability of the survey was assessed in a sample of 11 baseball coaches. Each coach completed the survey twice with a 10-day washout period in-between and absolute intra-rater agreement was measured with a weighted Cohen’s kappa statistic. The survey demonstrated excellent intra-rater absolute agreement with a weighted kappa value of 0.87 and excellent internal consistency with a Cronbach's alpha of 0.97. 34, 35

SURVEY SAMPLING

Approximately 18,500 high school baseball coaches were contacted through email to participate in the online survey. Participant recruitment was conducted by the National High School Baseball Coaches Association and through access to the Clell Wade Coaches Online Directory. Both organizations have directories containing email addresses of thousands of high school baseball coaches throughout the United States. These organizations directly contacted the participants through their email database and provided them with the link to the survey.

The investigators of this study did not have access to participants’ emails or any other personal identification information. Participation in the survey was voluntary and all responses to the survey were anonymous. Prior to beginning the survey, participants read the consent form and checked the "I agree" option if they wished to consent to the study. Participants were included in the study if they were willing and able to complete the online survey. Participants were excluded if they did not complete the required survey questions or selected the "I do not agree" to consent option prior to filling out the survey. Responses to the online survey were prospectively collected for three consecutive months from February to April 2020. Approval from the institutional review boards at the University of Kentucky and the University of Evansville were obtained prior to data collection for this descriptive survey study.

STATISTICAL METHODS

According to the National Federation of State High School Associations, there are approximately 20,000 high school baseball coaches in the United States. Therefore, a sample size of 377 participants was needed to ensure the responses reflected the views of the population with a 95% confidence interval and a 5% margin for error. 36 Descriptive statistics for nominal and ordinal data were summarized through frequencies and percentages and analyzed for differences with a one-way chi-square test. Cross tabulations and chi-square tests of independence were used to consider associations between use of arm care programs and coaching experience, age, and education level. An alpha level of $p < 0.05$ was considered statistically significant for all tests. All data analyses were performed with SPSS statistical software (IBM SPSS Statistics for Mac, Version 26.0).

RESULTS

A total of 688 (3.7%) high school baseball coaches throughout the United States responded to the online survey between February 3, 2020 and April 7, 2020. Of these 688 surveys, 34 were excluded due to insufficient completion of questions beyond the demographics section. Therefore, the remaining 654 surveys represented an inclusion rate of 96% (654/688) and were used for data analyses. Demographic information for the coaches’ age, years of coaching experience, educational level obtained, age of players coached, and level of players coached is displayed in Table 1.

APPLICATION AND CHARACTERISTICS OF ARM CARE PROGRAMS

In high school baseball coaches who responded to the survey, 87.3% (n=571/654) reported that they have their players perform an arm care program to maintain/improve upper extremity health (Table 2). Amongst the coaches who perform an arm care program, there were more coaches performing group-based programs (81.4%, n=465/571) than individualized arm care programs (18.6%, n=106/571) which were specific to the players’ needs ($p<0.001$) (Table 2). Overall, 85.2% (n=557/654) of coaches reported that they would be interested in an arm care screening tool to better inform their programs. Furthermore, 71.1% (n=59/85) of coaches who are not currently doing an arm care program would be interested in an arm care screening tool to guide their program ($p<0.001$).

Chi-Square analysis revealed no significant relationship between the age of the high school baseball coach and whether the coach chose to use an arm care program with their players ($p=0.325$). However, coaches over the age of 40 years were significantly more likely to design individualized arm care programs for their players compared to group-based programs ($p=0.002$). Coaches with greater than seven years of coaching experience were significantly more likely to use an arm care program ($p<0.001$) and individualize the program to address the specific needs of their players ($p<0.001$). There was no significant relationship between use of arm care programs and the coaches’ level of terminal degree achieved ($p=0.458$) (Table 3).

BARRIERS TO ARM CARE IMPLEMENTATION

The coaches who did not perform arm care programs identified the largest barrier reported was not seeing the benefit of an arm care program (41%, n=34/83) and not having enough staff to assist (31.3%, n=26/83) (Figure 1). Only 11% of 85 coaches reported that lack of time was a major barrier to implementing arm care exercises. Moreover, 96.6%
Table 1: Demographics of the High School Coaches

<table>
<thead>
<tr>
<th>Question</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How old are you?</td>
<td></td>
</tr>
<tr>
<td>&lt;20 years</td>
<td>0 (0)</td>
</tr>
<tr>
<td>20-29 years</td>
<td>77 (11.8)</td>
</tr>
<tr>
<td>30-39 years</td>
<td>190 (29.1)</td>
</tr>
<tr>
<td>40-49 years</td>
<td>205 (31.3)</td>
</tr>
<tr>
<td>&gt;50 years</td>
<td>182 (27.8)</td>
</tr>
<tr>
<td>What level of team do you coach?</td>
<td></td>
</tr>
<tr>
<td>Recreational team</td>
<td>25 (13.5)</td>
</tr>
<tr>
<td>School team</td>
<td>619 (84.9)</td>
</tr>
<tr>
<td>Traveling team</td>
<td>5 (0.8)</td>
</tr>
<tr>
<td>Other</td>
<td>5 (0.8)</td>
</tr>
<tr>
<td>What is the age of the baseball players you coach?</td>
<td></td>
</tr>
<tr>
<td>&lt;15 years</td>
<td>13 (2.0)</td>
</tr>
<tr>
<td>15-18 years</td>
<td>636 (97.4)</td>
</tr>
<tr>
<td>19-22 years</td>
<td>4 (0.4)</td>
</tr>
<tr>
<td>&gt;22 years</td>
<td>1 (0.2)</td>
</tr>
<tr>
<td>How many years have you been involved in coaching baseball?</td>
<td></td>
</tr>
<tr>
<td>&lt;1 year</td>
<td>5 (0.8)</td>
</tr>
<tr>
<td>1-3 years</td>
<td>33 (5.0)</td>
</tr>
<tr>
<td>4-6 years</td>
<td>80 (12.2)</td>
</tr>
<tr>
<td>7-10 years</td>
<td>95 (14.5)</td>
</tr>
<tr>
<td>&gt;10 years</td>
<td>441 (67.5)</td>
</tr>
<tr>
<td>What is the highest education level you have achieved?</td>
<td></td>
</tr>
<tr>
<td>High school/GED</td>
<td>7 (1.1)</td>
</tr>
<tr>
<td>Some college</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Bachelor of Science</td>
<td>265 (40.5)</td>
</tr>
<tr>
<td>Master's degree</td>
<td>303 (46.3)</td>
</tr>
<tr>
<td>Doctoral degree</td>
<td>22 (3.4)</td>
</tr>
</tbody>
</table>

(n=552/571) of coaches allow the players to perform arm care during practice time. Sixty percent (n=342/571) of coaches consider 10-20 minutes of practice time dedicated to arm care exercises reasonable and 36.8% (n=205/571) encourage their players to perform their exercises 3x/week (Table 2).

INJURY PREVENTION AWARENESS AND BELIEFS

Most high school coaches (64.1%, n=366/571) who have their players perform arm care programs reported that the main goal for the program is prevention of injuries (Figure 2). Among high school baseball coaches, 97.7% (n=639/654) either "strongly agree" or "agree" that injury risk factors should be monitored throughout the entire season (Table 4). However, when surveyed on which risk factors contributed most to pitching injuries, the majority of coaches reported that reduced shoulder ROM was the largest contributor (42.4%, n=277/651) followed by pitching > 8 months per year (33%, n=215/651). However, throwing with a fatigued arm and playing catcher as a secondary position were only identified as risk factors in 16.7% (n=109/651) and 2% (n=12/654) of coaches surveyed, respectively (Figure 3). Furthermore, 27.7% of 654 surveyed coaches were either "not sure" or "disagreed" that a previous injury increases risk for future injuries.

Overall, 98.3% (n=643/654) of high school baseball coaches believe that arm care programs can reduce throw-
Table 2: Arm Care Application and Characteristics

<table>
<thead>
<tr>
<th>Questions for Coaches</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you currently have your players perform a program to improve arm health?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>571 (87.3)</td>
</tr>
<tr>
<td>No</td>
<td>83 (12.7)</td>
</tr>
<tr>
<td>Which of the following best describes your arm care program?</td>
<td></td>
</tr>
<tr>
<td>Group-based - general program that is similar to all players</td>
<td>465 (81.4)</td>
</tr>
<tr>
<td>Individualized - each player receives different exercises specific to their needs</td>
<td>106 (18.5)</td>
</tr>
<tr>
<td>Would you be interested in a 3-minute screen to help individualize your arm care program?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>557 (85.2)</td>
</tr>
<tr>
<td>No</td>
<td>97 (14.8)</td>
</tr>
<tr>
<td>Should pitchers participate in an exercise program to improve/maintain arm health?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>570 (99.8)</td>
</tr>
<tr>
<td>No</td>
<td>1 (0.2)</td>
</tr>
<tr>
<td>Do your players perform the arm care program during baseball practice time?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>552 (96.6)</td>
</tr>
<tr>
<td>No</td>
<td>19 (3.4)</td>
</tr>
<tr>
<td>How many times per week do your players perform your arm care program during the season?</td>
<td></td>
</tr>
<tr>
<td>1x/week</td>
<td>9 (1.6)</td>
</tr>
<tr>
<td>2x/week</td>
<td>79 (14.2)</td>
</tr>
<tr>
<td>3x/week</td>
<td>205 (36.8)</td>
</tr>
<tr>
<td>4x/week</td>
<td>51 (9.2)</td>
</tr>
<tr>
<td>5x/week</td>
<td>107 (19.2)</td>
</tr>
<tr>
<td>6x/week</td>
<td>96 (17.2)</td>
</tr>
<tr>
<td>7x/week</td>
<td>10 (1.8)</td>
</tr>
<tr>
<td>What time of year do you have your players perform your arm care program?</td>
<td></td>
</tr>
<tr>
<td>Preseason only</td>
<td>7 (1.2)</td>
</tr>
<tr>
<td>Offseason only</td>
<td>19 (1.8)</td>
</tr>
<tr>
<td>Start of season to end of season</td>
<td>40 (7)</td>
</tr>
<tr>
<td>Preseason to end of season</td>
<td>337 (59)</td>
</tr>
<tr>
<td>Year around</td>
<td>177 (31)</td>
</tr>
</tbody>
</table>

DISCUSSION

The overarching purpose of this survey was to investigate the usage of arm care programs by high school baseball coaches to promote arm health. The results of the survey demonstrated greater than 87% of responding high school coaches implement arm care programs. From the perspective of the coach, the primary objective for arm care programming is to prevent injuries, but the results suggest that their injury prevention awareness and strategies are limited. The notion that arm care exercise programs can reduce injury incidence is not a novel concept as several prior studies have supported this outcome. The data suggest that coaches believe that parents play the largest role in preventing baseball injuries. Interestingly, coaches believed that parents and medical professionals such as physical therapists, athletic trainers, and physicians play a much smaller role in preventing baseball injuries. Only 2.8% (n=18/654) of high school coaches believed that parents played the greatest role in injury prevention, whereas only 1.5% (n=10/654) of coaches believed that medical professionals were responsible. (Figure 4).

![Figure 2: Coaches’ response to the primary goal of their arm care program](image)
Table 3: Comparisons Between Coaches Demographics and Use of Arm Care Programs

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes (%)</th>
<th>No (%)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the age of the coach associated with use of arm care programs?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;40 years</td>
<td>85.8%</td>
<td>14.2%</td>
<td>0.325</td>
</tr>
<tr>
<td>&gt;40 years</td>
<td>88.4%</td>
<td>11.6%</td>
<td></td>
</tr>
<tr>
<td>Is age associated with use of group vs. individualized arm care program</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;40 years</td>
<td>88.2%</td>
<td>11.8%</td>
<td>0.001</td>
</tr>
<tr>
<td>&gt;40 years</td>
<td>76.9%</td>
<td>23.1%</td>
<td></td>
</tr>
<tr>
<td>Is coaching experience associated with use of arm care programs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-6 years of experience</td>
<td>72.9%</td>
<td>27.1%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>&gt;7 years of experience</td>
<td>90.5%</td>
<td>9.5%</td>
<td></td>
</tr>
<tr>
<td>Is coaching experience related to use of group or individualized arm care?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-6 years of experience</td>
<td>88.4%</td>
<td>11.6%</td>
<td>0.043</td>
</tr>
<tr>
<td>&gt;7 years of experience</td>
<td>80.2%</td>
<td>19.8%</td>
<td></td>
</tr>
<tr>
<td>Is education level related to use of arm care programming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No college degree</td>
<td>84.4%</td>
<td>15.6%</td>
<td>0.458</td>
</tr>
<tr>
<td>College degree</td>
<td>12.4%</td>
<td>87.6%</td>
<td></td>
</tr>
<tr>
<td>Is education level related to use of group or individualized arm care</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No college degree</td>
<td>77.8%</td>
<td>22.2%</td>
<td>0.467</td>
</tr>
<tr>
<td>College degree</td>
<td>81.8%</td>
<td>18.2%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Injury Prevention Awareness Survey Responses

<table>
<thead>
<tr>
<th>Statements</th>
<th>SA</th>
<th>A</th>
<th>NS</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm care programs can reduce elbow/shoulder injuries in high school baseball pitchers?</td>
<td>68%</td>
<td>31%</td>
<td>1.7%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Having a previous injury will lead to an increased risk for a future injury?</td>
<td>25%</td>
<td>48%</td>
<td>19%</td>
<td>9%</td>
<td>0%</td>
</tr>
<tr>
<td>Deficits in the hips and/or core can contribute to injuries of the shoulder or elbow?</td>
<td>45%</td>
<td>42%</td>
<td>13%</td>
<td>0.5%</td>
<td>0%</td>
</tr>
<tr>
<td>Injury risk factors should be monitored throughout the entire season?</td>
<td>71%</td>
<td>27%</td>
<td>2%</td>
<td>0.3%</td>
<td>0%</td>
</tr>
</tbody>
</table>

SA = strongly agree, A = agree, NS = not sure, D= disagree, SD = strongly disagree

modal arm care programming has been shown to reduce the incidence of medial elbow injuries in youth baseball players by nearly 50%. However, this is the first survey which has explored arm care and injury prevention from the perspective of the high school coach. Although 13% of coaches do not currently implement an arm care program, 71% (n=59/83) of those coaches are interested in using a screening tool to aid in designing a program.

The primary objective of this survey was to determine if coaches use group-based or individualized arm care programs. It also sought to explore how the coaches’ age, education, and experience level influenced the type of arm care programs implemented. The majority of high school baseball coaches who responded to this survey reported using group-based arm care programs. This is not surprising as the only arm care programs which have been explored in the current literature are group-based programs. Older and more experienced coaches tended to implement individualized arm care programs more so than younger coaches with less coaching experience. One possible explanation for this relationship could be that longer tenured coaches may have observed better player durability with individualized arm care programming. This may be due to the variability of different combinations of risk factors among
individuals such as body mass index, biomechanics, or muscle flexibility.\textsuperscript{37} Furthermore, increasing the dosage of exercises designed to target a specific risk factor may maximize the outcome.\textsuperscript{37} To date there have been no studies which have evaluated individualized arm care programs in baseball players. However, in high school soccer players, Huebner et al\textsuperscript{37} reported that an individualized injury prevention program significantly lowered the injury risk in 21 out of 44 players. Baseball players may also benefit from individualized arm care exercises, but future research is needed to determine if targeting risk factors specific to the individual is more effective than group programming in this population.

The secondary purpose of this survey was designed to identify barriers that discouraged coaches from implementing arm care programs for their players. It was hypothesized that lack of time would be a major barrier to implementation, but only 11\% (n=9/83) of responding coaches identified this as a limitation. Interestingly, 41\% of 83 respondents not using arm care programs reported lack of benefit of the program as the primary reason. This is somewhat a paradoxical perspective as 98.3\% of all coaches surveyed also agreed that arm care programs can reduce shoulder/elbow injuries. It is possible that coaches have been taught that arm care exercises can reduce injuries but are hesitant to buy in to program implementation due to lack of observed effectiveness.

The second most frequently cited barrier to arm care implementation reported by coaches surveyed was insufficient staff. This is not surprising as additional support staff in high school programs are typically limited due to marginalized budgets.\textsuperscript{38,39} However, researchers have shown that arm care exercises can reduce injury incidence in adolescent baseball players without additional staff or equipment. In a prospective cohort, Shitara et al\textsuperscript{32} reported a 36\% reduction in upper extremity injury incidence in high school baseball players who performed posterior shoulder stretching. Likewise, Sakata et al\textsuperscript{40} found that a 10-minute warm up program that targeted multiple physical risk factors reduced the incidence of medial elbow pain by nearly 50\% in youth baseball players. Neither program by Shitara et al\textsuperscript{32} or Sakata et al\textsuperscript{40} required additional equipment and was performed independently by the players.

Finally, this survey explored high school baseball coaches’ current awareness and beliefs of injury prevention. The responding high school coaches demonstrated variability in knowledge of risk factors and injury prevention measures. Whereas many coaches acknowledged that dysfunction in hips and core can contribute to throwing related injuries, only 25\% of coaches strongly agreed that previous injury can lead to a future injury. Research has suggested that a history of a previous injury is one of the strongest and most consistently reported risk factors for future injury.\textsuperscript{12,40–42} Also, reduced shoulder ROM was selected by high school coaches as the risk factor contributing the most to injury. Multiple studies have reported that limited shoulder ROM can contribute to increased injury in high school and professional baseball players. Specifically, Shanley et al\textsuperscript{8} reported that high school baseball players with $>25^\circ$ glenohumeral internal rotation deficit (GIRD) were 4.8 times greater risk of having an upper extremity injury. Shitara et al\textsuperscript{32} reported that a 20$^\circ$ GIRD was associated with 2.7 times greater odds of injury. In professional players, total shoulder range of motion differences of greater than 5$^\circ$ have been significantly related to injury incidence.\textsuperscript{18} Although the responding coaches were able to successfully identify reduced shoulder ROM as a risk factor, it is concerning that far fewer coaches considered increased pitching volume as a major concern for arm injury.

In the current survey, only 17\% (n=109/654) of respondents identified throwing with a fatigued arm as the primary injury risk factor. It was expected that pitching with arm fatigue would be identified as the greatest risk factor due to literature showing that throwing with a fatigued arm increases the odds of upper extremity injury 13-fold (95\% CI, 3.22 to 55.09).\textsuperscript{43} Throwing for greater than eight months of the year which has been shown to increase injury risk five-fold was identified as the primary risk factor in 33\% of respondents. Hibberd et al\textsuperscript{16} reported that pitchers who also play catcher as a secondary position are nearly three times greater risk for injury but only 2\% (n=12/654) of responding coaches identified this the primary risk factor. Research has shown that loss of shoulder strength during season may play a role in arm injury in baseball players. A study performed by Tyler et al\textsuperscript{9} on a sample of high school baseball players reported that preseason supraspinatus weakness increased the risk of having substantial injury resulting in missing greater than three games by four-fold (RR 4.6, 95\% CI, 1.4 to 15.0). However, despite this research, only 6\% (n=58/654) of high school coaches ranked strength as the major contributor to injury. The coaches tended to focus on motion deficits of the shoulder perhaps because of the long-standing nature of this information but inconsistently reported throwing volume a major factor. This suggests that coaches may require updated education related to injury risk factors.

The results of those surveyed indicate that the majority of high school coaches accept the primary role of preventing baseball injuries. High school coaches feel that they can positively impact the health and well-being of their players more effectively than healthcare providers despite their poor knowledge of injury risk factors. In conjunction with the majority of coaches using arm care programs, it appears that time is not a limiting factor. In fact, responding coaches dedicate 10-20 minutes of practice time three times per week to arm care exercises. However, coaches and re-
habilitation professionals could do a better job collaborating on risk factors and injury prevention strategies. Future research is needed to gain insight into the resources commonly used by coaches for injury prevention information. It is unlikely high school baseball coaches are aware of this medical literature which may explain why there is a disconnect between current medical literature and knowledge of high school coaches. This may make it difficult for high school coaches to implement and design effective arm care programs for their players. Collaborative efforts between rehabilitation professionals and coaches are needed to provide educational opportunities for injury prevention strategies. This may include providing up to date information in a location which is easily assessable and practically applicable for the coaches' everyday needs.

This study is not without limitations. First, these survey data were based on self-report which may have resulted in reporting bias by the responding coaches. Because the majority of responders were more positive in arm care program use, the coaches surveyed were likely biased toward this value. Additionally, the nature of the survey design cannot confirm actual practice therefore the results of the coaches' injury prevention knowledge could be skewed. Second, the authors used email to attempt to survey a geographically diverse sample of high school coaches throughout the United States. However, technologic restrictions such as limited access to a computer or internet may have resulted in a selection bias. Lastly, while this survey did report on the usage of arm care programs, it did not specifically inquire about how effective the coaches felt these programs are at preventing injury.

CONCLUSION

The results of this survey suggest that the majority of high school baseball coaches implement group-based arm care exercise programs to prevent injury. Coaches who were older and more experienced were more likely to individualize their arm care programs. Lack of time is not a major barrier to implementation of arm care programming. High school coaches believe they are the most impactful at preventing baseball injuries and devote practice time multiple days per week to arm care exercises. However, the responding coaches exhibited inconsistent risk factor awareness and dated injury prevention beliefs. Therefore, better educational collaboration between rehabilitation professionals and high school coaches regarding injury risk factors and preventative strategies is warranted.

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REFERENCES


29. MLB. Major League Baseball. Pitch Smart.


Appendix 1

Shoulder Isokinetic Strength Balance Ratio in Overhead Athletes: A Cross-Sectional Study

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Keywords: balance ratio, isokinetic strength, overhead athletes, shoulder rotation

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Background
Studies have grouped different overhead sports and evaluated together the isokinetic strength of shoulder internal (IR) and external (ER) rotator muscles. However, muscular adaptations could be a consequence of the specific sport, and some strength imbalance between these muscles may exist as a consequence of the muscular demand unique to the sport. Therefore, grouping different overhead sports together may not be adequate.

Purpose
To compare strength balance ratios between different overhead sports (volleyball, handball, swimming, judo, baseball, softball, functional movements performed at high-intensity interval training, and tennis) with a control athletic group (no overhead group).

Study design
Cross-sectional study.

Methods
A total of 237 athletes were submitted to isokinetic shoulder strength tests. The isokinetic concentric and eccentric peak torque values of shoulder internal IR and external ER rotator muscles were measured. Conventional (CR) and functional strength ratios (FR) were calculated.

Results
There were no significant differences between the sports for the CR in the male group. Female softball athletes (90.4±13.6%) had a significantly higher CR than judo (67.3±6.9%), volleyball (74.9±15.9%), and swimming athletes (70.3±8.7%). In the female group, judo athletes had lower FR values (0.76±0.19) than soccer athletes (1.31±0.35), volleyball athletes (1.24±0.27), functional movements performed at high intensity (1.10±0.1), and softball athletes (1.40±0.39). Female handball athletes also had a lower FR (0.99±0.25) than soccer athletes (1.51±0.35) and softball athletes (1.40±0.39). Male handball (0.90±0.23), tennis (0.86±0.30), and judo (0.68±0.22) athletes had lower FR values than soccer athletes (1.20±0.21) and volleyball athletes (1.25±0.28).

Conclusions
CR for males may be analyzed together, as there were no significant differences between them. However, for females, the CR for softball athletes should be analyzed individually. As there were several differences between the overhead sports according to the FRs, the authors suggest caution in grouping overhead athletes across multiple sports. These

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results could have important implications for the design of injury prevention and rehabilitation programs associated with the shoulder joint in overhead sports.

**Level of Evidence**

**INTRODUCTION**

The repetitive pattern of muscle use can cause specific musculoskeletal adaptations and bilateral strength deficiency, or musculoskeletal strength imbalance between antagonistic muscles of the joint, mainly in asymmetric sports. The muscular isokinetic strength profiles of athletes may help in understanding these specific muscular adaptations for each sport.

Muscular strength balance between agonist and antagonist muscles is of fundamental importance for joint stability, ensuring a dynamic centering of the humeral head, mainly while an athlete is playing sports. Therefore, the strength balance ratio is of fundamental importance, independently of the athlete's sex. Traditionally, isokinetic strength testing has been considered an important tool for monitoring training adaptations and for objectively quantifying the strength balance ratio between agonist and antagonist muscles. Regarding the shoulder joint, rotator cuff muscle synergies exhibit an important action that ensures dynamic centering of the humeral head to the glenoid. Edouard et al. showed that the relative injury risk of the shoulder joint was 2.57 if athletes had an imbalanced muscular strength profile. For this reason, it is important to have appropriate balance between shoulder internal (IR) and external (ER) rotator muscles.

Many studies have grouped different sports together and, in many cases, have evaluated isokinetic strength and the effect of exercise programs in a broad category of "overhead athletes". However, it is unknown whether shoulder muscular balance ratios are similar between overhead sports. If the balance ratios are different between sports, analyzing the balance ratios together may be erroneous. To the best of the authors' knowledge, there are no data that suggest that muscle adaptations due to overhead sports are similar to justify grouping overhead sports. Several studies have evaluated adaptive changes in the shoulder in athletes of several different sports, such as judo, handball, tennis, baseball, badminton, volleyball, and swimming, but no studies have compared the strength balance between overhead sports.

Overhead movements are the main gesture in sports such as volleyball, handball, tennis, swimming, and baseball, but there are several distinctions between these sports. They have different movement executions and muscular actions, and they use different implements, such as different types of balls or rackets. Thus, it is important to know if these differences produce unique adaptations in shoulder strength balance. Knowledge about differences between the overhead sports in terms of muscle adaptation could help design tailored prevention and rehabilitation programs for athletes. Thus, the aim of this study was to compare the strength balance ratios between overhead athletes from the different sports. It was hypothesized that strength balance ratios would be different between overhead athletes in different sports, supporting the notion that these athletes should be investigated based on their specific sport rather than categorized as general overhead athletes.

**METHODS**

**PARTICIPANTS**

Athletes were recruited from competitive teams (regional level) in São Paulo (Brazil) through direct contact from January to September 2017. To this end, the research coordinators visited the teams and invited the coaches and athletes to participate in the study. Data were collected from February to October 2017. Volunteers were from eight different sports: volleyball, handball, swimming, judo, baseball (for men) and softball (for women), functional movements performed at high-intensity interval training, tennis, and soccer. Soccer athletes served as a control group, since there is minimal upper limb involvement in this sport (goalkeepers were excluded from the sample).

To be included, athletes had to have trained at least two hours per day, five times per week during at least the last two years. Exclusion criteria included activity or resting shoulder pain (greater than 3 out of 10 on the visual analog scale), upper limb swelling, inability to perform physical exercises, systemic diseases, surgery in the last year, orthopedic injuries, interrupted physical training because of shoulder pain in the last six months, and/or other dysfunctions that limit the ability to complete the testing protocol.

The participants and/or their parents/guardians (for those under 18 years old) were informed about the aim of the study and gave their written consent to participate in the protocol. In addition, athletes under 18 years old gave their written consent before participation. All experimental procedures were approved by the Research Ethics Committee of the Universidade Federal de São Paulo and conformed to the principles outlined in the Declaration of Helsinki.

**ISOKINETIC STRENGTH TEST**

Before each test, the dynamometer was calibrated according to the manufacturer’s specifications. Athletes assumed a seated position, and standard stabilization strapping was placed across their chest and hips (Figure 1). The ER and IR rotator muscles from the dominant shoulder were assessed with the athletes’ upper limbs abducted at 90 degrees (deg) in the frontal plane and the elbow flexed at 90 deg, which is the same position adopted for shoulder muscle isokinetic evaluation in previous studies. This position has been recommended for evaluations because it approximates the throwing position. The range of motion was set to 50 deg of IR rotation and 70 deg of ER rotation to replicate an overhead serving motion and to be the same angles used in previous studies. Before
the isokinetic test, athletes performed a five-minute warm-up exercise protocol, followed by low-intensity dynamic stretching exercises for lower limbs, to avoid stretching influence in strength values. Following the warm-up period, athletes randomly completed concentric and eccentric isokinetic shoulder strength tests with the dominant limb using an isokinetic dynamometer (System 4 Biodex Medical Systems Inc., Shirley, NY, USA). Before the test, the athletes performed three trial movements with submaximal performance to familiarize themselves with the equipment, angular speeds, and concentric and eccentric actions.

The concentric test consisted of five maximal repetitions of shoulder IR and ER at 60 and 240 deg/sec, respectively. The angular speed of 60 deg/sec was chosen as the lowest angular speed to avoid high joint pressure while producing the highest torque values. Additionally, 240 deg/sec was chosen as the highest speed, once it is close to the functional movements speed without increasing the risk of injury associated to eccentric action. Other studies have also used the same isokinetic test speeds for isokinetic strength evaluation. The eccentric test consisted of five maximal repetitions at 240 deg/sec. Between sets, participants had 60 seconds of rest time. All athletes were tested by a single evaluator who was trained and experienced in the use of isokinetic devices. During the test, athletes were given the same verbal encouragement. Visual feedback from the computer screen was not permitted. The variables evaluated were the shoulder ER and IR peak torque in concentric action at 60 and 240 deg/sec, respectively, and ER rotator peak torque in eccentric action at 240 deg/sec. With this information, conventional (CR) and functional balance ratios (FR) were calculated. The CR was calculated as concentric ER peak torque at 60 deg/sec to concentric IR peak torque at 60 deg/sec (ER/concentric:IR-concentric). The FR was calculated as eccentric ER peak torque at 240 deg/sec to concentric IR peak torque at 240 deg/sec (ER/concentric:IR/concentric).

STATISTICAL ANALYSIS

The normal distribution of each variable was analyzed and confirmed by the Kolmogorov–Smirnov test. The homogeneity of the variance was verified by Levene’s test. All variables were shown as the mean and standard deviation (SD). To compare sports, one-way ANOVA was used. ANOVA was complemented by the Tukey post-hoc test when the threshold of significance was reached. Statistica software (version 12.0, USA) was used to process the analyses. The level of significance was set at p < 0.05 and the power level at 0.80.

RESULTS

Two hundred and sixty-four athletes were screened for participation, and of these, 27 were excluded, so 237 athletes comprised the sample. The 27 athletes excluded from the initial sample were as follows: 3 had upper limb surgery, 11 suffered an orthopedic injury in the last six months, and 13 fell pain during the test. Figure 2 shows the participants’ flow through the study. The characteristics of the athletes are described in Table 1. One-way ANOVA revealed a statistically significant difference between ages of the female groups (F[7,101]=12.52, p<.001, observed power 1.0) and of the male groups (F[7,120]=15.81, p<.001, observed power 1.0). There was also a significant difference between body mass of the female groups (F[7,101]=10.55, p<.001, observed power 1.0) and of the male groups (F[7,120]=7.57, p<.001, observed power .99). Regarding height, there was also a significant difference between female groups (F[7,101]=22.99, p<.001, observed power 1.0) and male groups (F[7,120]=6.95, p<.001, observed power .99).

The values of CR and FR of male and female athletes from different sports are shown in Table 2. One-way ANOVA revealed a statistically significant effect of sport on CR in the female group (F[7,101]=3.55, p=.002, observed power .96) and in the male group (F[7,120]=2.29, p=.031, observed power .82). There was also a significant effect of sport on FR in the female group (F[7,101]=7.10, p<.001, observed power .99) and in the male group (F[1,120]=6.95, p<.001, observed power .99).

Figure 1: Positioning assumed by the participant during isokinetic evaluation of the shoulder.
Table 1: General characteristics of athletes from different sports (overhead and control). Data are presented as the mean ± SD (n).

<table>
<thead>
<tr>
<th>Sports</th>
<th>Age (years)</th>
<th>Body mass (kg)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (soccer)</td>
<td>F: 18.2 ± 0.4 (n=16)</td>
<td>M: 23.4 ± 5.4 (n=20)</td>
<td>F: 61.7 ± 5.6 (n=16)</td>
</tr>
<tr>
<td>Handball</td>
<td>F: 28.6 ± 5.0 (n=20)</td>
<td>M: 29.0 ± 5.2 (n=22)</td>
<td>F: 71.6 ± 6.0 (n=20)</td>
</tr>
<tr>
<td>Volleyball</td>
<td>F: 23.6 ± 5.6 (n=19)</td>
<td>M: 18.1 ± 0.3 (n=17)</td>
<td>F: 75.6 ± 8.1 (n=19)</td>
</tr>
<tr>
<td>Judo</td>
<td>F: 27.4 ± 3.3 (n=15)</td>
<td>M: 31.8 ± 4.5 (n=14)</td>
<td>F: 61.4 ± 9.1 (n=15)</td>
</tr>
<tr>
<td>Tennis</td>
<td>F: 24.0 ± 9.1 (n=9)</td>
<td>M: 27.6 ± 6.4 (n=13)</td>
<td>F: 64.4 ± 3.6 (n=6)</td>
</tr>
<tr>
<td>Swimming</td>
<td>F: 22.5 ± 2.5 (n=6)</td>
<td>M: 21.0 ± 0.5 (n=6)</td>
<td>F: 61.2 ± 7.5 (n=6)</td>
</tr>
<tr>
<td>FMHI</td>
<td>F: 29.7 ± 3.3 (n=17)</td>
<td>M: 28.7 ± 4.5 (n=17)</td>
<td>F: 61.5 ± 8.3 (n=16)</td>
</tr>
<tr>
<td>Softball</td>
<td>F: 22.7 ± 2.0 (n=10)</td>
<td>M: 58.7 ± 8.0 (n=10)</td>
<td>F: 83.5 ± 11.5 (n=9)</td>
</tr>
<tr>
<td>Baseball</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

F: female, M: male, FMHI: functional movements performed at high intensity. The differences observed were related to the same sex. *p < 0.05 – different from control group; †p < 0.05 – different from handball group; ‡p < 0.05 – different from volleyball group; §p < 0.05 – different from judo group; ††p < 0.05 – different from tennis group; ‡‡p < 0.05 – different from swimming group; #p < 0.05 – different from FMHI group.

Figure 2: Study design according to the characteristics of the participants

DISCUSSION

The aim of the current study was to compare the CR and FR between overhead sports (volleyball, handball, swimming, judo, tennis, functional movements performed at high-intensity interval training, and baseball/softball) with a control group composed of soccer athletes. The main findings were that the CR was not significantly different between all male overhead sports and between the overhead sports and the control group. Only female softball athletes had a higher CR than female judo, volleyball, and swimming athletes. Conversely, the FR was significantly different between the sports evaluated. In the female group, the judo and handball athletes had lower FR values, and for male athletes, judo, handball, and tennis athletes had lower FR values.
Softball athletes had the highest CR. High values for this variable indicate weakness of the shoulder IR rotator muscles relative to the strength of the ER rotator muscles. The specificity of the throwing movement of this sport may contribute to this finding. Indeed, a softball throw is substantially different from other sports. At the moment a softball is thrown, the shoulder joint has less than 90 deg of flexion. Consequently, the shoulder's IR action is not as clear as with other sports that involve an overhead throw, using more than 90 deg of shoulder flexion. Ellenbecker and Davies\(^8\) suggested that the CR should be between 66% and 75% in order to establish good joint stability and to avoid shoulder injuries. Therefore, besides the softball athletes presenting higher CR values (90.4 ± 13.6%) than the judo (67.3 ± 6.9%), volleyball (74.9 ± 15.9%), and swimming athletes (70.3 ± 8.7%), the softball group also had values that were higher than the recommended values in the literature.

To the best of the authors' knowledge, there are no previous studies about isokinetic shoulder strength balance in softball athletes. Therefore, these are the first data showing shoulder strength imbalance in these athletes. Given that there were no significant differences in the CR between the female control, handball, volleyball, judo, tennis, swimming, and functional movements performed at high-intensity interval training groups, it is reasonable to suggest that these sports could be analyzed together in future studies. CR for all the male groups evaluated in this study were all similar; therefore, it is also reasonable that the CR data for men from the overhead sports in this study can be grouped and analyzed together.

Male athletes from the functional movements performed at high-intensity interval training modality—besides presenting CRs that were not significantly different from the other sports—had a mean CR value lower (63.5 ± 8.8%) than the literature recommendation (66–75%)\(^8\) which is also lower than previous literature data for this sport.\(^9\) Athletes from the functional movements performed at high-intensity interval training modality characteristically applied a powerful sportive gesture, especially related to the shoulder ER muscle. In functional movements performed at high-intensity interval training, there are no throwing actions, which could limit the development of the shoulder ER muscles. This situation corroborates the presence of a low CR.\(^13\) Hadzic et al.\(^38\) evaluated volleyball athletes’ IR and ER muscles in the same angular speed and test position. The authors found CR of 61% and 74% for male and female athletes, respectively. Female volleyball athletes from the current study had very similar results (75%), but male volleyball athletes had a higher CR (81%). Comparing handball athletes from the current study with previously published data from the same test angular speed and position, similar values were observed for the CR. Andrade et al.\(^14\) found a CR of 79% for female handball athletes, and Andrade et al.\(^15\) found the CR to be 72% for male handball athletes, while the current study found it to be 76% for female and 67% for male handball athletes.

For the female group, judo athletes had the lowest FR values, which were significantly lower than the values in the control, volleyball, functional movements performed at high-intensity interval training, and softball groups. The second lowest FR values were in handball athletes, which were lower than in the control and handball groups. The FR is characterized by the ER peak torque in eccentric action divided by the IR peak torque in concentric action; therefore, lower values indicate a low eccentric strength of ER muscles. Noffal\(^36\) hypothesized that eccentric ER torque should be greater than concentric IR torque to be able to overcome and to decelerate the shoulder movement generated by the concentric action of IR muscles. The results in female judo and handball athletes were not only lower than those of the other studied groups, but their mean values were also lower than those reported for shoulder stability (FR > 1.0).\(^36\) Regarding female handball athletes, the data reported in the literature\(^14\) were higher than those observed in the current study. These authors found a FR of 1.21 ± 0.28 for the dominant upper limb; however, these authors evaluated the isokinetic strength at 300 deg/sec, and the higher speed used in their study could be responsible for the higher FR values. Along these lines, Edouard et al.\(^7\) found lower FR values (0.75 ± 0.15) for a population with the same characteristics; however, they assessed the isokinetic strength at

### Table 2: Conventional (CR) and functional (FR) balance ratios of the athletes from different sports, grouped by sex. Data are presented as means ± SD.

<table>
<thead>
<tr>
<th>Sports</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>80.4 ± 12.0</td>
<td>78.4 ± 22.3</td>
</tr>
<tr>
<td>FR</td>
<td>1.31 ± 0.35</td>
<td>1.20 ± 0.21</td>
</tr>
<tr>
<td>Handball</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>76.6 ± 12.2</td>
<td>67.4 ± 28.5</td>
</tr>
<tr>
<td>FR</td>
<td>0.99 ± 0.25(^†)</td>
<td>0.90 ± 0.23(^†)</td>
</tr>
<tr>
<td>Volleyball</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>74.9 ± 15.9(^‡)</td>
<td>80.9 ± 14.2</td>
</tr>
<tr>
<td>FR</td>
<td>1.24 ± 0.27</td>
<td>1.25 ± 0.28</td>
</tr>
<tr>
<td>Judo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>67.3 ± 6.9(^‡)</td>
<td>66.7 ± 10.8</td>
</tr>
<tr>
<td>FR</td>
<td>0.76 ± 0.15(^‡)</td>
<td>0.68 ± 0.22(^‡)</td>
</tr>
<tr>
<td>Tennis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>72.2 ± 13.3</td>
<td>66.6 ± 10.9</td>
</tr>
<tr>
<td>FR</td>
<td>1.11 ± 0.33</td>
<td>0.86 ± 0.30(^‡)</td>
</tr>
<tr>
<td>Swimming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>70.3 ± 8.7(^‡)</td>
<td>70.5 ± 10.9</td>
</tr>
<tr>
<td>FR</td>
<td>1.13 ± 0.27</td>
<td>1.15 ± 0.23</td>
</tr>
<tr>
<td>FMHI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>76.4 ± 12.0</td>
<td>63.5 ± 8.8</td>
</tr>
<tr>
<td>FR</td>
<td>1.10 ± 0.1</td>
<td>1.00 ± 0.22</td>
</tr>
<tr>
<td>Baseball/Softball</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR (%)</td>
<td>90.4 ± 13.6</td>
<td>79.0 ± 16.2</td>
</tr>
<tr>
<td>FR</td>
<td>1.40 ± 0.39</td>
<td>1.05 ± 0.24</td>
</tr>
</tbody>
</table>

**FMHI**: functional movements performed at high intensity. The differences observed were related to the same sex. \(^*p<0.05\) different from control; \(^‡p<0.05\) different from volleyball; \(^*p<0.05\) different from softball/baseball; \(^\dagger p<0.05\) different from FMHI; and \(^\ddagger p<0.05\) different from swimming.
60 deg/sec. In the present study, a higher angular speed test (240 deg/sec) was chosen because it was closer to the functional throwing action than the lower speed (60 deg/sec) selected by Edouard et al. Conversely, an angular test speed higher than 240 deg/sec was not employed because it is hard for athletes to perform eccentric action at angular speeds that are too high (commonly they cannot reach very high eccentric speeds). Therefore, it is difficult to compare study results because the angular speeds tested were different.

Similar to the female group, the male judo and handball athletes, in addition to the tennis athletes, also had low FR values. The judo athletes had lower FR than the control, volleyball, swimming, baseball, and functional movements performed at high-intensity interval training athletes. Likewise, handball and tennis athletes had lower FR values than the control and volleyball groups, and tennis athletes also had lower FR than swimmers. Andrade et al. evaluated handball athletes and assessed muscular isokinetic strength at 90 (concentric mode) and 300 deg/sec (eccentric mode) and also found mean FR values lower than 1.0. Additionally, Saccol et al. observed FR lower than 1.0 for tennis athletes.

Strength evaluations at different isokinetic angular speeds were not performed, which could be considered a study limitation; it could be helpful to compare the results with previously published data. Therefore, future studies should be performed at different speeds. Another recommendation for future studies is to include other sports commonly grouped in overhead classification, such as badminton, water polo, or lacrosse.

**CONCLUSIONS**

CR for male overhead athletes may be analyzed together because there were no significant differences between them. However, for females, CR for softball athletes should be analyzed individually because they had higher values. As the FR for the male group had several differences across overhead sports, grouping all the evaluated sports, in order to evaluate these variables, should be done carefully. The sports that can be grouped together based on the FR analysis are volleyball, swimming, functional movements performed at high-intensity interval training, and baseball, or in a different group handball, judo, and tennis. For analyzing FR in a female group, overhead athletes (volleyball, swimming, softball, functional movements performed at high-intensity interval training, tennis) may be grouped and analyzed together, as there were no differences between them; only female judo and handball athletes should be excluded from the group. In general, these results could have important implications for the design of training programs and injury prevention, as well as rehabilitation programs associated with the shoulder joint and "overhead athletes."

**CONFLICTS OF INTEREST**

The authors declare no conflicts of interest.

Submitted: August 28, 2020 CDT, Accepted: November 26, 2020 CDT

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Table 3: Significant p values for pairwise comparisons

<table>
<thead>
<tr>
<th></th>
<th>Soccer (controls)</th>
<th>Handball</th>
<th>Volleyball</th>
<th>Judo</th>
<th>Tennis</th>
<th>Swimming</th>
<th>FMHI</th>
<th>Softball/Baseball</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer (controls)</td>
<td>X</td>
<td></td>
<td>F = 0.02*</td>
<td>F &lt;0.01*</td>
<td>M &lt;0.01*</td>
<td>M &lt;0.01*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handball</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volleyball</td>
<td></td>
<td></td>
<td></td>
<td>F &lt;0.01*</td>
<td>M &lt;0.01*</td>
<td>M &lt;0.01*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Judo</td>
<td>M &lt;0.01*</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Swimming</td>
<td>M &lt;0.01*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>M = 0.04</td>
<td>X</td>
</tr>
<tr>
<td>FMHI</td>
<td></td>
<td></td>
<td></td>
<td>F &lt;0.01*</td>
<td>M &lt;0.01*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Softball/Baseball</td>
<td>F &lt;0.01*</td>
<td>F = 0.04†</td>
<td>F &lt;0.01†</td>
<td>F &lt;0.01†</td>
<td>M = 0.01</td>
<td>F =0.04†</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P values for FR; † p values for CR; F = female; M = male.
REFERENCES


A Comparison of Resting Scapular Posture and the Davies Closed Kinetic Chain Upper Extremity Stability Test

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Keywords: Davies closed kinetic chain upper extremity stability test, Kibler scapular classifications, movement system, upper extremity performance tests

BACKGROUND

In orthopaedic practice, it is well established that weak scapular stabilizers and an unstable scapula is related to shoulder dysfunction. Faulty scapular position has been linked to decreased scapular stability and is thought to be a result of weak or unbalanced timing in the recruitment of scapulothoracic dynamic stabilizing muscles. Kibler has described a four-type classification of scapulothoracic dysfunction. Functional performance testing is used to objectively measure activities that simulate various desired activities. The reliability of assessing the four static scapular positions may be important in diagnosing shoulder dysfunction. An understanding of the scapular position and its relationship to functional performance testing is needed.

PURPOSE

The purpose of this study was to determine if a static scapular test, the Kibler scapula classification, in healthy participants affects the ability to perform a closed chain functional test that involves the use of the scapula and the upper extremity, the Davies Closed Kinetic Chain Upper Extremity Stability Test (CKUEST). A secondary analysis was performed to evaluate the reliability of a student physical therapist and an experienced physical therapist to identify scapular type by observation.

STUDY DESIGN

Multicenter, single session descriptive cohort

METHODS

Sixty-one healthy participants (33 males, 28 females; mean age 24.19±2.61) completed testing across two locations in one testing session. Blood pressure and heart rate as well as height and weight were measured for each participant. Participants were classified by visual observation of Kibler scapular classification. The average number of CKUEST touches, a normalized score, and a power score were calculated for each participant. Three trials were performed and participants were required to take a 45-second rest break between each CKUEST trial.

RESULTS

One way analysis of variance (ANOVA) showed statistically significant differences in Type I and Type IV Kibler scapula classification for the CKUEST power score, however when an ANCOVA controlled for body mass index, there was no statistically significant difference. A strong correlation r=.94 was observed between student and experienced physical therapist in evaluating all four types of Kibler scapular classification.

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INTRODUCTION

Alterations of the resting scapula position and dynamic scapular motion are frequently observed by sports physical therapists in patients with shoulder disorders from overuse injury in the overhead athlete.1–3 These alterations have been collectively classified by Kibler,4–7 three of which are thought to result in abnormal scapulohumeral rhythm and shoulder arthrokinesematics and one that is considered normal scapular position.7 Abnormal scapulohumeral rhythm or dyskinesia can be considered either a cause or a result of shoulder disorders and adversely affect function.8 Evaluation of the Kibler classification can help in developing strategies to address shoulder dysfunction. During evaluation of the patient with shoulder dysfunction, scapular position should be examined statically and dynamically.9 The Kibler classification examination is a static scapular position test except for the last portion which involves observation of the position of the scapula in full shoulder flexion.

In terms of upper extremity performance, the Davies Closed Kinetic Chain Upper Extremity Stability test (CKCUEST) should be considered. The CKCUEST is a unique dynamic physical performance test because it assesses upper extremity function while most physical performance tests are related to the lower extremity.10–12 Most upper extremity sport activities involve closed kinetic chain activities. Closed kinetic chain upper extremity activities promote proprioception, joint stability, and high levels of activation of the scapular dynamic stabilizer muscles.13–17

The CKCUEST requires stability of the muscles that attach to the scapula, therefore, the CKCUEST may also be used as a scapular stability assessment. These scapular stabilizing muscles are active in both open and closed kinetic chain activities.17,18 The CKCUEST is a valid and reliable test that provides a measure of power and upper extremity stability.10,19 To perform the test, the participant is asked to assume a push-up position (men) or modified push-up position (females) and perform maximal speed alternating reaches to a tape target spaced 36 inches apart for 15 seconds. The number of touches to the tape is recorded for three 15-second trials. Three potential scoring outcome measures can be calculated from the CKCUEST: average number of touches, a normalized score, and a power score.20–22

The primary purpose of this study was to determine if a static scapular test, the Kibler scapula classification, in healthy participants affects the ability to perform a closed chain functional test that involves the use of the scapula and the upper extremity, the Davies CKCUEST. A secondary analysis was performed to evaluate the reliability of the student physical therapist and experienced physical therapist to identify scapular type by observation. The hypotheses were that those with a Type IV or normal Kibler scapula classification would perform better on the Davies CKCUEST and that students and experienced therapists would have a moderate (> 0.60) inter rater reliability of identifying scapular type by observation.

METHODS

PARTICIPANTS

Sixty-three healthy participants were recruited across two locations. Participants were recruited from two public university campuses by flyer and word of mouth from Wichita State University and Northern Arizona University. The local institutional review boards approved the study. All participants were informed of the benefits and risks of the study before signing an institutionally approved informed consent document to participate. Participants were required to be between 18 to 40 years old to participate and to be able to speak English. Exclusion criteria for the study included: currently pregnant, current bout of shoulder or upper body pain, diagnosis of any shoulder condition in the past year, diagnosed hypertension or respiratory distress. All participants were asked about each of these conditions to ensure appropriate ability to participate in this study.

INSTRUMENTATION

KIBLER SCAPULAR CLASSIFICATIONS

Scapular classifications were described first by Kibler.7 Type I represents abnormal scapular control about a horizontal axis. Type II represents abnormal scapular control about a vertical axis. Type III represents excessive upward movement and abnormal control around a sagittal axis. Type IV is normal with bilaterally symmetric scapula. Multiple authors have investigated Kibler scapular classifications in the resting position that is with the participant standing in their normal posture with both arms at their sides therefore this was the case for this study.4,6,23,24 In the current study, Kibler scapular classifications were identified by visual observation.

DAVIES CLOSED KINETIC CHAIN UPPER EXTREMITY STABILITY TEST

To perform the CKCUEST, the participant is asked to assume a push-up position and perform maximal speed alternating reaches to a tape target spaced 36 inches apart for 15 seconds. The number of touches to the tape is recorded for three 15-second trials.12 Some authors modify the push-up
the Davies CKCUEST starting position was performed with the participant was asked to assume a push up position and this or 91.4 centimeters apart were placed on the floor. The participant’s body weight (kg) divided by 15. The CKCUEST normalized score is obtained by dividing the number of touches by the height of the participant. The CKCUEST power score is obtained by multiplying the average touches by 68% of the participant’s body weight (kg) divided by 15.

**PROCEDURES**

Healthy participants aged 18 to 40 years old were recruited via flyers and advertising around the community. The order of procedures was the same for all participants. Each participant was weighed and height was measured followed by blood pressure and pulse rate being measured by a student physical therapist at both locations. Blood pressure was measured following the Frese et al guidelines and abnormal blood pressure or pulse rate excluded the participant from participation in the study secondary to unidentified high blood pressure that did not resolve after resting five minutes.

The student physical therapist then reviewed the Davies CKCUEST procedure with the participant. For all participants, female and male, two pieces of tape located 36 inches or 91.4 centimeters apart were placed on the floor. The participant was asked to assume a push up position and this became the starting position for the participant. Initially, the Davies CKCUEST starting position was performed with the hands spread apart to be touching the tape. Recently authors have suggested that placement of the hands in the starting position should correspond to the anthropometric characteristics of the participant. Authors have also modified the CKCUEST by performing only one trial or two trials as opposed to three trials. In the current study, female participants were offered a choice of the modified position or the standard push-up position and performed all three trials of the CKCST. Authors have suggested that CKCUEST scores can provide three potential scoring outcome measures from the CKCST: average number of touches, a normalized score, and a power score. The CKCUEST normalized score is obtained by dividing the number of touches by the height of the participant. The CKCUEST power score is obtained by multiplying the average touches by 68% of the participant’s body weight (kg) divided by 15.

**STATISTICAL METHODS**

Sample size calculation was based on having 80% power for the primary outcome of scapular posture and performance on the Davies CKCUEST. Data were analyzed using SPSS v24 (IBM Inc, Armonk, NY). A p-value of less than .05 was considered statistically significant. A one-way analysis of variance (ANOVA) was used to examine the effect of Kibler scapular type to the CKCST and an analysis of co-variance (ANCOVA) using body mass index (BMI) as a control. All assumptions were met to run the ANCOVA to evaluate the co-variate. A prospective design was used to evaluate the reliability via Pearson Correlation Coefficients between student physical therapists and experienced physical therapists in identifying Kibler scapular type as correct or incorrect assessment.

**RESULTS**

The demographic characteristics of the 61 participants who completed testing (33 males, 28 females; mean age 24.19±2.61) are provided in Table 1. The most common Kibler scapular type was that of a type IV normal scapular position seen in 50 (49%) participants, followed by Type I seen in 20 (33%) of the participants. Two participants were excluded from participation in the study secondary to unidentified high blood pressure that did not resolve after resting five minutes.

**KIBLER SCAPULAR CLASSIFICATION AND THE CKCUEST**

Table 2 provides the means and 95% confidence intervals (CIs) for the average number of touches, normalized and power score for the CKCUEST for all participants. Results of the one way ANOVA showed statistically significant differ-

<p>| Table 1: Demographic Characteristics of the Participants (N=61) of the Current Study |
|---------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Demographic Characteristic</th>
<th>No. (%)</th>
<th>Weight (kg) a</th>
<th>Height (m) a</th>
<th>Age (y) a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>33 (54.1)</td>
<td>77.53 (8.47)</td>
<td>1.80 (.05)</td>
<td>24.24 (1.97)</td>
</tr>
<tr>
<td>Female</td>
<td>28 (45.9)</td>
<td>24.14 (3.25)</td>
<td>1.66 (.07)</td>
<td>21.14 (3.25)</td>
</tr>
<tr>
<td>Kibler type I</td>
<td>20 (33)</td>
<td>68.65 (9.78)</td>
<td>1.66 (.07)</td>
<td>23.90 (1.21)</td>
</tr>
<tr>
<td>Kibler type II</td>
<td>11 (18)</td>
<td>65.56 (14.12)</td>
<td>1.69 (.11)</td>
<td>24 (3.00)</td>
</tr>
<tr>
<td>Kibler type IV</td>
<td>30 (49)</td>
<td>75.91 (9.75)</td>
<td>1.76 (.08)</td>
<td>24.47 (3.15)</td>
</tr>
</tbody>
</table>

a Weight, height and age are reported as mean (SD).

The student physical therapist then reviewed the Davies CKCUEST procedure with the participant. For all participants, female and male, two pieces of tape located 36 inches or 91.4 centimeters apart were placed on the floor. The participant was asked to assume a push up position and this became the starting position for the participant. Initially, the Davies CKCUEST starting position was performed with the hands spread apart to be touching the tape. Recently authors have suggested that placement of the hands in the starting position should correspond to the anthropometric characteristics of the participant. Although others have concluded that the distance of the placement of the tape that is being reached to corresponds to anthropometric characteristics and maturational stages of the participant potentially putting a participant with a narrower build at a disadvantage. Authors have also modified the CKCUEST by performing only one trial or two trials as opposed to three trials. In the current study, female participants were offered a choice of the modified position or the standard push-up position and performed all three trials of the CKCST. Authors have suggested that CKCUEST scores can provide three potential scoring outcome measures from the CKCST: average number of touches, a normalized score, and a power score. The CKCUEST normalized score is obtained by dividing the number of touches by the height of the participant. The CKCUEST power score is obtained by multiplying the average touches by 68% of the participant’s body weight (kg) divided by 15.
Table 2: Kibler Scapula Classification (type) with Performance of Davies Closed Kinetic Chain Upper Extremity Stability Test with Mean and Standard Deviations for Normalized Score, Age, Average Touches, and Power Score (N=61)

<table>
<thead>
<tr>
<th>Kibler Type</th>
<th>CKCUEST</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normalized score</td>
<td>14.80 (2.33)</td>
<td>13.71, 16.05</td>
</tr>
<tr>
<td>1</td>
<td>Age</td>
<td>23.90 (1.21)</td>
<td>22.70, 25.11</td>
</tr>
<tr>
<td></td>
<td>Average touches</td>
<td>26.24 (3.66)</td>
<td>24.37, 28.37</td>
</tr>
<tr>
<td></td>
<td>Power score</td>
<td>81.55 (19.06)</td>
<td>75.95, 92.37</td>
</tr>
<tr>
<td></td>
<td>Normalized score</td>
<td>14.09 (3.73)</td>
<td>12.62, 15.79</td>
</tr>
<tr>
<td>2</td>
<td>Age</td>
<td>24.00 (3.00)</td>
<td>22.38, 25.63</td>
</tr>
<tr>
<td></td>
<td>Average touches</td>
<td>24.65 (6.05)</td>
<td>22.15, 27.55</td>
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<tr>
<td></td>
<td>Power score</td>
<td>72.91 (22.35)</td>
<td>65.62, 87.80</td>
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<tr>
<td></td>
<td>Normalized score</td>
<td>14.83 (2.26)</td>
<td>13.77, 15.71</td>
</tr>
<tr>
<td>4</td>
<td>Age</td>
<td>24.46 (3.14)</td>
<td>23.46, 25.45</td>
</tr>
<tr>
<td></td>
<td>Average touches</td>
<td>26.83 (4.21)</td>
<td>25.02, 28.31</td>
</tr>
<tr>
<td></td>
<td>Power score</td>
<td>92.63 (22.35)</td>
<td>82.73, 96.27</td>
</tr>
</tbody>
</table>

CKCUEST= Closed Kinetic Chain Upper Extremity Stability Test; SD= standard deviation; CI=confidence intervals
The CKCUEST normalized score is obtained by dividing the number of touches by the height of the participant
The CKCUEST power score considers the weight of the participant by multiplying the average number of touches by 68% of the participant's weight in kilograms.

ences between participants with Type I and Type IV Kibler scapular classification for the CKCUEST power score but no differences for the average number of touches or the normalized scores. Results of the ANCOVA, when controlled for the body mass index revealed no significant differences between participants with differing Kibler scapular classifications and the CKCUEST power score (Figures 1, 2, 3). Of note, females that chose the modified push-up position for the CKCUEST accounted for 5% of participants.

RELIABILITY OF SCAPULAR CLASSIFICATION BETWEEN THE STUDENT PHYSICAL THERAPIST AND THE EXPERIENCED PHYSICAL THERAPIST

Pearson Correlation Coefficients between the student physical therapist and the experienced physical therapist at both locations are presented in Table 3. The inter rater reliability of student physical therapists and experienced physical therapist from both locations was excellent in evaluating the Kibler scapular classification (ICC=.96; 95% CI, 0.92, 0.99).

DISCUSSION

The purpose of this study was to determine if the Kibler scapular classification affects the ability to perform the CKCUEST in healthy participants. The first hypothesis that those with a normal Kibler scapula classification would perform better on the Davies CKCUEST was rejected. The results from the current study show that Kibler scapula position does not affect the ability to perform the CKCUEST in healthy young adults. Identifying Kibler scapular position(s) has been clinically useful to describe static scapular positions but may not reflect functional scapular abilities.

Deng et al investigated four different positions (at rest and end range of elevation in the sagittal, scapular and coronal planes) and found that 90.8% of patients with shoulder complaints had an abnormal resting scapular position when the patients' arms were by their side and at rest. Deng et al described this as scapular dyskinesia, which the
authors of the current study would suggest as incorrect because dyskinesia as a clinical description implies upper extremity motion and instead abnormal resting position was found in a static position, which is not the true resting position of the scapula. Forty-nine percent of healthy participants in the current study had normal or type IV Kibler scapula classifications. None of the healthy participants with type I or type II had any symptoms.

Differences were only identified between those with Type I and Type IV Kibler scapular classification for the CKCUEST power score. Additionally, when controlled for body mass index no significant differences were present between participants with varied Kibler scapular classification types and the CKCUEST power score. Perhaps the lack of association is because it is a comparison of a visual observation of a static scapula position being compared to a dynamic stabilization test of the scapula stabilizers. Another potential reason may be that those with Kibler Type I scapular dyskinesia may represent a “normal asymmetry” in a healthy population. Future studies should include a larger sample size that includes subjects with a variety of Kibler scapular positions.

The interrater reliability of a second year student physical therapist at two separate locations to identify Kibler scapula types was excellent when compared to the experienced physical therapist. This is in contrast to authors who have noted low interrater reliability (k=0.084) in evaluating Kibler scapular classifications of uninjured professional baseball players. McCleure et al investigated 142 uninjured athletes and found satisfactory reliability (k=0.48 to 0.68) with percent agreement ranging between 75% to 82% but they evaluated both a static limbs position and asked participants to go through flexion and coronal plane abduction using a 5 to 5 lb barbell. The current study approach did not include barbells to influence visual observation of Kibler classification. In terms of side-to-side comparison, authors have found low interrater reliability for classifying the Kibler scapular position (k=0.264 for left, k=0.157 for right). The ability of a first year or novice student and an experienced physical therapist to reliably agree on the scapular posture by observation examination is presently unknown. Authors have also reported a limitation of interpretation of scapular position with video analysis. McCleure et al also used video analysis for interpretation and reported coefficients ranging between 0.48 and 0.61 with percentage agreement ranging from 75% to 82% between examiners. Tate et al tried to validate the McCleure et al study by using 66 of the same 142 participants used in the McCleure et al study. Tate et al used three-dimensional electromagnetic kinematic testing and noted less scapular upward rotation or Type III scapula in the participants that McClure et al investigated and classified. Thus, visual observation of scapular position underestimated the three-dimensional electromagnetic kinematic testing or more simply stated what they saw did not correspond to precise measurements of scapular motion. Uhl et al categorized symptomatic and asymptomatic athletes into a yes/no method in which those with abnormal scapular dyskinesia were labeled as having dyskinesia and were not specifically categorized by scapular type. They found a sensitivity of 76% and positive predictive value of 74% using the yes/no method. Interestingly, they also noted that testing symptomatic patients showed a higher frequency of multiple-plane scapular asymmetries. Deng et al investigated the Kibler classification system in four different positions but concluded that the resting position of the scapula was the best position to assess in patients with shoulder dysfunction. In the current study, this static resting position of the scapula was reliable between student and experienced clinician but was not associated with CKCUEST performance.

Authors investigating the CKCUEST have suggested that the test has excellent reliability for adolescents, for physically active adults, sedentary adults, and sedentary adults diagnosed with shoulder impingement syndrome, for Division 1 college athletes, collegiate basketball athletes, for handball athletes, and collegiate baseball athletes. The majority of these studies have examined test-retest reliability and three of these studies investigated and reported the average number of touches, normalized score, and power score.
Use of the power score and normalized score requires further investigation. Goldbeck and Davies first described the power score using 68% of the participant's weight in kilograms based on Dempster's work. The power score considers the weight of the participant by multiplying the average number of touches by 68% of the participant's weight in kilograms. Tucci et al. used the power score and report that 68% of the participant's weight in kilograms corresponds to the weight of the arms, head and trunk. Dempster is often cited as the classic paper for considering the mass of body segments but used adult male cadavers between 52 to 83 years of age to derive the 68%. Recently, authors have suggested that using older male cadavers do not correspond to younger adults or appreciate sex differences. Authors have separated body segment mass by sex and suggest that the mass of the head, trunk, upper arms, forearm, and hands equal 60.28% for males and 58.23% for females of the total mass of the body. Virmavirta et al. concluded that inter-individual differences among athlete groups may be large and that the selection of segment body mass for analysis is not clear. Virmavirta et al suggest using a precise body segment model specifically for athletes. For example, gymnasts have different segmental body mass compared to throwers or hockey players. Considering that the use of the power score may not be specific enough for athletes, the authors of the current study controlled for BMI for the average number of touches of the CKCUEST and for the power and normalized score and found no statistically significant relationship to Kibler scapular position. The authors of the current study suggest that the use of a power score of 68% should not be used for athletes or for females based on the variability found in the literature on segmental body mass for younger athletes. Instead, a power score of 60.28% should be used for males and 58.23% for females to be precise. This approach should be adopted until sport specific normative data for body segment mass are gathered in a large population of athletes.

The normalized score considers the height of the participant by dividing the number of touches by the height of the participant and has also been questioned. Authors have suggested that the height of the participant, the maturation stage, or anthropometric measurements such as shoulder width place for those with a narrower build creates a performance disadvantage for the CKCUEST. Callaway et al suggest that the original CKCUEST starting position of placement of the hands 36 inches apart is not justified. Callaway et al suggest that using 36 inches as the starting position is inappropriate for both sexes as taller participants will have a greater advantage over shorter participants which leads them to suggest a different starting position appropriate to the height of the participant. Callaway et al investigated four different starting positions (36 inches, shoulder breadth, acromial distance, and 50% of the participant's height) and reported that the starting position at 50% of the participant's height resulted in the smallest standard error of measurement and minimal detectable change of all three positions. Callaway et al only investigated males in their study so it is unknown if performance improves in females using this starting position. Taylor et al. used shoulder width as the starting position for male and female collegiate athletes as an attempt to adjust for body-size heterogeneity of the athlete. In the current study, the authors offered the participant the choice of starting position to correspond to the shoulder width of the participant. Regarding the normalized score, the authors of the current study suggest more evidence is needed on the use of the normalized score. Specifically, it is important to have normative data on how height affects the starting position and performance of the CKCUEST across all types of athletes. The authors of the current study suggest that since the original paper on the CKCUEST investigated this test as an upper extremity performance test of endurance, three trials of the test should be performed and performance of fewer than three trials alters the purpose of the original test. Maintaining a standardized approach of three trials should be used in the clinic as the original intent of the CKCUEST is related to endurance.

The authors of the current study did exclude two participants secondary to unidentified high blood pressure that precluded them from participation in exercise. The authors of the current study suggest that future studies investigating the CKCUEST should take blood pressure measurements on all participants especially since upper extremity exercise increases systolic blood pressure much more so than lower extremity exercise. As a precaution, any patient that is unknown to a clinician that performs upper extremity exercise should have their blood pressure measured by their therapist. For example, a per diem physical therapist that is covering a holiday that does not know any of the patients should consider taking blood pressure measurements on unfamiliar patients due to the increase in systolic blood pressure during upper extremity specific exercise.

The authors of the current study identify that experimental studies have limitations. One limitation was that the order of testing was standardized (visual observation of Kibler classification followed by three trials of the CKCUEST) and therefore may not mimic the clinical setting. Another limitation is that the study was done at two separate locations involving healthy participants that self-reported if they had a shoulder injury over the past year or current shoulder pain. As the current study used only healthy participants, findings should be extrapolated with caution to those following rehabilitation for upper extremity injury. It is unknown if the participants had any actual previous shoulder injuries or other musculoskeletal conditions that were not identified.

CONCLUSIONS

Sports physical therapists commonly evaluate patients with upper extremity injury or conditions and observe abnormal scapular position in the affected extremity. In the current study, resting Kibler scapular position did not affect the ability to perform the Davies CKCUEST in healthy young adults. However, the ability to identify Kibler scapular positions was reliable between second year students and experienced physical therapists. The authors suggest future studies should investigate varied starting positions and the use of the power and normalized scores for the CKCUEST.
CONFLICTS OF INTEREST

The authors do not have any conflict of interest to report.

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REFERENCES


Shoulder Strength and Closed Kinetic Chain Upper Extremity Stability Test Performance in Division III Collegiate Baseball and Softball Players.

Background
Shoulder strength measured with a handheld dynamometer (HHD) and the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) are clinical tools that have been used to measure athlete's performance and track their progress.

Purpose
The specific aims of this study were to describe baseball (BB) and softball (SB) players isometric strength measures and their performance on the CKCUEST; examine the relationships between strength and the CKCUEST; compare isometric strength measures of the throwing and non-throwing arms; and compare the strength and the CKCUEST measures between BB and SB players.

Study Design
Observational cohort study.

Methods
Participants included 50 DIII BB and 24 DIII SB players. Shoulder strength for the internal and external rotators were measured using a HHD and the CKCUEST was performed. The CKCUEST score and power were calculated. Descriptive statistics and paired t-tests were used to compare throwing and non-throwing shoulder strength. Independent t-test was used to compare BB and SB players shoulder strength and the CKCUEST measures.

Results
The BB players demonstrated significant strength differences between the throwing and non-throwing shoulders and the internal rotators were significantly stronger than the external rotators (p < 0.05), while the strength ratio of the internal and external rotators was not different between arms (p=0.87). The SB players demonstrated no significant strength differences between the throwing and non-throwing shoulders for the internal and external rotators or the strength ratio of the rotators (p > 0.05). There were no significant differences between the strength of the internal and external rotators of the non-throwing shoulder (p=0.075) or the throwing shoulder (p=0.096). The BB players throwing and non-throwing shoulders produced significantly more internal and external force than the SB players (p < 0.001), however, the internal/external rotators strength ratio were similar (p=0.32, p=0.50). The CKCUEST power had inverse and significant correlations (p=0.006, p=0.003) with SB players internal and external rotators, respectively. The CKCUEST power was significantly different between BB and SB players (p < 0.001).
Conclusion
This study presented shoulder rotator strength and CKCUEST reference values for DIII BB and SB players. BB players demonstrated more strength but overall, less symmetry compared to SB players. CKCUEST power may be considered for the evaluation of athletes.

Level of Evidence
Level III

INTRODUCTION
The physiological demands of overhead sports on the shoulder may predispose athletes to injuries.1–4 Shoulder impairments are common for collegiate baseball (BB) and softball (SB) players.5,6 Impaired rotator cuff muscle strength may alter glenohumeral joint mechanics, contribute to painful shoulder conditions or lead to shoulder injury during the season.1,6,7–8 Imbalances in muscle strength of the rotator cuff has been suggested to be related to the unilateral repetitive nature of overhead throwing activities. Specifically, increased muscle strength of the internal rotators as compared to the external rotators.1,4,9–13

The strength of the shoulder musculature can be objectively and reliably measured in the clinical setting using a handheld dynamometer (HHD).13

"Clinician-friendly" physical performance tests, such as the Closed Kinetic Chain Upper-Extremity Stability Test (CKCUEST), are increasingly being used to examine and screen overhead athletes.14–17 The CKCUEST is an objective, easy functional test that can be used to measure components of muscle performance of the shoulder complex in a closed-kinetic chain position and places high demands on its stabilizers. Moreover, the test movement requires coordination between muscles of the trunk, shoulder, elbow, wrist and hand.18 Performance on the CKCUEST has been reported for Division I (DI) college football players,15 recreational athletes,16 as well as Division III (DIII) BB players.17

DIII BB has the largest number of participating players (15,465) compared to DI (10,429) and DII (10,660) in the United States.19 Similarly, there were more SB players participating in DIII (7,646) compared to DI (6,942) and DII (5,992).19 A review of the literature showed that there are few reports that describe shoulder characteristics of DIII BB and SB players related to muscle strength and performance on the CKCUEST. Clinicians need to be able to identify the normal shoulder performance characteristics when examining and creating intervention strategies for DIII BB and SB players. A thorough review of the literature found no other studies that examined the relationship between the CKCUEST and shoulder strength or described the results of DIII BB and SB players.

The specific aims of this study were to: describe BB and SB players isometric strength measures and their performance on the CKCUEST; examine the relationships between strength and the CKCUEST; compare isometric strength measures of the throwing and non-throwing arms; and compare the strength and the CKCUEST measures between BB and SB players.

METHODS
PARTICIPANTS.
BB and SB players were recruited from one DIII college to participate in this study during the preseason. The inclusion criteria were: 1) BB or SB collegiate athletes; 2) who were over the age of 18 years; and 3) had no current shoulder injury or medical conditions that precluded them from participation in sports. The Institutional Review Board approved this study.

DATA COLLECTION.
Participants completed demographic and history information and then were randomly assigned to begin with either the CKCUEST or dynamometric strength testing. The order of the throwing and non-throwing shoulder testing also was randomly assigned.

INTERNAL AND EXTERNAL ROTATOR ISOMETRIC STRENGTH TESTING.
Study participants performed a 5-minute warm up which consisted of slowly lifting a submaximal weight through the full internal rotation and external rotation range of motion while in the testing position for 10 repetitions followed by a 3-minute rest period prior to strength testing. One investigator collected all strength measurements using a handheld dynamometer (Lafayette Instrument, Lafayette, Indiana, USA). Strength was assessed in the prone position for the external rotators and internal rotators with the shoulder abducted to 90°, elbow flexed to 90° and the forearm pronated (Figure 1). A small towel was placed under the distal humerus. The examiner manually stabilized the humerus and placed the dynamometer on the distal radius 1 cm proximal to the wrist crease. The HHD was placed on the volar and dorsal aspects of the wrist to measure the strength of the internal and external rotators, respectively. To assess peak isometric force, the athletes were instructed to hold the arm against a gradually increasing force for a total of five seconds "make test".1 The average peak force (kg) was divided by the athlete’s body mass in kg (BM) to calculate the standardized force production (%BM).

Good intrarater and interrater reliability of hand-held dynamometry (HHD) for strength testing of the internal and external rotators have been reported.20,21 To ensure accurate reliability and validity of all included measures used in this study, a pilot study was performed utilizing 20 collegiate athletes. The shoulder strength of the internal and external rotators demonstrated high intra-rater and inter-rater reliability with intraclass correlation coefficients (ICC).
of .95 and .99 for internal rotators and .98 and .98 for external rotators.

CLOSED KINETIC CHAIN UPPER EXTREMITY STABILITY TEST.

The CKCUEST test has excellent test-retest reliability (ICC = 0.92). Additionally, a pilot study was performed and found the intra-rater and inter-rater for the CKCUEST to be ICC = .91 and .99, respectively. Two pieces of tape were placed 36 inches apart on the ground (Figure 2). The BB players were asked to assume the push-up position and the SB players used the modified push-up position with the shoulders kept directly over the hands. Participants were asked to make as many ‘touches’ of each piece of tape as possible within 15 seconds and the examiner counted the number of touches. Three trials were performed and the mean score of the three trials was calculated. A rest period of 45 seconds was given after each trial. The CKCUEST score and power were also calculated by using the following two formulas,

\[
\text{Score} = \frac{\text{average number of touches performed on the CKCUEST}}{\text{height (m)}}
\]

\[
\text{Power} = 68\% \times \text{body weight (kg)} \times \text{average number of touches performed on the CKCUEST}
\]

DATA ANALYSIS.

SPSS (IBM Corp. IBM SPSS Statistics for Windows, Version 26.0. Released 2019. Armonk, NY: IBM Corp.) was used to perform: 1) descriptive statistics for the strength of the internal and external rotators of the throwing and non-throwing shoulders and the CKCUEST; 2) paired t-tests to compare the strength measures of the throwing and non-throwing arms; 3) Pearson product-moment correlation coefficient to calculate the relationships between strength and the CKCUEST; 4) independent t-tests to compare the shoulder strength and the CKCUEST of BB and SB players; and 5) independent t-tests to compare the effects of the BB player’s field position on the shoulder strength and the CKCUEST variables. There was an insufficient number of SB pitchers (n=4) to complete a comparison between pitchers and other field positions. It was estimated that 30 participants would be sufficient to provide a good point estimate of isometric strength and the CKCUEST measures using a 95% confidence level and a population size of 13,465 DIII BB players.

RESULTS

Seventy-four DIII collegiate athletes (50 BB and 24 SB players) with an age range of 18-21 years old agreed to participate (Table 1). All participants signed an institutionally approved informed consent. The strength expressed as %BM and the CKCUEST measures for BB and SB players are presented (Tables 2 & 3). All measurement values met the assumptions for parametric analysis.

There were significant differences between the BB players’ throwing and non-throwing shoulders for both the internal and external rotators (p = 0.012 & 0.047, respectively) with mean strength differences (95% CI) of 1.12 %BM (0.25, 1.96) and 0.92 %BM (0.01, 1.8), respectively. There were significant differences in the strength of the internal and external rotators within each shoulder (p = 0.008 & 0.013, respectively). The mean differences (95% CI) were 2.55 %BM (0.55, 4.56) for the internal rotators and 2.36 %BM (0.6,
Table 1. Participants Characteristics.

<table>
<thead>
<tr>
<th>Participants Characteristics</th>
<th>Baseball (SD)</th>
<th>Softball (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.3 (1.0)</td>
<td>19.2 (1.0)</td>
</tr>
<tr>
<td>Years Competing (years)</td>
<td>13.8 (2.8)</td>
<td>13.6 (2.2)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.77 (.07)</td>
<td>1.64 (.06)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>84.2 (11)</td>
<td>69.8 (9.7)</td>
</tr>
<tr>
<td>Sports Position (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitcher</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Catcher</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Infield</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Outfield</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

SD=Standard Deviation, m=Meter, kg=Kilogram

Table 2. Strength Characteristics (Mean & SD) of and Differences Between Baseball and Softball Players Non-Throwing & Throwing Shoulders.

<table>
<thead>
<tr>
<th>Side</th>
<th>BB †</th>
<th>SB</th>
<th>Mean Difference (BB - SB)</th>
<th>95% CI of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lower</td>
<td>upper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR Strength as % BM*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Throwing</td>
<td>23.75 (6.89)</td>
<td>17.73 (4.47)</td>
<td>6.02</td>
<td>3.36 - 8.69</td>
</tr>
<tr>
<td>Throwing</td>
<td>24.86 (8.03)</td>
<td>18.46 (5.53)</td>
<td>6.40</td>
<td>3.20 - 9.60</td>
</tr>
<tr>
<td>ER Strength as % BM*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Throwing</td>
<td>21.39 (5.14)</td>
<td>16.46 (2.87)</td>
<td>4.93</td>
<td>3.07 - 6.79</td>
</tr>
<tr>
<td>Throwing</td>
<td>22.31 (5.39)</td>
<td>17.10 (3.19)</td>
<td>5.21</td>
<td>3.21 - 7.21</td>
</tr>
<tr>
<td>IR/ER Strength Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Throwing</td>
<td>1.14 (.30)</td>
<td>1.08 (.19)</td>
<td>.06</td>
<td>-.06 - .18</td>
</tr>
<tr>
<td>Throwing</td>
<td>1.14 (.31)</td>
<td>1.07 (.20)</td>
<td>.06</td>
<td>-.06 - .18</td>
</tr>
</tbody>
</table>

BM=Body Mass, SD=Standard Deviation, CI=Confidence Interval, IR=Internal Rotation, ER=External Rotation, BB=Baseball, SB=Softball.
*Statistically significant difference between Baseball and Softball (p < .001).
†Statistically significant difference between throwing and Non-throwing arms.

Table 3. Closed Kinetic Chain Upper Extremity Test (CKCUEST) Differences Between Baseball (N=50) and Softball (N=24) Players.

<table>
<thead>
<tr>
<th></th>
<th>BB Mean (SD)</th>
<th>SB Mean (SD)</th>
<th>Mean Difference</th>
<th>95% CI of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lower</td>
<td>upper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CKCUEST</td>
<td>18.89 (3.76)</td>
<td>17.54 (3.12)</td>
<td>1.35</td>
<td>-4.160 - 3.12</td>
</tr>
<tr>
<td>CKCUEST Power*</td>
<td>71.35 (14.40)</td>
<td>55.37 (11.64)</td>
<td>15.98</td>
<td>9.26 - 22.70</td>
</tr>
<tr>
<td>CKCUEST Score</td>
<td>10.73 (2.56)</td>
<td>10.72 (1.92)</td>
<td>.016</td>
<td>-1.039 - 1.07</td>
</tr>
</tbody>
</table>

CI=Confidence Interval, SD=Standard Deviation, BB=Baseball, SB=Softball.
*Statistically significant difference p < .001.

4.09) for the external rotators of the throwing shoulder and non-throwing shoulders, respectively. However, the internal/external rotators strength ratio was not significantly different for either shoulder. When comparing BB pitchers to all other field positions there was no significant difference in any of the strength or CKCUEST measures (Table 4). There were no significant differences between the SB players throwing and non-throwing shoulder strength for the internal (p=0.116) and external rotators (p=0.109). Moreover, there were no significant differences between the
strength of the internal and external rotators of the non-throwing shoulder (p=0.075) or the throwing shoulder (p=0.096). There was an insufficient number of SB pitchers (n=4) to complete a comparison between the pitchers and other field positions (Table 2).

The throwing and non-throwing arms of BB players produce significantly more internal and external rotation force than the SB players (p < 0.001). However, there was no statistically significant difference (p=0.31 & 0.30) in the internal/external rotators strength ratio of the throwing and non-throwing shoulders, respectively (Table 2). Among the CKCUEST measures, only the CKCUEST power showed significant differences (p < 0.001) between BB and SB players (Table 3).

Scatterplots were viewed to examine bivariate correlation and linearity between the strength and the CKCUEST measures. No curvilinear relationships were identified. There was no correlation between any measure of shoulder strength and the CKCUEST in BB players. Similarly, SB players also demonstrated no correlation between any of the throwing or non-throwing shoulder strength measures and the CKCUEST or CKCUEST score. However, SB players showed significant (p< 0.01) and moderate correlations between the CKCUEST power and strength of the internal rotators (r = -.54 & -.57) and external rotators (r= -.58 & -.58) of the throwing and non-throwing arm, respectively.

**DISCUSSION**

Descriptive studies enhance the ability of practitioners to accurately interpret examination data. One of the main purposes of this study was to describe the isometric shoulder strength measures of the internal and external rotators for DIII collegiate BB and SB players. Electromyographic analysis has shown that the shoulder internal rotators are the primary upper limb accelerators during overhead throwing while there is high supraspinatus, trapezius, and external rotator muscle activity during the follow-through phase.4,24,25 The rotator cuff strength of BB and SB players can be measured using a variety of tools including manual muscle testing, isokinetic dynamometry and HHD. HHD has been shown to be an effective alternative to manual muscle testing to improve objectivity in the clinical setting and is more readily available to clinicians than isokinetic dynamometry.

In this study, BB players demonstrated slightly higher levels of strength in their throwing shoulders compared to the non-throwing shoulders (Table 2). However, the ratio of strength between the internal and external rotators for the throwing and non-throwing arm not significantly different. The strength values for the throwing shoulder internal rotators reported in this study are consistent with other studies that reported on high school pitchers and professional players with average strength that ranged from 18.7 to 25% BM.10,11,26,27 Only one study by Mullaney et al.,4 who tested 13 collegiate BB pitchers, reported higher internal rotators strength values (Appendix A). The strength of the external rotators of the throwing shoulder in this study was slightly higher than those reported in the literature for high school and professional BB pitchers that reported average strength ranging from 16.1 to 17.5% BM.10,11,26,27 Mullaney et al.4 reported strength values of the external rotators that were consistent with the current results.

The BB players internal rotators were stronger than the external rotators bilaterally, which is consistent with previous studies of high school, collegiate and professional players.1,4,7,27 This strength differential between the internal and external rotators has been reported for BB pitcher and non-pitchers.8,9 Cook et al.9 suggested that this may be a natural imbalance of the shoulder musculature. Hurd et al.26 found that the strength of the internal rotators was

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**Table 4. Comparison of Baseball Players Strength Measures (%BM) for Pitchers (N = 14) and Other Field Positions (N = 36).**

<table>
<thead>
<tr>
<th>Position</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper Limit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CKUEST</td>
<td>Pitcher</td>
<td>19.10 (4.51)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>18.82 (3.50)</td>
</tr>
<tr>
<td>CKUEST Power</td>
<td>Pitcher</td>
<td>72.73 (15.87)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>70.81 (13.99)</td>
</tr>
<tr>
<td>CKUEST Score</td>
<td>Pitcher</td>
<td>10.84 (2.73)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>10.69 (2.04)</td>
</tr>
<tr>
<td>IR Strength Throwing Shoulder as % BM</td>
<td>Pitcher</td>
<td>22.13 (5.90)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>25.92 (8.56)</td>
</tr>
<tr>
<td>ER Strength Throwing Shoulder as % BM</td>
<td>Pitcher</td>
<td>19.47 (4.65)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>23.41 (5.30)</td>
</tr>
<tr>
<td>Strength Ratio IR/ER Throwing Shoulder</td>
<td>Pitcher</td>
<td>1.16 (.28)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>1.12 (.33)</td>
</tr>
</tbody>
</table>

CKCUEST=Closed Kinetic Chain Upper Extremity Stability Test, BM=Body Mass, SD=Standard Deviation, CI=Confidence Interval, IR=Internal Rotation, ER=External Rotation.
positively associated with the peak shoulder external-rotation moment. They postulated that the demands on the posterior musculature during pitching are associated with the need to counterbalance the limb acceleration produced by the internal rotators.26

The results of this study demonstrated that the strength of the throwing and non-throwing shoulders in SB players were not statistically different. Also, the strength of internal and external rotators of each shoulder were similar. Only one study reported the strength of the internal and external rotators for 14 high school SB players (mean age 16.5 years) and had slightly lower values than those found in this study.28

The BB players demonstrated stronger but asymmetrical shoulder strength while the SB players had weaker but symmetrical shoulder strength. These findings were consistent with Riemann et al.20 who also found that healthy young men were stronger than women, while the strength ratio of the internal and external rotators for both the throwing or non-throwing arms of men and women were similar. The authors hypothesize that the differences between DIII Collegiate BB and SB players may be gender-related as opposed to sports related adaptations.

There are a growing number of performance measures that clinicians can use to screen and evaluate athletes. The CKCUEST has been found to have excellent reliability and agreement as well as good construct, convergent and discriminant validity.14 The CKCUEST performance of the BB and SB players in this study was similar to healthy collegiate males and females.29–31 Contrarily, the performance of BB players in this study were lower than those reported for collegiate DIII male BB players,17 DI collegiate football players15 and healthy collegiate males.22 No other study has reported the CKCUEST performance for collegiate SB players.

Among the CKCUEST measures (number of touches, power and score), only the CKCUEST power showed a significant difference between BB and SB players (Table 3) and was inversely correlated with the strength of the internal and external rotators in SB players. These observations may be partly explained by gender differences and/or the fact that the BB players performed the CKCUEST from the modified push up position. When comparing the CKCUEST performance of men and women, using the power may be considered for evaluation of athletes. However, more studies are needed to confirm this finding.

A review of the literature indicated that no other studies evaluated the relationship of the CKCUEST and shoulder strength in collegiate BB or SB players (Appendix B). In this study, there was no relationship between CKCUEST and any of the throwing or non-throwing shoulder strength measures for BB players. Negrete et al.30 found no relationship between the CKCUEST and maximal throwing distance in a group of healthy recreationally active men and women. Studies included in a recent systematic review indicated that the relationship between upper extremity strength and power measures in athletes is weak and positive.14 The negative relationship found in this study between the SB players’ CKCUEST power and strength measurements may be a spurious correlation. The utilization of body weight in the calculation of CKCUEST power and the standardization of the strength measures to the individual’s body weight may explain this negative relationship.

In this group of DIII BB players, the position on the field did not seem to make a difference in any of the strength or CKCUEST measures. The majority of research for high school, collegiate and professional BB players has focused on pitchers, thus making it difficult to compare the current results of other field players to similar studies (Appendix A and B). This highlights the need for additional research that includes all field positions for BB and SB at all levels of competition to help validate reference values for the entire team.

When evaluating reference values related to HHD it is important for researchers and clinicians to consider the testing procedure (make or break test), the device used, the subjects’ ages, genders, and level of athleticism.20,32–36 There are a variety of testing positions described in the literature for measuring the strength of the internal and external rotators using a HHD including prone, supine, sitting and standing positions (Appendix A).32,37 Riemann et al.20 reported that the prone testing position (90º shoulder abduction) was associated with more external rotation force for both men and women and less internal rotation force in women than the seated neutral or 30–30–30º positions. Their strength values were consistent with the results of this study and may indicate that DIII collegiate BB and SB players have similar shoulder strength as healthy college aged adults.20 It is recommended that there be a standardized methodology of HHD when screening the shoulder strength of BB and SB players to enhance the ability for researchers and clinicians to make comparisons between groups of athletes.32,37

The limitations of this study include the single site for data collection, the use of a sample of convenience and the smaller sample size of SB players. It should be noted that the participants of this study were measured during the preseason and there is a potential for strength changes throughout the season. The difference between the shoulder strength results using HHD of this study and those listed in Appendix A may be related to the different testing methods used.

Future research should focus on the shoulder performance characteristics and biomechanical analysis of the throwing motion of all DIII BB and SB field positions to determine the unique characteristics of these groups and their associated risk for injury. Future research should also focus on the clinical usefulness of the CKCUEST to determine how it could most effectively be utilized in the clinic and on the field.

CONCLUSION

The reference values presented in this study may be used to enhance the interpretation of the examination findings related to DIII BB and SB players. BB players demonstrated stronger internal and external rotators but overall, less symmetry between and within their throwing and non-throwing shoulders when compared to SB players. Although the CKCUEST number of touches or score were not correlated to the isometric strength of the internal or external rotators nor differentiated between BB and SB players, the CKCUEST power did and may be considered for the evalu-
CONFLICT OF INTEREST

Authors have no conflict of interest related to this manuscript.
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A

Appendix B
Background and Purpose

Neck pain in the United States is pervasive and contributes to disability. While the majority of neck pain in young and healthy individuals is neuromusculoskeletal in nature, screening for red flags is necessary for ruling-out serious medical pathologies. The purpose of this case report is to describe a young and healthy male subject with a primary complaint of acute neck pain with multiple underlying upper extremity superficial vein thromboses (UESVTs).

Case Description

The subject was a 27-year-old male active-duty Soldier referred to physical therapy by his primary care provider (PCP) for acute left-sided neck pain. Prior to physical therapy, the subject had been treated with cyclobenzaprine, oxycodone-acetaminophen, trigger point injection and had undergone a D-dimer to rule out a potential thrombus due to air travel and lower extremity immobilization.

Outcomes

The subject underwent a D-dimer, Doppler ultrasound, pharmacological treatment of Rivaroxaban, and was referred to hematology/oncology to rule out systemic causes of SVTs. Evidence of subtle increases in blood pressure over the course of three months, a positive D-dimer, and symptoms incongruent with clinical presentation contributed to referral to a hematology/oncology specialist and a diagnosis of multiple UESVTs. The subject was able to return to his previous level of activity by six months and remained free of SVTs at two-year follow-up.

Discussion

UESVT events are rare and can be challenging to identify. This case report describes a unique presentation of acute neck pain caused by underlying UESVTs in an otherwise healthy and active young male.

Level of Evidence

Level 4

BACKGROUND AND PURPOSE

Young and healthy subjects presenting with neck pain in the absence of a clear mechanism of injury or apparent contributing factors can present unique challenges. Determining if the subject is appropriate for physical therapy care can be especially challenging when the subject is referred to physical therapy from a physician assistant following a visit to the emergency department. While neck pain is a common occurrence, affecting 15.1% of the U.S. population during any given three-month period,1,2 the potential for serious underlying conditions requiring referral exist. Screening for red flags in subjects with neck pain is critical to the clinical decision-making process and determination of appropriateness for physical therapy services.
The development of UESVTs are largely restricted to hospitalized populations; use of endovascular devices (e.g., PICC lines and peripheral venous lines) and in subjects with malignant cancers, infection or inflammatory processes, during pregnancy/post-partum or with haptogastrointestinal pathologies.3,4 Much less commonly (incidence 1/100,000), UESVTs have been reported in male subjects under the age of 30 due to Paget-Schroetter Syndrome (effort thrombosis) or Thoracic Outlet Syndrome (TOS). 4,5 In these rare cases, the presence of repetitive upper extremity movements cause microtrauma to the endothelium creating thromboses. Clinical signs of UESVTs occur in roughly a third of those diagnosed, with the most common signs including erythema, indurated cord, edema, and pain.5,6

The purpose of this case report is to describe an example of a young and healthy subject presenting with a primary complaint of neck pain with underlying UESVTs.

CASE DESCRIPTION

The subject was a 27-year-old, right-hand dominant, male, active-duty U.S. Army Soldier with a chief complaint of acute 12-day history of left-sided neck pain (Figure 1). The subject’s neck pain was preceded by a relatively short, two-hour airplane flight, in which he reported falling asleep in an “awkward position” for approximately 20 minutes. Following the flight, the subject initially reported experiencing neck stiffness which progressed to mild pain by the next morning, and to moderate pain by day 8, prompting the subject to schedule an initial encounter for neck pain with his PCP. The subject denied significant past medical history or recent events of trauma to his neck but did report having woken with similar neck pain about three months prior which resolved on it’s own within the same week. The subject was in excellent overall health with the exception of a healing Lisfranc injury to his left lower extremity which he incurred two months prior and had used bilateral axillary crutches for approximately six weeks after the lower extremity injury. The timeline of encounters is represented in Figure 1.

Treatment for this episode of neck pain included the subject visiting a civilian chiropractor twice and a massage therapist once before seeing his PCP for neck pain. The subject reported minimal temporary relief of his symptoms and growing difficulty in being able to maintain any prolonged positions with his visits to the chiropractor and massage therapist. Nine days following onset of pain, and the subject’s first visit with his PCP, he was treated with trigger point injections (Marcaine/Lidocaine) in the upper trapezius muscle with temporary relief in symptoms. His PCP also prescribed Hydrocodone/Acetaminophen (5mg/325mg), Ibuprofen (800mg), and Cyclobenzaprine (10 mg).

On day 11 following initial onset of symptoms, the subject was unable to sleep or find any relief with medication or changing positions and visited a civilian emergency department. The emergency room physician ordered cervical spine radiographs which were unremarkable and diagnosed him with a neck strain. He was prescribed Percocet for pain relief and instructed to follow-up with his PCP. The next day he followed-up with his PCP (PCP visit number 2, 12 days since the onset of his pain) during which a D-dimer test was ordered and he was referred to physical therapy. The subject’s PCP requested he be seen as soon as possible for acute neck pain. The subject’s most immediate goal was to manage pain so that he could get some sleep.

INITIAL PHYSICAL THERAPY EVALUATION

The subject described his neck symptoms as constant, variable, sharp, deep, and primarily located over his mid- to lower-left cervical paraspinal musculature with some discomfort noted in the left upper trapezius and scapular region. He denied radiating pain into either upper extremity, numbness or tingling, double vision, blurry vision, difficulty swallowing, dizziness, upper extremity weakness, or unexpectedly dropping objects. The subject had no observable dysarthria, nystagmus or ataxia of gait. He rated his pain with medication (Percocet) at a 2/10 on the Numeric Pain Rating Scale (NPRS)7 during the evaluation, with complaints of neck stiffness, particularly during cervical extension. He reported that his pain increased to 10/10 on the NPRS with active movement, especially looking up, in addition to significant difficulty laying down in any position to sleep.

Observation of the subject revealed no erythema, edema, or deformity of the neck or upper extremities. The subject’s active range of motion was restricted in cervical extension, and he was unable to position himself in neutral due to pain. Cervical flexion was limited to 10 degrees before pain onset with complaints of “significant muscle stretch.” Left side-bending was limited to 30 degrees and right-side bending was 45 degrees. Cervical rotation was within normal limits and not overly provocative of symptoms in either direction. Upper extremity shoulder motion was within normal limits, with discomfort at end-range left shoulder flexion into this left upper trapezius region. Passive range of motion was slightly better with cervical extension to 5 degrees, cervical flexion to 45 degrees with muscle stretch end-feel, and cervical rotation within normal limits with no provocation of symptoms.

Palpation revealed no apparent deformities or tissue texture abnormalities. Manual muscle testing was deferred at the initial visit due to heightened pain with motion testing. He had significant tenderness to palpation of the left paraspinal muscles, greatest adjacent to C5-6 levels with palpable taut muscle bands of the left paraspinals, mid-portions of the left sided upper trapezius and mild tenderness at the insertion of left levator scapulae muscle. Palpation of the left first rib posteriorly elicited reproduction of the subject’s pain. Passive accessory intervertebral movement assessment with anterior-to-posterior testing and up-gliding elicited the most discomfort and guarding at C5-6. The subject had difficulty positioning into cervical quadrant assessments, which were negative for radiating symptoms. The supine cervical distraction test was also negative for reduction in symptoms. Light touch sensation and deep tendon reflexes were assessed and found to be intact and symmetrical.

The initial exam findings were relatively benign. Following a thorough review of the subject’s past military medical history, the absence of significant injury or systemic disease, and an unremarkable family history, the physical ther-
Figure 1: Timeline of Medical and PT encounters


The subject verbally consented to manual physical therapy including Grade V thrust manipulation in the supine position in an anterior-to-posterior direction of the left first rib with cavitation, supine cervicothoracic junction manipulation without cavitation, prone cervicothoracic junction manipulation with cavitation, supine up-glide cervical manipulation at C5-6 without cavitation. Post-treatment cervical extension improved by 10 degrees. Due to the subject’s favorable response to trigger point injection, dry needling treatment was considered an appropriate adjunct therapy. The subject provided written consent to dry needling of the left and right paraspinal muscles at levels C5-7 which provided no additional functional benefit. The subject was instructed to perform active range of motion exercises and advised to use heat or ice as needed based on preference to assist with pain.

Figure 2: Patient Blood Pressure Timeline

*PCP: Primary Care Provider; PT: Physical Therapist; Hem/Onc: Hematology Oncology

The subject’s initial clinical impression was that the subject’s pain was most likely musculoskeletal in nature. There were no signs or symptoms suggesting significant pathology or the need for referral. The physical therapist’s initial clinical impression was that the subject’s pain was most likely musculoskeletal in nature. There were no signs or symptoms suggesting significant pathology or the need for referral.8

INITIAL PHYSICAL THERAPY TREATMENT

The subject returned to physical therapy for follow-up two days later (after the weekend) in visible distress and discomfort. He reported that his symptoms were slightly improved the evening after the initial physical therapy treatment and that the improvement was sustained through to the next morning, but that his pain worsened the following day. He reported feeling nauseous and described a “clawing and gripping pain” deep into his left upper trapezius and neck area, but denied numbness, tingling, or radiating symptoms into the upper extremities. With the exception of increased pain, the subject denied any changes, any potentially precipitating events, or activities that could explain his severe increase in pain. Due to the significant increase in the subject’s pain, the physical therapist once more reviewed the subject’s medical records, to include recent vital signs. Upon further review, it was noted that there was a subtle upward trend in the past three months of blood pressure measurements (Figure 2) following a Lisfranc injury two months prior and continued increases during the encounters for neck pain. Additionally, there was an elevated D-dimer test result that had not yet been reviewed by the PCP. The subject’s D-dimer test was valued at 261, with the normal range being reported 0-230. Considering the subject’s intractable pain with pharmacological treatment, physical therapy intervention and especially in light of the high blood pressure readings and high D-dimer blood test, the physical therapist became more concerned that the subject’s pain was not musculoskeletal in nature. The physical therapist initiated an immediate referral back to the subject’s PCP with the suggestion of a Doppler ultrasound evaluation.

PHYSICAL THERAPY EVALUATION #2

in the subject’s pain, the physical therapist once more reviewed the subject’s medical records to include recent vital signs. Upon further review, it was noted that there was a subtle upward trend in the past three months of blood pressure measurements following a Lisfranc injury two months prior and continued increases during the encounters for neck pain. Additionally, there was an elevated D-dimer test result that had not yet been reviewed by the PCP. The subject’s D-dimer test was valued at 261, with the normal range being reported 0-230. Considering the subject’s intractable pain with pharmacological treatment, physical therapy intervention and especially in light of the high blood pressure readings and high D-dimer blood test, the physical therapist became more concerned that the subject’s pain was not musculoskeletal in nature. The physical therapist initiated an immediate referral back to the subject’s PCP with the suggestion of a Doppler ultrasound evaluation.
OUTCOME

The subject’s PCP ordered an UE duplex ultrasound Doppler which revealed that he had several thromboses of the superficial vein network of the left upper extremity, specifically the cephalic vein and mid- and distal portions of the basilic veins. His PCP immediately referred him to the emergency department where he was screened for pulmonary embolism with a chest computed tomography (CT) which was found to be negative. He was also treated with an anticoagulant, Rivaroxaban (Xarelto). The subject was prescribed a therapeutic dose of Xarelto (15mg) to be taken orally twice daily for 21 days. After completing the first three weeks of anticoagulant medication, the subject’s dose was decreased to 20mg once daily and ordered to be taken for six additional weeks. He discontinued use of Xarelto after this time. The emergency department referred the subject to specialty care in hematology/oncology to rule out more potential underlying causes of the subject’s UESVTs. The hematology/oncology specialist reported no remarkable findings, also coming to the conclusion that repetitive upper extremity use while on crutches contributed to the subject’s UESVTs development. At both six-month and two-year follow-up, the subject had no recurring symptoms nor symptomatic SVTs since that time.

DISCUSSION

Despite the unlikely occurrence of UESVTs in young and healthy individuals, there are conditions which may create opportunities for thromboses to form in the upper extremity. Specifically, repetitive retroversion, hyperabduction and extension of the arm have been proposed to be mechanism by which undue stress is caused to the endothelium of the subclavian vein resulting in a coagulation cascade. Although there is no literature specific to SVTs, long-haul flights (>6hr) have also been associated with a 2.3-2.8-fold increase in risk for developing venous thrombosis-related complications when compared to shorter flights. Although it was noted in the subject’s history that he had taken a short flight prior to the onset of his symptoms, there is minimal evidence that short duration flights result in DVT, SVT, or related thrombosis-related complications. The incidence of neck pain caused by a superficial or deep vein thrombosis (DVT) in the upper extremity is less frequent than reported cases of leg pain from a DVT. In light of the subject’s history of Lisfranc injury followed by using bilateral axillary crutches for a prolonged period, it is plausible that this subject developed UESVTs, also described as effort thromboses, as a result of his prolonged crutch use. The subject was also questioned further regarding his crutch use and stated that he would often use a single crutch on his injured left-side, further contributing to repetitive stress.

While the subject in this case report did not present with any red flags at the initial evaluation, his response to treatment was concerning at follow-up. Common risk factors, clinical signs, and symptoms for SVT are not well defined, however the known risks, signs, and symptoms for DVT are presented in Table 1. While clinical signs and symptoms related specifically to UESVTs are less commonly reported in the literature, a common clinical sign of UEDVT, including PE, is increased heart rate, while edema of the arm or hand may occur, it is less common. A review of the subject’s electronic medical record (EMR) demonstrated no significant increases in heartrate or respiratory rate. The subject’s EMR did show gradual, but notable increases in blood pressure following prior to the onset of his LE injury several months prior, peaking at his second physical therapy appointment. Blood pressure has not been identified as a predictive clinical sign of UEDVT or UESVT and may have been reflective of the body’s natural response to pain. Nonetheless, observation of prolonged, elevated, and rising blood pressure prompted the physical therapist to consult with the subject’s PCP. Other findings associated with an increased risk of thrombosis include having blood type AB or factor V gene mutation. The subject described in this case report had type O positive blood, and his factor V gene mutation was not reported. Physical therapists suspecting a thrombosis in their subject should include blood type and factor V gene mutation results in their consideration of risk for thrombosis. Individuals with blood clotting disorders such as antithrombin III, protein S, or protein C deficiencies may also have an increased risk for developing thrombosis. Finally, medications may contribute to increased risk of thrombosis, such as oral contraceptives, antipsychotics, and alcohol. The subject described in this case report did not have a history of medication or substance misuse which might contribute to an increased risk or susceptibility to developing an UESVT. Objective findings of elevated blood pressure and a borderline high D-Dimer triggered an immediate referral to a physician for additional testing. A physical therapist acting in a direct access role has sufficient training to screen and identify more sinister diagnoses, like the one presenting in this case.

An SVT is not inherently life-threatening on its own, but could potentially lead to a more concerning DVT or pulmonary embolism (PE). Subjects who are typically diagnosed with UESVTs are older and have multiple comorbidities, so it was out of the ordinary to find one in this younger, healthy individual. The military setting is unique in that healthcare providers have immediate access to all health and medical records for a subject. In civilian outpatient populations, this subject might have not been referred as quickly to the appropriate provider without history of vital records. Physical therapists operating in environments without access to vital records should consider obtaining vital signs, including blood pressure measurement, on all of their subjects.

UESVTs are more commonly seen in older subjects (>65 years), with multiple comorbidities demonstrating clinical signs of increased heart rate, indurated cord, upper extremity discoloration, and/or arm and hand edema. Notably, these clinical signs are only seen in smaller percentages of the population and are inconsistent across individuals. Other findings which might alert a physical therapist to possible UESVTs include the subject having an AB blood type, having factor V gene mutations, or being on thrombosis-inducing medication such as oral contraceptives. Finally, in populations where UESVT might be less commonly
Table 1: Predictors of SVT, DVT, & PE Compared to Case Report Patient Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Characteristics of Patients with SVT, DVT, PE*</th>
<th>Patient characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Factors (%)</td>
<td>62 years (range: 48-73)(^1)</td>
<td>27 years</td>
</tr>
<tr>
<td></td>
<td>Female (66)</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Confinement to bed (5)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Recent travel (7)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Congestive heart failure or respiratory insufficiency (5)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Acute infectious disease (4)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Pregnancy or post-partum period &lt;6 weeks (5)</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Personal history of VTE (43)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Family history of VTE (26)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Cancer (8)</td>
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</tr>
<tr>
<td></td>
<td>Active cancer (4)</td>
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</tr>
<tr>
<td></td>
<td>Previous cancer (4)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>SVT in a non-varicose vein (22)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Chronic reduced mobility (4)</td>
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</tr>
<tr>
<td></td>
<td>Biological thrombophilia (5)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Hormonal contraception (5)</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Hormone replacement therapy (2)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Obesity (BMI &gt;30 kg/m(^2))</td>
<td>No (BMI = 23.7)</td>
</tr>
<tr>
<td>Symptoms</td>
<td>Vague shoulder or neck discomfort(^3)</td>
<td>Severe neck and upper shoulder pain**</td>
</tr>
<tr>
<td></td>
<td>Arm or hand edema(^3)</td>
<td>Not present</td>
</tr>
<tr>
<td>Signs</td>
<td>Heart rate 75-94 beats/min(^2)</td>
<td>53-71 beats/min</td>
</tr>
<tr>
<td></td>
<td>Supraclavicular fullness(^2)</td>
<td>Not present</td>
</tr>
<tr>
<td></td>
<td>Palpable cord(^2)</td>
<td>Not present</td>
</tr>
<tr>
<td></td>
<td>Extremity cyanosis(^2)</td>
<td>Not present</td>
</tr>
<tr>
<td></td>
<td>Dilated cutaneous veins(^2)</td>
<td>Not present</td>
</tr>
<tr>
<td></td>
<td>Jugular venous distention(^2)</td>
<td>Not present</td>
</tr>
<tr>
<td></td>
<td>Unable to access central venous catheter(^2)</td>
<td>n/a</td>
</tr>
<tr>
<td>Blood type</td>
<td>AB(^4)</td>
<td>O+</td>
</tr>
<tr>
<td>Lab values</td>
<td>Factor V Gene Mutation</td>
<td>Reported in up to 11% of patients diagnosed UEDVTs(^3)</td>
</tr>
<tr>
<td></td>
<td>Antithrombin III deficiency</td>
<td>Reported in 2-4% of patients diagnosed with UEDVTs(^3)</td>
</tr>
<tr>
<td></td>
<td>Protein S deficiency</td>
<td>Present in ~4% of patients diagnosis with UEDVTs(^3)</td>
</tr>
<tr>
<td></td>
<td>Protein C deficiency</td>
<td>Present in 4-7% of patients diagnosed with UEDVTs(^3)</td>
</tr>
</tbody>
</table>

From (Bauersachs, 2013\(^1\); Joffe Hylton V. & Goldhaber Samuel Z., 2002\(^2\); Le Gal et al., 2006\(^3\); Spiezia et al., 2018\(^4\))

*Literature is limited on signs and symptoms related to SVT; signs & symptoms of DVT, PE included here.
**Indicates potential marker for SVT, DVT, or PE evident here.

suspected, physical therapists might consider Paget-Schroetter Syndrome (effort thrombosis) or Thoracic Outlet Syndrome (TOS).\(^4,5\) In these rare cases, the presence of repetitive upper extremity movements cause microtrauma to the endothelium creating thromboses described in this subject due to overuse of an axillary crutch on the affected side. While the incidence of UESVTs is quite low, a thorough subjective and objective physical therapy examination, with reflective consideration of subject response to treatment, are likely to lead to appropriate referral.
CONCLUSION

Systems review with vital signs assessment (i.e., heart rate, blood pressure, respiratory rate, and temperature) provide valuable objective information related to patient status, potentially revealing undiagnosed medical conditions, and giving a snapshot of a patient’s general health and well-being. Physical therapists should collect vitals for each patient at their initial evaluation regardless of past medical history; subsequent readings can be used as a comparison and possible indication for physician referral. The subject described in this case report was younger and otherwise healthier than the typical patient who might present with an UESVT. Aside from consulting the ultrasound Doppler and CT findings, the only indication of thrombosis was a steady rise in blood pressure across several healthcare visits. Performing a thorough systems review with vital signs assessment adds minimal time and should be considered standard practice for patient encounters.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

“The subject described in this case report was informed that the data concerning the case would be submitted for publication and subject confidentiality has been protected according to the U.S. Health Insurance Portability and Accountability Act.”

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REFERENCES


Background
More than fifty percent of people with limb amputations participate in sports or physical activity following amputation. Athletes with limb amputations may face additional challenges including phantom limb pain (PLP), psychological barriers, prosthetic complications, and gait abnormalities. Prevalence of PLP in the general amputee population is estimated to be as high as 85%. Despite the high prevalence of PLP, there is little research regarding the use of gait training as a treatment for PLP among both the general amputee population and athletes.

Case Description
A 20-year old female collegiate track and field athlete presented with phantom knee pain brought on with running. The athlete demonstrated deficits in core and hip strength as well as decreased single leg stability bilaterally. Running gait analysis revealed circumduction with the prosthesis for limb advancement and increased vaulting with push off on the sound (uninvolved) limb. Gait retraining strategies were implemented to address video analysis findings and create a more efficient running gait and address phantom limb pain symptoms.

Outcomes
Rehabilitation and gait retraining strategies were effective in improving several clinical and functional outcomes in this case. Significant improvements were noted in PLP, running gait mechanics, and the patient’s psychological and functional status as measured with a standardized outcome tool, the Patient-Reported Outcomes Measurement Information System® (PROMIS®).

Discussion
Running gait training following amputation could be a crucial component of rehabilitation for athletes in an attempt to lessen pain while running, especially in those experiencing phantom limb pain (PLP). Utilization of a multidisciplinary team in the gait retraining process is recommended. There is a need for further research to determine the effects of running gait retraining for management of PLP in athletes with amputation.

Level of Evidence
5

INTRODUCTION
More than fifty percent of people with limb amputations participate in sports or physical activity following amputation. Exercise has been shown to positively influence self-esteem, perceived body image and better control of physical function in this population.1 Unfortunately, for many indi-
viduals, participation in sports may decrease following amputation due prosthetic barriers, including poor prosthetic fit and the prohibitive expense of a sports prosthesis.1

Additionally, athletes with amputations may experience pain resulting from the compensatory and asymmetrical movements that frequently occur following amputation. Older age, more proximal amputation and vascular changes are associated with impairments in activities of daily living and are likely obstacles to athletic endeavors.1 Athletes with amputations face further challenges when returning to activity including phantom limb pain, psychological barriers, prosthetic complications, and gait abnormalities.

Phantom limb pain (PLP) is defined as pain perceived as originating from the absent limb. Onset may occur soon after amputation or years later, although the majority of individuals with amputation report onset of symptoms within one year of amputation with reduced prevalence thereafter.2 In a study of adults with a history of upper extremity amputations, two typical peak periods of onset were noted: one month after amputation and one year after amputation.3 The experience of PLP is variable and the etiology is not well understood. Proposed causes include altered peripheral neural mechanisms (including peripheral nerve irritation or neurona), central neural mechanisms, or psychogenic factors including depression, anxiety, and altered body perception.24 Risk factors for the development of PLP include pain in the affected limb prior to amputation, pain in the intact residual limb, upper extremity amputation, and female gender. Prevalence of PLP in the general amputee population is estimated to be as high as 85%.5 There are no published data on the incidence of phantom limb pain in athletes with amputations.

Despite the high prevalence of PLP, there is little research regarding the use of gait training programs as a treatment for PLP among both the general amputee population and athletes. One systematic review evaluated gait training interventions post-amputation but did not address outcomes regarding PLP nor did it include athletes.6 While gait training with a prosthetic limb is an important component of rehabilitation following lower extremity amputation, it need not end once functional community ambulation has been achieved. For runners and other athletes with amputations, gait training can be a key aspect of rehabilitation to facilitate safe mechanics during higher levels of physical activity such as running and sports. Gait retraining may also have the potential to reduce phantom limb pain in lower extremity amputees through improved gait mechanics.

The purpose of this case report is to describe the use of running gait retraining strategies to address phantom limb pain in a collegiate athlete with transfemoral amputation. Due to a paucity of literature on this topic, when presented with the opportunity to provide gait training for one such transfemoral amputee collegiate sprinter it was necessary to develop a novel program utilizing a multidisciplinary approach.

METHODS

CASE SUBJECT

A 20-year old female National Collegiate Athletic Association (NCAA) Division III collegiate track and field athlete presented to her certified athletic trainer with phantom knee pain. Her medical history included right transfemoral amputation four years prior due to tibial osteosarcoma. At the initial presentation, the athlete reported two weeks of increased phantom knee pain with running, stair negotiation, and walking uphill. The athlete reported that she first noticed the pain one year ago, but it was now more persistent despite no new injuries or significant changes in training. Pain was reported to begin a few minutes into a running workout and continued throughout training and post-workout. The athlete experienced minimal to no pain at rest. In addition to pain, the athlete also expressed concern regarding the efficiency of her running gait.

After evaluation by her team physician, the athlete was referred to physical medicine and rehabilitation for physician consultation regarding phantom limb pain. The physician report stated that her right transfemoral amputation was well-healed with no evidence of skin breakdown, erythema, or tenderness. There were no concerns about her mood or affect at that time, and her walking gait was described as a normal reciprocal gait with right transfemoral amputation. It was recommended that she start gabapentin 300 milligrams daily. There were no diagnostic imaging studies performed at that time. The athlete reported no previous or concurrent rehabilitation for management of PLP, including gait retraining.

Prior to amputation, the athlete had participated on her high school cross country and track and field teams, focusing primarily on distance events. Post-amputation, she had not received any formal gait training to facilitate return to running. Since returning to running, the athlete had competed mostly in sprint events, although she reported being able to run comfortably at only one speed regardless of event or distance.

The athlete presented to her physical therapy evaluation wearing her walking prosthesis, with her running blade prosthesis in hand. She reported actively participating in preseason collegiate track workouts but was limiting her running activity due to PLP symptoms. The athlete reported no complaints or pathology of her sound limb. Her goals included being able to run comfortably without pain and to eventually complete a 5k.

PROSTHESIS DESIGN

The subject of this case report utilizes a socket design which focuses on maximum comfort and control, all while achieving a light-weight solution. Suction suspension minimizes in socket movements that may trigger undesired pain and skin breakdown. These characteristics are imperative for a highly active individual with increased demands. Thin socks were also implemented to maximize suction and minimize energy loss. The athlete’s prosthetic knee (Cheetah Knee by Ossur, headquartered in Reykjavik, Iceland) (Figure 1a and 1b) is an ideal choice for running and sprinting activities. The polycentric design promotes stability in stance,
but allows controlled deceleration during athletic activities. Multiple aspects of swing can be adjusted independently to yield the most energy and time efficient outcomes. The athlete's prosthetic foot (Flex Run by Ossur) leverages optimal prosthetic ingenuity with Nike's traction and sole technologies. The foot does not require a sneaker, and the stiffness and design varies according to an athlete's weight in order to facilitate an optimal energy storage and return. When ordering this type of prosthetic foot, one must consider the loads placed on it (a function of patient weight) and the frequency (a function of velocity) in which it will compress. Loads and frequencies change between running and ambulation, and therefore when categorized for running, such a foot would not be optimal for everyday ambulation.7

PHYSICAL THERAPY EVALUATION

Initial evaluation by a physical therapist specializing in running medicine revealed hip extension strength deficits bilaterally, with the involved right leg exhibiting 4-/5 strength and sound left limb with 4/5 strength. Hip abduction muscle strength was 4/5 bilaterally. Sound limb plantarflexion and inversion strength were also 4/5. Standard core strength measurements were unable to be assessed due to the amputation, however the athlete was observed to demonstrate decreased core stability as evidenced by increased anterior tilt and lumbar lordosis during performance of supine and standing core exercises. The athlete demonstrated knee valgus and pronation on the sound limb with single leg squatting, and decreased stability with single leg balance bilaterally. She was unable to balance unilaterally on her prosthetic side, in either her walking or running prosthesis.

A 2-D video analysis of the athlete's running gait with her running blade prosthesis was taken at the initial physical therapy visit. Due to reported discomfort when running on a treadmill, videos were taken outdoors over a series of five 75-meter trials. Initial findings of the running gait analysis revealed circumduction with the prosthesis for limb advancement and increased vaulting with push off on the sound limb. During swing phase relative to the prosthesis, the athlete demonstrated increased abduction as well as ipsilateral trunk lean at mid swing, followed by significant hip flexion and internal rotation to further advance the prosthesis in preparation for initial contact. Decreased knee flexion with the prosthesis was noted throughout swing phase primarily due to limb circumduction momentum. The athlete utilized a slight posterior trunk lean during initial contact and midstance on the prosthetic side, versus an upright posture with initial contact and midstance on the sound limb. Increased lumbar lordosis, knee valgus and pronation were noted during midstance on the sound limb. The athlete demonstrated a forefoot strike pattern on the sound limb. There was evidence of overstriding bilaterally in her video gait analysis.

INTERVENTION

Early intervention consisted of core and hip strengthening exercises bilaterally, focusing on pelvic stability during reciprocal leg movement. Sound limb strengthening was also implemented to address dynamic valgus and pronation tendencies noted during both the initial examination in standing and video gait analysis with running. Dynamic exercises were performed to improve balance and strength while weight shifting on and off the prosthetic side during stepping movements. This was initiated in the athlete's walking prosthesis and progressed to the running blade prosthesis, utilizing multiplanar and multi-height stepping and lunging exercises. Single leg balance exercises were introduced bilaterally as well. Ultimately, exercises focusing on turnover, speed and power were implemented (Table 1). Throughout the course of rehabilitation, exercises in these categories were progressed both in the clinic and for the athlete's home program.

It was crucial that the athlete develop confidence in her use of the running blade prosthesis, as it differed greatly from the capabilities of her day-to-day prosthesis. One strategy to increase confidence was named "fast feet" and consisted of quickly shifting weight from one leg to another. This required the athlete to accept weight onto the prosthetic side, then push off to land back on the sound limb without any forward motion initially. Speed, time spent on each limb and base of support were variables that were manipulated over time to increase challenge as the athlete's skill and capacity progressed. This activity required the athlete's weight to be balanced on her forefeet. As the video gait analysis revealed, the athlete already employed a forefoot strike pattern on her sound limb while running. This was beneficial, as the prosthetic foot requires a forefoot strike pattern with running.8,9 The prescribed "fast feet" exercise enabled her to build strength, balance and assurance while transferring and maintaining weight onto the forefoot of her running blade prosthesis.

Figure 1: Static alignment of prosthesis with patient loading sound and involved sides equally
The initial goal of running gait modification was to decrease the stride length and vaulting noted on video analysis, as the working theory was that the excessive impact sustained while landing on the prosthetic limb was contributing to the athlete’s symptoms. To address this, forward motion was added to the “fast feet” exercise, starting with a wide base of support. This helped the athlete learn to push off her sound limb and land on her prosthetic leg quickly. Progression included increasing speed and narrowing base of support until the athlete began to run more naturally. Through this strategy, stride length decreased and the vaulting seen on initial gait analysis was minimized, although a circumduction pattern for limb advancement remained. The athlete did not experience pain with these drills in clinic, during her home exercise program, or during track practice sessions.

Given that her prosthesis included a hydraulic knee, it was desirable to build a more efficient running gait pattern in which her knee flexed and extended in the sagittal plane, rather than the circumduction pattern that had been observed. A forefoot strike pattern assisted with this, as pressure on the forefoot combined with a forward lean is required to facilitate prosthetic knee flexion.9,10 Static and dynamic exercises emphasizing controlled hip flexion and knee drive were introduced to facilitate this mechanism. These aimed to help the athlete increase balance, strength and confidence in weight bearing through the toe of her prosthesis in order to facilitate the transition to knee flexion during running to produce a more natural and efficient gait pattern.11 As the athlete became more comfortable with this running pattern, additional running drills were added to develop her ability to run at varying speeds.

As the athlete progressed to running at different speeds, stride length changes were noted. A return of increased stride length when sprinting was noted bilaterally. While this may have initially been due to fear of prosthetic swing clearance, it was only exhibited during sprinting and therefore might simply represent a functional adaptation for generating speed and power. Further observation demonstrated that the athlete maintained knee flexion through swing phase on the prosthetic side despite this change in stride length. There was no degradation of her newly developed knee flexion and she was able to sprint without vaulting and with equal stride length bilaterally.

The athlete’s athletic trainer reported that she continued to work with the athlete on occasion as well providing heat, ice, and electrical stimulation in the training room. The remainder of the athlete’s rehabilitation exercises were performed on the athlete’s own time and with physical therapy. The athlete did participate in indoor and outdoor track workouts with her collegiate team throughout the course of her rehabilitation.

OUTCOMES

Over the course of rehabilitation, the athlete in this case demonstrated significant improvements in several clinical and functional outcomes, including reported PLP symptoms, running gait pattern, psychological measures, and overall function. The athlete had complete resolution of her phantom limb pain after eight weeks of rehabilitation. As a result, she did not initiate the prescribed medication and did not require additional follow up from physiatry. There were no adverse events or skin breakdown during the course of physical therapy.

Running gait pattern improvements were measured via 2D video gait analysis. Running gait analysis was performed at the first visit and approximately every two weeks throughout the first four months of rehabilitation. Kine
dynamic and still-frame analysis of key phases of the gait cycle demonstrated post-treatment improvements in limb circumduction, stride length, and vertical displacement. Using 2-D analysis, marked improvements in cadence, trunk lean and peak abduction of the athlete’s prosthesis were noted. (Table 2) Following her gait retraining interventions, the athlete demonstrated increased hip abduction and reduced hip flexion and internal rotation during swing phase with her prosthesis. The athlete also demonstrated im-

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**Table 1: Exercise Interventions and Progressions**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Focus</th>
<th>Progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core activation</td>
<td>pelvic stability with reciprocal leg motion</td>
<td>Single leg bridging with foam roller, Standing bird dog, Side planks, Suspension trainer (TRX) knee drives</td>
</tr>
<tr>
<td>Weight Acceptance</td>
<td>Increase confidence with weight bearing and stability on running prosthesis</td>
<td>Double leg squatting, Multi-directional lunging, Single leg balance, Standing single leg weight shifts, Wall lean knee drive</td>
</tr>
<tr>
<td>Strength</td>
<td>Sound limb dynamic stability</td>
<td>Single leg heel raises, Lateral step downs, Lateral lunges, Single leg hip hinge progression</td>
</tr>
<tr>
<td>Speed</td>
<td>Encourage quick turnover, forefoot weight bearing and decreased stance time</td>
<td>Fast feet, Agility ladder, High knees, Rear kicks</td>
</tr>
</tbody>
</table>

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Table 2: Gait Analysis Changes

<table>
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<tr>
<th>Time of Treatment</th>
<th>2 months</th>
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<tbody>
<tr>
<td>Therapy Sessions</td>
<td>6 visits</td>
</tr>
<tr>
<td><strong>Changes in Gait Pattern</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Initial</strong></td>
<td><strong>End</strong></td>
</tr>
<tr>
<td>Cadence</td>
<td>140 spm</td>
</tr>
<tr>
<td>Forward Trunk Lean (midstance)</td>
<td>5°</td>
</tr>
<tr>
<td>Peak Hip Abduction (prosthesis, swing phase)</td>
<td>11.0° abd</td>
</tr>
</tbody>
</table>

Spm= steps per minute, abd= abduction, add= adduction

Table 3: PROMIS® Scores

<table>
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<tr>
<th>Time of Treatment</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Therapy Sessions</td>
<td>16 visits</td>
</tr>
<tr>
<td>PROMIS® Scores</td>
<td></td>
</tr>
<tr>
<td><strong>Initial</strong></td>
<td><strong>End</strong></td>
</tr>
<tr>
<td><strong>T-score</strong></td>
<td><strong>T-score</strong></td>
</tr>
<tr>
<td>Adult Physical Function</td>
<td>50</td>
</tr>
<tr>
<td>Adult Pain Interference</td>
<td>52</td>
</tr>
<tr>
<td>Adult Depression</td>
<td>39</td>
</tr>
</tbody>
</table>

Note: In most cases across most domains, a PROMIS® score of 50 represents the mean in the U.S. general population and a standard deviation is described as a 10 point change. (22)

Physical and psychological outcomes were assessed using the Patient-Reported Outcomes Measurement Information System® (PROMIS®). The PROMIS® computer adaptive testing instruments are validated, publicly available, NIH-developed instruments that determine standard scores of various self-reported patient outcomes such as physical function, depression, and pain interference. Over seven months totaling 16 visits, the subject of this case report demonstrated improvement in self-reported PROMIS® scores across three domains: Adult Physical Function, Adult Pain Interference, and Adult Depression, with the largest improvement noted in Adult Pain Interference (1.3 SD). (Table 3)

DISCUSSION/CONCLUSION

Running gait training following amputation could be a crucial component of rehabilitation for athletes in an attempt to lessen pain while running, especially in those experiencing phantom limb pain (PLP). Currently, the authors are unaware of any literature regarding gait retraining to address phantom limb pain in amputee runners. It was unclear what led to the development of phantom limb pain in this particular athlete, though in general the development of PLP is not fully understood. The authors suspect that the cause of PLP in this case was multifactorial. Because the PLP occurred mostly with running and not at rest, it was hypothesized that inefficient running gait was a key contributing factor.

A few potential mechanisms for PLP are described in the literature. One potential cause of PLP is explained by a peripheral nerve irritation hypothesis. In this pathway, mechanical irritation of the distal residual limb generates PLP via noxious stimulation of a peripheral nerve. This explanation may be applicable in this case, as we do believe that the athlete's inefficient running gait pattern could have contributed to abnormal stress on her distal residual limb. In this case, PLP improved after a rehabilitation program that included running gait interventions which has the potential to decrease peripheral nerve irritation of the distal residual limb.

A few variables within a running prosthesis which can adversely affect athletic performance include suboptimal socket suspension and componentry malalignments. The athlete in this case did experience prosthesis fit difficulties towards the end of her physical therapy intervention, reporting loosening of the socket when running and the feeling that her prosthesis was “falling off.” This loosening was observed to create increased internal rotation of the prosthesis with hip flexion while running and overall reduced running speed. While the literature does describe dissatisfaction with prosthesis as a possible contributing factor to PLP, in this case the athlete's symptoms had resolved prior to the onset of fit issues and resulting pros-
thesis modifications. Modifications to the socket were made by the athlete’s prosthetist and thin socks were provided to help accommodate limb volume fluctuation, ultimately providing a better fit. The athlete’s symptoms did not return throughout her prosthesis adjustment period. While the fit of the running prosthesis was not believed to be a factor in the onset of PLP in this case, additional study of a larger cohort would be required to determine if these variables might explain PLP in other transfemoral amputee athletes, with or without competitive running aspirations.

Changes in physical function, pain and mood were assessed through a self-reported outcome measurement (PROMIS®), where a t-score of 50 is indicative of the general US population within each domain. Age related norms have also been established for each of the listed domains; for age range 18-34 years norms are as follows: Adult Physical Function: 55.1 (SD 8.4) Adult Pain Interference 47.8 (SD 9.0) and Adult Depression: 52.5 (SD 10.9). The authors are unaware of established norms related to individuals with amputation; further study into this domain could be indicated. The case athlete demonstrated the most improvement in pain interference, with a final t-score of 39. Remarkably, the subject concluded her treatment with a t-score less than both the general population and her peers. She also reported a final t-score of 54 in the Adult Physical Function domain, equal to both general and age-related norms in the United States population.

The positive benefits of activity on mood and psychological health are well known, but the effects were not able to be specifically delineated in this single case. The athlete did demonstrate improvement in PROMIS® score in the depression domain, however this did not achieve the suggested minimal clinical important difference (MCID) of greater than .5 of the standard deviation. It is noted that the athlete’s beginning and end PROMIS® scores for Adult Depression were below the average and age-related population norms, potentially indicating better mood compared to general population and/or peers. While the current case did not yield enough data to draw definitive conclusions about changes in depression, this could be an interesting area of future study should this area of rehabilitation be expanded to a larger population.

A limitation of this case report was the use of a 2D video analysis system rather than the 3D video analysis which is typically considered the gold standard. However, the use of a 2D system can be ideal in a clinical setting and is often a more practical and cost efficient tool for the rehabilitation clinician. Measurements of trunk lean and peak hip abduction were taken on a still frame, and are therefore not as accurate as compared to 3D measures. Despite the limitations of 2D data capture, there were significant clinical changes in peak hip abduction based on degree of change and visual observation (Figure 2). Changes described in this study were consistently noted at the same phase of running respectively and occurred over multiple strides of each recorded run.

Improvement in core strength and stability were an imperative part of this athlete’s rehabilitation, as it was necessary to increase pelvic control to promote ideal trunk position with running. While traditional core strength measures have been described and utilized in able-bodied athletes, the authors are unaware of the validity of these same tests in the case of an athlete following amputation. Further investigation into the validity of these tests for the amputee population should be completed in the future.

Future investigations could explore gait retraining techniques used in this case toward the development of a program that could be applied to other transfemoral or transtibial amputee athletes. Other opportunities for study include examination of factors associated with the development of PLP in runners to better understand if there are risks for development of PLP unique to the amputee athlete population versus the general amputee population, or if there are actually other protective factors at work. Additional study of a larger cohort would be required to determine if the factors and interventions illustrated in this case might respectively explain or treat PLP in other transfemoral amputee athletes, with or without competitive running aspirations. Since PLP in general is poorly understood it is important to keep in mind that rehabilitation programs may vary in an attempt to individualize treatment approaches for a wide variety of needs until a greater understanding of key variables and treatment pathways emerge.

CONCLUSIONS

This case report summarizes the successful evaluation and treatment of a female collegiate running athlete with transfemoral amputation that presented with PLP and running gait impairment. Key principles in the case of this athlete include diagnosis of running gait impairment by a physical therapist specializing in running medicine as well as a unique rehabilitation program designed by this therapist to address the gait abnormalities that we believe significantly contributed to the resolution of her PLP. Over the course of her treatment, this athlete worked with a multidisciplinary team including team athletic trainer, team physician, physical therapist, prosthetist and physical therapist. The unique expertise of each of the providers discussed in this report was beneficial to the care of this athlete and is a good model going forward for the collaboration that is necessary for a suc-
cessful outcome in this type of case.

CONFLICTS OF INTEREST

The authors of this paper have nothing to disclose.
REFERENCES


A Criterion Based Rehabilitation Protocol for ACL Repair with Internal Brace Augmentation

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Keywords: anterior cruciate ligament, internal brace, movement system, rehabilitation

The anterior cruciate ligament (ACL) is one of the main stabilizing structures of the knee and its rupture is a common injury in young active adults. ACL reconstruction has been the preferred operative management of an ACL rupture for several decades; however, success rates are variable. Recently, interest in arthroscopic primary repair of the ligament has increased. The repair is augmented with an Internal Brace (IB), which is an ultra-high strength suture tape that bridges the ligament. This technique protects the ligament during the healing and the ligament is encouraged to heal naturally, whilst not requiring any external braces. It acts as a stabiliser to permit early mobilization and optimise rehabilitation.

As understanding of rehabilitation has progressed, there has been an increased focus on early weight-bearing and achieving full range of movement. While detailed criterion-based rehabilitation protocols exist for ACL reconstruction, this is not the case for ACL repair. The purpose of this commentary is to present a novel criterion-based rehabilitation protocol following ACL repair surgery augmented with an IB.

Level of Evidence

INTRODUCTION

The anterior cruciate ligament (ACL) is one of the main stabilizing structures of the knee, acting to prevent excess anterior tibial translation and internal rotation. Rupture of the ACL is a common injury with an incidence of up to 84 per 100,000 adults and a risk of up to 3.7% per year in professional athletes. Untreated ACL ruptures can lead to joint instability, soft tissue injuries and joint degeneration.

Early attempts at primary ACL repair were associated with poor outcomes, including a high failure rate in athletes, but these were open procedures with lengthy periods of immobilisation. Consequently, ACL reconstruction became the preferred operative treatment of ACL rupture. However, this method has also been associated with a number of issues. Firstly, the graft does not restore the proprioceptive properties of a native ligament, with fewer than two thirds of patients returning to their pre-injury activity level. Secondly, the procedure can be associated with clinically significant morbidity following graft harvest including hamstring muscle weakness (hamstring grafts) and anterior knee pain (patellar tendon graft). The development of new arthroscopic techniques for ACL repair has resulted in a renewed interest in this procedure with good short term outcomes.

The Internal Brace (IB) is an ultra-high strength 2mm wide polyethylene tape (FiberTape, Arthrex, Naples, FL) that bridges the repaired ACL, from tibia to femur. This technique protects the ligament during the healing and remodelling phase, acting as a secondary stabilizer once the ligament is healed. The femoral fixation of the IB uses a button, and a knotless bone anchor is utilized on the tibial end; in addition to anatomical repair of the ACL. The ligament is encouraged to heal naturally, while not requiring any external braces. This allows accelerated rehabilitation with early mobilization and the IB will theoretically protect against injury recurrence. As a result of this, the rehabilitation following surgery can be approached differently from that after standard ACL reconstruction. This clinical commentary outlines a new rehabilitation protocol that may be appropriate for patients undergoing ACL repair with internal bracing. Although the rehabilitation protocol itself is not necessarily accelerated, it is felt that the ACL repair with...
the IB facilitates a faster rate of progression through the required criterion (compared to a non-augmented repair) for the majority of patients.

PROPOSED REHABILITATION PROTOCOL

Many protocols are based upon time frames for progression,\textsuperscript{14} however in this criterion-based protocol, the emphasis that attainment of measurable milestones should form the criteria for progressing to the next phase. In addition, it is essential patients are completing all the exercises from the previous phase competently and without pain, before progression, as outlined in Figure 1.

PRE-OPERATIVE REHABILITATION

The goals of this phase are to:
- Protect the unstable knee
- Reduce swelling
- Maintain quadriceps function
- Maximize knee extension

The patient should be assumed to have an unstable knee at this stage and flexion should be limited to 90 degrees (with an aim to maintain full extension).\textsuperscript{15} The focus of the exercises should be modified based on the severity, irritability, and nature of the injury. Open-chain bodyweight quadriceps exercises are recommended with lower limb triple extension (with resistance limited to a TheraBand). Stretching should focus on areas of tightness identified during initial assessment. Hamstring and calf length should be assessed with maintenance of gluteal and core muscles as able.\textsuperscript{16}

Precautions and restrictions need to be taken to protect the knee. A compression garment is advised with functional tasks during the day, with the leg being elevated and rested when exercises are not being performed. Ice should also be applied to the knee post exercise and when required to manage pain and swelling.

IMMEDIATE POST-OPERATIVE REHABILITATION (PHASE I)

Progression through phases is entirely criteria led (Figure 1), however the expected duration of this phase spans post-operative days 1-10. The restoration of range of motion (ROM), especially active knee extension is a critical component of this phase.\textsuperscript{17}

The main goals in this phase to allow progression are: ability to walk without crutches, full active ROM in the knee, good pain management, and effusion Grade 1+ (Table 1) or less. It is also important to ensure that trunk/hip stability and quadriceps activation are maintained.\textsuperscript{18} The restoration of a normal gait pattern is also an important component of this phase, ACL-deficient patients can ambulate with a characteristic flexed-knee gait, which can complicate tibiofemoral and patellofemoral mechanism restoration.\textsuperscript{19,20}

The three domains that the exercises focus on in all phases are: ROM, strength and control, and proprioception and balance. The exercises reflect the importance of ROM in

<table>
<thead>
<tr>
<th>Grade</th>
<th>Clinical Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No wave produced on downstroke</td>
</tr>
<tr>
<td>Trace</td>
<td>Small wave on medial side on downstroke</td>
</tr>
<tr>
<td>1+</td>
<td>Large bulge on medial side with downstroke</td>
</tr>
<tr>
<td>2+</td>
<td>Effusion returns to medial side after upstroke</td>
</tr>
<tr>
<td>3+</td>
<td>Cannot move fluid out of medial side of knee</td>
</tr>
</tbody>
</table>

Technique: the examiner strokes upwards from the medial joint line. A downward stroke on the distal lateral thigh is performed and a wave of fluid is observed at the medial knee.

Phase I.

Flexion and extension should be encouraged actively within limits, in this phase flexion is limited to 100 degrees

Figure 1: Overview of progression through rehabilitation protocol

Table 1: Knee Effusion grading and clinical exam on stroke test
with normal hyperextension (this can be practitioner administered passively as well) as active knee extension is crucial to this phase of recovery.\textsuperscript{21} Other recommended exercises to improve ROM in this phase include: patellar mobilizations, static quadriceps and gluteal contractions (isometrics), posterior chain soft tissue interventions, ankle pumps, and stretching of the calf and hamstrings. Low resistance work on an exercise bike is also permitted for up to 10 minutes, which encourages ROM and early introduction to cardiovascular fitness.

Strength and control is focused on the quadriceps muscle group as persistent weakness following ACL repair has been associated with increased morbidity.\textsuperscript{22} Recommended exercises to focus on this muscle group in this phase are: quadriceps setting, short arc quadriceps (over a towel roll), active straight leg raises, and long arc quadriceps. Hamstring strengthening should be done with a resistance band. Wall slides (from 0 to 45 degrees) and calf raises are also recommended in this phase. In addition to the muscles of the thigh, hip control and strengthening is recommended, in non-weight bearing with particular focus on hip extension and abduction.\textsuperscript{21} Core conditioning to improve lumbo-pelvic stability with emphasis on strengthening transversus abdominis is recommended;\textsuperscript{23} however, this should be performed without any lower limb loading. Gait education and gait drills are also an important component to return the patient to full weight bearing status. In this phase, all open chain quadriceps exercises should be without load. Proprioception and balance are not the key focus of this phase and the only application of this domain is low grade knee proprioception exercises. Exercises should address deficit findings during objective assessment and be tailored to individual patients during each rehab phase.

At this early post-operative stage, restrictions are important to protect the knee. Ice, rest, and a compression garment are recommended as per the pre-operative instructions. In addition to this, leg crossing, running, jumping, twisting, and pivoting are all prohibited.

**EARLY POST-OPERATIVE REHABILITATION (PHASE II)**

This phase builds on the previous one and its expected duration is from weeks 1 to 5. From this phase onwards, the patient should have a full weight-bearing status. The focus is maintained on ROM of the knee and flexion is now permitted to 110-120 degrees with full knee hyperextension.

Restrictions for this phase are similar to Phase I. A compression garment is no longer required but the recommendations on ice, rest, and prohibited movements are unchanged.\textsuperscript{15}

The major change in goals is the requirement to achieve stair reciprocal ascending and descending. ROM in flexion needs to be achieved within 30 degrees of unaffected side, along with full extension.

ROM exercises are maintained from the previous with minimal alterations. The time permitted on the exercise bike can be increased to 15 minutes, maintaining low resistance to encourage ROM and cardiovascular exercise. Active ROM exercises as described above can be carried out if the patient does not have access to an exercise bike.

Progression in strength exercises allows light loading (1-2kg) of open chain quadriceps exercises as pain and effusion allows within the ROM restrictions of this phase. Wall slides can be progressed to 90 degrees of flexion as pain allows. Closed chain exercises are introduced through light resistance-based knee extension (such as a Pilates Reformer Supine Leg Press). If the patient does not have access to a reformer or leg press, controlled wall squats can be used. Core conditioning to improve lumbo-pelvic stability with emphasis on strengthening transversus abdominis is recommended.\textsuperscript{23} Core exercises added during this stage include supine hamstring bridges and supine gluteal bridges.\textsuperscript{16}

On a stable base, static single leg stance is tested to ensure that the positioning of the hip and pelvis are adequate. On an unstable base (balance pad/cushion) double leg stance with arm movements is recommended for challenges to balance and proprioception.\textsuperscript{24}

**INTERMEDIATE POST-OPERATIVE REHABILITATION (PHASE III)**

The expected duration of this phase is from weeks 3-5. In addition to objective ROM testing for progression, the Knee Injury and Osteoarthritis Outcome Score (KOOS) is incorporated at the end of the phase to assess patient progress.\textsuperscript{25} The tool is split into five domains: Pain, Symptoms, Activities of Daily Living (ADL), Sports/Recreation, and Quality of Life. As rehabilitation progresses, the focused domains and expected scores transition with it. During this phase, agility exercises are introduced and neuromuscular (NM) control is developed to ensure sufficient control for running as the program progresses.

ROM exercises are continued, with knee flexion up to 130 degrees and there is progression of resistance on the exercise bike, with an increase in duration of up to 30 minutes. Quadriceps strength is progressed with advancement of open chain quadriceps loading and inclusion of closed chain loading (body weight squats and lunges).\textsuperscript{16} The introduction of shallow single squats (up to 45 degrees of knee flexion) will also contribute to quadriceps strengthening. Step work is progressed through increased step height and the introduction of lateral movements and hamstring loading can be advanced. Early landing NM control can be commenced through Supine Pilates Reformer and jump board work, and 4-inch step downs are also an acceptable alternative at this stage. As in the previous phases, there is a continuation of core and trunk conditioning.\textsuperscript{25} Once comfortable with single leg stance including arm movements on a stable base, patients can slowly progress to an unstable base. The introduction of side-stepping, carioca, and other agility level exercises focuses on balance improvement.

It is important to monitor pain and effusion as the patient is introduced to new activities and ensure that there is symmetrical patterning of the lower extremities on squat/lunge-based activities. The restriction on prohibited movements is lifted, however the patient should not yet be allowed to run at this stage. As the phase nears completion, the KOOS is used to determine eligibility for progression. The pain, symptoms and ADL domains are focused upon and scores >75% in each of these domains would deem the patient eligible to phase IV.
Table 2: “Soreness” Rules to guide rehabilitation

<table>
<thead>
<tr>
<th>Soreness Rules</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Soreness during warm-up that continues</td>
<td>2 days off, drop down one level</td>
</tr>
<tr>
<td>2. Soreness during warm-up that goes away</td>
<td>Stay at level that led to soreness</td>
</tr>
<tr>
<td>3. Soreness during warm-up that goes away but returns during the session</td>
<td>2 days off, drop down one level</td>
</tr>
<tr>
<td>4. Soreness the day after session (not muscle soreness)</td>
<td>1 day off, do not advance program to next level</td>
</tr>
<tr>
<td>5. No soreness</td>
<td>Advance 1 level per week or as instructed by physiotherapist</td>
</tr>
</tbody>
</table>

Table 3: Rehabilitation Running Program

<table>
<thead>
<tr>
<th>Running Progression</th>
<th>Treadmill or Outdoors</th>
<th>Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 km walk; 0.2 km jog x 10 (4 km)</td>
<td>Jog straights /walk bend (4 km)</td>
<td></td>
</tr>
<tr>
<td>0.2 km walk; 0.4 km jog x 7 (4.2 km)</td>
<td>Jog straights / jog 1 bend every 2nd lap (4 km)</td>
<td></td>
</tr>
<tr>
<td>0.2 km walk; 0.6 km jog x 5 (4 km)</td>
<td>Jog straights / jog 1 bend every lap (4 km)</td>
<td></td>
</tr>
<tr>
<td>0.2 km walk; 0.8 km jog x 4 (4 km)</td>
<td>Jog 1.75 laps / walk 1 curve (2 km)</td>
<td></td>
</tr>
<tr>
<td>Jog full 4 km</td>
<td>Jog all laps (2 km)</td>
<td></td>
</tr>
<tr>
<td>Jog 5 km</td>
<td>Jog 5km</td>
<td></td>
</tr>
<tr>
<td>Jog 6 km</td>
<td>Jog 6 km</td>
<td></td>
</tr>
<tr>
<td>Alternate between running and jogging every 0.5 km x 6</td>
<td>Alternate between running on the straights and jogging on the bends (6km)</td>
<td></td>
</tr>
</tbody>
</table>

LATE POST-OPERATIVE REHABILITATION (PHASE IV)

This phase is the final controlled rehabilitation phase before the patient begins the transition to sport-specific rehabilitation and is expected to last from weeks 5-8. The restrictions on ROM are lifted and full flexion and hyperextension are encouraged. From this phase onwards, restrictions are based on the “soreness” rules (Table 2) to guide the intensity and frequency of rehabilitation.26 The patient is still prohibited from running and it is important to monitor kinetic chain ROM and control (e.g. ankle dorsiflexion and hip control) to prevent overload of the anterior knee.

ROM exercises should continue unmodified if there is a perception of tightness or a tendency to stiffen. There is graded progression of open chain quadriceps loading, with an aim to achieve >80% strength when compared to the unaffected side via dynamometry (isokinetic or hand-held). Closed chain loading is also increased, limiting range to 50% to ensure good eccentric control.16 Single leg squat depths are increased to 90 degrees of flexion and lunge activities are altered to incorporate multi-directional movements. NM landing control exercises are also commenced using landing from step or mini jumps. There is continuation of hamstring, trunk and bridge conditioning. Single leg balance is progressed and sport-specific components (catch/throw) are introduced. Agility work is advanced into tight space movement drills and ‘cutting’ movements (e.g. figures of 8) are introduced.

The symptom, pain and ADL domains of the KOOS are still the focus of this phase with >95% score a criterion for progression.

TRANSITIONAL PHASE (PHASE V)

The emphasis during this phase (weeks 8-12) is the continued progression of activity level and the transition to sport-specific rehabilitation (Phase VI). The focus of the KOOS changes to the function and sports/recreation domain and dictates progress.24 The “soreness” rule (Table 2) will dictate progress and anterior knee overload continues to be avoided.26 The restriction on running is lifted and the running program (Table 3) is commenced. This program should not be performed more than four times/week and no more than every second day. A maximum of two levels can be progressed in a seven-day period.14

There is progression of closed chain quadriceps loading,
with regards to both weight and depth of movement. Landing exercises are advanced with an increase in step height, single leg landing control and the introduction of rotational components. Sport specific work can also be added at this stage if indicated (e.g. Olympic lifts or slide board work). Multi-component agility circuits are used allowing a mix of static and dynamic stability.

The goals by the end of this phase are to achieve limb symmetry index of: quadriceps strength >90%, hop testing >85%, KOOS (Function, Sports/Recreation) >75% and Y-balance test composite score >85%.27

SPORT-SPECIFIC REHABILITATION (PHASE VI)

This phase is expected to begin after 12 weeks. The "soreness" rules continue to be followed to monitor frequency and intensity of rehabilitation.26 The running program is continued and once it is completed, the relevant sport-specific components are developed and advanced.

The depth and weight of closed chain loading of the quadriceps continues to be progressed, plyometric components can be added to landing component exercises and conditioning of hamstring, bridge and trunk work should be continued. Advanced cutting, twisting and turning movements can be added with progressive exposure to training drills, finally working towards open play.

The goal domains mirror phase V with expected advancement of limb symmetry index to achieve Quadriceps strength >95%, hop testing >95%, KOOS (Function, Sports/Recreation) >95% and Y-balance test composite score >95%.

In addition to the Phase VI goals, the patient must adequately demonstrate sport-specific readiness. Consequently, additional sport-specific testing may be required to determine the readiness of return to play.

ADDITIONAL KNEE LIGAMENT INJURY

ACL injuries commonly present with associated ligamentous or meniscal injuries. These need to be considered alongside the ACL repair both surgically and in planning the patient’s rehabilitation.28 It is important to identify the most limiting factor requiring protection, this will guide the decision making for any multi-injury situation.18

MEDIAL COLLATERAL LIGAMENT (MCL)

The MCL is commonly injured in an ACL rupture. Non-operative management of this injury can delay progression of rehabilitation proportional to the degree of injury, however deviation from the guidelines is not required. Concurrent traditional repair of the MCL may require a flexion minimizing brace for six weeks.29 However, the IB method can be utilized for operative repair of MCL injuries, which may allow these post-operative limitations to be avoided and rehabilitation expedited as per the protocol.

ANTEROLATERAL LIGAMENT (ALL)

The ALL is not reinforced routinely during ACL reconstruction or repair surgery; however, the IB technique has been applied to it to improve tibio-femoral rotatory stability in the presence of ACL injury. In high risk groups, such as young female patients, those with hypermobility, gross instability or desire to return to high demand pivoting sports, this technique can be beneficial to reduce re-rupture rates. This may also allow greater confidence in progressing the patients’ rehabilitation and should not affect advancement through the protocol.30

MULTI-LIGAMENT INSTABILITY

The rehabilitation of these patients is inevitably prolonged and due to the increased complexity and potential for multiple, staged surgeries. Rehabilitation in these cases should be guided by the surgeon/post-operative protocols. Early surgical intervention has shown better outcomes than delayed surgical repair.31 There is a potential for utilization of the IB in some of the injuries which may expedite recovery when compared to a traditional repair/reconstruction, where six to eight weeks of immobilization is often recommended.32 However, there are presently no reported case series of IB use and recovery in these multi-ligament injuries.

DISCUSSION

As the understanding of post-operative ACL rehabilitation has progressed, there has been an increased focus on early ROM and early weight-bearing. Initial ACL repair studies without IB had the extremity immobilized in a long leg cast at 30 degrees of flexion following the operation.33-40 Dependant on the protocol, this cast was kept on for two weeks,27,35 six weeks,32,34,35,37,38 or eight weeks31 before transitioning to rehabilitation exercises. More recently, patients were not immobilized in a cast but instead used knee bracing, which was locked in extension.41-45 Some rehabilitation protocols locked this for a fixed time frame: two days,46 four days,47 or two,40 three,3 two and four35 weeks. Other protocols were patient dependant and the brace was locked in extension until volitional quadriceps control had returned.41,42 This overall conservative approach to rehabilitation may have contributed to muscle atrophy, joint stiffness and ultimately poorer outcomes as a result.

There is limited focus on specific rehabilitation exercises following ACL repair in the literature. Multiple authors make references to quadriceps strengthening,32,34,37,38 though in all of these papers it occurs following the removal of external immobilization. ACL repair with augmentation using the IB means there is no requirement for any fixed external brace immobilization post-operatively and rehabilitation can be commenced in a timely fashion.

There has been greater focus on rehabilitation following ACL reconstruction, with focus shifting from protocol driven recovery to progression-based programs.46 While detailed, criterion-based rehabilitation protocols exist for ACL reconstruction,15,17 this is not the case for ACL repair. Therefore, a criterion-based rehabilitation protocol for ACL repair with IB augmentation is proposed in this paper. This regimen has been used in a cohort of ACL repair patients, where good patient reported outcomes have been reported at two years post-operatively.49 However, as this is a novel technique and the data currently only exist during case se-

International Journal of Sports Physical Therapy
ries. As IB usage increases in ACL repairs, more robust and detailed data will be available regarding its long term uses, advantages, and pitfalls in a patient population.

CONCLUSION

This is the first evidence-informed rehabilitation protocol specifically designed for patients who have undergone an isolated primary ACL repair using an IB. The effects of concomitant injuries and their effects on rehabilitation have been discussed. Critical clinical milestones have been presented to guide rehabilitation progression and guidelines for activity frequency/intensity modification and return to running suggestions have also been offered.

CONFLICT OF INTEREST

GM is a consultant for teaching for Arthrex and has a patent for the InternalBrace, outside the submitted work. No other author has any conflict of interest to declare.

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REFERENCES


30. Mackay GM, Blyth MJG, Anthony I, Hopper GP, Ribbons WJ. A review of ligament augmentation with the InternalBraceTM; the surgical principle is described for the lateral ankle ligament and ACL repair in particular, and a comprehensive review of other surgical applications and techniques is presented. *Surg Technol Int*. 2015;26:239-255.


This paper presents a four-stage plyometric program to be undertaken as part of criterion-based rehabilitation for athletes with anterior cruciate ligament reconstruction (ACLR). After ACLR, the patient experiences alterations of joint mobility, gait and movement patterns, neuromuscular function and general physical fitness. Plyometric training is an important component for neuromuscular and movement re-conditioning after ACLR. Effective use of plyometrics can support enhancements in explosive sporting performance, movement quality and lower risk of injury. Plyometric training, as a component of the ACL functional recovery process, can aid in restoring function and supporting timely return to sport. However, few patients undertake or complete a plyometric program prior to return-to-sport. To truly impact individual patients, a stronger focus on research implementation is needed from researchers to translate efficacious interventions into practice. In designing a plyometric program, it is important to match the specific plyometric tasks to the functional recovery status of the ACLR patient. To do this, it is important to understand the relative intensity of plyometrics tasks, align these tasks to the ACL functional recovery process and monitor the athlete as part of criterion based rehabilitation. Plyometric intensity is based on the intensity of efforts, the vertical and/or horizontal momentum prior to ground contact, the ground contact time and the surface or environment on which they are performed on/in. Furthermore, how the person technically performs the task will influence joint loading. There should be a gradual increase in task intensity and specificity throughout the program, with all tasks used for both neuromuscular and motor control re-conditioning. The aim of this paper is to provide recommendations to clinicians on how to design and implement plyometric training programs for the ACLR patient, as part of the functional recovery process.

Level of evidence

INTRODUCTION

A key goal within sports medicine is to improve the outcomes of patients after major injury. It appears that many patients fail to return-to-sport (RTS) and/or previous sporting performance levels after anterior cruciate ligament reconstruction (ACLR).1–4 Those who RTS, do so often at much elevated risk of re-injury, with typically around nearly one in three young athletes experiencing a knee re-injury,5,6 generally within the first two years after RTS.7 Current opinion is that in order to improve athlete outcomes after ACLR, there is a need to optimize the processes and practices of rehabilitation.8,9 Key areas suggested in need of improvement are the restoration of neuromuscular performance (e.g., strength and power) and movement quality of patients prior to RTS after ACLR.8–11 Following ACLR, at the time of RTS, patients often present with deficits in knee extensor maximal strength12–14 and rate of force development (RFD),15,16 as well as lower limb/closed chain strength15 and power.17 Furthermore, patients often RTS with movement asymmetries during an array of functional tasks18–23 thought to predispose them to increased risk of injury.7,24–26
Recommendations for Plyometric Training after ACL Reconstruction – A Clinical Commentary

One highly valued element of rehabilitation after ACLR is the use of plyometric training.\(^8\) Plyometric exercises involve a stretch-shortening cycle, which is a commonly observed phenomenon involving a rapid lengthening of a muscle tendon unit, immediately followed by a rapid shortening (for a review see Davies et al.).\(^27\) Plyometric training has long been used to optimize explosive sporting performance (e.g., speed, jump height) of athletes and is regarded as an excellent training method, due to the wide ranging neuromuscular and motor control benefits.\(^28\)–\(^32\) In particular, plyometric training has been reported to be superior to more traditional resistance training for development of explosive lower limb performance (power/RFD).\(^30\)–\(^33\) as well as effective at eliciting gains in maximal strength,\(^32\) and sports performance variables, such as linear\(^34\) and multiple directional\(^35\) movement speeds.

Ebert et al.\(^35\) reported that only 30% of patients completed a plyometric program prior to RTS after ACLR.\(^35\) A key issue with implementing plyometric training into the functional recovery process of ACLR patients is a lack of guidance within the literature on how and when to do it. Plyometric tasks vary in their intensity and specificity, with typical peak ground reaction forces (GRF) ranging from 1.5-7 times body mass.\(^36\)–\(^40\) Inappropriate plyometric task choice could thus be expected to cause adverse reactions on an unprepared person after major lower limb injury. There is a need to support practitioners on how to effectively use plyometrics after major lower limb injury, such as ACLR. To do this, there is a need to understand the types of plyometrics available, their relative loading/intensity and understand how to systematically incorporate plyometric training as part of the ACL functional recovery pathway. Therefore, the aim of this paper is to provide recommendations to clinicians on how to design and implement plyometric training programs for the ACLR patient, as part of the functional recovery process. This will hopefully aid in the barriers between research and effective implementation into practice.

PLYOMETRIC TRAINING AFTER ACL RECONSTRUCTION – KEY CONSIDERATIONS IN PROGRAM DESIGN

Designing a plyometric training program to develop neuromuscular performance and movement quality, while respecting tissue healing, is an important consideration for the rehabilitation specialist.\(^9\),\(^41\) In planning effective plyometric use and progressions, it is important to have consideration of optimal loading (defined as the load applied to structures that maximizes physiological adaptation)\(^41\) to bring about specific neural, morphological and mechanical adaptations.\(^41\) Optimal plyometric program design entails an understanding of the specific loading demands of the various plyometric tasks, so a series of optimal progressions can be planned. It is important to consider the intensity of movement or the specific external and internal loading of the task(s). External forces are the result of equal and opposite forces acting on the body according to the laws of motion (e.g., Newton’s laws), while the internal joint loads will depend on how the GFR loads are distributed throughout the body. Load is actively accepted/dissipated via the neuromuscular system and absorbed passively via the tendons, ligaments and joints during movements. Internal hip-, knee-, and ankle-extension (plantarflexion) moments must be produced via eccentric, isometric and concentric muscle contractions to control joint motion, absorb the kinetic energy of the body at impact and produce force and power to propel the body ballistically during plyometric tasks.\(^42\) Inability to accept load either due to deficits in strength, would mean a greater reliance on joint complexes (tendon, ligament and joint structures) for passive force absorption.\(^43\) It is important to understand the specific loading demands of the various tasks, the patients capacity to tolerate these loading demands (e.g., strength and movement quality) and understand how the patient has responded to the specific loads on an individual level (e.g., monitoring loading response).

PLYOMETRIC TASK INTENSITY AND COMPLEXITY

In terms of plyometric loading, it is important to consider the peak external loads of the tasks, the joint specific internal moments, the neuromuscular activation/muscle forces as well as the neuromuscular control challenge. In addition, consideration of volume load is important.

During movement, an individual must produce and accept force via its application to the ground according Newtons laws of motion. Newtons third law dictates that there will be an equal and opposite reaction, whilst Newtons second law, the law of acceleration, dictates movement acceleration will be a product of force application relative to body mass (Force = mass x acceleration). Intensity of plyometric tasks can be considered on the basis of peak GRFs, which typically occur during the eccentric/landing phase, but also peak concentric forces (and power) are important on a performance level. In addition, the rate of force acceptance and development is important. This is essentially the rate of change in force during the landing and jumping phases of a plyometric task.

Peak external loading is largely dictated by task selection, the neuromuscular capacity to accept and develop force (e.g., strength), surface/environment and ground contact time (GCT)/instruction:

i) Task selection: Plyometric tasks can be considered based on stance and body positioning at take-off/landing, consisting of unilateral and different bilateral versions (Table 1 and Figure 1). During the eccentric phase of a plyometric task, the athlete will need to decelerate the center of mass, prior to producing force and power to ballistically propel oneself as part of the plyometric action. The peak eccentric forces will largely be dictated via the velocity or the relative momentum of the system, as a whole at impact/landing.\(^40\) The higher the momentum (mass x velocity) prior to/ at impact, the greater the eccentric work required to decelerate the body. As such, intensity of effort and height of landing and/or horizontal speed prior to deceleration are major determinants of peak loading of plyometric tasks.

ii) Strength: greater total lower extremity energy absorption in the sagittal plane has been associated with smaller vertical GRF and greater knee-flexion displacements during
Table 1: The four types ofplyometric task based on stance position at landing and/or take-off, with description and examples.

<table>
<thead>
<tr>
<th>Plyometric type</th>
<th>Description</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral</td>
<td>Involve eccentrically accepting load on one limb and then concentrically developing force and power to accelerate again on one limb. This includes jumping from one limb to the other (e.g., bounding/running), or continuous same limb plyometrics (e.g., hops).</td>
<td>Bounding (alternating bounds, speed bounds, bounds for height etc.); SL SJ, SL CMJ, SL drop jump; lateral jumping and hopping; rotational hopping/jumping</td>
</tr>
<tr>
<td>Bilateral (symmetrical)</td>
<td>Both limbs accept and produce force simultaneously from a symmetrical stance position</td>
<td>BL SJ, BL CMJ, BL drop jump; tuck jump</td>
</tr>
<tr>
<td>Bilateral (asymmetrical)</td>
<td>Both feet take off and/or contact the ground simultaneously but in different positions. As such, the demand placed on each leg is different and shared.</td>
<td>Split jumps, same stance landing, alternating leg position</td>
</tr>
<tr>
<td>Bilateral (with timing off-set)</td>
<td>Typically involve landing on one limb before taking off on the other limb. These exercises can be defined as skipping type movements and do not characterize the typical stretch shortening cycle motion on a single limb.</td>
<td>Skipping Alternating box split jumps</td>
</tr>
</tbody>
</table>

iii) **Surface:** a compliant surface will deform under load and as such joint loading is influenced by the surface stiffness. Performing plyometrics in water or on sand has been shown to reduce the high impacts and results in less muscle soreness than performing plyometrics on more rigid surfaces. For example, at the appropriate depth of water in the pool, there appears to be a reduction of around 45–60% in peak GRFs recorded from plyometric exercise in water versus on land.46

iv) **GCT:** peak force and particularly RFD and rate of power development will also be dictated by GCT. The RFD and rate of power development will be a function of force/power produced divided by the GCT, derived as the reactive strength index. GCT and associated RFD are influenced by task choice but also instructions given for performance of the task (e.g., land and jump leaving the ground as quickly as possible).40 GCT (and associated RFD and neural activation during the task) are important considerations in terms of specificity of training adaptations. Improvements in explosive neuromuscular performance appear to be specific to the GCT, with longer GCT (>250-500 ms) suited to acceleration and multidirectional movement performance, whilst linear based (horizontal and vertical) fast (GCT < 200 ms) plyometrics may be better suited for developing linear peak running speeds.

As well as peak external loading, it is also important to consider the relative internal joint loading and associated neuromuscular activation and muscle forces. Internal joint loads should be considered across three planes of motion (sagittal, frontal and transverse). During functional tasks, there is a load sharing across joints and muscle groups.48 The relative ‘torque’ experienced at each joint and subsequent muscle forces will be a product of the resultant GRF and the respective distance away from the joint (torque = force x distance). The specific joint loading will be influenced by task selection, and kinematics during the task. For example, altering the trunk alignment during plyometric exercise would alter the center of mass and position it closer or further away from the joint.49 A more upright and stiff posture, described as a quadriceps dominant behavior, has been correlated with higher knee-extensor moments. Greater hip flexion to knee flexion ratios during plyometric type tasks has been shown to reduce knee-extensor moment and knee energy absorption and increase hip loading.49

Altered frontal- and transverse-plane knee loading has been shown to contribute to greater ACL loading.54–57 It is recommended to avoid at risk movement biomechanics, specifically a knee dominant motor strategy (e.g., upright trunk positioning) in conjunction with altered frontal (hip and tibial abduction) and transverse plane (tibial rotations and/or internal hip rotation) motions during plyometric tasks, as these will exacerbate knee and ACL loading.54–57
lar control challenge/loading, when prescribing plyometric progressions. It is thought that effective use of plyometrics can support improved movement quality and reduce ACL injury risk.\textsuperscript{31,32,58–60} It is known that strength training does not directly improve movement quality during sport-type movements.\textsuperscript{61} Instead, there is a need to incorporate more sport type movements to relearn and improve movement coordination during sport-type tasks.\textsuperscript{62} Plyometric drills can improve neuromuscular control in athletes, which can become a learned skill that transfers to sporting competitive movements,\textsuperscript{51} aiding in the restoration of sport-specific movement quality after injury. For optimal motor learning (defined as 'the process of an individual’s ability to acquire motor skills with a relatively permanent change in performance as a function of practice or experience'),\textsuperscript{63} it is important that the tasks are performed repeatedly with good movement quality.\textsuperscript{64,65} Thus, it is important to provide the right challenge to neuromuscular control, with progressive increases in movement complexity, as well as rate and intensity of loading.\textsuperscript{66}

While considering the specific loading of a singular task or repetition is important, as discussed, it is also important to consider the volume of loading. Volume load is the result of many actions during a session or over time (e.g. day/week/month). It is known that high recurrent loading of the ACL can lead to graft creeping and eventually failure.\textsuperscript{67} Furthermore, issues such as patellofemoral pain syndrome are typically the cumulation of chronic overload\textsuperscript{68} and common after ACLR.\textsuperscript{69–71} It is recommended to monitor the cumulative loading of respective tasks, which can be done through documenting the exercise sets/foot contacts alongside the task intensity.

\textbf{ARE THEY STRONG ENOUGH?}

It is well accepted that sufficient strength of the lower limb(s) is important for implementation of plyometrics.\textsuperscript{72–75} Inability to accept load would mean a greater reliance on joint complexes (tendon, ligament and joint structures) for passive force absorption.\textsuperscript{43} Considering the various descriptors of load, it would seem appropriate to have an understanding of the patients ability for compound muscle strength, to be able to tolerate the external ground reaction forces. Assessing and tracking closed chain strength (e.g., squat and/or leg press strength) can support optimal task progressions.\textsuperscript{5,9,76} It is important that the plyometric tasks are aligned to the strength status of the athlete and that task intensity supports and tracks with improvements in strength and functionality. The assessment of closed chain strength (e.g., leg press/squat strength) has been suggested to determine the readiness for the introduction of running on treadmill (e.g., 1.25 times body mass single leg press)\textsuperscript{9,76} unilateral plyometrics (1.5 times body mass single leg press)\textsuperscript{8,76} and RTS (2 times body mass single leg press).\textsuperscript{8,76}

Additionally, it is important to understand each joint’s ability to withstand loads. The ankle, knee and hip/trunk must accept and produce force in a load sharing manner,\textsuperscript{68} depending upon the task and the specific movement quality of the patient. Knee extensor strength is a major barrier to functional progressions after ACLR\textsuperscript{77} and so understanding the knee extensors strength of the ACLR athlete is important to implement and progress plyometric tasks. Patients will typically display large deficits in knee extensor strength in the early weeks after surgery (e.g., 50% deficits at four weeks post ACLR).\textsuperscript{78} Restoring knee extensor strength is essential to allow for movement based retraining and implementation of plyometrics.\textsuperscript{9,79} Assessing knee extensor strength using concentric or isometric assessment of the isokinetic dynamometer or recording knee extension loads used in rehabilitation (eg, 8 or 10 repetition maximum) can provide indication of knee extensor strength to support plyometric implementation and progressions. Knee extensor limb symmetry index (LSI) is often used to support progression through stages of an ACLR rehabilitation pathway.\textsuperscript{8,9} It can be used to support decision making of when patients are ready to perform certain functional tasks including jogging on the treadmill (LSI, 0.70),\textsuperscript{9,76,80} single leg landing and jumping drills (LSI, 0.80),\textsuperscript{8,9} RTS training (LSI, 0.90)\textsuperscript{8,76} and return to high level competitive sport (LSI, 1.0).\textsuperscript{8,80}

\textbf{DO THEY MOVE WELL ENOUGH?}

As well as aligning plyometric loading to strength, it is also important to align plyometric task complexity to movement capabilities. So, it would appear important to know if an athlete is able to perform the task sufficiently well and safely prior to training prescription. Furthermore, it is important to monitor movement quality during the task. This would aid in ensuring that the athlete performs the task with appropriate kinematics before progressing to a subsequently harder task (either higher loading or greater movement complexity or both).

In assessing and training movement quality it is important to understand what movement quality is and which factors may affect performance.\textsuperscript{66} Movement quality after ACL injury has been defined as ‘the ability to control the limbs and achieve sufficient balance and kinematic alignment during functional activities, not displaying movement asymmetries or risk factors linked to ACL injuries’.\textsuperscript{5,66} Importantly, the definition makes no reference to what is acceptable loss of balance or deviation of kinematics away from normal, or actually what normal or ideal is.\textsuperscript{66} In fact, it is thought there likely exists no ‘ideal’ or ‘perfect’ way to move.\textsuperscript{66} According to the dynamic systems theory,\textsuperscript{81} there are multiple factors which can influence the expression of movement quality, which should be considered when training and assessing movement quality.\textsuperscript{66} These can be summarized as a complex interaction between individual (organistic constraints), task constraints and the environment or context in which the task is been performed (environmental constraints).

Despite the ambiguity in assessing movement quality, it is here and elsewhere\textsuperscript{8,9,76} proposed to utilize a relatively simple qualitative movement analysis method to support progression through tasks and through ACL rehabilitation stages as part of criterion based rehabilitation. This can provide information on movement quality during the tasks at hand, and to be able to provide feedback to the patient, to create a continuous learning environment to solve the task and optimally progress.\textsuperscript{76} It is suggested to monitor the
patient’s ability to maintain control of the body utilizing teaching and training of optimal frontal plane (pelvis, trunk and lower limb, Figure 2a) and sagittal plane control (Figure 2b), depending upon the specific task. If the tasks cannot be performed at a minimum task competency, then the tasks should be simplified. Qualitatively assessing movement quality (frontal and sagittal plane) as part of the ACL functional recovery process during foundation, landing, plyometric and sport-specific tasks is also recommended. This can provide some objective guidance to support criterion driven ACL functional recovery.

CAN THEY TOLERATE THE LEVEL OF LOADING?

A key part of optimal load management is adjusting the training according to the response to exercise. Any functional based progression has to be in line with the biological healing and ability of the joint to withstand the loading demands. Pain and swelling can be used to determine exercise based progressions as these factors will relate to the loading stress experienced by the knee. Progression to more intense or complex tasks should only be allowed when there is no or minimal pain (e.g., 0-2 on the numeric rating scale) or swelling (stroke test) increase in response to previous tasks. Pain and/or swelling response would indicate excessive previous loading levels to the knee joint and an adverse reaction, which may then limit optimal adaptation. Furthermore, after unaccustomed exercise, there may be an exercise induced muscle reaction, resulting in delayed onset muscle soreness. The degree of muscle reaction depends on many factors including exercise type, duration, intensity and habituation to the exercise. Tasks that are too strenuous will result in significant muscle reaction, which may take substantial time to recover and may limit the ability to train in the subsequent days. Monitoring the muscle soreness can provide an indication of the muscle specific loading and required recovery time, which can then support subsequent training modifications.

PLYOMETRIC PROGRESSIONS AFTER ACLR– A FOUR-STAGED PROGRAM ALIGNED TO THE REHABILITATION PATHWAY AFTER ACLR

For effective design of plyometric programs for the ACLR patient, it is imperative that any such program be aligned to the functional recovery approach and overall goals as a whole. These goals include restoring knee specific factors, neuromuscular function of many muscle groups and types of function (e.g., maximal isolated and functional strength and explosive neuromuscular performance), movement quality and sport-specific fitness. Although, there is still not an international consensus on ACL rehabilitation, there has been considerable research recently published toward standardizing the ACL rehabilitation journey. Current best practice for ACL rehabilitation appears to involve criterion-based rehabilitation through a series of stages. The functional recovery process can be broadly separated into pre-operative, early, mid and late stage rehabilitation and RTS training.

Below is presented a four-staged plyometric program aligned to the ACL functional recovery process. This considers i) the plyometric tasks and associated intensity and complexity, ii) the required movement quality and strength to perform these tasks and iii) monitoring considerations, specifically daily monitoring (e.g., pain and swelling, soreness rules) but also monitoring as part of criterion-based ACL functional recovery. In general, the program has some rules or themes which include progressions in intensity and specificity of the movements with progressive increases in entry speeds (vertical loading height/ horizontal velocity), a gradual reduction in GCT, progression from bilateral to unilateral tasks and from linear (vertical to horizontal to lateral) to multi-planar tasks. Furthermore, it is recommended to use different surfaces, beginning with more compliant surfaces and progressing to stiffer surfaces (Figure 3).

Progressions through stages and exercises within the stage is based on good quality performance of the tasks, ideally no or only minimal pain (e.g., <2/10 on numeric rating scale) and/or swelling of the joint to the specific loading demands and continued improvement in lower limb strength. Each stage should be completed in sequence and an athlete cannot perform any task in the stage without meeting the specific stage criteria (Table 2). As it aligns to the rehabilitation process after ACLR, meeting specific criteria as part of criterion based rehabilitation is recommended. The four-stage program compliments and aligns to the authors published ACL functional recovery programs. These involve comprehensive overviews of the mid-stage, late-stage and RTS training stages. The plyometric program begins in the mid-stage of rehabilitation (Stage 1), with Stages 2 and 3 aligned to the late-stage and Stage 4 to the RTS training stage.

Stage 1 of the program uses low intensity plyometrics, characterized as bilateral off-set and bilateral asymmetrical, but also with sub-maximal bilateral symmetrical tasks (to support movement re-training). The rise in height of the center of mass above neutral position is typically minimal. GCTs should be long (> 1-2s) and the main theme is to support movement retraining, primarily with a focus to

**Figure 2**: A, an easy to utilize and teach model of movement analysis based on three lines in the frontal plane, with a line to assess trunk stability/alignment, pelvis stability/alignment and limb stability/alignment. B, depicts the sagittal plane view which is dependent upon the task but a function of ankle to knee and knee to hip alignments. From Buckthorpe et al.
support treadmill gait re-education. Estimated GRFs are less than two-times body mass per limb. The program is completed alongside foundation movement re-education, functional strengthening (e.g., squat, deadlift, single leg progressions), bilateral landing tasks and isolated strength training. Importantly, during this first stage, which occurs during the mid-stage of rehabilitation after ACLR, the patient will have significant knee extensor strength deficits. Knee extensor weakness is a significant barrier to being able to perform functional tasks. Furthermore, significant strength deficits result in biomechanical compensatory strategies. This may include compensatory use of the hip extensors instead of the knee extensors during unilateral tasks or compensatory loading of the un-injured limb during bilateral tasks. Even when achieving the optimal kinematics (e.g., correcting the compensatory movement pattern of greater hip to knee flexion), there is still typically inhibition of the quadriceps, resulting in lower neuromuscular recruitment, which may result in insufficient stimulus for adaptation. As such, the benefits of plyometric training for strength development is likely minimal in this stage. It is essential to ensure optimal technique during the movements, ideally using real-time biofeedback, to support appropriate motor learning. Poor task selection may result in movement compensations, which could interfere with optimal motor repatterning. Thus, quality over quantity and intensity is recommended. It is essential to focus on isolated strengthening techniques to overcome the quadriceps weakness and restore normal quadriceps strength during this stage. In terms of recommended plyometric tasks for this stage, these can be seen in figures 4 to 6 and within Table 2.

Stage 2 of the program commences when the athlete can achieve the necessary late-stage rehabilitation criteria (Table 2). This means they must have a good single leg squat (defined as good control of the movement with no presence of excessive dynamic knee valgus, altered motor strategy or trunk and pelvis deviations), sufficient closed kinetic chain (single leg loads > 1.25 times body mass) and knee extensor limb symmetric index (>80%, LSI) and able to run on the treadmill with good kinematics. Key themes of late-stage ACL rehabilitation are developing single limb eccentric control (deceleration/landing) and restoring power and maximal eccentric strength. However, there is a strong use of bilateral plyometric tasks for developing explosive lower limb strength and high load mechanics. The stage now allows for maximal effort bilateral plyometrics for automatization of the motor pattern, but more specifically for improving kinetics in explosive movement tasks. Consideration though of landing height is needed. A key aim of the stage is to achieve a good bilateral drop jump (kinetics and kinematics) (30 cm) and single leg landing/deceleration control. Example tasks can be seen in Figures 7 to 10 and within Table 2.
Table 2: A plyometric program approach across four stages aligned to the functional recovery framework after ACL reconstruction. Particular training goals, use of plyometrics, progression criteria, training planning considerations, with specific movement exercises and progressions are presented.

<table>
<thead>
<tr>
<th>Typical weeks*</th>
<th>10-14</th>
<th>15-18</th>
<th>19-22</th>
<th>23-29</th>
</tr>
</thead>
</table>

### General goals of stage

<table>
<thead>
<tr>
<th>Plyometric use</th>
<th>Pliometric stage</th>
<th>Criteria to enter plyometric stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low intensity predominantly bilateral plyometrics at sub-maximal intensity to support eccentric/motor control and preparation for running</td>
<td>Develop functional strength</td>
<td>Ability to run of treadmill for 10 mins @8km/h</td>
</tr>
<tr>
<td>Moderate intensity bilateral and unilateral plyometrics with view to developing lower limb power and eccentric control, particularly unilateral deceleration capabilities</td>
<td>Develop closed chain eccentric strength</td>
<td>Good BL drop jump mechanics</td>
</tr>
<tr>
<td>Higher intensity bilateral and unilateral plyometrics with view to developing lower limb power and multipolar motor control and acceleration capabilities</td>
<td>Develop unilateral eccentric control</td>
<td>Good SL drop jump mechanics</td>
</tr>
<tr>
<td>Isokinetic LSI knee extensor and flexor &gt;80%</td>
<td>Restore neuromuscular function markers to within at least 10% (knee and adjacent joint specific strength and closed kinetic chain and power)</td>
<td>Isokinetic LSI knee extensor and flexor &gt;90%</td>
</tr>
<tr>
<td>Isokinetic LSI knee extensor and flexor &gt;90%</td>
<td>Restore high load movement quality</td>
<td>Closed chain strength &gt; 1.5 times body mass (BRM) or 2 x times body mass (1RM/peak isometric force)</td>
</tr>
<tr>
<td>Isokinetic LSI knee extensor and flexor &gt;90%</td>
<td>Restore aerobic fitness</td>
<td>Isokinetic LSI knee extensor and flexor &gt;90%</td>
</tr>
</tbody>
</table>

### Criteria to enter plyometric stage

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plyometric type</td>
<td>BL off-set BL asymmetrical BL symmetrical (sub-max)</td>
<td>BL off-set BL asymmetrical BL symmetrical UL (linear)</td>
<td>Bilateral off-set Bilateral asymmetrical Bilateral symmetrical UL (multi-planar)</td>
<td>Bilateral off-set Bilateral asymmetrical Bilateral symmetrical UL (multi-planar)</td>
</tr>
<tr>
<td>Volume (foot contacts)</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
</tbody>
</table>

### Training planning

<table>
<thead>
<tr>
<th>Training planning</th>
<th>Plyometric Tasks</th>
<th>Other movement tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunge push back</td>
<td>BL SJ (in place, forward)</td>
<td>Stage 3 plyometrics in pool (~60% body height)</td>
</tr>
<tr>
<td>SJ to box</td>
<td>BL CMJ (in place, forward)</td>
<td>Treadmill running (12-20 km/h)</td>
</tr>
<tr>
<td>CMJ to box</td>
<td>BL drop jump (30 cm box)</td>
<td>Outdoor pre-planned coordination program (multi-directional movement demands)</td>
</tr>
<tr>
<td>Skips in place</td>
<td>Split jump (same leg land)</td>
<td>High speed linear running/sprinting</td>
</tr>
<tr>
<td>Step up jump (same leg)</td>
<td>Step and land (forward, lateral, standing and from running on spot)</td>
<td>On-field sport-specific training with re-active movements, contact/perturbation drills, as well as skills training</td>
</tr>
<tr>
<td>Step up jump (alternating)</td>
<td>Step-land-push back (forward, lateral, standing and from running on spot)</td>
<td></td>
</tr>
<tr>
<td>Step and hold (forward)</td>
<td>Treadmill running (12-20 km/h)</td>
<td></td>
</tr>
</tbody>
</table>

### Other movement tasks

- SL movement progressions (from BL squat to UL squat)
- Bilateral landing from step
- Trampoline SL landing
- Re-integration to treadmill running
- Stage 2 plyometrics in pool (~60% body height)

### R. O. M.

- Range of motion (R. O. M.)
- Numeric rating scale (NRS)
- Limb symmetry index (LSI)
- Squat (SJ)
- Counter movement jump (CMJ)
- Repetition maximum (RM)
- Single leg (SL)
- Unilateral (UL)
- Return to sport (RTS)
- Change of direction (CoD)
- Drop jump (DJ)

* Time is only indicative, and the protocol should be always customized on patient’s response.
**Stage 3** transitions to a greater use of unilateral plyometrics and is performed in conjunction with a multi-directional on-field coordination program (pre-planned coordination tasks). It transitions from forward and vertical unilateral plyometric to lateral and then multidirectional unilateral plyometric tasks. The key aim by the end of the stage is to have good kinematics during high speed change of direction and good single leg drop jump and hop performance (multiplanar). Ideally movement quality would be confirmed using qualitative analysis of sagittal and frontal plane kinematics, using high speed (e.g., 240Hz) camera systems. Unilateral plyometrics play a key role in supporting movement progressions and unilateral control, whilst bilateral plyometrics are used to support enhancements in neuromuscular function (strength, power and RFD) in this stage. Key aspects of the unilateral exercises are to support enhanced motor control with gradually reducing GCT to mimic sport-type tasks (e.g., progressing from 1-2 s GCT to 0.25-0.4 s GCT). Example tasks can be seen in figures 11 to 14 and within Table 2.

**Stage 4** builds on Stage 3 and focuses on the use of maximal unilateral plyometric tasks for motor pattern automatization as well as enhancement in neuromuscular performance. Furthermore, in terms of motor patterning, a key aim of the stage as a whole is to progress to re-active movements and prepare for sport-specific training (Table 2). Creating perturbations during plyometric tasks to challenge neuromuscular control is recommended (Figure 15). A key aim of the stage is to achieve good re-active movement performance under sporting type tasks to prepare for sport-specific practice. To RTS, it is recommended to possess good movement quality during sport-type tasks and under sport-specific situations. It is recommended to visually assess and use video recordings of sport-specific movements (e.g., reactive cutting or change of direction at an obstacle) during on-field sessions and/or specific field based assessments. Patients should also have completed an on-field rehabilitation process, corrected muscle strength imbalances and restored their physical fitness.

**SUMMARY**

This clinical commentary presents a four-stage plyometric program for the ACLR athlete, which can be undertaken as part of criterion-based rehabilitation. Plyometric training should form a key component of the functional recovery process after ACLR. Used effectively, plyometrics can support enhancements in strength, movement quality, explosive neuromuscular function and athletic performance. Plyometric intensity is based on the intensity of efforts, the vertical and or horizontal momentums/velocities prior to impact, the ability of the neuromuscular system to accept those loads, the GCT, the surface compliance/environment (e.g., land or pool) and movement quality during the task. It is important to align the plyometric program to the overall ACL functional recovery program and overall functional recovery status of the athlete. There should be a gradual increase in task intensity and specificity and all tasks should be used for neuromuscular and/or motor control re-conditioning.

Figure 5: A sub-maximal bilateral jump (countermovement or squat) with controlled landing with a focus on eccentric acceptance and good ankle, knee and hip flexion angles. Preforming this on sand or similar surface will reduce peak ground reaction forces allowing for a longer dissipation of force.

Figure 6: Example of performing a bilateral jump onto a box, either from squat or countermovement jump. The box will allow for an increased focus on concentric power development and slow stretch-shortening cycle with the countermovement jump, while reducing the landing impact forces due to limiting the height the patient will land from.
Figure 7: Images of a countermovement or squat jump in place with maximal height. The removal of the box results in higher landing forces due to landing from a higher height.

Figure 8: A single leg drop jump in the pool which can be performed one stage earlier at an appropriate depth (around 1 m) or waist height.

Figure 9: The tuck jump performed on sand. The patient lands (A) and immediately jumps again (B) raising their legs with symmetrical heights and alignments before landing (C) and repeating the action for a series of jumps. As the patient would land from the maximal height of the jump, the landing intensity is typically higher than that of the drop jump.
Figure 10: A lateral jump from left to right limb (A) with controlled landing and stabilization (B).

Figure 11: Loaded bilateral countermovement or squat jumps

Figure 12: A lateral jump from left to right limb (A) with landing (B) and immediate jump back to the right limb (C), as opposed to just landing in which occurs during Stage 2.
Figure 13: A single leg drop jump with use of other box to challenge control and reduce final landing heights.

Figure 14: Use of on-field for higher intensity running and bounding exercises.

Figure 15: A lateral jump and return with A) a rope and B) medicine ball to create perturbation and/or exaggerated lateral momentum
CONFLICT OF INTEREST

The authors report no conflict of interests relevant to the content of this review.
REFERENCES


11. Buckthorpe M, Roi GS. The time has come to incorporate a greater focus on rate of force development training in the sports injury rehabilitation process. Muscles Ligaments Tendons J. 2018;7(4):455-461. doi:10.32098/mltj.03.2017.05


63. Schmidt RAWC. Motor Learning and Performance. Champaign: Human Kinetics;2005


The Neuroplastic Adaptation Trident Model: A Suggested Novel Framework for ACL Rehabilitation

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Keywords: anterior cruciate ligament, neuroplasticity, motor learning, movement system, return to sport

Anterior Cruciate Ligament (ACL) injuries are common in athletic populations and there are many factors that contribute to a return to play decision. Human movement is diverse and variable, and it is important for patients recovering from an ACL injury to develop a variety of movement strategies for athletic performance. Variability of movement during sport may help to decrease injury risk by preparing the individual to handle many different situations and improve problem solving. ACL injuries result in neurophysiological dysfunction due to a disruption of the afferent information from the native mechanoreceptors in the ligament. Following injury, the brain enters a neuroplastic state and can adapt and change positively or negatively based on the rehabilitation or lack thereof. This commentary presents a novel framework for rehabilitation called the Neuroplastic Adaptation Trident Model that takes into account respected methods for attempting to achieve positive neuroplastic changes. This structured framework provides clinicians with reproducible methods to employ as part of the rehabilitation process to maximize motor control and motor learning. Suggested dosage and implementation are proposed to lead to a consistent and gradually progressive challenge throughout the entire rehabilitation process that takes advantage of the time from surgery until return to play. The purpose of this clinical commentary is to describe the Neuroplastic Adaptation Trident model and provide examples for clinical implementation. This method should be studied further to determine true effectiveness; currently, it is presented as a theoretical model based on best current evidence regarding ACL injury and rehabilitation of neurophysiologic dysfunction.

Level of Evidence

5

THE PROBLEM

The Anterior Cruciate Ligament (ACL) is an important stabilizing structure in the knee for individuals that wish to perform regular cutting activity. ACL injury rates vary among different populations, but there are an estimated 200,000 ACL injuries annually with 75% of those undergoing reconstruction within the first year.1,2 Further complicating the assessment of the overall cost of ACL injury is the high rate of re-injury that occurs after an individual has returned to their desired level of activity, with estimates on average at 20%3 across all populations and as high as 29% in a young, active population.4 These data tend to come from larger studies with heterogeneous populations, making it difficult for clinicians to apply the information to a specific patient. Insurance limitations can place a burden on clinicians by limiting them to a small number of visits over an almost year-long recovery process. Even when clinicians do have regular contact with the patients, the heterogeneity of physical therapy interventions across clinicians creates further confusion within outcome data.

ACL rehabilitation is not a new phenomenon, with the first published cases coming at the turn of the 20th century.5,6 Despite thorough research conducted over the last fifty years, several variables remain at play that make it difficult to determine best practice for both surgical and rehabilitation techniques. Graft selection, patient compliance, and insurance limitations are just some of the confounding variables that relate to the success of a primary ACL reconstruction (ACLR). As the understanding of biomechanics, tissue healing timelines, and neuromuscular control mechanisms has improved, so too have the rehabilita-
tion protocols. Over the last decade there have been several attempts to identify the underlying causes behind high reinjury rates, and each piece of research evidence adds to the depth of clinical understanding of the problem.

Return to sport testing is one of the efforts made to decrease the risk for secondary injuries following an ACL rupture, but there is still considerable debate on what comprises the best battery of tests. Clinicians typically utilize a combination of strength testing, hop testing, and patient-reported outcome measures to inform a return to sport decision, but Losciale et al. recently published a systematic review that demonstrated the lack of a significant association between passing these tests and a second injury.7 There is evidence to support the use of several different components within a return to sport cluster, but there is no consensus in the evidence on which combination of components to utilize.7 Several authors have examined quadriceps strength between limbs and found persistent asymmetries after ACLR.8–11 The uninjured leg gets weaker in the post-operative phase, however, and using it as a comparative standard could lead to an overestimation of individuals’ symmetry and knee function. Normative values compared to bodyweight may therefore be a better measure.8,12 Another promising component of the return to sport cluster is psychological readiness following injury. Factors such as not trusting the knee or fear of new injury contribute to poor outcomes following ACLR,13,14 and outcomes assessing emotions, confidence, and risk appraisal have shown predictive ability to determine likelihood of return to sport.15–17

In addition to modifiable factors like strength and psychological readiness, other factors have also been studied. Time has been shown to be an especially important consideration. When return to sport is delayed from six to nine months, the re-injury rate can be reduced by more than 50% for each month of delay.11 Beischer et al. recently found that young athletes who return to sport before nine months have a re-injury rate seven times that of their counterparts who delay return to after nine months.18 There are many possible explanations for why time is an important component; however, it likely is a factor of an increased opportunity to build strength and gain confidence.

The problem with looking at any single variable is that it inherently leads to a linear model for explaining injury risk by taking that variable and drawing a conclusion directly from it. Bittencourt et al. suggest that a complex systems approach is more appropriate for injury prediction because of its reliance on probability rather than direct causality.19 The authors discussed the importance of recognizing that relationships exist among many different determinants, and that the interplay of those relationships is constantly changing based on how the variables interact with each other. Ultimately, a pattern will emerge from the determinants, and that, too, will provide recursive feedback into the system, which will continue to react and adapt to the changing environment. When taking the complex systems model into consideration, the fact that psychological variables, isolated quadriceps strength, and time from surgery can all be components in re-injury risk starts to become clearer.

Time from injury seems to have the most promise for reducing injury risk, but by itself time is a confounding variable in this sense. There needs to be a better explanation for why time from injury matters. One likely explanation for the importance of time from injury is the concept of variability of movement. Traditional views on variability of movement have suggested that there was “one correct movement pattern” and that any alterations from that should be adjusted. Dynamical systems theory suggests, however, that variability is inherent in human movement, and both necessary and ideal for normal function.20 Expert-level performance in several different athletic events, for instance, has been shown to have high levels of variability within the body part, leading to low variability for output and very consistent outcomes.20 Bartlett et al. believe that the variety of potential movement patterns is important because of the flexibility it provides to account for unanticipated changes in the environment.20 Several authors have demonstrated that when attending to a ball during a cutting task, subjects exhibit changes in knee, hip and trunk biomechanics.21,22 Regardless of the implications that these findings have on injury risk, it certainly suggests that there is not one single way that patients will move to perform a cutting maneuver, and that attentional resources play a role in movement performance. Training variable movements in a variety of settings is imperative to safely prepare a patient for return to a dynamic environment. Harbourne et al. advanced the dynamic systems approach by providing guidelines for physical therapists to use to promote motor learning utilizing movement variability.23 By increasing task and environmental complexity, the patient can practice and ultimately can learn how their efforts create an effect on their surroundings. Initial performance will be erratically variable and poor as they attempt to acquire control over the novel skill. That performance will transition to relatively low variability as they focus on their efforts and demonstrate improvements. Finally, they will transition to a consistent level of variability as the patient’s skill can be translated to increasingly complex situations. Does time as a decision factor merely allow for the higher likelihood that the patient transitions out of that middle phase and into the advanced phase? If time is truly just allowing the patient to learn more movement strategies and increase their variability, is there some way to accelerate that process? Current ACL rehabilitation methods fail to efficiently address movement variability, movement pattern acquisition, and long-term motor pattern retention. The purpose of this clinical commentary is to describe the Neuroplastic Adaptation Trident Model and provide examples for clinical implementation.

THE SOLUTION

In order to best understand rehabilitation and return to play considerations, one must first understand the pathological process that occurs as a result of the injury. Surgical management for an ACL tear aims to correct the biomechanical function of the ligament, but it is unable to address the neurosensory component. The ACL contains afferent nerve fibers connecting via the articular branch of the posterior tibial nerve.24 Those nerve fibers are primarily located near the femoral attachment of the ligament and provide impor-
tant joint position sense through Pacinian, Ruffinian and Golgi-like mechanoreceptors. Without the mechanoreceptors a noticeable gap develops in the afferent information regarding joint position and movement that the brain receives. In addition to the lost afferent feedback, the reflexive muscular splinting mechanism that comes with ACL quick stretch is also lost. After ACL rupture, when the connection to the articular branch of the posterior tibial nerve has been lost, the brain enters a neuroplastic state in order to compensate for the loss. Neuroplasticity is a state of cortical adaptability and refers to the broad idea that the brain can adapt and change based on internal and external stimuli. Some of the potential mechanisms include synaptogenesis, neurogenesis and neurochemical changes, although specifics remain the subject of considerable debate. It is generally accepted that the brain is a plastic organ and, when input changes occur, the brain will adapt to those changes.

Functional magnetic resonance imaging (fMRI) studies conducted on individuals following ACL reconstruction demonstrate changes in cortical and cerebellar activation patterns. Specifically, increased activation in the primary motor cortex, secondary somatosensory area, and lingual gyrus suggests that ACL injury and subsequent recovery change how the brain functions. Additionally, decreased activation in the cerebellum suggests a loss of automaticity in movement and an increased need for attentional awareness. In addition to those changes in activation, Zarzycki et al. measured resting motor thresholds (RMT) of the motor cortex using transcranial magnetic stimulation (TMS) and demonstrated decreased corticospinal excitability as soon as two weeks following ACL reconstruction. To date there have been no intervention-specific studies looking at the effect that rehabilitation can have on this parameter, but multiple studies have shown that corticospinal excitability changes occur after ACL reconstruction, and that they persist for years. This breadth of research supports the postulation of Kapreli et al. that ACL injuries cause dynamic changes to the central nervous system, and that these injuries should be considered "neuropsychologic dysfunction, not a simple peripheral musculoskeletal injury". The brain clearly enters a neuroplastic state following ACL injury, but neuroplasticity is not inherently goal-oriented or directional. Plasticity changes can be influenced by behavior and rehabilitation methods, or a lack thereof. Grooms et al. proposed that an increased reliance on visual feedback and internal locus of control during rehabilitation could potentially explain negative changes that occur after injury.

In order to best understand rehabilitation goals for sensory interaction, it is important to first examine a normal state. Extensive research and modeling has been completed on the process by which the central nervous system processes and utilizes sensory input to maintain static balance, known as sensory reweighting. Peterka describes a closed feedback loop system, where information from the proprioceptive, visual, and vestibular systems are dynamically interpreted, weighted, and acted upon, with the resulting system output being fed back in as a new systemic input. The brain adjusts, or reweights, the relative contribution of each of the sensory systems based on the demands of the environment. In a relatively stable environment, where changes to the visual and proprioceptive system are occurring slowly, around .5 deg/sec, the brain relies heavily on the proprioceptive (50% relative contribution) and visual (33%) systems, with relatively minor influence from the vestibular system (17%). However, when the dynamic changes to the environment increase, as is expected in athletic participation, to a faster speed, 8 deg/sec, the brain reweights the relative contributions to rely almost exclusively on the vestibular system (82% relative contribution) with the proprioceptive (15%) and visual (3%) systems developing a diminished role. Although there may be limited validity in extrapolating from this data to a chaotic athletic environment, understanding how the brain reweights sensory contributions to balance is very important for rehabilitation purposes.

In an attempt to maximize the neuroplastic state of the brain and contribute to positive changes, clinicians need to take into account the principles of motor control and motor learning. Motor learning is the process of acquiring or altering motor skills to create a permanent change in performance. There are several different models that have been developed to explain motor learning, but they include common factors or variables such as feedback, cueing, focus of attention, rehearsal schedule, contextual interference, task relevance, and amount of practice. Fitts and Posner developed a model of motor learning based on a continuum of cognitive, associative, and autonomous stages. In the cognitive stage the patient must develop an awareness of the desired task and how to control the movement. They will transition to the associative phase when they begin to utilize the trained movement pattern in other tasks or environments to which they devote attentional resources. Ultimately, the patient needs to transition to the autonomous stage, where they unconsciously select that movement pattern during the appropriate tasks. An individual’s relative stage of learning dictates what other factors can be utilized to influence motor learning. For example, if the individual is in the cognitive stage of learning, a clinician may only be able to alter one variable at a time (e.g. practice schedule), whereas an individual in the autonomous stage may need to have multiple variables altered at a single time (e.g. contextual interference, feedback, and attentional focus). To best address the various stages of learning, a clinician must have strong understanding of the various tools or strategies available to influence motor learning.

An easy starting point for motor learning discussion is the use of rehearsal schedule, which can be divided into blocked, serial, or random practice. Blocked practice utilizes high repetitions of a single task and should be dedicated to novel movements or movements with high complexity. It leads to improved performance quicker than other rehearsal schedules, but it displays limited retention of the specific skill. Serial practice incorporates several tasks in a repeated pattern and should be utilized as the individual progresses into the associative stage of motor learning. To maximize retention and transition to the autonomous stage, random practice, or multiple movements performed in an undetermined order, is necessary. Random rehearsal will result in an initial decrease in performance, but an increased ability for the individual to perform the skill at a later point in
time. Randomized rehearsal is superior to blocked practice in terms of retention of a specific motor skill due to contextual interference.

Gokeler et al. outlined the principles of motor learning as they can be utilized for ACL rehabilitation, and identified four key concepts to consider: external focus of attention, implicit learning, differential learning, and self-controlled learning and contextual interference. Internal focus is when one's attention is on the movement of a body part, whereas external focus directs the individual's attention to the effects of the movement on an interaction with the environment. Providing an external focus of attention accelerates the learning process, and a higher level of skill is achieved sooner due to the utilization of unconscious processes. In coordination with external focus of attention is the use of implicit learning, which emphasizes cueing related to how the movement feels, rather than a specific set of instructions. Implicit cues like "land softly" or "explode off the ground" assist in developing anticipatory skills and decrease the cost of attentional resources needed to complete a task.

Differential learning takes the concept of rehearsal schedule and incorporates variability of movement skills. Differential learning relates to the dynamical systems approach discussed by Bartlett et al. by randomizing the performance of several tasks that all address the same general movement pattern. Contextual interference bridges a gap between cognition and skill acquisition in which interference by cognitive or physical means leads to higher levels of learning and retention of a specific skill, despite an initial decrease of performance. By shifting attentional resources to a secondary focus, the individual learns to execute the primary task automatically, instead of with conscious control. Initially the decreased ability to focus cognitive resources on the task will hinder performance, but as the brain adapts to the new challenges and inputs, it will develop new movement strategies and increase the variability of available movement patterns. Self-controlled learning is an important motivation tool to keep the individual committed to the rehabilitation process. Patients who are in control of the situation, even in simple ways, are more likely to become invested in the process.

Wulf et al. dove deeper into the concepts of motivation and attention in developing the OPTIMAL theory of motor learning. OPTIMAL is an acronym for Optimizing Performance through Intrinsic Motivation and Attention for Learning, and the authors emphasize self-efficacy and control. According to the OPTIMAL theory of learning, an individual with no autonomy and low expectations will inherently have a more internal focus and decreased performance. That decreased performance will feed back into the system, further decreasing expectancy for performance and harming future attempts. However, an individual who has higher autonomy and enhanced expectations will focus more externally on the task, leading to improved motor performance.

The theoretical frameworks developed by Gokeler et al. and Wulf et al. are excellent resources to work from but fall short of providing a practical structure to rehabilitation. One consideration that is noticeably absent is dosage volume. In orthopedic injury, research assessing adequate dosage for motor learning is sparse, but stroke research suggests that larger amounts of repetitions result in better outcomes. The physical act of a repetition is only part of the process of motor learning, however, and the cognitive processes of problem solving and movement selection also need to be considered. When learning new motor patterns, individuals should not simply repeat the result of a solution over and over (blocked practice), but rather should practice the act of problem solving. Individual variability for movement pattern acquisition mandates that optimal dosing will not likely be a single value for each patient, but needs to be individualized.

Another prominent motor learning method for neurophysiologic dysfunction is constraint-induced movement therapy (CIMT), developed by Taub et al. CIMT was designed to treat functional loss as a result of stroke, but it is based on the concept of neuroplasticity. The main principles of CIMT are repetitive, task-oriented training for several hours a day, a transfer package to employ new skills from the clinic into the real world, and constraining the patient to utilize the affected body part. Major takeaways from this model are the concept of the transfer package and the regular utilization of the new skills in real-life situations.

The combination of these models and systems led to the development of a novel framework for structuring the prescription of exercises to maximize positive neuroplastic adaptations following ACL reconstruction. The primary goals for the model are to accelerate the motor learning process in order to maximize movement variability and prepare athletes for safe return to a chaotic athletic environment. This framework (outlined below) demonstrates utilization of a staged approach to ACL rehabilitation. The Neuroplastic Adaptation Trident Model is a treatment framework developed to practically implement motor learning principles into orthopedic rehabilitation. It is based on a "trident" of neuroplastic exercise in which the base of the trident represents sensory stimulus, and each prong represents decision-, reaction-, and distraction-based tasks, respectively. Complexity of tasks can be increased by incorporation of one or multiple prongs of the trident (Figure 1).

Sensory stimulus is the base-level component that clinicians need to consider in all interventions to maximize sensory re-weighting during exercise. Rapidly changing environments require more vestibular and proprioceptive input, and so rehabilitation methods should minimize reliance on the visual system. There are two methods to challenge sensory stimulus, through isolation (targeting a single system) or combination (targeting two systems simultaneously). In order to train the sensory systems, a clinician can control information in three ways: decreased input, absent input, and incorrect input. Clinicians can choose to challenge each of the sensory systems in a variety of ways, in order to decrease reliance on that particular system during the tasks (Table 1).

The somatosensory system is challenged with decreased or incorrect input through changing the surface-to-limb interface, or by changing body position for the task. The visual system is the easiest to manipulate and can be challenged in any of the three methods mentioned. Clinicians can decrease visual input through the use of stroboscopic
Table 1: Sensory Stimuli

<table>
<thead>
<tr>
<th>Involved Systems</th>
<th>Methods of Control</th>
<th>Manipulation Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatosensory</td>
<td>Decreased input</td>
<td>Isolation</td>
</tr>
<tr>
<td>Visual</td>
<td>Absent Input</td>
<td>Combination</td>
</tr>
<tr>
<td>Vestibular</td>
<td>Incorrect Input</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Single Leg Balance: Sensory Manipulation Methods

<table>
<thead>
<tr>
<th></th>
<th>Somatosensory</th>
<th>Visual</th>
<th>Vestibular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased</td>
<td>Change in footwear or surface</td>
<td>Stroboscopic glasses, pinhole glasses</td>
<td>Head turns, head circles, head alphabet</td>
</tr>
<tr>
<td>Absent</td>
<td>Unable</td>
<td>Eyes closed or covered</td>
<td>Unable</td>
</tr>
<tr>
<td>Incorrect</td>
<td>Airex, BOSU, etc.</td>
<td>VR goggles</td>
<td>Unable</td>
</tr>
</tbody>
</table>

This example provides several options that a clinician can utilize first in isolation and then in combination as the patient performance improves.

Table 3: Decision Possibilities

<table>
<thead>
<tr>
<th>Types of Decision</th>
<th>Methods of Cueing</th>
<th>Cueing Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Either/Or</td>
<td>Visual</td>
<td>Responsive</td>
</tr>
<tr>
<td>Multiple Options</td>
<td>Auditory</td>
<td>Arbitrary</td>
</tr>
</tbody>
</table>

glasses or pinhole glasses, forcing the brain to de-prioritize the visual input it is receiving. Additionally, visual input can be removed by closing or blocking the eyes. And finally, the clinician can provide incorrect visual information through the use of virtual reality (VR) goggles. This technique forces the patient to continue utilizing their visual system, but only for cognitive tasks and not for relevant balance information. The vestibular system is challenged by dynamically changing the head and eye position and movements. By isolating and combining the sensory systems clinicians can address differential learning and contextual interference to maximize motor learning, as well as induce constraints on the systems being utilized to isolate deficits. The therapist may choose not to manipulate sensory stimuli during an intervention, but it should always be the first consideration due to the known importance of decreasing reliance on visual information. See Table 2 for examples.

The first prong of the trident builds upon the foundation of sensory stimulus considerations and adds complexity. Any rehabilitation exercise can be considered a primary task, and decision-based tasks are defined as altering a primary task based on an external cue. Decision-based tasks introduce randomization into task performance and emphasize the process of problem solving as an exercise itself (Table 3).

The first component is the number of options available.
Table 4: Decision-Based Task: Lunge Example

<table>
<thead>
<tr>
<th></th>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Either/Or Responsive</td>
<td>Point to Left or Right</td>
<td>Say &quot;Left&quot; or &quot;Right&quot;</td>
</tr>
<tr>
<td>Multiple Options Responsive</td>
<td>Mirror Left, Right, Forward, Backward</td>
<td>Say &quot;Left&quot;, &quot;Right&quot;, &quot;Squat&quot;</td>
</tr>
<tr>
<td>Either/Or Arbitrary</td>
<td>Green light = Right Red light = Left</td>
<td>Odd numbers = Left</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Even numbers = Right</td>
</tr>
<tr>
<td>Multiple Options Arbitrary</td>
<td>Green light = Right Red light = Left Blue light = Squat</td>
<td>Odd numbers = Left</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Even numbers = Right</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clap = Squat</td>
</tr>
</tbody>
</table>

Example of how to incorporate decision-based principles into a simple lunge exercise. Rather than blocked dosing with a set number of repetitions, these options introduce random practice and contextual interference.

Table 5: Reaction Possibilities

<table>
<thead>
<tr>
<th>Types of Reaction:</th>
<th>Methods of Perturbation:</th>
<th>Methods of Motor Skills:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push</td>
<td>Known Outcome</td>
<td></td>
</tr>
<tr>
<td>Pull</td>
<td>Random Outcome</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Jump: Perturbation Reaction Methods

<table>
<thead>
<tr>
<th></th>
<th>Push to left in the air</th>
<th>Pull to left in the air</th>
<th>Might be a push to left or might not be during jump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>Push</td>
<td>Pull</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Push either to left or forward in air</td>
<td>Pull either left or forward in air</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Might have a push in any direction or no push</td>
</tr>
<tr>
<td>Complex</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Neuroplastic Adaptation Trident Model: A Suggested Novel Framework for ACL Rehabilitation

As the patient becomes more proficient in the primary skill, the clinician needs methods to challenge the performance of that movement with secondary tasks. The second prong of the trident is reaction-based tasks, which are secondary tasks that a patient must complete while still performing the primary movement (Table 5).

Table 4 provides examples.

The addition of a new challenge will decrease the attentional resources available for the primary task and force the patient to interact with a stimulus in their environment. Reaction tasks are either perturbation based, where the clinician provides a stimulus to body position, or motor skill based, where the patient must complete a hand/eye skill. Simple perturbation reaction tasks are typically uniplanar with a single known push or pull stimulus. Complex perturbation reaction tasks can become multiplanar and incorporate the addition of unknown stimuli (Table 6).

Simple motor skill reaction tasks include a secondary task with a known outcome, such as catching a ball. Complex motor skill reaction tasks incorporate a decision-based component into the secondary task, requiring the patient to process information and change performance of the secondary task based on the environment (Table 7).

Reaction-based tasks continue to build on an external focus of control and add contextual interference through randomizing practice. Like decision-based tasks, reaction tasks force the patient to practice problem solving and lead to an acquisition of more motor patterns, contributing to greater movement variability.

The final prong of the Trident builds on complexity by...
utilizing cognitive resources to complete an additional challenge and/or tertiary task. Distraction-based tasks increase the cognitive load for something that is unrelated to the primary tasks and can be accomplished by utilizing the principles of decision and reaction-based tasks (Table 8).

Simple distraction tasks utilize a primary motor task that the patient is working to develop and incorporate a secondary task that changes the attentional focus. This can include questions based on semantic knowledge and progress to questions based on problem solving. Complex distraction tasks will include a reaction and/or distraction secondary task and incorporate a tertiary level component to the exercise. Distraction-based tasks have a strong emphasis in contextual interference and external focus of control. They challenge the problem-solving process, and utilize attentional resources, increasing the automaticity and autonomy for the primary task. Table 9 provides examples.

There are several considerations regarding dosing that need to be addressed. The first consideration is deciding when to implement neuroplastic interventions and how often they should be utilized. Based on the CIMT research, our model recommends implementing sensory stimuli and decision-based tasks immediately as part of the rehabilitation process. These methods should be utilized repetitively throughout the day as part of the home exercise program, and it is imperative that clinicians target the transfer package through patient education on incorporating these daily movement skills. There are simple phone applications that can create a random yes/no stimulus that patients can use for either/or decision-based tasks. Not only can the patient change sensory input through foot placement on a pillow/blanket/towel, eyes open vs closed states, and head turns horizontal or vertical, but they can at least introduce a serial practice schedule by cycling through different combinations of those states during exercises like weight shifts, squats, lunges, etc. Stroke research on neurophysiological dysfunction tends to recommend high dosage for motor learning, but there is no clear consensus on exactly what that volume should be; additionally, there are recommendations to individualize dosing.52 Hauptmann et al. found that for healthy individuals, improvement between sessions for a motor task was based on their proximity to saturation, defined as a plateau in performance that is individually-determined.53 With these findings in mind, the authors recommend that the majority of a rehabilitation session be conducted using this framework, but that each exercise be assessed individually for qualitative saturation. The important thing for the clinician to watch for is a plateau in performance, which will not necessarily come at ideal performance within the session. If the patient completes 5-10 repetitions consecutively without any improvement in performance, the clinician should move on to a new task. Based on the authors’ experience, patients tend to demonstrate improvement with at least one in-person session per week, as long as the patient is motivated and committed to continuing to practice these principles as part of a home exercise program. Additionally, autonomy of the patient must be considered in order to enhance motivation. The patient should be an active participant in selecting exercises and given options to choose from throughout the session.

### Table 7: Single Leg Balance: Motor Skills Methods

<table>
<thead>
<tr>
<th>Known Outcome:</th>
<th>Random Outcome:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch a football</td>
<td>Catch colored ball: Red= Right hand Green= Left hand</td>
</tr>
<tr>
<td>Kick a soccer ball</td>
<td>Catch a stick that is 3 colors, instruction on which color to grab in air</td>
</tr>
</tbody>
</table>

This example shows both known and random outcome tasks that the patient will have to complete while working on single leg balance.

### Table 8: Distraction Possibilities

<table>
<thead>
<tr>
<th>Task Options:</th>
<th>Difficulty Options:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary</td>
<td>Simple</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Complex</td>
</tr>
</tbody>
</table>

### STAGE 1

The primary goals during the acute phase of rehab are managing joint effusion, restoring full knee joint range of motion (ROM), and facilitating active quadriceps contraction. It is important for the clinician to find ways to transfer these principles to the home exercise program for repeated practice. While the patient performs quadriceps setting exercises with neuro-muscular electrical stimulation (NMES), they can wear virtual reality (VR) goggles to provide incorrect visual stimuli to decrease or eliminate internal focus on the quadriceps contraction. External cueing should be utilized during this intervention by having the patient “push into the table” or “think about kicking a ball.” Sensory stimulus can also be manipulated during weight bearing and balance interventions by changing footwear, surface, orientation (i.e. double leg vs. tandem stance), or visual input (decreased, absent, incorrect) in isolation.

Decision-based tasks should be initiated to promote random practice early in the rehabilitation process. Simple decision-based tasks can utilize “either/or” options such as weight shifts with visual pointing of left or right, or body-weight squats with verbal cues of “stop” and “go.” Decision-based tasks are advanced by adding more than two options (i.e. weight shifts to the right, left, or forward with auditory or visual cueing) and by introducing complex cueing. Color cues add complexity by correlating different colors with different directions, forcing the patient to problem solve before executing a task. A simple tool for randomization of color stimuli is the Vector Ball (Eye on Ball Inc., Oviedo, FL), which randomly lights up red, green or blue on impact. To incorporate differential learning into the complex cues, some colors can correlate with a different task altogether, or a change in cueing rules. Other complex cueing methods can include verbal numbers, initially as “either/or,” in which even numbers correspond with weight shifts to the right.
and odd numbers correspond with weight shifts to the left. Once the patient displays competence with a variety of cueing options, decision-based tasks should be further progressed with increased complexity of sensory stimulation. Introduction of stroboscopic glasses to decrease visual input and initiation of head turns or eye movements to challenge the vestibular system in isolation are good initial steps. Further advancement includes a combination of interventions to challenge multiple sensory systems while the patient performs decision-based exercises.

Simple reaction-based tasks should also be initiated in this phase, with an easy version of a secondary motor control task, such as catching a ball. These tasks can be performed while performing exercises such as squats, wall sits, or bridges in order to emphasize an external focus of attention on the secondary task. As with decision-based tasks, sensory stimulus can be manipulated during this task to increase complexity once competence is demonstrated.

In addition to decision and reaction tasks, distraction-based tasks should also be incorporated during this phase in order to further challenge attentional resources. Simple, semantic based questions or math problems added during exercises distract the patient from primary and/or secondary task performance. An example of a challenging task would be utilizing the VR goggles and 360-degree interactive pictures taken with an iPhone application. The pictures include nine people wearing various colored jerseys with the numbers 1-9 and standing in various positions. For this intervention, the rehab specialist asks questions of varying difficulty that the patient needs to answer. Simple versions of VR questions include "where is number 5?" or "what color is number 2 wearing?" requiring the patient to scan the visual environment by dynamically moving the head. More complex questions such as "what color is 15 divided by 3?" or "what numbers are not standing?" force more cognitive processing and problem solving. Appendix A provides examples of interventions during this phase.

**STAGE 2**

Primary emphasis for the post-acute stage of rehabilitation should include motor patterning, light loading, resistance training, and improving the ability to load dynamically. With an emphasis on promoting proper motor patterning and low-intensity resistance training, decision-based tasks can be incorporated to promote randomization. An example of a decision-based intervention is lateral band walks using the Vector Ball for complex cueing to determine which direction the patient should step. Once the patient demonstrates competence, sensory stimulus can be further limited by use of stroboscopic glasses.

Reaction-based tasks are progressed in this stage of rehabilitation to include simple perturbation tasks with a known stimulus to initiate the movement. Lateral lunges with a therapist delivered push or pull perturbation, alters task initiation, promotes differential learning, and increases movement variability. These reaction-based perturbation lunges can be advanced by progressing the perturbations to include both forward and lateral lunges, or by altering the sensory input of the patient. Complex reaction-based tasks are also utilized in this stage. Progressing from the simple reaction-based task used in Stage 1 for single leg balance, the patient can be instructed to catch a ball with the right, left or both hands based on verbal instruction from the therapist. The cueing could be advanced to arbitrary cues by utilizing the number system mentioned above in Stage 1 (i.e. even number for left hand and odd number for right hand) or by bouncing the Vector Ball to the patient with the completion of the secondary task dictated by the color on impact (e.g. red catch right hand, green catch left hand, blue catch with both hands).

A major component of rehabilitation during this phase is the emphasis placed on muscle strength and hypertrophy. The scope of this paper is to focus on neuroplasticity interventions, but for additional resources regarding strengthening parameters the work of Reiman et al. and Welling et al. should be consulted for programming considerations.\(^{34,35}\) It cannot be emphasized strongly enough that strength training is of the utmost importance during rehabilitation and should not be sacrificed.

While the patient is working on developing strength, they must also learn shock absorption and load dissipation to prepare for the demands of linear running. This training must begin at an intensity less than bodyweight until strength capacity is able to meet the demands of jumping and landing. An aquatic environment and a sled-based training system like the MVP Shuttle (Shuttle Systems, Bellingham, WA) are both excellent ways to train impact mechanics with a decreased load. Initially, the patient would perform blocked practice for double-leg jumps, continuous single-leg jumps, and alternating single-leg jumps to develop competence for the desired triple flexion to triple extension movement. The therapist should use external cues such as "soft" or "land on egg shells" to teach the patient to feel how their movement causes an interaction with the environment. Implicit learning can be accomplished by having the patient look straight ahead to discourage visual input of the landing, forcing them to utilize other senses to

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**Table 9: Single Leg Balance Primary**

<table>
<thead>
<tr>
<th></th>
<th>Distraction Secondary</th>
<th>Catch Secondary and Distraction Tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple:</td>
<td>Say number of fingers being held up</td>
<td>Simple Arithmetic (addition and subtraction)</td>
</tr>
<tr>
<td>Complex:</td>
<td>VR Goggles with people wearing colored jerseys, &quot;What color is 12 divided by 3?&quot;</td>
<td>Count backwards from 100 by 7's</td>
</tr>
</tbody>
</table>

This example demonstrates the varying levels of difficulty that cognitive tasks can have, as well as the ability to utilize distraction-based tasks as secondary or tertiary levels.
increase awareness of body position and anticipate landing. In order to transition from blocked or serial practice to random practice, the therapist should incorporate simple decision-based tasks by utilizing verbal cueing of "stop" and "go" as well as "right" or "left" to determine which leg the patient would land on and initiate the next jump. To advance the complexity of decision-based tasks, the therapist can increase the number of options (e.g. "right," "left," "both"), utilizing arbitrary cueing (e.g. numbers or colors that correlate which leg to land), and sensory manipulation (e.g. stroboscopic or pinhole glasses, closed eyes, or landing on an Airex pad (Airex, Sins, Switzerland) for a known and unknown landing surface).

Distraction-based tasks will increase contextual interference when completing the primary task. While the patient performs a squat exercise with an emphasis on avoiding a lateral shift, the therapist asks simple questions or poses cognitive tasks (e.g. What is your phone number? What is your jersey number? Spell a certain word, count up from three starting from zero, list as many colors as possible, etc.). To incorporate a tertiary task the patient performs a primary decision-based task of lunging or squatting based on the visual color cue; the patient also completes a secondary task of catching a ball; and the patient is given a tertiary task to answer simple math problems. These complex versions of interventions in which the therapist incorporates elements from all aspects of the Trident should only be utilized when the patient demonstrates competency with the primary and secondary tasks. In the later stages of rehab, further combination of the different prongs of the Trident are introduced. See Appendix A for examples of interventions during this phase.

STAGE 3

The advanced stage of rehabilitation emphasizes the progression of plyometrics and power activities, running and cutting mechanics, and sport/position-specific activities. Athletes should only begin interventions in this stage when they have restored an adequate amount of quadriceps strength to complete bodyweight impact exercises. The progression of plyometric activities proceeds with incorporation of each prong in isolation, followed by a combination of all three prongs to increase complexity of the primary task. It should be acknowledged that the interventions described should be done in addition to traditional high intensity plyometric training. These interventions are designed to challenge movement variability, but traditional plyometric prescription will do a better job of increasing power and explosive muscle qualities.

Body-weight plyometrics are a foundational component during this stage of rehabilitation. By this stage, the patient should be well prepared to handle higher-level manipulation of sensory input with stroboscopic glasses, jumping and landing on an unstable surface (e.g. Airex pad or BOSU ball (Bosu, Ashland, OH)), and altering head movements (e.g. nodding or shaking head while executing plyometric task). To incorporate decision-based tasks, the patient, while jumping, is provided a verbal or visual cue to determine which leg to land on and initiate the next jump. To incorporate reaction-based tasks, perturbations can be included initially as a known stimulus then progressed to unknown stimuli. Additionally, motor tasks such as catching a Vector Ball based on the color emitted while landing from the jump can be utilized. Lastly, in order to incorporate distraction-based tasks, inclusion of cognitive tasks (same list in Stage 2) should be utilized while the patient performs plyometric activities.

When prescribing exercise, the therapist should continuously be considering the base of the Trident, sensory stimuli and how to integrate a single prong of the Trident with sensory manipulation. First, the therapist should incorporate a decision-, reaction-, or distraction-based emphasis with a single form of sensory manipulation. This could include a decision-based plyometric to land on a certain leg based on a cue combined with sensory manipulation of landing on an Airex pad. The therapist could also utilize a reaction-based plyometric such as landing from a jump after a perturbation in the air, with the sensory manipulation of closed eyes.

After utilizing a single prong with sensory manipulation, a combination of two or more prongs should be performed (i.e. decision with reaction, decision with distraction, reaction with distraction or all three). These exercises with increasing complexity are designed to mimic the dynamic demands of an athletic environment and to improve movement variability. Decision with reaction tasks can include landing on a specific leg in response to a verbal cue while receiving a known in-air perturbation. A decision with distraction could be the patient performing a 90-degree rotational jumps in response to a visual cue while the patient lists as many prime numbers as possible. A reaction and distraction task could involve the patient performing continuous lateral line hops while catching a Vector Ball with the appropriate hand based on the color emitted and spelling specific words listed by the therapist. As always, the therapist should consider the underlying base of the Trident, sensory stimulation, with all tasks. Once the therapist becomes comfortable with the different prongs of the Trident and how to manipulate them, exercise selection becomes limitless. Refer to Figure 2 for a progression flow chart of increasing complexity.

Another method to increase difficulty is to utilize the

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**Figure 2: Progression Flow Chart**

Visual representation of the progressive increase in complexity when utilizing the Neuroplastic Adaptation Trident Model.
prongs in sequence, either the same prong repeated (e.g. decision-based task followed by another decision-based task) or using different prongs (e.g. decision-based task followed by a reaction-based task). Due to the dynamic nature of sport, with a constantly evolving environment, incorporating sequenced tasks is a necessity. Sequenced decision-based tasks could be as simple as a verbal right or left 45-degree angle change of direction, followed shortly by a second verbal cue. Sequencing a decision-based task into a reaction-based task could involve the patient performing a depth jump followed by a cut in a given direction based on a verbal cue, and then followed by catching a football. See Appendix A for examples of interventions during this phase.

STAGE 4

In order to progress to the final stage before returning to sport, the patient must have developed an adequate amount of strength, power and explosiveness in controlled environments. Emphasis for the return to sport stage of rehabilitation must include high-intensity running and cutting with the addition of open-decision sport and position-specific activities. The key during this stage of rehabilitation, and the main difference between Stage 3 and Stage 4, is the attempt to emulate the demands of the sport as closely as possible. This should include a continuation of the components of the trident with increasing difficulty for preparation for the chaotic environment of competition. See Appendix A for examples of interventions during this phase.

DISCUSSION

ACL injuries are a common phenomenon and continue to remain prevalent, and clinicians and researchers are continuously searching for the best way to decide when a patient is appropriate to return to activity. Quadriceps strength has shown promise as a valuable return to play criterion, and it is appropriate to return to activity. Quadriceps strength has demonstrated a decrease in the risk for re-injury. The parsimonious explanation for this suggests that time allows for a better return of strength and an improved psychological readiness. Functional return to sport tests successfully assess the movement variability that occurs during this delay, but testing specific tasks (e.g. single leg hop, triple hop, etc.) does not measure the patient’s ability to respond to a changing environment using different motor strategies. Further time from injury provides the opportunity to add more motor strategies and more experiences into the complex system of injury risk. A key component of time from injury is the acquisition of motor strategies to increase the amount of movement variability, and rehab should focus on accelerating that process.

Neuroplasticity, or the ability for the brain to adapt and change, is a burgeoning field with several known parameters on how to affect motor control and motor learning. The loss of mechanoreceptor input from the native ACL and traditional rehabilitation methods have combined to show changes in motor cortex activation and sensory processing within the brain. It is the author’s preference to manipulate visual input initially due to the high reliance on vision following injury, but any sensory manipulation provides neuroplastic stimulation. If rehabilitation specialists acknowledge neurophysiological dysfunction, and implement the known parameters to affect positive neuroplastic changes, the logic follows that outcomes will improve. Regardless of improvement, this procedure will further the understanding of best rehabilitation practices for a common yet complicated injury.

There are limitations in what the current evidence supports. First, the majority of motor learning research, particularly in regard to dosage has been conducted on individuals after a stroke. While it is accepted that an ACL tear results in neurophysiological dysfunction, there may be something about the magnitude of changes in the brain after a stroke that impacts rate of learning. Further studies should be conducted on ACL-injured patients specifically to identify adequate dosage for retention of movement pattern changes. The second limitation is that while fMRI and TMS studies have shown neural changes after ACLR, some or all of those changes may be necessary compensatory adaptations to the injury, such as the increased activity of the secondary somatosensory area to accommodate for the decreased volume of afferent information following the loss of mechanoreceptors. Further research should first evaluate the effect that those findings have on injury rates and whether there truly is something that needs an intervention. Researchers should then study the Trident Model, or at least components of it, and elucidate how these interventions impact fMRI and TMS measures. The most important future for rehabilitation is for surrogate clinic-based tests that therapists can utilize practically, rather than depend on fMRI and TMS. VR technology has a lot of promise as a method to challenge cognitive processing and vestibular function. The addition of force plates to assess loading and response to perturbation should also be explored.
The Trident Model serves as a framework compiling current best evidence into a practical system for rehabilitation specialists and researchers to address a missing component in ACL rehabilitation. One of the strengths of the Trident Model is the deep-rooted basis in well-established and understood concepts. Built upon the basic science of neuroanatomy and instituted through the incorporation of strength and conditioning principles along with the inclusion of OPTIMAL theory and other methods of motor learning, this model includes a current best understanding of how to address these impairments. Equally as important, the model takes complex concepts and creates a practical framework that clinicians can adapt in practice. Further, by outlining the concepts and general dosage recommendations, this model provides researchers with something that can be objectively studied in randomized controlled trials.

CONFLICTS OF INTEREST
The authors have no conflicts of interest to disclose.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A: Example interventions by stages

Appendix B: Glossary of terms
Netball is a predominantly female team sport which is played worldwide. Netball is becoming more popular in the United States following its countrywide introduction to schools and community centers. A unique characteristic of netball is the footwork rule which restricts players to a one-step landing after catching the ball. Most netball landings are single-leg landings resulting in high vertical ground reaction forces and high skeletal tissue forces. Thus, high-risk landing events that have the biomechanical potential for injury occur frequently. Noncontact knee ligament injuries are common following a knee abduction collapse when landing. Because the consequences of noncontact knee ligament injury are profound, strategies are needed to mitigate the burden of such injury for players, teams, and society.

The purpose of this clinical commentary is to demonstrate how theoretical principles, different types of research, and different levels of evidence underpin a rational clinical reasoning process for developing noncontact knee ligament injury prevention screening procedures in netball. The theoretical principles that are discussed in this commentary include injury control, the sequence of prevention, principles of screening in injury prevention, the multifactorial model of injury etiology, complex systems theory, and systems science. The different types of research that are reviewed include descriptive and analytic-observational studies. The different levels of evidence that are discussed include prospective studies, cross-sectional studies, and clinicians' own kinesiological modelling. Subsequently, an integrated approach to the evidence-informed development of noncontact knee ligament injury prevention screening procedures is presented. Clinical practice suggestions include a selection of evidence-informed screening tests that are quickly and easily implemented with netball players in local communities. The need for repeated screening at strategic timepoints across a season/year is explained. Sports physical therapists will find this commentary useful as an example for how to undertake clinical reasoning processes that justify the content of screening procedures contributing to noncontact knee ligament injury prevention in community-level netball.

**Level of Evidence**

**BACKGROUND AND PURPOSE**

Netball is a predominantly female team sport with millions of players across 117 countries. Netball evolved from women's basketball in the 1890s, was first played in England in 1895, and later became popular across the British Commonwealth. In England in 2017, there were 180,200 adult netball players which increased to 321,200 players by 2019. In 2018, there were 486,618 registered netball players in Australia and 145,000 registered players in New Zealand. In the United States (US), netball is a relatively new sport which gained popularity in the 1980s. Recently, Miami hosted the World University Netball Championships in 2016 and the US Open Netball Championships attracted over 100,000 viewers in 2017. Now, Netball America has...
members in 33 states and a new high-performance development pathway exists following the success of the US University Netball Team. Community-level netball participation in America is expected to grow following netball’s countrywide introduction to schools and community centers and tournaments at venues such as Madison Square Garden. With increased sport participation comes an increase in injury frequency. Because of growing participation in netball in America, it is prudent for sports physical therapists to become familiar with the nature of the game and to consider primary injury control interventions with community-level players.

Netball is a court-based team game played over 15-minute quarters. Netball is played on indoor and outdoor courts and requires rapid acceleration, deceleration, and change-of-direction running along with jumping, leaping, and ball throwing/catching when attempting to score a goal in the opponent’s territory. A unique characteristic of netball is the ‘footwork rule’ which restricts players to a one-step landing after catching the ball. In other words, after touching down with one foot, players can only take one more step with the other foot to decelerate the body; after this, players may pivot on the touchdown foot before passing the ball to a teammate. The requirement to obey the footwork rule and stop suddenly with one step results in frequent single-leg landing (SLL) with vertical ground reaction force (VGRF) ranging from 3.5 to 5.7 times bodyweight (BW). The VGRF is of interest because it contributes to shear, compression, and rotation forces experienced by the lower-limb joints and because SLL and double-leg landing (DLL) are involved in 27.1-73.8% of injury events. Knee injuries account for substantial proportions of netball lower-limb injuries. Across studies, the majority of netball knee injuries are of a noncontact nature. Trauma accounts for 26% of knee injuries referred to the emergency room and approximately one-third of netball-related hospitalizations. Anterior cruciate ligament (ACL) and meniscus tears occur in netball with a respective frequency of 17.2-22.4% and 4.5-52.7%. When comparing netball to basketball, female ACL sprains and meniscus tears demonstrate higher proportions in netball (17.2%, 4.5%) than basketball (11.1%, 4.1%). Considering ACL-reconstruction (ACLR) incidence between sports, a higher rate of ACLR is also evident in netball (188/100,000 participants) than basketball (109/100,000 participants). Anterior cruciate ligament and meniscus injuries result in profound consequences such as physical disability, substantial healthcare costs, disrupted academic studies, premature retirement from netball, post-trauma osteoarthritis, and depression. Risk of suicide can also exist after sports injuries. Because of such consequences, interventions are needed to mitigate the burden of knee ligament injury for players, teams, and society, and prolong players’ safe netball participation across the lifespan.

The purpose of this clinical commentary is to demonstrate how theoretical principles, different types of research, and different levels of evidence underpin a rational clinical reasoning process for developing noncontact knee ligament injury prevention screening procedures in netball. An understanding of theoretical principles that support clinical practice is critical for designing evaluation and treatment interventions, deploying such interventions in the correct clinical context at the right time, and setting clinicians’ and athletes’ expectations appropriately relative to desired outcomes. This commentary will discuss how theoretical principles and different levels of evidence can be translated to and applied within sports physical therapy practice for primary prevention screening for noncontact knee ligament injury in community-level netball. Several paradigms will illustrate the implications of selected theoretical principles for such practice, including stages of injury control, sequence of prevention, and appropriate application of clinical reasoning.
of screening in injury prevention,\textsuperscript{50} multifactorial model of injury etiology,\textsuperscript{51} complex systems theory,\textsuperscript{52} and systems science.\textsuperscript{53,54} This commentary is original because no similar work exists in the netball literature. Sports physical therapists will find this commentary useful as an example for how to undertake clinical reasoning processes that justify the content of screening procedures contributing to noncontact knee ligament injury prevention in community-level netball.

DESCRIPTION OF THEORETICAL PRINCIPLES

STAGES OF INJURY CONTROL

Injury control refers to preventing or reducing the severity of injury\textsuperscript{45,49} and includes prevention, acute care, and rehabilitation phases of healthcare.\textsuperscript{44,45} Injury prevention refers to primary prevention of injury; that is, prevention of first-time injury to a bodypart.\textsuperscript{46,55} Injury prevention includes all countermeasures to eliminate or minimize the occurrence of injury.\textsuperscript{43,46} Injury prevention, therefore, does not refer to literal prevention of \textit{all} injury cases but the prevention of as many cases as possible.\textsuperscript{43,46,55} Injury prevention seeks to reduce the probability of sustaining an injury rather than to achieve certainty that all cases can be averted.\textsuperscript{44,46,56} For the sports physical therapist, practice which recognizes prevention of all noncontact knee ligament injuries across time is not possible relative to probability theory (the likelihood that one event will occur given all possible outcomes)\textsuperscript{57,58} facilitates action from a place of scientifically-informed realistic intention and good conscience.\textsuperscript{59}

SEQUENCE OF PREVENTION

Injury prevention includes evaluation and intervention procedures that combine to decrease the probability for and incidence of injury.\textsuperscript{44,46} The "sequence of prevention" refers to a process intended to culminate in such outcomes.\textsuperscript{49} The process includes four steps: 1. establish the incidence and severity of injury (epidemiology); 2. establish the factors contributing to and mechanisms of injury; 3. introduce prevention countermeasures (interventions); 4. assess intervention effectiveness by repeating step one.\textsuperscript{49} This process has been elaborated upon by other researchers;\textsuperscript{48} and correspond to long-standing public health disease prevention models.\textsuperscript{44,46} This commentary addressed step one (above) by establishing the frequency of ACL injury and ACLR in netball. This commentary addresses step two (below) by considering noncontact knee ligament injury mechanisms (i.e. mechanics of injury) and the factors associated with them (i.e. etiology of injury). The implication is that when a thorough undertaking of step two has occurred the sports physical therapist can consider appropriate evaluation (screening) procedures that, in turn, inform the content of step three and its interventions.\textsuperscript{44,46}

PRINCIPLES OF SCREENING IN INJURY PREVENTION

In medicine, screening is a process to identify the presence or absence of disease.\textsuperscript{60} In sports medicine, the analogy is screening as a process to identify the presence or absence of injury.\textsuperscript{50} In injury prevention, the intent is to intervene before an injury occurs rather than diagnose an existing injury.\textsuperscript{50} Screening in injury prevention, therefore, is a process to identify characteristics (factors) that increase athletes’ probability of sustaining an injury.\textsuperscript{50} These characteristics are then termed ‘risk factors’.\textsuperscript{51,58} Risk factors are intrinsic (inside) and extrinsic (outside) to the player.\textsuperscript{46,49,61} In netball, examples of intrinsic and extrinsic risk factors for noncontact knee ligament injury appear in Table 2. Risk factors are also modifiable and nonmodifiable (Table 2).\textsuperscript{62} Modifiable risk factors (e.g. muscle strength) and nonmodifiable risk factors (e.g. age) can and cannot be altered with conservative interventions, respectively.\textsuperscript{62} For the sports physical therapist, the implication of intrinsic/extrinsic and modifiable/nonmodifiable risk factors is that the type and number of risk factors included in a screening test battery requires careful consideration. This consideration ensures the most clinically-acceptable risk factors are evaluated and screening procedures are performed time-efficiently.

MULTIFACTORIAL MODEL OF INJURY ETIOLOGY

Because the probability of sustaining an injury is influenced by a combination of intrinsic and extrinsic risk factors, the etiology (cause) of injury is multifactorial.\textsuperscript{51,65} A combination of intrinsic (‘predisposing’) risk factors can sensitize a player to injury,\textsuperscript{51,64} while a combination of extrinsic (‘necessary’) risk factors must be present for an injury to occur.\textsuperscript{51,64} Therefore, the temporal relationship of risk factors is critical: some combination of intrinsic and extrinsic risk factors must exist before an injury event can happen (Figure 1).\textsuperscript{51,64} When a combination of factors produces an injury event within a specific situation, the factors are termed a "sufficient cause".\textsuperscript{51,63,64} Screening to determine the presence/absence of intrinsic risk factors, therefore, relates to identifying an athlete predisposed to injury ("predisposed athlete")\textsuperscript{51,65,66} (Figure 1). When a predisposed athlete enters a situation containing extrinsic risk factors, the athlete becomes susceptible to injury ("susceptible athlete")\textsuperscript{51,65,66} (Figure 1). When the intrinsic and extrinsic risk factors interact within a specific situation as a sufficient cause, an injury event manifests (Figure 1).\textsuperscript{50,63,65,67} Therefore, for the sports physical therapist in netball, injury prevention screening is about identifying the predisposed player possessing intrinsic risk factors for noncontact knee ligament injury before entering a competitive environment (e.g. outdoor court), context (e.g. league match), or situation (e.g. offensive play).

COMPLEX SYSTEMS THEORY

A complex system is a collection of interacting components where the behavior of the whole system cannot be predicted with 100% accuracy from the behavior (status) of one component alone.\textsuperscript{52,68,69} Given the human body is composed of multiple systems (e.g. skeletal, muscular, nervous, etc.) where each system itself is composed of many parts, an athlete is, by definition, a complex system. A netball player’s physiological (e.g. hydration levels, glycogen levels), physical (e.g. joint range-of-motion [ROM], muscle strength),
Table 2: Examples of intrinsic and extrinsic risk factors for noncontact knee ligament injury in netball

<table>
<thead>
<tr>
<th>Intrinsic Risk Factors</th>
<th>Extrinsic Risk Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modifiable</td>
<td>Nonmodifiable</td>
</tr>
<tr>
<td>Joint stiffness</td>
<td>Age</td>
</tr>
<tr>
<td>Muscle strength</td>
<td>Sex</td>
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<tr>
<td>Balance</td>
<td>Femoral intercondylar</td>
</tr>
<tr>
<td>Neurocognitive</td>
<td>General joint</td>
</tr>
<tr>
<td>Landing movement</td>
<td>Playing surface</td>
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</tbody>
</table>

Figure 1: Example recursive and multifactorial model of netball noncontact knee ligament injury etiology (Modified from references 51, 65-67)

and psychoemotional (e.g. stress, anxiety) status can change between matches, across the season, and across the off-season. A netball match’s environment (e.g. outdoor vs. indoor court) and context (e.g. annual league vs. weekend tournament) can alter from week-to-week. A netball player, therefore, competes within repeating (recursive) loops that
span different units of time (e.g. match-to-match, season duration, off-season duration) where sets of risk factors can alter/adapt within and between units of time (Figure 1).\textsuperscript{52,65} As such, multiple interacting risk factors form a complex "web of determinants" that shift the probability for injury up-and-down across time.\textsuperscript{46,51,52,65,70} Given probability theory\textsuperscript{57,58} and complex systems theory,\textsuperscript{52,68–71} injury prevention screening is not contextual to predicting which specific player will get injured.\textsuperscript{46,50} Injury prevention screening is instead contextual to identifying athletes with combinations (patterns) of risk factors that contribute to an increased probability for injury.\textsuperscript{46,50} For the sports physical therapist, noncontact knee ligament injury prevention screening should aim to identify patterns of modifiable intrinsic risk factors (multifactorial 'risk profile')\textsuperscript{52} for one point-in-time. Screening is then repeated (serial screening) at appropriate timepoints across a season/year to reveal changes in a player's risk profile.\textsuperscript{50}

SYSTEMS SCIENCE

Systems science refers to viewing a clinical problem-space as a system of interconnected, interacting components.\textsuperscript{54,69,72} Systems science is a foundation for complex systems theory which, in turn, informs the design of complex clinical interventions.\textsuperscript{73} A fundamental principle in systems science is the use of different types of research to develop clinical interventions.\textsuperscript{54,69,72} In sports physical therapy, an example of a systems science approach to problem-solving is using different levels of evidence\textsuperscript{42} (e.g. prospective research + cross-sectional research + individual opinion) in clinical reasoning processes. The integration of different types of research in a clinician's reasoning yields a richer understanding of a problem-space than when one kind of research is considered alone.\textsuperscript{54,69,72} In this commentary, descriptive\textsuperscript{58} (injury mechanisms) and analytical-observational\textsuperscript{58} (cross-sectional, prospective) \textit{in vivo} and \textit{in vitro} human research studies are combined with basic kinesiological modeling to develop rational screening procedures contributing to noncontact knee ligament injury prevention in netball (Figure 2).

MECHANISM OF NONCONTACT KNEE LIGAMENT INJURY IN NETBALL

Knowledge of the mechanism of knee injury gives insight into a player's movement patterns at the instant-of-injury and the anatomical structures that are damaged. This knowledge contributes to step two of the sequence of prevention.\textsuperscript{49} Descriptive studies report small proportions (4.5-18.7\%) of netball injuries occur during sudden stops when running or cutting to change direction\textsuperscript{21,25,27} with larger proportions (27.0–73.8\%) occurring during landings.\textsuperscript{20,21,23,25} Other descriptive work reports 38-50\% of knee injuries,\textsuperscript{25,26} 81.5\% of ACL injuries,\textsuperscript{27} and 100\% of medial collateral ligament (MCL) injuries\textsuperscript{25} occurred during landings. Specifically, all landing ACL injuries,\textsuperscript{53,8\%} occurred during SLLs and 46.2\% occurred during DLLs.\textsuperscript{27} Of all netball knee injuries, 24-29\% followed contact with another player,\textsuperscript{20,21,23,25} although such injuries were not subdivided into direct or indirect contact\textsuperscript{74} (Table 1). One group performed detailed video analyses of netball ACL injuries and reported 50\% followed indirect contact when airborne and contesting for the ball and 50\% were noncontact when landing from a mid-air pass.\textsuperscript{27} Together, descriptive studies indicate the majority of netball knee injuries are noncontact.\textsuperscript{20,21,23,25–27}

Concerning whole-body kinematics when landing, support-leg trunk ipsilateral lateral flexion coupled with knee abduction was observed in 83.3\% of netball noncontact ACL injuries.\textsuperscript{27} Frontal plane trunk motion relative to the knee is of interest because it can increase support-leg knee abduction forces.\textsuperscript{75} Because whole-body kinematics occur over a support-leg (i.e. weight-bearing leg), knee abstraction motions are coupled with hip adduction and internal rotation (IR), knee flexion and IR, and foot pronation.\textsuperscript{27,76} The coupled trunk, hip, knee, and foot motions are termed a "valgus collapse"\textsuperscript{75} where knee valgus is synonymous with knee abduction. Concerning local knee joint kinematics, human cadaver (\textit{in vitro}) research is useful for gaining insight into how joint kinematics influence ligament loads. Anterior tibial displacement (ATD), abduction, and IR generate ACL load/stress and elongation/strain.\textsuperscript{77–79} When such uniplanar motions are superimposed on each other to elicit a combined motion pattern of ATD + abduction + IR, ACL stress and strain increase exponentially.\textsuperscript{77–79} Because of the abduction component, the pattern also generates MCL stress and strain.\textsuperscript{79,80} Knee multiplanar combined motions such as those just described have been observed in 83.3\% of netball noncontact knee injuries.\textsuperscript{27} When the mechanism of noncontact knee ligament injury is understood, the sports physical therapist can devise injury prevention screening procedures that identify which players may be predisposed to landings with kinematic patterns linked to injury-inducing events.

BIOMECHANICS OF NETBALL LANDINGS AND HIGH-RISK EVENTS

After knowledge of the mechanism of noncontact knee ligament injury is gained from descriptive studies, cross-sectional laboratory-based studies are employed to acquire a deeper understanding of the biomechanics of athletic tasks linked to the injury-inducing events (Figure 2). Specifically, laboratory-based studies are useful for developing a detailed kinetic and kinematic profile of athletic tasks associated with the mechanism of noncontact knee ligament injury. This profile then facilitates a deeper understanding of why such athletic tasks are 'high-risk' events that contain the potential for injury and further contributes to step two of the sequence of prevention.\textsuperscript{49} Because the majority of knee injuries occur during landings,\textsuperscript{25–27} focus will now be on the kinetics and kinematics of netball landings as high-risk events using variables popular in the netball literature.

The peak VGRF is of interest because it represents a ground impact force that contributes to compression/shear/rotation forces experienced by the knee joint.\textsuperscript{18,19} For DLLs after catching a pass, VGRFs were 5.7BW\textsuperscript{16} For SLLs with and without catching a pass, VGRFs were 3.5–5.7BW\textsuperscript{16,17} and 3.4BW,\textsuperscript{81} respectively. The time-to-peak VGRF (TTPVGRF) is of interest because short TTPVGRFs correspond to higher rate-of-loading of skeletal tissues\textsuperscript{82} and a significant
challenge for the neuromuscular system relative to attenuating potentially harmful forces away from bone/cartilage/ligament tissue.\textsuperscript{82,83} In DLLs after catching a pass, TTPVGRFs were 48.8ms.\textsuperscript{16} In SLLs with and without catching a pass, TTPVGRFs were 30.6-42.1ms\textsuperscript{16,17} and 43.7ms,\textsuperscript{81} respectively.

The peak braking force (BF) refers to horizontal ground reaction forces (HGRFs) which push players posteriorly when landing with anteriorly-directed momentum.\textsuperscript{84} The BF is of interest for the same reason as the VGRF and because it provides additional insight into potentially harmful tissue loading factors.\textsuperscript{17,82,85} For DLLs after catching a pass, BFs were 1.7BW.\textsuperscript{16} For SLLs after catching a pass, BFs were 1.4-3.3BW.\textsuperscript{16,17} The time-to-peak BF (TTPBF) is of interest for the same reason as the TTPVGRF. In DLLs after catching a pass, TTPBFs were 44.3ms.\textsuperscript{16} In SLLs after catching a pass, TTPBFs were 23.9-44.7ms.\textsuperscript{16,17}

External and internal moments come from outside (e.g. VGRF) and inside (e.g. muscles) the body, respectively, and tend to cause joint rotation.\textsuperscript{18,19} Peak external moments are of interest because they estimate the tensile forces experienced by ligaments.\textsuperscript{19,86} In biomechanical modelling, external and internal moments balance each other and are equal and opposite in direction.\textsuperscript{18,19} Studies which only report knee internal moments of a specific size can, therefore, assume the knee experienced external moments of the same magnitude. For DLLs without catching a pass, knee internal adduction moments (opposing knee external abduction moments) were 0.38Nm/kg.\textsuperscript{87} For SLLs after catching a pass, knee internal adduction moments (opposing knee external abduction moments) were near 0.40Nm/kg.\textsuperscript{85}

Frontal plane peak knee abduction angles are of interest because higher angles result in higher ACL and MCL stress/strain.\textsuperscript{77–80} As ligament strain increases with higher abduction angles, the point of ligament damage gets closer.\textsuperscript{88} For DLLs with and without catching a pass, knee abduction angles were 8.6°\textsuperscript{89} and 12.1°,\textsuperscript{87} respectively. For SLLs after catching a pass, knee abduction angles were 5.2°.\textsuperscript{89}

Sagittal plane lower-limb joint displacement is of interest because small displacements are linked to ‘stiff’ landings and large displacements are linked to ‘soft’ landings.\textsuperscript{90–92} As for short TTPVGRFs, stiff landings are associated with higher tissue peak loads and rate-of-loading than soft landings.\textsuperscript{90,91,93} In DLLs without catching a pass, knee flexion at initial contact (IC) was 21.1° and at peak flexion was 85.2°, giving a mean displacement of 64.1°.\textsuperscript{87} In SLLs after catching a pass, knee flexion at IC was near 15° and at 50% of stance phase was near 60°.\textsuperscript{85} In other SLLs after catching a pass, knee flexion at IC was 16.3° and at peak flexion was 60.3°, giving a mean displacement of
When the kinetic and kinematic profile of netball landings is familiar, 'high-risk' events that contain the potential for excessive loading of knee ligaments and injury can be better identified and understood. Decreased lower-limb flexion displacement during landing is related to increased VGRFs \cite{94,96} increased knee abduction moments \cite{94,96} and increased ACL tensile loads. \cite{93} Increased VGRFs are related to increased knee anterior shear forces. \cite{97,98} Increased knee external abduction moments are related to increased ACL and MCL loads. \cite{77,79} Higher rates-of-loading of the knee ligaments are more likely to cause tissue failure than lower rates-of-loading. \cite{99,100} Thus, netball DLLs and SLLs contain high-risk biomechanical features that contain the potential for noncontact ACL and MCL injury.

DEVELOPING NONCONTACT KNEE LIGAMENT INJURY PREVENTION SCREENING PROCEDURES

Having combined real-world observation of noncontact knee injury mechanisms (descriptive research) with laboratory-based study of landing tasks that simulate high-risk events (cross-sectional research), specific screening procedures can be considered relative to selected biomechanical features that contain the potential for noncontact knee ligament injury (Figure 2). The injury-inducing events and high-risk tasks discussed above require sophisticated equipment (e.g. 3D motion analysis) to determine kinetic/kinematic features (e.g. external abduction moment). Because such equipment is not typically available to community-based sports physical therapists, clinic-based 'surrogate' procedures related to 3D kinetic/kinematic features are required. Surrogate procedures are chosen using cross-sectional studies employing correlation or simple linear regression designs (Figure 2). Prospective studies reporting associations between intrinsic risk factors and future injury are also used to identify potential screening procedures (Figure 2). Alongside cross-sectional and prospective research, clinicians' opinions (i.e. critical thinking \cite{101} + clinical reasoning \cite{102}) derived using basic kinesiological modelling \cite{103,104} (e.g. identifying which muscles control joint motions in specific directions) can be additionally employed (Figure 2). Integrating different types of research (descriptive + cross-sectional + prospective + opinion) results in rich overall decision-making. \cite{54,65,72} Because little netball correlation, simple linear regression, or prospective research has been performed, the design of netball-specific knee ligament injury prevention screening draws from other related studies.

The Beighton score includes joint assessments to identify individuals with general joint hypermobility (GJH), \cite{105,106} which is prevalent in child \cite{107} and adult \cite{108,109} netball players. No published work has examined relationships between Beighton scores and knee biomechanical characteristics derived from 3D motion analysis of DLL/SLL tasks. In contrast, GJH is prospectively linked to an increased risk of all knee injuries \cite{110} and noncontact ACL injuries \cite{111} in athletic females. General joint hypermobility assessment using the Beighton score procedures may be useful for identifying players predisposed to increased risk for noncontact knee ligament injury.

The ankle is an important component in the lower-limb kinetic chain. \cite{112} In DLLs, decreased straight-knee ankle dorsiflexion (DF) ROM measured with a goniometer was related to increased VGRFs, knee external abduction moments, and knee abduction displacements. \cite{113,114} In DLLs, decreased bent-knee ankle dorsiflexion ROM measured with the weight-bearing lunge test (WBLT) was related to decreased knee flexion displacements. \cite{115} No prospective work has reported an association between ankle dorsiflexion ROM and noncontact knee ligament injury. Screening ankle DF ROM with a goniometer or the WBLT may provide data for identifying players predisposed to sub-optimal landing biomechanics.

The lateral trunk muscles influence pelvis position and motion \cite{104,116} and pelvis position and motion influence knee biomechanics. \cite{104,117} In SLLs, decreased trunk rotation strength measured with an isokinetic dynamometer (IKD) was related to increased knee abduction displacement. \cite{118} In a single-leg squat (SLS), decreased isometric side-bridge strength measured with a handheld dynamometer (HHD) \cite{119} and decreased strength-endurance measured via holding-time \cite{120} were related to increased knee abduction angles. In prospective work, large trunk lateral flexion displacements following laterally-directed perturbations were linked to higher odds for experiencing noncontact ACL injury. \cite{121} Screening lateral trunk muscle performance with a HHD or isometric holding-times may have utility for identifying players predisposed to sub-optimal landing biomechanics and risk for noncontact knee ligament injury.

Lower-limb muscles generate internal moments that absorb foot-ground impact forces \cite{19} and stress-shield skeletal tissues from excessive loads. \cite{122} Outside 3D motion analysis, lower-limb internal moment generating ability is inferred using strength tests. \cite{123} For SLLs, decreased isometric hip abduction strength measured with a HHD was related to increased knee abduction angles. \cite{124} For SLLs, decreased isometric hip external rotation (ER) strength measured with a HHD was related to increased VGRFs, knee external abduction moments, knee abduction angles, and knee anterior shear forces. \cite{86,124} and decreased isometric knee ER strength measured with an IKD was related to increased knee IR angles. \cite{125} For SLLs, decreased SLS strength measured with a barbell and decreased isometric knee flexion strength measured with an IKD were related to increased knee abduction and IR angles. \cite{126} In prospective research, decreased lower-limb strength estimated with one-repetition-maximum (1RM) barbell back-squats was associated with increased odds for traumatic knee injuries. \cite{127} In other prospective and case-control work, decreased isometric hip abduction and ER strength estimated with a HHD \cite{128} and decreased knee flexion strength estimated with an IKD \cite{129} were associated with noncontact ACL injuries. Screening hip and knee muscle strength with double- and single-leg strength tests may be useful for identifying players predisposed to sub-optimal landing biomechanics and risk for noncontact knee ligament injury. Considering kinesiological modelling, given that the quadriceps and gastrocnemius/soleus control knee flexion and ankle DF, respectively, \cite{103,104} and the dissipation of landing impact forces, \cite{92} screening of knee extensor \cite{130} and ankle plantarflexor \cite{131,132} muscle strength is wise. Isokinetic dy-
rnometers and HHDs can be expensive and not easily available to community-based practitioners.\textsuperscript{130} Alternatively, leg press, knee flexion, and knee extension resistance machines can be more readily accessible.\textsuperscript{130} Single-leg IRM strength tests can be performed with netball players in local communities and contribute to knee injury prevention procedures.\textsuperscript{130,133} Combining free-weight and resistance machine procedures for double-/single-leg strength testing may be the most thorough approach.\textsuperscript{66}

Balance is the process of maintaining the body’s center-of-mass and center-of-pressure within its base-of-support via internal moments countering external moments that act to destabilize the body and its joints.\textsuperscript{134} Balance is a sensorimotor process involving proprioceptive, visual, and vestibular sensory information used by the central nervous system to adjust motor output and maintain postural equilibrium.\textsuperscript{134} For SLLs, increased single-leg stance center-of-pressure excursion (worse balance) was related to increased knee external abduction moments.\textsuperscript{135} In prospective studies, reduced dynamic balance defined by three (anterior/posteromedial/posterolateral) of the six directions in the Star Excursion Balance Test (SEBT) was associated with increased odds of lower-limb injuries including knee sprains.\textsuperscript{136} The SEBT has since been modified to use just the anterior, posteromedial, and posterolateral directions in the form of the Y-Balance Test (YBT).\textsuperscript{137} Reduced YBT performance defined by a reduced anterior/posteromedial/posterolateral composite score\textsuperscript{138} and a reduced anterior score alone\textsuperscript{139} have been prospectively linked to lower-limb noncontact injuries. Reduced static balance defined by a computer-force plate system has been associated with increased ACL injury frequency.\textsuperscript{140} Screening single-leg balance (SLB) with procedures such as the SEBT, YBT, and timed eyes-open/eyes-closed balance may provide data for identifying players predisposed to sub-optimal landing biomechanics and risk for noncontact knee ligament injury. Timed eyes-closed SLB tests have been used in preseason screening for community-level netball players.\textsuperscript{25,141}

Neurocognitive performance refers to cerebral neural functions contributing to cognition and includes processes such as visual attention, visual memory, verbal memory, processing speed, reaction time, and dual-tasking.\textsuperscript{142,143} Neurocognitive performance is integrated with sensorimotor functions (proprioception, neuromuscular control) to activate skeletal muscle and maintain joint stability during athletic tasks.\textsuperscript{142} No published work has examined relationships between measures of neurocognitive performance and knee biomechanical characteristics derived from 3D motion analysis of DLL/SLL tasks. One study, however, reported that decreased neurocognitive performance (decreased visual memory) was associated with increased knee abduction angles during sidestep cutting.\textsuperscript{144} Preseason neurocognitive assessment using the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) procedures\textsuperscript{145–147} was linked to in-season lower-limb sprains\textsuperscript{148} and noncontact ACL injuries.\textsuperscript{149} Screening neurocognitive performance with the ImPACT procedures or other computerized systems may have utility for identifying players predisposed to sub-optimal knee biomechanics and risk for noncontact knee ligament injury.

Movement screening is the process of assessing athletes’ kinematic patterns relative to the biomechanics of injury mechanisms and high-risk events that contain the potential for noncontact knee ligament injury. Because 3D motion analysis equipment is not easily accessible to community-based practitioners, 2D motion analysis procedures have been developed using commonly available high-definition video cameras. During landings, 2D measurements of frontal plane knee kinematics (e.g. knee abduction angle) are not related to 3D measurements.\textsuperscript{150–152} During a SLS, however, 2D measurements of frontal plane knee kinematics are related to 3D measurements.\textsuperscript{150,153,154} Therefore, 2D motion analysis is not advocated for assessing DLL/SLL frontal plane knee kinematics.\textsuperscript{150–152} Conversely, use of a SLS in netball knee injury prevention screening is advocated because its knee biomechanical characteristics are related to those in netball-specific leap-landings.\textsuperscript{155} If high-definition video cameras are not accessible, generic observational DLL (e.g. Landing Error Scoring System [LESS]-Real Time [LESS-RT]),\textsuperscript{156} Tuck Jump Assessment [TJA])\textsuperscript{157}, SLL (e.g. Qualitative Analysis of Single-Leg Loading\textsuperscript{158}), and SLS\textsuperscript{158,159} movement screens have been developed where the observer visually scores the athlete’s hip-knee-ankle kinematics according to pre-defined criteria. Generic DLL movement screens such as the LESS and TJA are not related to the biomechanics of netball-specific SLLs.\textsuperscript{160} One group reported the reliability of the ‘Netball Movement Screening Tool’ (NMST) which contains 10 tasks deemed relevant to assessing netball knee injury risk.\textsuperscript{161} The NMST has not been used further beyond another group who employed the NMST to evaluate outcomes from a performance training program.\textsuperscript{162} For prospective work, increased trunk ipsilateral lateral flexion and knee abduction measured with 2D motion analysis during a SLL were associated with increased frequency of noncontact knee soft tissue injury.\textsuperscript{163} Increased ”dynamic knee valgus” measured with 2D motion analysis during a SLL was evident in female athletes who later experienced a noncontact ACL injury compared to those who did not.\textsuperscript{164} Poor (higher) LESS scores have been prospectively associated with increased frequency of noncontact ACL injury.\textsuperscript{165} Screening whole-body and knee kinematics with procedures such as 2D motion analysis and observational movement screens may be useful for identifying netball players predisposed to sub-optimal landing biomechanics and risk for noncontact knee ligament injury.

The lower-limb functional performance test (FPT) includes hop, jump, linear-sprint, change-of-direction, and agility tasks.\textsuperscript{166} In knee injury prevention, single-leg FPTs are recommended to isolate each lower-limb and expose unilateral deficits that can remain hidden in double-leg tasks.\textsuperscript{166} In netball, SLL versus DLL occurs on 58.5-67.1% of occasions\textsuperscript{14,167} and, therefore, single-leg FPTs are important components of netball-specific knee injury prevention screening. Single-leg FPTs (e.g. hop, leap) recreate the joint compression/shear/torsion/rotation forces encountered in sport-specific activity\textsuperscript{166,168,169} and are measured using performance-related variables such as distance (centimeters) or time (seconds).\textsuperscript{166,170,171} No study has examined the association between single-leg FPT performance-related variables and knee biomechanical characteristics derived from 3D motion analysis of DLL/SLL...
tasks. For prospective research, athletes with a single-hop-for-distance mean distance of ≥64% of height for either limb were at increased risk of thigh and knee injuries and athletes with a side-to-side difference (asymmetry) of >10% for the single-hop-for-distance experienced more frequent noncontact ankle and foot trauma. Screening single-leg FPTs may provide data for identifying netball players predisposed to increased risk of noncontact knee ligament injury. Further considerations include that some FPTs may be more suited to assessing lower-limb force production (e.g. vertical-hop) versus force absorption (e.g. horizontal-hop) ability. The shared variance between vertical-hop and horizontal-hop performance in netball players is low and, therefore, such tests capture different aspects of lower-limb motor-performance.

Recently, screening of a community-level adult netball team using single-leg FPTs revealed that side-to-side asymmetries of >10% for the triple-hop-for-distance, single-hop-for-distance, and vertical-hop existed for 8.7%, 8.7%, and 52.2% of players, respectively. Given such considerations, netball knee injury prevention screening may require a selection of different single-leg hop FPTs.

**DISCUSSION: CLINICAL INTEGRATION AND APPLICATION**

Based on the different types of research cited in the previous section, suggested noncontact knee ligament injury intrinsic risk factor screening procedures appear in Table 3. In terms of integrating and applying such procedures in sports physical therapy practice in netball, it may not be necessary to perform all tests in Table 3. Clinicians can decide for themselves which procedures are viable based on their local logistical constraints (e.g. equipment/personnel/finance/time availability). When a battery of procedures has been assembled, and given the recursive nature of netball training and competition, serial screening should occur at appropriate timepoints across a season/year to reveal changes in a player’s risk profile.

The majority of screening procedures in Table 3 are for modifiable intrinsic risk factors for which conservative interventions are applicable. One intrinsic risk factor, the Beighton score for GJH, is nonmodifiable. The value of including such a nonmodifiable risk factor is that further supplementary sensorimotor control interventions for enhancing knee functional joint stability can be considered for those classed as having GJH.

When a battery of screening procedures has been administered, the sports physical therapist should design a targeted intervention program to address intrinsic risk factors that are of specific concern (e.g. hip abductor muscle strength, balance, reaction time). These interventions then contribute to stage three of the sequence of prevention. During stage three and across the competitive season, noncontact knee ligament injury incidence requires monitoring. At the end of the season, noncontact knee ligament injury incidence is compared to that of previous seasons; this represents stage four of the sequence of prevention and is a critical evaluative step in any primary prevention strategy for injury. Future research should endeavour to identify modifiable intrinsic risk factors for noncontact knee ligament injury specifically in netball. Research should be performed for all levels of the game and all competitive age groups.

**SUMMARY**

Netball is a team court-sport played worldwide and becoming more popular in the US. Noncontact knee ligament injuries are common due to a knee abduction collapse during landing. High-risk landing events that contain the biomechanical potential for noncontact knee ligament injury are common in netball. Cross-sectional research, prospective research, and kinesiological modelling provide insight into modifiable intrinsic risk factors linked to high-risk landing biomechanics and actual noncontact knee ligament injury incidence. This clinical commentary has described how theoretical principles (injury control, sequence of prevention, principles of screening in injury prevention, multifactorial model of injury etiology, complex systems theory, systems science), different types of research (descriptive, analytic-observational), and different levels of evidence (prospective, cross-sectional, clinician’s opinion) underpin a rational clinical reasoning process that develops screening procedures for community-level netball noncontact knee ligament injury prevention. An example of how such theories, research, and evidence can be applied by the sports physical therapist has been provided in the form of detailed explanations for suggested screening procedures (Figure 2, Table 3) and comments on the need for repeated screening at strategic timepoints across a season/year.

**CONFLICT OF INTEREST STATEMENT**

The author declares there are no conflicts of interest.

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Table 3: Suggested netball-specific noncontact knee ligament injury prevention screening tests*†

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Test</th>
<th>Example Variable</th>
<th>Related Study Reference number</th>
</tr>
</thead>
<tbody>
<tr>
<td>General joint hypermobility</td>
<td>Beighton score</td>
<td>Composite score‡</td>
<td>105</td>
</tr>
<tr>
<td>Ankle joint DF mobility</td>
<td>Straight-knee passive DF ROM with a goniometer</td>
<td>°</td>
<td>113, 114</td>
</tr>
<tr>
<td></td>
<td>Weightbearing lunge test</td>
<td>cm</td>
<td>115</td>
</tr>
<tr>
<td>Trunk muscle strength</td>
<td>Side-bridge isometric strength with a HHD</td>
<td>%BW</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>Side-bridge isometric hold</td>
<td>s</td>
<td>120</td>
</tr>
<tr>
<td>Lower-limb muscle strength</td>
<td>1RM modified barbell single-leg squat</td>
<td>%BW, LSI, A-A</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>1RM single-leg leg-press</td>
<td>%BW, LSI, A-A</td>
<td>130</td>
</tr>
<tr>
<td>Hip muscle strength</td>
<td>Side-lying straight-leg hip abduction isometric strength with a HHD</td>
<td>%BW, LSI, A-A</td>
<td>124</td>
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<tr>
<td></td>
<td>Prone bent-knee hip ER isometric strength with a HHD</td>
<td>%BW, LSI, A-A</td>
<td>124</td>
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<tr>
<td>Knee muscle strength</td>
<td>1RM single-leg knee extension</td>
<td>%BW, LSI, A-A</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>1RM single-leg knee flexion</td>
<td>%BW, LSI, A-A</td>
<td>130</td>
</tr>
<tr>
<td>Ankle muscle strength</td>
<td>1RM standing single-leg straight-leg calf-raise</td>
<td>%BW, LSI, A-A</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>1RM seated single-leg bent-leg calf-raise</td>
<td>%BW, LSI, A-A</td>
<td>132</td>
</tr>
<tr>
<td>Balance</td>
<td>Star Excursion Balance Test</td>
<td>%LL, LSI, A-A</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>Anterior/posteromedial/posterolateral</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y-Balance Test</td>
<td>Composite score‡</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cm, A-A</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Eyes-closed single-leg balance</td>
<td>s, LSI, A-A</td>
<td>25, 141</td>
</tr>
<tr>
<td>Neurocognitive performance</td>
<td>ImPACT Composite score‡</td>
<td>Lower-limb movement</td>
<td>2D high-definition video single-leg Peak ipsilateral 163, 164 patterns drop-vertical-jump trunk lean angle, ° Peak knee abduction angle, ° 2D high-definition video single-leg Peak ipsilateral 150 squat trunk lean angle, ° Peak knee abduction angle, ° LESS-RT Composite score‡ 156 QASLL Composite score‡ 158</td>
</tr>
</tbody>
</table>

* Modified from reference 66.
† All single-leg tests are performed for both right and left sides.
‡ = see Related Study citation for scoring system. 
DF = dorsiflexion; ROM = range-of-motion; ° = degrees; cm = centimeters; HHD = handheld dynamometer; %BW = percentage of bodyweight = (weight lifted (kg) ÷ bodyweight (kg)) × 100; s = seconds; 1RM = one repetition maximum; LSI = limb symmetry index (%) = (right side score ÷ left side score) × 100; A-A = absolute-asymmetry = LSI of 100% − player’s actual LSI (with ‘+’ or ‘−’ sign then removed); ER = external rotation; %LL = percentage of leg-length = (distance hopped (cm) ÷ leg-length (cm)) × 100; ImPACT = Immediate Post-Concussion Assessment and Cognitive Testing; 2D = two dimensional; LESS-RT = Landing Error Scoring System-Real Time; QASLL = Qualitative Analysis of Single-Leg Loading; FPT = functional performance test; %H = percentage of standing height = (distance hopped (cm) ÷ standing height (cm)) × 100.

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REFERENCES


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Clinical Commentary/Current Concept Review

Rehabilitation Following Posterior Shoulder Stabilization

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Posterior shoulder instability has historically accounted for 2–5% of instability cases. However, recent reports estimate posterior instability accounts for approximately 24% of all operative glenohumeral instability cases. Those with posterior instability are typically athletes who participate in overhead throwing sports and weightlifting. Overhead throwing, specifically during the late cocking phase and follow through, places significant demands on the glenohumeral joint leading to a significant risk for developing posterior shoulder instability. The military population is also subject to posterior shoulder instability due to repetitive microtrauma such as pushups, martial arts, and weightlifting.

The presentation of posterior instability can be variable, with pain being the common complaint rather than instability. This can complicate prompt and accurate treatment and lead to declining athletic performance. Etiologies include acute trauma, repetitive microtrauma, and voluntary dislocation. Given recent reports of the high prevalence of posterior shoulder instability, there is a need for increased awareness of effective rehabilitation protocols.

For those who have failed nonoperative treatments and elect to undergo surgical intervention, a comprehensive and focused rehabilitation protocol can optimize patient recovery and facilitate return to full activity. Currently, there is limited literature regarding post-operative rehabilitation after surgical management for posterior instability. Therefore, the purpose of this clinical commentary is to present a post-surgical rehabilitation program for patients following posterior shoulder labral repair, with recommendations based upon best medical evidence.

Level of Evidence
5

INTRODUCTION

Posterior shoulder instability has been noted in recent reports to occur at a higher prevalence than originally believed, with many cases occurring in active populations. In most cases, primary surgical treatment for posterior shoulder instability—a posterior labral repair—is indicated for those patients who have failed conservative management and demonstrate persistent functional limitations. In order to optimize surgical success and return to a prior level of function, a comprehensive and focused rehabilitation program is crucial. Currently, there is a limited amount of literature focusing on rehabilitation after surgery for posterior instability. Therefore, the purpose of this clinical commentary is to present a post-surgical rehabilitation program for patients following posterior shoulder labral repair, with recommendations based upon best medical evidence.

ANATOMY AND BIOMECHANICS

The glenohumeral joint relies on an intricate balance of static and dynamic stabilizers. These include the labrum as well as capsuloligamentous and osseous structures, including the glenoid and humeral head. The labrum enhances static stability by increasing glenoid depth and acts as an anti-shear bumper throughout shoulder motion. The rotator cuff and scapulothoracic musculature are the primary dynamic stabilizers. It has been shown that the subscapularis muscle is particularly important as a dynamic stabilizer in posterior instability. In addition, the scapular position on the chest wall, protraction, and medial border stabilization with high quality rhythm is important to ensure posterior stability of the shoulder joint. Any disruption to these structures can compromise stability and lead to glenohumeral subluxation or dislocation. Several anatomic differences exist between the posterior and an-
terior anatomic structures. The posterior band of the inferior glenohumeral ligament (IGHL) has been shown to be thinner than the anterior band of the IGHL.\textsuperscript{11} Additionally, a biomechanical study found that the cross sectional area of the posterior shoulder capsule was thinner in patients with posterior and multidirectional instability.\textsuperscript{12} If this is the case, a lesser force may be necessary to disrupt the posterior capsuloligamentous structures and may explain why repetitive microtrauma represents a common cause of posterior instability.\textsuperscript{13} Glenoid retroversion may also be a major contributor to posterior instability.\textsuperscript{14,15} Gottschalk et al reported that glenoid retroversion was significantly increased in patients with posterior instability (-15.4° ± 5.1°) when compared with anterior instability (-12.1° ± 6.9°; \(p < 0.016\)).\textsuperscript{16} Although it is unknown if retroversion precedes instability or if instability leads to retroversion, an association seems to exist.\textsuperscript{7}

**SURGICAL TREATMENT**

Surgical intervention typically is indicated for patients who have failed conservative treatment, or for those with posterior instability from an acute traumatic incident with apparent soft tissue or osseous pathology.\textsuperscript{17} In the absence of humeral or glenoid bone loss, typically an arthroscopic posterior labral repair +/- capsular repair is performed with suture anchors, which leads to high levels of return to play and patient satisfaction.\textsuperscript{3,5,18} Concomitant pathologies are common and should be addressed. These include superior labrum anterior to posterior (SLAP) tears, reverse Hill-Sachs lesions, and rotator cuff tears.\textsuperscript{7} When glenoid bone loss or glenoid dysplasia is present, some have advocated for bone augmentation procedures or glenoid osteotomy.\textsuperscript{1,13,19–23}

**POST–OPERATIVE REHABILITATION**

Successful rehabilitation following posterior labral repair relies on close communication between the surgical team and physical therapist regarding post-operative restrictions and protocols. Chronicity of the condition, tissue quality, and the size of the surgical repair may influence outcomes. Rehabilitation typically consists of five phases: (I) protection phase, (II) active range of motion and muscle endurance, (III) initial resistance strengthening, (IV) advanced muscular strengthening and power, and (V) return to sport. The following rehabilitation protocol is a combination of expert opinion and scientific evidence aimed at maximizing functional outcomes after posterior labral repair. It should be noted that the operating surgeon should be involved in the individualization of each patient’s rehabilitation protocol based on intra-operative findings. A criterion-based progression developed by the present manuscript’s authors provides a suggested framework to assist clinicians in guiding their patients through the phases of rehab. It is a combination of subjective and objective findings that will suggest the patient’s functional readiness to progress. The criterion includes assessment of pain levels, Quick DASH scores, active and passive range of motion, scapular mechanics, muscular endurance, strength, and functional test-

**PHASE I – PROTECTION PHASE**

The goals of Phase I are to protect the surgical repair, decrease post-operative pain, minimize edema, maintain mobility of accessory joints, and most importantly, to educate the patient. Initiation of physical therapy may begin as soon as post-operative day 1. The first post-surgical physical therapy visit includes collection of a thorough history, evaluation of the current post-operative status, and establishment of meaningful functional goals with the patient. The physical therapist should then review the surgical findings and procedure, post-operative restrictions, rehabilitation protocol, and prognosis. Together with the patient, the physical therapist will develop a plan of care and supplemental home exercise program that suits patient’s expectations and needs.

Passive range of motion (PROM) of the shoulder joint may be initiated immediately or may be deferred for up to two weeks post-operatively, depending on surgeon preference and specific patient related factors. The main factors that determine the length of the immobilization period are tissue quality and size of the surgical repair. During this time, the patient is immobilized in a sling with an abduction pillow which supports the glenohumeral joint in the scapular plane and minimizes stress on the surgical repair. Cryotherapy also is an important adjunct to decrease pain, muscle spasm, and edema.\textsuperscript{24} The authors recommended cryotherapy to be utilized five to six times daily for 30 minute intervals during the first two weeks post-operatively. Compression socks and ankle pumps are also recommended to decrease the inherent risk of developing deep vein thrombosis.

Whether PROM of the shoulder joint is indicated or not during the early protection phase, it is imperative to maintain mobility of the joints surrounding the shoulder. To achieve this, the patient is educated regarding active range of motion of the cervical spine, elbow, wrist, and hand. Gentle scapular retraction and depression exercises are utilized to encourage postural muscular activation and prevent anterior shoulder stiffness. All exercises can be performed out of the sling and are recommended to be performed three to four per day.

**INITIATION OF PASSIVE RANGE OF MOTION**

PROM of the shoulder is initiated once cleared by the operating surgeon. PROM is typically introduced two weeks post-operatively and is utilized to prevent post-operative stiffness. At this time the surgical repair is in the very early stages of tissue healing and protected passive motion is utilized without placing stress on the surgical repair. Depending on the extent of the repair, PROM of the shoulder is typically limited to 120° of forward flexion, 90° of abduction, and internal rotation to the abdomen with the arm resting at the patient’s side. External rotation may be limited to 30° to limit any stresses throughout the shoulder joint, though this is case and surgeon specific. These restrictions are typically in place for an additional four weeks until the patient has reached six weeks post-operative. Ad-
ditionally, posterior loading of the glenohumeral joint and internal rotation when the arm is away from the body, such as reaching behind the body, should be avoided for at least six weeks to avoid stress through the posterior ligamentous complex where the repair was performed. The physical therapist begins by performing gentle PROM within the outlined restrictions. Progression of PROM is continued until symmetrical movement of both shoulders is achieved or functional norms are demonstrated.

COMPONENTS OF DYNAMIC GLENOHUMERAL JOINT STABILITY

When implementing initial muscle activation, it is important to understand the factors that influence dynamic shoulder stability. The dynamic stabilizers consist of the rotator cuff and scapulothoracic musculature which work in concert to stabilize the glenohumeral joint during functional motion. The subscapularis works with the infraspinatus and teres minor to create the anterior-posterior force couple, which generates dynamic stability by compressing the humeral head into the glenoid fossa. Additionally, the subscapularis, infraspinatus, and teres minor provide an inferomedial force that counteracts the superior directed force of the deltoid during arm elevation. These mechanisms emphasize the importance of proper re-introduction of muscle firing patterns to ensure dynamic joint stability with functional movement that may have been compromised prior to surgical intervention.

ISOMETRICS

To promote early protected dynamic joint stability, submaximal isometrics of the rotator cuff and the scapulothoracic musculature are typically introduced two to four weeks following the initiation of PROM. Timing associated with the introduction of these exercises is based on clinical judgment of the treating therapist including but not limited to the patient’s ability to tolerate such exercises due to pain and discomfort. Submaximal isometrics exercises target the subscapularis, infraspinatus, deltoid, and rhomboids. These exercises can be performed in a home program while standing in a doorway using the wall as resistance. The patient is instructed to gently push into the wall in each position, starting at approximately 25% of the maximal force and increasing force production until sufficient firing patterns of the targeted musculature are established. During this time, it is critical for the treating therapist to monitor pain, assess the quality of these firing patterns, and assist with muscle facilitation to ensure proper muscle activation. Pain free performance and scapular control is emphasized throughout the completion of these exercises.

CRITERIA TO PROGRESS

Prior to progressing to the active motion phase, the patient should be able to passively achieve the range of motion noted in the criteria to ensure sufficient glenohumeral joint mobility. Initial scapular control and mobility is also evaluated at this time by determining the patient’s ability to perform an active scapular clock. This includes the movement of scapular retraction, protraction, elevation, and depression. When the patient can perform this with minimal substitution patterns, the patient possesses initial scapulothoracic muscle firing patterns and scapular mobility to progress to the active motion phase. The complete criteria to progress to the next phase of rehabilitation is summarized in Table 1.

| Table 1: Criteria to Progress to Active Range of Motion and Muscle Endurance |
|---|---|
| Criteria | Passing Score |
| Pain | < 3/10 |
| Quick DASH score | <60% |
| PROM | Flexion 120° Abduction 90° External rotation 30° |
| Ability to Perform Scapular Clock | Yes |

PHASE II – ACTIVE RANGE OF MOTION AND MUSCLE ENDURANCE

Once the patient has met the criteria to progress to Phase II and active motion is permitted by the treating surgeon, the patient begins with active assisted range of motion (AAROM) with progression to active range of motion (AROM). This typically occurs at five to six weeks post-operatively. The goal of this phase is to normalize AROM, improve rotator cuff and periscapular muscular endurance, and establish normal scapulohumeral mechanics with basic functional activities. At this time the surgical repair is in the preliminary phases of tissue healing, and specific exercises are utilized to minimize stress on the surgical repair by continuing to avoid posterior loading and internal rotation when the arm is away from the body. This phase also continues to progress rotator cuff and scapulothoracic musculature activation to restore dynamic joint stability.

ACTIVE ASSISTED RANGE OF MOTION

AAROM typically begins one week prior to the initiation AROM to facilitate muscle recruitment and joint motion required for active motion. AAROM exercises are introduced in supine or prone positions to decrease the gravitational stress through the joint, and then progressed to seated and standing as tolerated by the patient. In the supine position, the patient can begin AAROM with the help of the contralateral upper extremity or lightweight wooden dowel moving into forward flexion, external rotation, and internal rotation within surgical restrictions. To assist with more specific functional motion, standing supported forward flexion is a safe option for AAROM, showing submaximal active control of rotator cuff and periscapular muscles to allow for proper retraining of the muscular firing patterns (Figure 1). This exercise is easily performed as part of a home exercise program with the use of a ski pole or a lightweight wooden dowel and can be progressed by the addition of moving through multiple planes of assisted motion.
When possible, the patient is encouraged to perform exercises in front of a mirror for visual feedback to avoid common compensation patterns such as shrugging or thoracic extension. It is important that the physical therapist utilize verbal and tactile cueing to ensure the patient is demonstrating appropriate scapular control while minimizing substitution patterns.

**ACTIVE RANGE OF MOTION**

AROM is initiated when the patient is able to perform isometric and AAROM exercises with appropriate muscle activation and mechanics with minimal pain. Initiation of AROM typically begins at week six post-operatively and is progressed to full pain free motion in all planes. Once AROM is indicated, the patient can discontinue the use of his or her sling and begin light activities of daily living.

AROM begins with exercises that minimize stress on the repair, demonstrate short lever arms, and produce minimal muscle activation of larger accessory muscles. This typically begins in a supine position, progressing to standing exercises as muscular firing patterns improve. Recommended exercises are based on literature that demonstrate high electromyography (EMG) activity of the rotator cuff and scapulothoracic musculature.\(^{28-32}\) It is important to remember that during AROM, proper rotator cuff activation is imperative to provide dynamic joint stability. When the rotator cuff is not functioning properly, there may be a significant increase in humeral migration and impingement with active upper extremity elevation.\(^{33}\) The following exercises are recommend for initiating AROM in the patient’s rehab program and then into the home program when appropriate.

When initiating activation of the supraspinatus muscle, a gradual progression to the “full can” exercise is recommended. The patient can begin by performing the “salute” exercise (Figure 2) in the supine position, moving through forward flexion in the scapular plane with the elbow slightly bent to minimize the lever arm. This exercise can be increased in difficulty by performing the lawn chair progression, where the patient lies in a reclined position and progresses to a seated position as muscular endurance of the rotator cuff adapts to increasing gravitational demands. In the seated or standing position, the patient will progress to the “full can” exercise (arm in full extension), which has been shown to produce excellent supraspinatus activation.\(^{28}\)

Activation of the infraspinatus muscle can be achieved by performing side lying external rotation (Figure 3). This exercise has been shown to demonstrate the highest EMG activation for the infraspinatus and teres minor compared to other exercises.\(^ {29}\) Initial activation of the subscapularis can be achieved by performing standing internal rotation at 0° abduction and later progressing to 90°.\(^ {30}\) When appropriate, the patient can progress to prone external rotation at 90° abduction, which has been shown to demonstrate high levels of subscapularis, supraspinatus, and infraspinatus activation (Figure 4).\(^ {29,31}\)

Endurance of the scapulothoracic musculature in concert with the rotator cuff is key to establishing proper scapulohumeral rhythm and stability with active motion.\(^ {34}\) The prone row has been shown to demonstrate middle trap and rhomboid activity, while limiting a long lever arm.\(^ {32}\)
prone full can has been shown to demonstrate high EMG levels of the supraspinatus, lower trapezius, and the posterior fibers of the deltoid. The serratus anterior (SA) is an important scapulothoracic muscle that contributes to posterior shoulder stability by maintaining scapular position on the thorax and preventing scapular winging. To initiate targeted activation of the serratus anterior, the patient can perform the exercise supine with the shoulder in 90° of flexion with scapular protraction, also known as “supine punch.”

Supine open kinetic chain (OKC) and proprioceptive neuromuscular facilitation (PNF) exercises can also be introduced at this time. Early in rehabilitation, PNF exercises play an important role in developing and facilitating muscular strength and endurance, joint stability, and neuromuscular control. Rhythmic stabilization exercises are a specific type of PNF that can be used to improve stability of the shoulder girdle. To promote posterior shoulder stability the patient can perform the “supine punch” as described earlier while the physical therapist provides external perturbations (Figure 5). The PNF exercises can be progressed further in later stages of rehabilitation.

CRITERIA TO PROGRESS

Prior to progressing to the initial resistance strengthening phase, AROM within indicated ranges must be restored with minimal pain and proper muscle firing patterns. Scapulohumeral mechanics and muscular endurance are evaluated during active motion by using scapular dyskinesis testing and Repeated AROM Fatigue Protocol noted in the criterion respectively. When the patient can perform these activities with a passing score, the patient possesses adequate joint motion, scapulohumeral mechanics, and muscular endurance to progress to the initial strengthening phase. The complete criterion to progress to Phase III of rehabilitation is outlined in Table 2.

SOFT TISSUE CONSIDERATIONS

During the course of rehabilitation, the patient will likely experience range of motion and soft tissue restrictions that may influence the stability of the glenohumeral joint. Due to the nature of the posterior instability repair, it is likely the patient will experience posterior capsular stiffness and shortening of the length of the anterior shoulder musculature. Manual techniques including stretching, soft tissue mobility and gentle joint mobilizations should be utilized to address impairments. Gentle posterior and inferior joint mobilizations can be utilized after six weeks to assist specifically in increasing internal rotation and abduction range of motion respectively. Selected low load prolonged stretches can typically begin at seven weeks post-operatively.

PHASE III – INITIAL RESISTANCE STRENGTHENING

Initial resistance strengthening is introduced once criteria in Table 2 have been met and the patient is at least eight weeks post-operative. At this time the labrum is thought to be in the later stages of healing and can withstand preliminary loading of the tissue. The goal of this phase is to further progress rotator cuff and periscapular muscular strength and establish scapulohumeral control with increasing load to progress functional overhead activities.

Resistance based strengthening exercise begin by performing AROM exercises stated in Phase II and adding resistance bands or light free weights. Side lying external rotation, noted above for its high level of EMG activation of the infraspinatus and teres minor, can be progressed by adding free weights. The patient can also perform standing external rotation and internal rotation exercises using a resistance band or cable system. Similar to prone rows noted in Phase II, the patient may perform standing resistance band rows to promote middle trapezius and rhomboid strengthening. The patient can perform prone external rotation at 90° abduction with added weight to further enhance dynamic joint stability by strengthening the subscapularis, supraspinatus, and infraspinatus activation. The patient can also progress the prone “Full Can” exercise with added free weight to further strengthen the supraspinatus, lower trapezius, and posterior fibers of the deltoid (Figure 6).
Table 3: Criteria to Progress to Advanced Strengthening

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Passing score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quick DASH</td>
<td>&lt;20%</td>
</tr>
<tr>
<td>AROM: flexion, abduction, external rotation</td>
<td>&gt;90% of contralateral side</td>
</tr>
<tr>
<td>Manual muscle testing or hand-held dynamometer:</td>
<td>4/5 or greater or &gt;80% on hand-held dynamometer in all planes</td>
</tr>
<tr>
<td>Full can</td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td></td>
</tr>
<tr>
<td>Belly press</td>
<td></td>
</tr>
<tr>
<td>External rotation at 0°</td>
<td></td>
</tr>
<tr>
<td>Internal Rotation at 0°</td>
<td></td>
</tr>
</tbody>
</table>

SA activity can be progressed by adding free weights to the "supine punch" described earlier. The standing wall slide with shoulder elevation above 90° is another exercise that promotes good SA EMG activity. This exercise can be progressed by adding a foam roller and band around the wrist to increase posterior rotator cuff activation (Figure 7). During all exercises, it is essential that the physical therapist monitors the patient’s movement patterns and cues the patient accordingly to ensure proper scapulohumeral mechanics and muscle activation patterns. Once this is achieved, progression to the next phase is considered.

CRITERIA TO PROGRESS

Prior to progressing to advanced strengthening, the patient should be pain free during all activities of daily living and be able to perform all strengthening in Phase III without issue. The patient should demonstrate nearly full pain free AROM prior to progressing. Strength symmetries are also evaluated through manual muscle testing or preferably by using a handheld dynamometer (HHD). It is recommended that the patient achieve shoulder strength of 4/5 or 80% of the uninvolved side as noted on the HHD. The complete criterion is noted in Table 3.

PHASE IV – ADVANCED STRENGTHENING AND POWER

ADVANCED STRENGTHENING

Advanced strengthening is introduced once the criteria in Table 3 have been met, which typically occurs three months post-operatively. At this point, the posterior labrum and capsule are thought to be healed and able to withstand increased load demands. The goal of advanced strengthening is to continue progression of the rotator cuff and periscapular strengthening and further enhance dynamic shoulder stability while also emphasizing control with posterior loading to maximize advanced upper extremity function.

In order to enhance posterior rotator cuff stability, standing resisted external rotation can be performed, starting with the patient’s shoulder abducted to 45° and then progressing to 90°. Standing resisted internal rotation with the shoulder abducted to 90° has been shown to demonstrate high EMG levels of rotator cuff, posterior deltoid, middle and lower trapezius and can be utilized as well.

To further enhance posterior stability, closed kinetic chain exercises (CKC) can also be introduced. The "supine punch" discussed earlier can again be progressed by initiating a CKC position and performing a push up with scapular protraction. This exercises is commonly known as the "push up plus" and has been shown to demonstrate high EMG levels of SA activity. This is initiated by having the patient...
Table 4: Criteria to Progress to Power Exercises\textsuperscript{45,51,52}

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Passing score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual muscle testing or hand-held dynamometer:</td>
<td></td>
</tr>
<tr>
<td>Full can</td>
<td>5/5 or greater or &gt;90% on hand-held dynamometer in all planes</td>
</tr>
<tr>
<td>Abduction</td>
<td></td>
</tr>
<tr>
<td>External rotation at 90°</td>
<td></td>
</tr>
<tr>
<td>Internal Rotation at 90°</td>
<td></td>
</tr>
<tr>
<td>Hand-held Dynamometer ratio: ER/IR at 90°</td>
<td>Ratio &gt;70%</td>
</tr>
</tbody>
</table>

CRITERIA TO PROGRESS

Once the patient can perform advanced exercises without difficulty and with proper scapulohumeral mechanics, progression to the power portion of Phase IV is considered. Shoulder strength symmetries are again assessed for improvement to a higher percentage, in addition to determining the patient’s strength ratio of external rotation/internal rotation with the use of the HHD. Various studies in the literature indicate that a normal functioning shoulder demonstrates strength ratios of 60-70\%, promoting dynamic stability of the glenohumeral joint specifically with higher level activities such as weightlifting and throwing.\textsuperscript{42,45} The complete criterion to progress to the power portion of Phase IV is outlined in Table 4.

POWER EXERCISES

Once the patient has met the criteria listed in Table 4, they can begin power exercises, which typically occurs five months post-operatively. The goal of this portion of phase IV is to further enhance dynamic stability with advanced overhead activities, while introducing explosive muscular power with sport or occupational specific movement patterns. Plyometric exercises play an important role in the progression of rehabilitation and the development of power. It has been shown that plyometric exercises lead to increased shoulder power, endurance, enhancement of joint position sense and kinesthesia, and increased throwing power compared to isotonic exercises alone.\textsuperscript{47} Introduction to plyometric exercises can be accomplished by performing two-handed drills and progressing to one handed drills. For example, the patient can perform a two handed chest pass to a rebounder using a weighted medicine ball and then work towards higher levels of shoulder elevation, perform the exercise against a wall and progressing to the floor to increase loading demands.\textsuperscript{41} Increased difficulty with higher muscular demands can be achieved by adding unstable surfaces such as a BOSU ball. CKC exercises can also be advanced by utilizing rhythmic stabilization with external perturbations in positions such as a static hold of the “push up plus” (Figure 8). The patient can progress further by performing a plank with alternating shoulder taps. It is essential that the therapist monitors the patient’s mechanics to avoid excessive posterior translation of the humerus while promoting proper scapular placement on the rib cage to maximize stability.

and then finally advancing to one handed pass.\textsuperscript{44} A plyometric exercise that emphasizes deceleration of the shoulder girdle musculature is the reverse throw. The therapist will throw a light weighted ball to the patient from behind. The patient will catch the ball while slowing down the ball’s velocity (Figure 9). Progression of the CKC exercises noted in previous phases can also be progressed to plyometric exercises. An example of this is the plyometric push up that can be performed initially on the wall and then progressed to the floor position.

PHASE V - RETURN TO SPORT

Prior to return to sport specific training, the administration of a series of sport specific functional tests are recommended to determine the patient’s safety and readiness (Table 5).\textsuperscript{48–52} Once the patient is able to pass the functional testing pertinent to their sport, the surgeon and physical therapist should jointly decide if the patient is ready to return to sport specific training. Once cleared, sport specific training exercises such as a return to throwing program are initiated. This includes a gradual progression back into the specific demands of the sport using joint irritability as a guide. It is recommended that off days be used to continue a maintenance exercise program focusing on...
Table 5: Criteria to Return to Sport - Functional testing

<table>
<thead>
<tr>
<th>Functional test</th>
<th>Passing score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Medicine Ball Plyometric Bounce</td>
<td>Completion of 60 sec 2lb med ball bounce at 165 beats per minute</td>
</tr>
<tr>
<td>Single Arm Shot Put</td>
<td>Complete 6lb throw &gt;90% distance of contralateral side</td>
</tr>
<tr>
<td>Closed Kinetic Chain Upper Extremity Test</td>
<td>&gt;21 touches in 15 seconds</td>
</tr>
<tr>
<td>Upper Extremity Y Balance Test</td>
<td>&gt;90% distance of contralateral side (Normalized score)</td>
</tr>
</tbody>
</table>

flexibility, cardiovascular endurance, upper extremity, and core strengthening.

CONCLUSION

The purpose of this clinical commentary is to provide an expert opinion and evidence-based rehabilitation protocol following posterior labral repair. Successful rehabilitation involves close communication between the surgical team, the physical therapist, and the patient throughout recovery. A customized protocol should be established based on surgical findings and specific patient needs. A criterion-based approach through the phases of rehabilitation are outlined to allow safe and individualized return to prior level of functioning. Phase I focuses on maximal protection of the surgical repair while regaining protected glenohumeral passive range of motion and initiation of gentle muscle engagement surrounding the shoulder. Phase II includes the introduction of AROM and progression of proper firing patterns of the rotator cuff and scapulothoracic musculature. Phase III consists of resisted strengthening exercises using bands and free weights to enhance dynamic glenohumeral joint stability. Phase IV progresses strengthening and power of the shoulder girdle utilizing advanced CKC and plyometric exercises while highlighting dynamic control with posterior loading of the shoulder. Phase V focuses on returning the patient back to his or her specific sport. Restoring and maximizing dynamic joint stability is essential to optimal recovery and is the focus of the rehabilitation program. The main goal of this rehabilitation process is to allow the patient to return to his or her prior level of unrestricted activity.

CONFLICTS OF INTEREST

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Dr. Millett reports grants, personal fees and other from Arthrex, from Smith & Nephew, from Siemens, from Össur, from Medibridge, from Springer Publishing, from VuMedi, outside the submitted work.

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REFERENCES


Clinical Commentary/Current Concept Review

Osteochondral Allograft Transplantation in Professional Athletes: Rehabilitation and Return to Play

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Keywords: osteochondral allograft transplantation, rehabilitation, return to sport, physical therapy

For the treatment of large chondral and osteochondral defects of the knee, osteochondral allograft transplantation (OCA) is an effective solution with relatively high rates of return to sport. In professional athletes, rehabilitation following OCA is a critical component of the process of returning the athlete to full sports activity and requires a multidisciplinary team approach with frequent communication between the surgical and rehabilitation teams (physical therapists, athletic trainers, coaching staff). In this review, we describe our five-phase approach to progressive rehabilitation of the professional athlete after OCA, which takes into account the biological processes of healing and optimization of neuromuscular function required for the demands of elite-level sport. The principles of early range of motion, proper progression through the kinetic chain, avoidance of pain and effusion, optimization of movement, regimen individuation, and integration of sports-specific activities underlie proper recovery.

For the treatment of large chondral and osteochondral defects of the knee in young athletes, osteochondral allograft transplantation (OCA) is an effective solution that involves the single-stage transfer of viable, mature articular cartilage to replace diseased cartilage tissue.\(^1\) OCA has the advantage of providing a biomechanically functional hyaline cartilage surface that has the ability to bear joint loading immediately after transplantation. As a result, post-operative rehabilitation and return to activities after OCA may be accelerated compared to other cartilage repair strategies that implant immature cartilage tissue. Return to sport rates in athletes following OCA have been reported between 75-82%\(^2\)-\(^4\) with return typically occurring at 8-12 months after surgery.\(^5\) These patients experienced a clinically significant improvement in pain, functionality, and activity levels as indicated by Knee Injury and Osteoarthritis Outcome Score (KOOS), Tegner, and Marx scores.\(^2\) As a result, OCA has become a mainstay of treatment in high level athletes.

Rehabilitation after OCA surgery can be difficult for any patient population but is particularly challenging for the professional athlete due to the requisite physical demands on the knee and psychological pressures involved in returning to sport at the same or higher level. The cartilage defects cause pain and kinetic movement dysfunction that affects these patients for a considerable amount of time prior to surgical intervention, and in turn make rehabilitation after surgical intervention difficult and frustrating for both the athlete and the rehabilitation specialist. When designing a rehabilitation program, it is essential for athletes to adhere to the entire rehabilitation process starting from date of surgery and extending through the return to full sport phase. Compliance with a home program is essential for consistent progress and the return of proper joint function. Should an athlete attend therapy session for three times a week for approximately one hour sessions, the supervised sessions only comprise about 2% of an entire 168 hour week; during the remaining 98% of time, the athlete is left responsible for personal rehabilitation.\(^6\) When planning rehabilitation with the professional athlete, functional demand is an important consideration. For example, the functional loading requirements for a professional basketball player varies greatly compared to a 45-year-old recreational basketball player.

A common theme in the rehabilitation protocol is the need for the rehabilitation specialist to ensure the repaired tissue and joint are properly loaded throughout the rehabilitation process to prevent any delays in progressive load advancement. Despite the initial standardized timeline for biological healing, progression varies upon the athlete, necessitating an individualized rehabilitation approach following surgery. Cautious progression should be utilized through criteria-based guidelines rather than fixed time-based guidelines in order to decrease rates of recurrent pain and/or joint effusion. Rehabilitation protocols vary widely for this surgical intervention with regard to weight bearing.
precautions, brace usage, exercise progression, progression criteria, and timeline for return to competitive activity. A number of these recommendations are based on the idea that rehabilitation protocols are dependent on the anatomic region repaired, patient-specific issues, and overall technical factors related to the surgical reconstruction. As such, rehabilitation following OCA is a critical component of the process of returning the professional athlete to full sports activity and requires a multidisciplinary team approach with frequent communication between the surgical and rehabilitation teams (physical therapists, athletic trainers, coaching staff). The following rehabilitation guidelines presented take into consideration the existing literature, current rehabilitation principles, and current basic science of osteochondral allograft integration after surgery (Table 1).

REHABILITATION PHASE PROGRESSION

PHASE I: IMMEDIATE POST-SURGERY (WEEKS 0-2)

Goals of this phase include reduction of pain and effusion, immediate ROM, and preliminary weight bearing through the joint. Weight bearing protocols after osteochondral allograft implantation is a topic of continuing discussion between surgeons, rehabilitation professionals, and the scientific community. Protocols vary greatly, ranging from immediate weight bearing to partial or non-weight bearing for 6 weeks to 3 months. However, numerous studies have expressed that overly aggressive weight bearing restrictions may overtax the allograft articular cartilage resulting in proteoglycan loss and deterioration of mechanical properties. A basic understanding of biological healing underlies the principle that proper tissue healing must occur in order to progress through the overall rehabilitation process. In the case of OCA, the graft is a composite of both a living mature hyaline cartilage and bone. Bone healing and integration via creeping substitution must occur in the early stages for the athlete. If the allograft bone does not integrate into the host bone, in vivo graft subsidence or delamination of the articular cartilage surface can occur as the graft sees higher loads. At the same time, it is known that moderate mechanical loading is healthy for articular cartilage of the knee as it promotes interstitial fluid flow in and out of the permeable collagen-proteoglycan matrix, facilitating the movement of nutrients from the synovial fluid into the collagen matrix and stimulating an anabolic chondrocyte response. At this time, there is a lack of consensus on the optimal post-operative weight bearing regimen after OCA, which is likely dependent on multiple factors, including the biochemical and mechanical properties of the transplanted graft at time zero and evolution of these properties during the early post-operative healing period, as well as the technical aspects of the transplant surgery (quality of press-fit fixation, topography of graft compared to host surface, etc). A recent study suggests that the surgeon’s experience can influence their preferences regarding post-operative rehabilitation guidelines. In any case, the rehabilitation professional must have proper and frequent communication with the referring surgeon and an understanding of their specific protocol in order to properly monitor the athlete for signs of joint overload throughout the rehabilitation process. In OCA patients, our experience has been that early weight bearing (20% foot flat weight bearing for 1-2 weeks post-surgery, followed by progression to full weight bearing) has an advantageous effect in preventing further muscle atrophy and allowing earlier progression to functional and fitness activities. This accelerated protocol, however, is dependent on robust mechanical fixation of the graft during surgery. During the first 2 weeks after surgery, signs and symptoms such as swelling and pain should be closely monitored, and the rehabilitation program should be adjusted in these cases. During this initial phase, the athlete wears a knee brace locked in extension to minimize shearing forces on the knee joint during weight bearing and preventing subsequent graft damage.

Immediate passive range of motion is permitted with the emphasis on attaining full knee extension as soon as possible. The avoidance of arthrofibrosis is also an important aspect of OCA rehabilitation. It is critical that the athlete gain full extension because the inability to do so in the early stages can lead to gait abnormalities, patellofemoral symptoms, and higher level biomechanical dysfunction in the later phases of rehabilitation. The goal is to achieve at least 0 degrees of extension within the first week post-surgery. Heel props can be performed with a towel or roll placed underneath the heel, allowing gravity to apply a prolonged low-load stretch into extension. This exercise should be performed frequently throughout the day in order to gain maximal extension. In addition to this, light stretching of the hamstring and gastrocnemius/soleus complex can help elongate posterior chain musculature, and enhance knee extension. Less emphasis is placed on achieving excessive knee flexion immediately after surgery, as the joint trauma from knee flexion can contribute to postoperative edema and pain. Passive ROM can provide neuromodulation of pain during acute conditions, but only when performed in a pain-free range. Forced flexion ROM past its natural limits can lead to increased overall pain, inflammation or effusion, and can inhibit further gains in motion. If the athlete is able to gain flexion range of motion to 90 degrees without end range stiffness or tissue restrictions within the first 2 postoperative weeks, it is sufficient to progress the patient through the rehab process. If the patient is able to push past this amount without any increased symptoms, then flexion is not restricted, given the range of motion is passive, and not requiring any voluntary muscular contraction. An exception to this protocol is OCA for focal patellar osteochondral lesions. In these cases, ROM is usually restricted to 90 degrees over the first 2 to 4 weeks depending on the lesion size, location, and surgeon protocol in order to protect the allograft.
### Table 1: Summarized Rehabilitation Protocol

<table>
<thead>
<tr>
<th>Phase</th>
<th>Phase I: Weeks 0-2</th>
<th>Phase II: Weeks 2-6</th>
<th>Phase III: Weeks 6-12</th>
<th>Phase IV: Weeks 12-20</th>
<th>Phase V: Weeks 20+</th>
</tr>
</thead>
</table>
| **Precautions** | • Range of motion (ROM): progress as tolerated (do not force ROM)  
  - 90 Degrees (deg) over first 2 weeks  
  • Adhere to weight bearing restrictions  
  - 20% foot flat weight bearing (FFWB) with bilateral axillary crutches for 2 weeks  
  • Brace Guidelines  
  - Ambulation with brace locked and bilateral axillary crutches  
  - Sleep with brace locked in extension for 1 week  
  • Avoid pillow under knee to prevent knee flexion contracture  
  • Control post-operative swelling | • Progress ROM as tolerated: do not force motion  
  - Weeks 2-4: partial weight bearing up to 50% with crutches  
  - Weeks 4-6: weight bearing as tolerated  
  • Brace Guidelines:  
  - Week 2-4: Unlock brace when proper quad control is established  
  - Discharge brace at 4 weeks (may use knee sleeve at this point, if needed)  
  • Avoid pillow under knee to prevent knee flexion contracture  
  • Control post-operative swelling | • Progress to full ROM  
  • Avoid pain with therapeutic exercises and functional activities  
  • Continue to control post-operative swelling  | • Avoid pain with therapeutic exercises and functional activities  
  • Control post-operative edema  | • Avoid pain with advanced strengthening, and plyometric activity  
  • Avoid pain with progression of return to running program  
  • Be cautious of patellofemoral overload with increased activity level  
  • Continue to control post-operative swelling  
  • Monitor overall load and volume  |
| **ROM/Soft Tissue** | • Immediate ROM after surgery  
  - Do not force ROM  
  • Emphasize full knee extension immediately  
  • Heel prop multiple times per day  
  • Lower extremity stretching (hamstring/gastrocnemius/soleus)  
  • Patellar mobilization as indicated (all planes) | • ROM goals (use as a guide)  
  - Week 3-0-105°  
  - Week 4-0-115/120°  
  - Week 6-0-130° (progressing to full ROM)  
  • Continue exercises from phase 1  
  • Heel slides against wall (if difficulty gaining ROM)  
  • Step knee flexion stretch, and supine hip flexor stretch when tolerated  
  • Maintain passive knee extension and patellar mobility  
  • Continue LE soft tissue treatment and stretching as needed | • Gradual increase of ROM to full ROM  
  • Continue exercises from phase 2  
  • Prone knee flexion stretches  
  • Maintain full passive knee extension  
  • Continue patellar mobilization as needed  
  • Continue with LE soft tissue program as needed  
  • Initiate foam rolling program  
  • Continue with LE stretching program (hip, hamstring, gastrocnemius/soleus)  
  • Add hip flexor and quad stretching | • Patient should demonstrate full ROM without limitations  
  • Continue LE soft tissue treatment as needed  | • Continued LE stretching  
  • Continued foam rolling program  
  • Adjunct with soft tissue massage if needed  |
| **Strength** | • Quadriceps re-education  
  • Quad sets, straight leg raises (SLR) with NMES  
  • SLR’s (all planes)  
  • Emphasize no extension lag during exercise  
  • Initiate primary core stabilization/Kinetic linking program  
  • Ab sets  
  • Pelvic bracing  
  • BKFO  
  • Side lying clam shells  
  • Ankle progressive resistive exercises (PRE)  
  • Consider blood flow restriction (BFR) program with FDA approved device and qualified therapist if patient cleared by MD  
  • Independent with home exercise program (HEP) that addresses primary impairments | • Continue Quadriceps re-education with NMES as needed  
  • Continue blood flow restriction (BFR) program if patient cleared by MD  
  • Bilateral Leg Press  
  - 60° → 0° arc (week 2-4)  
  - 90° → 0° arc (week 4-6)  
  • Initiate core stabilization/Kinetic linking program  
  • Standing bilateral heel raises- Week 2-3  
  • Short Cank Bike progressing to upright bike with adequate ROM (110-115 degrees of ROM)  
  • Multiplanar glute/Core/hip strengthening  
  - Bridges with t-band  
  • Standing clamshells  
  • Weight shift exercises with UE support  
  • Bilateral weight bearing proprioceptive exercises  
  • Single leg balance/propropriceptive activities after proper quad control obtained | • Progress stationary bike time  
  • Initiate interval bike program between weeks 10-12 for cardio  
  • Progress to elliptical  
  • Single leg pawing → retrograde treadmill  
  • Multiplanar gluteal/core/hip strengthening  
  • Continue exercises from phase II  
  • Romanian Dead Lift (RDL): double leg single leg  
  • Initiate open kinetic chain (OKC) knee extension (multiple angle isometrics)  
  • Progressing to isotonics (PRE)  
  • Progress to eccentric leg press (2 up/1 down)  
  • Emphasize slow eccentric lowering and good alignment  
  • Suspension training squats and chair/box squats  
  - Band around knees to promote gluteal activation and avoid valgus breakdown  
  • Promote movement through hips and | • Emphasize eccentric strength and control  
  • Continue to progress with squat program (PRE’s)  
  • Continue to progress with eccentric leg press (PRE’s)  
  • Progress with suspension training squats  
  • Eccentric DL squats (5/5/1 count)  
  • SL squats focusing on control and technique (proper hip hinge pattern)  
  • Progress with interval biking for endurance (time and resistance)  
  • Progress with step-ups/downs by increasing height and adding weight (intrinsic load)  
  • Advanced proprioception training (perturbations)  | • Advanced strength program 3-4 times/week  
  • Cardiovascular endurance training with continued load methods  
  • Bike/elliptical/stair machine/rower  
  • Glute activation exercises  
  • Chair/box squats  
  • Leg press (DL/SL)  
  - Eccentric leg press with proper control and alignment  
  • Multiplanar hip strengthening  
  • Front/back/lateral lunges  
  • RDL (DL/SL)  
  • Advanced kinetic linking progression  
  • Chops/lifts  
  • LE stretching/foam rolling program |
<table>
<thead>
<tr>
<th>Phase</th>
<th>Phase I: Weeks 0-2</th>
<th>Phase II: Weeks 2-6</th>
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<th>Phase IV: Weeks 12-20</th>
<th>Phase V: Weeks 20+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria for advancing</td>
<td>• Hydrotherapy when incisions are healed for gait, proximal strengthening, functional movements, balance and edema control-week 4-6</td>
<td>• Underwater treadmill/ anti-gravity treadmill gait training if gait pattern continues to be abnormal</td>
<td>• Continue to progress with aquatic program if available</td>
<td>• Continue with kinetic linking/ core progression</td>
<td>• Continue with kinetic linking/ core progression</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progressive lower seat height per strength gains</td>
<td>• Chair/box squats with proper form and without complaints of pain</td>
<td>• Isokinetic test ≥ 90% limb symmetry (if available)</td>
<td>• Isokinetic test ≥ 90% limb symmetry (if available)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progress to adding weights as appropriate (PRE's)</td>
<td>• Full pain-free ROM</td>
<td>• Independent with gym strengthening and maintenance program</td>
<td>• Independent with gym strengthening and maintenance program</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce step-up progression (week 6-8)</td>
<td>• Full weight bearing with crutches, dis-charge brace</td>
<td>• Movement without asymmetrical deviations and a hip dominant strategy</td>
<td>• Movement without asymmetrical deviations and a hip dominant strategy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Start with 4” step → 6” then step →8” step</td>
<td>• Demonstrate a normal gait pattern without deviations</td>
<td>• 80% limb symmetry (quadri-ceps and hamstring) with handheld dynamometry and functional testing</td>
<td>• Lack of apprehension with sports specific movement (eg. acceleration/deceleration, cutting)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Emphasize proper movement pattern (no hip drop, no valgus breakdown)</td>
<td>• Progressing toward full ROM</td>
<td>• No pain/inflammation after activity</td>
<td>• 90% limb symmetry (quadri-ceps and hamstring) with handheld dynamometry and functional testing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progress to adding weights as appropriate (PRE's)</td>
<td>• Normal patellar mobility (all planes)</td>
<td>• Movement without asymmetrical deviations and a hip dominant strategy</td>
<td>• Isokinetic test ≥ 90% limb symmetry (if available)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Front lunges Traveling lunges (don’t force ROM)</td>
<td>• Proximal strength &gt; 4/5</td>
<td>• Independent with HEP</td>
<td>• Independent with HEP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progress balance/proprception</td>
<td>• Normal patellar mobility (all planes)</td>
<td>• Diminished OKC – progress to isokinetic: moderate to high speeds</td>
<td>• Lack of apprehension with sports specific movement (eg. acceleration/deceleration, cutting)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rockerboard and SL rebounder (Progress to foam pad/½ foam roller)</td>
<td>• Minimal edema</td>
<td>• Return to running program at month 6</td>
<td>• Individualized per sport and patient need</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Sports specific balance</td>
<td>• Well controlled pain</td>
<td>• Must have good eccentric control with 8” step down</td>
<td>• Progressive strength and flexibility through entire kinetic chain (hips, knees, ankle)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Core/kinetic linking progression</td>
<td>• Independent with HEP</td>
<td>• Mass with good eccentric control with 8” step down</td>
<td>• Agility and balance drills</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce eccentric step-down program (week 8-12)</td>
<td>• Progressive gluteal/hip strengthening</td>
<td>• Be cautious of overloading the knee – monitor for swelling</td>
<td>• Progress with sport specific programs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Start with 4” step →6” step →8” step (assisted with railing)</td>
<td>• Continue phase II exercises</td>
<td></td>
<td>• Return to running program at month 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Emphasize proper movement pattern (no hip drop, no valgus breakdown)</td>
<td>• Lateral/Monster walks, Three-point steps/ Hip clocks, SL wall push, Windmills, Clamshells in modified side plank, and Bridge progression</td>
<td></td>
<td>• Must have good eccentric control with 8” step down</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progress to adding weights as appropriate (PRE's)</td>
<td>• Introduce eccentric step-down program (week 8-12)</td>
<td></td>
<td>• Progress with interval treadmill program (monitor knee load)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Front lunges Traveling lunges (don’t force ROM)</td>
<td>• Sports specific balance</td>
<td></td>
<td>• Cardiovascular training</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progressive gluteal/hip strengthening</td>
<td>• Core/kinetic linking progression</td>
<td></td>
<td>• • Bike/elliptical/Rower/Versaclimber</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Continue phase II exercises</td>
<td>• Progress BFR program to more weight bearing activities (i.e. squats, leg press)</td>
<td></td>
<td>• • Anaerobic interval training</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lateral/Monster walks, Three-point steps/ Hip clocks, SL wall push, Windmills, Clamshells in modified side plank, and Bridge progression</td>
<td>• Introduce eccentric step-down program (week 8-12)</td>
<td></td>
<td>• Gluteal activation exercises</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce eccentric step-down program (week 8-12)</td>
<td>• Sports specific balance</td>
<td></td>
<td>• Chair/box squats</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Start with 4” step →6” step →8” step (assisted with railing)</td>
<td>• Core/kinetic linking progression</td>
<td></td>
<td>• • Double leg (5/5/1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Emphasize proper movement pattern (no hip drop, no valgus breakdown)</td>
<td>• Progress BFR program to more weight bearing activities (i.e. squats, leg press)</td>
<td></td>
<td>• • Modified SL (eccentric control)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progress to adding weights as appropriate (PRE’s)</td>
<td>• Progressive gluteal/hip strengthening</td>
<td></td>
<td>• Multiplar hip strengthening</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Front lunges Traveling lunges (don’t force ROM)</td>
<td>• Continue phase II exercises</td>
<td></td>
<td>• Front/side/back lunges</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Progressive gluteal/hip strengthening</td>
<td>• Lateral/Monster walks, Three-point steps/ Hip clocks, SL wall push, Windmills, Clamshells in modified side plank, and Bridge progression</td>
<td></td>
<td>• SL Runners RDL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Continue phase II exercises</td>
<td>• Introduce step-up progression (week 6-8)</td>
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</tbody>
</table>
Immediate patellar mobility is a mainstay during this phase to reduce the amount of scar tissue that can develop post-surgically. The loss of patellar mobility may result in ROM complications along with difficulty recruiting proper quadriceps contraction. Often times, patellar mobilization is not adequately prioritized in the rehabilitation process, and the potential lack of mobility can lead to a loss of motion in the knee joint. Superior mobility of the patella is required for full knee extension, and inferior mobility is required for full knee flexion. The athlete should be instructed to perform this frequently throughout the day in order to obtain maximal patellar mobility. Soft tissue manipulation of lower extremity musculature post-operatively can also help with edema control. Attention should be given to soft tissue manipulation along the suprapatellar and infrapatellar pouch to facilitate overall patellar mobility and ease with ROM.

Restoration of quadriceps control is imperative in this phase of rehabilitation to aid in early strengthening. In the context of the professional athlete, this restoration of symmetric muscle function is a key aspect in a successful return to sport. This restoration should be initiated as early as post-operative day 1 in order to gain volitional quadriceps control, and aid in reducing knee edema and pain through the activation of the natural muscle pump. The use of electrical stimulation for quadriceps activation is encouraged in this phase, and has shown to facilitate return of volitional muscle activation as well. Due to the limited weight bearing status of the patient, exercises are limited to those such as quadriceps sets, and straight leg raises. An adjunct that can be used at this stage to help increase quadriceps strength is the addition of blood flow restriction.

Blood flow restriction (BFR) training can elicit positive muscle hypertrophy and strength adaptations in load compromised populations using light external loads of 20-30% 1 rep max. Although the application of BFR on patients who undergo cartilage transplants has not been heavily researched, its usage early on with electrical stimulation has been documented with the post ACL population with positive results. This presumably is due to the fact that it has been shown to decrease overall pain and effusion of the joint. This has been well documented in patients with knee osteo arthritis, patellofemoral pain and in-patient military personnel. The overall effect of exercise in populations with musculoskeletal conditions can be attenuated in the presence of pain due to a detrimental effect on motor control and muscle function and can lead to compensations and modified movement patterns. The usage of BFR early on has a two-fold effect in that it helps the overall reduction of pain and swelling, along with improving overall muscle hypertrophy working at lower loads, as to not irritate the healing joint complex. The enhancement of quadriceps activation and hypertrophy early on can have tremendous effects as the rehabilitation process progresses.

Along with activation of the quadriceps musculature, a preliminary development of core stabilization should be initiated during this phase. Athletic movement is dependent on the synergistic work of the entire kinetic chain, with the proximal musculature, including the hips and abdominal region, having a major role in linking the upper and lower kinetic chain. At times, core activation and stabilization is neglected due to the majority of emphasis being placed on regaining lower extremity function and control. Exercises such as abdominal and pelvic bracing, side lying clamsheles, and bilateral knee fall outs can help with activation of core musculature early in the rehabilitation process. It is important to understand that return to sport starts from post-operative day one. Ensuring that the athlete is engaged not only in lower extremity rehabilitation, but also reconditioning of their entire body throughout the process allows for timely progression, and a more readily return to sport at their optimal performance level while decreasing risk for re-injury.

Edema and pain control are important during the entire rehabilitation, but especially during these early phases. The benefits of cryotherapy for edema and pain control are well documented in the literature. Numerous studies have reported a progressive decrease in volitional quadriceps activity as the knee exhibits increased pain and distension. The usage of cryotherapy is essential to minimizing reflex inhibition, and restoration of normal quadriceps function. Studies showing usage of an active compression cold therapy system after anterior cruciate ligament reconstruction resulted in significant increased range of motion and functional knee scores compared to cold therapy alone. The usage of an active compression cold therapy unit is usually used for at least the first two weeks to maximize the benefits early on. Along with this, the athlete can benefit from a commercial knee sleeve or compression wrap to apply constant pressure and edema control during functional activities.
PHASE II: WEEKS 2–6

During this second phase of rehabilitation, the repaired tissue is healing and gaining strength, but it is still not quite mature. This transition phase can last up to 12 weeks following surgery. The goals of this phase are to normalize gait and progress to full active and passive motion of the knee complex. ROM can be progressed from Phase I with passive knee stretching along with early utilization of a stationary bike. Biking can start with a short crank (90mm) bicycle when knee flexion approaches 90 degrees, with subsequent use of a standard upright stationary bike for ROM progression once knee flexion improves to ~110 degrees. Caution should be taken not to aggressively force flexion ROM, which may result in increased pain, effusion and unwarranted inflammation. Early strengthening, with adherence to weight bearing progression, is advanced in this stage as well. Athletes can begin with bilateral leg press in a shortened arc (60 degree to 0 degree) with progression to 90 degree to 0 degree arc as ROM progresses.

Weight bearing should be advanced specific to surgeon protocol, but in a stepwise pattern in order to reduce adverse swelling and pain that may result from overaggressive loading and rapid increases in stress to the graft. A typical weight bearing progression begins with immediate toe touch weight bearing (20%), progressing to partial weight bearing (50%) with bilateral axillary crutches, transitioning to 75% weight bearing using a single axillary crutch, and finally weight bearing as tolerated while weaning off the assistive device. Balance training during this phase begins with weight shift exercises using upper extremity support and progressing to single leg balance/proprioceptive exercises as proper quadricep control is obtained. A proper gait pattern is imperative during the beginning stages to reduce subsequent gait abnormalities. Emphasis should be placed upon proper knee extension during heel strike, along with proper quadriceps activation and control during the stance phase. During the swing phase of the gait cycle, the athlete should be cued on proper knee flexion to avoid subsequent gait abnormalities. However, until proper quadriceps control is noted, the athlete is typically using a brace locked in extension to assist joint stability in the absence of quadriceps control. At times, prolonged usage of a brace can lead to a gait pattern where the athlete circumducts the hip during swing phase. Occasionally, this gait pattern can persist when the brace is removed. The resulting abnormal gait pattern may lead to hip or lower back pain secondary to muscular compensation. Hence, gaining quadriceps control early on is imperative for a proper gait pattern and timely discontinuation from brace usage. Exercises such as a hurdle step-over can be introduced at this time to educate proper quadriceps activation during ambulation and enhance reciprocal patterning that is important during the later phases of rehabilitation. (Figure 2) In most athletes, a normal gait pattern will be developed, but in certain cases, gait deviations can persist late in this phase of rehabilitation. In these cases, utilization of an underwater treadmill or anti-gravity treadmill can aid in reducing the load of the affected lower extremity and facilitate a proper gait pattern. Once quadriceps activation is achieved, the athlete should switch their focus on regaining independent neurological function. The use of biofeedback in this patient population has shown positive outcomes in enhancing volitional quadriceps contraction. The achievement of terminal knee extension is paramount in this patient population because normal arthrokinematics of the knee is required for a proper gait pattern, and more importantly, proper athletic movement. Abnormal joint arthrokinematics can predispose an athlete to increased patellofemoral and/or tibiofemoral joint contact forces resulting in increased pain, and potentially the inability to fully load the joint for athletic movement in later phases of rehabilitation. The addition of biofeedback at this phase enhances quadriceps control mitigating a quadriceps inhibited or flexed knee gait pattern. The sooner normal arthrokinematics of the knee joint occur, the sooner rehabilitation can progress.

The athlete should continue to progress with core stabilization at this phase. Athletic movement requires the proper linking of the lower and upper body for optimal athletic movement. The traditional model of the kinetic chain states that the human body is made up of a series of integrated links or segments (parts of a whole). It is a coordinated action of these body segments that allow optimal movement, generating power from ground reaction forces that are subsequently transferred to the final length of the chain. Introduction of kinetic chain linking progressions can start early on in the rehabilitation process and can help the athlete develop proper force generation in the later phases of rehabilitation. Intermuscular myofascial connections such as the superficial back line, deep front line, and spiral line (along with others) can impact overall force transmission and stability to the body during dynamic movements such as running, throwing and jumping. Integration of exercises such as double leg bridging with a hand around the knees to facilitate glute activation, modified and normal front planks along with modified side planks can help activate the posterior, anterior, and lateral planes which will be imperative in building a foundation for athletic movement. (Figure 3) These aspects can be started early on, but choosing the correct exercises is important so as to not put excessive joint pressure through the knee and healing graft during this phase.

Aquatic therapy may be a beneficial adjunct to therapy in the later phases of this phase. This is introduced only when the incision is completely healed, which normally occurs around 4–6 weeks post-operatively. The addition of aquatics can help the athlete progress with activities that they would normally not be able to do on land secondary to weight bearing restrictions. Exercises such as double leg squat, hip clock, and advanced ambulation exercises can be performed as the buoyancy of water decreases weight bearing forces. Weight bearing can be reduced to up to 25% of an athlete’s body weight when submerged to the axilla. Early initiation of controlled exercises in the pool can help the athlete return to functional activities sooner, and boost psychological morale in the athlete as well. The sooner the progression to regular functional activity, the sooner the athlete feels they are mentally prepared for returning to their sport.

The loss of function with a significant knee injury, as well as inability to participate in their sport can be psychologically difficult for the athlete, and often times can lead to an altered emotional state. Although it is early in the re-

International Journal of Sports Physical Therapy
hab process, it is valuable for the athlete to participate in some modification of their sport to remain connected in a positive way. Having a basketball player perform seated ball handling and shooting activities or having a tennis player perform seated forehand shots can allow for a smooth transition back to in-game mechanics. Initiating such activities such in this stage can help them on their mental journey of returning to sport.

**PHASE III: WEEKS 6-12**

This next transition phase of rehabilitation focuses on progressive strengthening, and typically lasts until 12 weeks post-operatively.\textsuperscript{34-57} Strengthening in this phase should transition to exercises that progressively load the knee joint. Careful consideration must be taken in this phase of rehabilitation as the athlete resumes most activities of daily living. Most athletes with osteochondral defects have experienced chronic pain associated with their lesions, as it is a common occurrence for this patient population to delay receiving definitive treatment. Because of this, the aspect of pain had been prevalent in their everyday activities before, and thus the idea of “some pain is normal” continues to be in their mindset. In this phase of rehabilitation, the athletes’ pain continues to dissipate, and they may want to return to their sport sooner than recommended. Proper education should be addressed with the athlete, placing an emphasis on the biologic healing required to take place in conjunction with progressive strengthening and conditioning necessary for a proper and safe progression. Multiplanar gluteus and hip strengthening should be introduced at this phase as weight bearing precautions and protocol allows. Examples of exercises emphasizing these muscle groups include standing hip clocks with band resistance, and lateral or monster walks. (Figure 4) Constant cues should be given to athletes regarding proper loading and proper joint alignment during these exercises. Valgus breakdown of the knee during these static exercises must be addressed with verbal and tactile cues; otherwise, these habits may persist during dynamic exercises in later phases. Valgus breakdown and subsequent improper movement patterns can lead to pain and discomfort in the knee, and often, frustration by the athlete due to lack of or slower progression in the rehabilitation program. Body weight squats can also be initiated in this phase with special focus on the movement pattern utilized. Athletes should be taught a proper hip hinge pattern permitting proper loading through the hips and proximal musculature to decrease pressure and load of
the knees. (Figure 5) During this phase, leg press emphasizing slow single leg eccentric control should be introduced. Kinematic analysis of the knee joint during jumping activities shows that the highest peak load across articular cartilage occurs with the knee in the fully extended position. Loading decreases as the joint goes into the flexed position, during which controlled eccentric flexion distributes the applied load and protects the articular cartilage and intra-articular structures. Teaching this eccentric control and enhancing the eccentric quadriceps strength is imperative in these athletes to help them realize that increasing this strength can help them decrease abnormal joint pressures and subsequent knee pain with progressive activities. This eccentric training should be continued throughout the rehabilitation process following this phase, as it has been shown to improve plyometric activities as well. As this phase progresses, single leg strengthening should also be introduced. Exercises such as front and side lunges, unilateral leg press, and single leg Romanian dead lifts can be utilized. Focus should be placed on slow eccentric control during these motions, along with keeping proper form throughout the exercise. (Figure 6) Athletes with an osteochondral lesion likely had been training with knee pain to a certain extent. Due to this pain and discomfort they have developed compensation mechanisms to complete exercise and training tasks, which can persist after the post-surgical process. It is essential for these athletes to use visual and tactile cues to perform these exercises with proper form and reduce the compensation mechanisms that have been engrained in their movement patterns. The post-operative rehabilitation program should involve the gradual progression of applied and functional stresses to provide a healthy stimulus for healing tissues without causing subsequent damage to the new graft.

Full ROM should be attained in this phase through continued use of the stationary bike along with hip flexor and quadricep stretching. The athlete should be encouraged to stretch and mobilize often throughout the day to avoid forceful manipulation of the knee joint and subsequent joint effusion. As this phase progresses, and normal active and passive ROM is achieved, the athlete can begin with self-directed soft tissue release techniques such as foam rolling and myofascial release. Progression through a foam rolling program can help improve flexibility of the lower extremities and in turn facilitate further gains in strength. The majority of athletes with focal chondral lesions have decreased lower extremity strength and more importantly a lack of single leg strength simply due to the fact of having progressive pain with strengthening exercises. The subsequent strength loss in these athletes can
lead to a "guarding" mechanism in the knee, which can be demonstrated by a flexed knee gait pattern, general lower extremity tightness, and increased tone around the knee joint and lower extremity. Teaching a proper foam rolling program can help decrease this tone, and increase overall proprioception so that proper movement patterns can be learned.\(^6^7\)

Lower limb based cardiovascular training should also be introduced early in this phase. As mentioned previously, athletes can demonstrate significant emotional disturbances and depression with significant knee injuries. There is ongoing evidence that shows the use of aerobic exercise multiple times a week can help decrease these disturbances.\(^6^8\) The constant high speed starting, stopping, and acceleration that is required in sports such as basketball or soccer involves a large demand on the anaerobic system.\(^6^9\) This system should be activated early on in the rehabilitation process allowing for a progressive advancement, rather than a delayed initiation in later phases of rehabilitation. Early-phase cardiovascular training should focus on the upper extremities. Examples include seated upper body ergometer, seated versaclimber, or use of a fan bike with upper extremities only. TABATA training is an effective anaerobic training method that can be implemented early in the process.\(^7^0,7^1\) This regimen includes 4 minutes of total exercise performed in intervals of 20 seconds of high intensity, followed by 10 seconds of rest (a total of 8 rounds is performed). Due to the continued healing in the graft, athletes are not able to train their cardiovascular system at a level to which they are accustomed. Early cardiovascular training with the upper extremities exercises this system, as well as their overall competitive nature. Low-load stationary biking with minimal resistance can be initiated around the 8-week mark. Initially, the athlete should progress with the total time of their sessions and be educated to not over work the knee joint which may cause increased edema, and possibly pain. An interval biking program progressing with speed and resistance can be started around the 8-10 weeks, provided the athlete has had no initial complaints with progressive increases in time. If a pool is available, aqua jogging in deep water can be initiated as a form of cardiovascular exercise and has shown to have good increases in anaerobic training as well.\(^7^2\) This can help facilitate a proper running pattern and provide a foundation for the later phases of running. More recently, there has been an increased awareness of the significant emotional components associated with athletes who suffer knee injuries. Anxiety and depression are common factors that occur when an athlete cannot participate in their sport after a knee injury.\(^7^3,7^4\) These feelings can be compounded in high level collegiate or professional athletes in whom their participation in sport may be essential to their livelihood. There is a mounting group of studies demonstrating that the use of aerobic exercise multiple times a week can mitigate these emotions in athletes.\(^5^8\) Many times these cardiovascular gains are focused on in the later phases of rehabilitation, but in the professional athlete’s case, cardiovascular gains that can be achieved safely should be started at this phase to ensure that optimal physical fitness gains can be achieved throughout the process.

Continuing to develop kinetic chain linking procedures in this phase is important so the athlete can learn to properly dissipate forces through the repaired knee joint and transfer force throughout the entire kinetic chain instead of heavily relying on the knee complex. Once optimal core activation is developed on the ground in phase 2, the decision has to be made to progressively transition to a more functional standing position, remembering that sequential activation has to be achieved before advancing to complex athletic movement. For example, a palloff press variation series can be implemented with either band or weighted resistance. Having the athlete move to a standing position challenges the body in the frontal (core timing/activation), sagittal (core strength), and transverse planes (rotational stability). (Figure 7) Doing this while maintaining standing trains the athletes to transmit forces from a stable base through the trunk and to the upper extremities for optimal force output.

Progression of proprioceptive exercises is important for this population as well.\(^7^5–7^7\) Double leg proprioceptive exercises should be progressed by using an unstable surface such as a BOSU ball or rocker board to challenge stability. Single leg balance should also be progressed by adding external perturbations and unstable surfaces. With all sporting activities, movement is unpredictable and random. This idea should be incorporated into proprioceptive activities, reiterating the idea that the athlete is working on a return to sport during all phases of rehabilitation.

**PHASE IV: 12-20 WEEKS**

Remodeling of the graft tissue starts during this phase and can last up to 6-12 months postoperatively.\(^5^4–5^7\) During this time frame, there is a continuous remodeling and integration of the OCA to resemble the pre-injury articular surface.\(^5^4–5^7\) This clinically correlates with the progression of overall training activities as most athletes approach a pain-free state. Movement education such as proper hip hinge pattern for basic DL lower leg strengthening activities (i.e. deadlifts, squats) are reinforced in this phase. Frequent movement assessments should be monitored as rehabilitation progresses. These assessments can range from a sim-
ple visual assessment of movement patterns to biomechanical analysis using a motion capture system. Although the joint is structurally repaired at this point and pain continues to improve, athletes may have developed altered movement patterns that became ingrained in their neuromuscular system. These discrepancies can continue to be present unless they are observed in a qualitative and quantitative manner and corrected previously during the rehabilitation process. A movement assessment for the athlete can help identify weaknesses in the kinetic chain, and aid in the development of a global plan to allow the athlete for a more efficient return to their sport.

Strength becomes a primary target during this phase. In previous phases, pain may have limited the athlete’s ability to perform strength training exercises. Eccentric strength losses, especially in the affected lower extremity must be improved during this phase to support the allograft. A muscle’s force-producing capacity is optimized when an external force exceeds that of the muscle while the muscle lengthens. Hence, the potential to improve muscle strength by overloading the muscle tissue is greater with eccentric strengthening than with concentric strengthening. The addition of single leg strengthening can be added, as long as the athlete does not have adverse effects such as effusion or pain during or after the exercise. Exercises such as single leg squats should also be progressed, continuing to stress the utilization of a proper hip hinge pattern. Furthermore, it may be beneficial to start with a modified supported single leg squat utilizing a yoga block, medicine ball, or a suspension system (TRX). (Figure 8) Leg press should also be progressed with weight in both the concentric and eccentric portion of strengthening. Eccentric step downs should be introduced as another method of eccentric quadricep strengthening with progressive joint loading. The athlete should be constantly educated on progression of exercise with weights and repetition while also considering load education. As the affected limb continues to strengthen, the increases in strength will in turn help them load the joint more. Athletes should be educated that although they have progressed well to this point, they should continue to monitor the overall load on their knee to prevent any persistent effusion or pain.

Cardiovascular exercises should be progressed at this time to include a variety of different exercise platforms. Trying to overcome the deconditioning that occurred over the first 12 weeks must be addressed so the athletes can progress back to sports in the final stage of rehabilitation. Athletes should continue to be encouraged to use the stationary bike and progress their interval biking program, increasing resistance and time. Elliptical training, stairmaster, and versaclimber can also be used to improve cardiovascular conditioning. Anaerobic training can also be progressed at this time with the methods mentioned before. To exercise the competitive nature of the athlete, implementing leaderboards or partner training may be effective in improving the overall psyche of the athlete as they progress with return to sport. A common question is when to start a running program. In many cases, athletes feel that the only way they can start to transition to normality is if they can begin to run. Running may have been a signifi-
cant source of pain preoperatively, therefore initiation of a running program may serve as a significant milestone and motivation for the athlete’s return to sport. Typically, returning to high intensity running is not warranted until 6-8 months depending on the surgeon protocol. The use of an anti-gravity treadmill (Alter-G treadmill) can be initiated near the 4-5 month mark as long as the athlete demonstrates good eccentric quadriceps strength in order to attenuate the forces produced while running. A simple objective measure that can be used to measure adequate eccentric strength is whether or not the athlete descend an 8’ step with good control and without movement deviations (trunk lean, hip drop, knee valgus). If an athlete is able to demonstrate this, and there has been sufficient healing of the graft site determined by the surgeon, then a return to running program can be safely started.

The progression of kinetic chain linking principles should continue to progress in this phase. Enhancing the athlete's ability to load with a stable single leg while having good core control is important to be able to eventually transfer their weight while performing explosive movements such as sprinting, pushing, hitting or throwing. However, the athlete should be able to maintain stability on a single leg with anti-rotational core stabilization before weight transfer and explosive movements are performed. A focus should be placed on trying to strengthen the entire kinetic chain and identifying any potential weaknesses at this point. (Figure 9) One potential method for identifying these deficiencies includes quantitative isokinetic testing which provides an objective measure for the athlete’s strength. The athlete’s ability to physically see the deficits in strength that remain when compared to a cohort group can have an impact on where they stand in their progression to return to full activity.

Modified sport activities may be reintegrated during this phase. For example, a basketball player can initiate ball handling drills and light form shooting on the court at this time, transitioning to light layup drills by the end of this phase. For tennis players, light forehand and backhand swings can be done in a static position, and transition into light lateral movements by the end of the phase. Load management is always a consideration with adverse effects of pain and or swelling potentially occurring as increasing loads are placed either too fast or too frequently. If these symptoms occur, further strengthening needs to occur before progressing with these activities.

**PHASE V: WEEKS 20 +**

The main goals of this phase are to regain high levels of proprioception, neuromuscular control, strength, and fitness with the intend to return to previous levels of athletic activity. The overall goal for any athlete is to not only to return to their sport, but to return to their sport at the highest level possible. As activity is increased during this phase to include progressive plyometric activity and agility training, caution should still be taken on potentially overloading of the patellofemoral joint with increased activity. Athletes need to continue to be diligent with their lower extremity strength gains in this phase allowing for proper support of their knee joint with higher level activities. An advanced strength program consisting of aspects of cardiovascular training with continued low load methods (stationary bike, fan bike, Elliptical, stairmaster, versaclimber, row machine), progressive glute strengthening, DL and SL squatting activities, core strengthening, and advanced kinetic linking (cable or band chops and lifts) is critical for athletes to reach the final phase of returning to sport. Proper plyometric technique needs to be fortified in this phase as well. Having the athlete learn how to properly generate force with their lower extremities, and more importantly, land in a safe manner will help them protect the knee joint and prevent any deleterious effects of advanced training. The progressive eccentric quadriceps training up to this point allows the athlete to be ready for these higher-level impact activities.

We routinely obtain a magnetic resonance imaging (MRI) assessment at 6 months to assess graft morphology. Ossous integration is not expected to be complete at this time. However, at 6 months, the allograft should show an intact articular cartilage surface, progressive bony incorporation with evidence of cross trabeculae, and no joint effusion (Figure 10). These objective measures, along with good movement, sufficient quadriceps control, and minimal (<20%) side-to-side strength differences, form our basis for permitting athletes to start high-impact activities such as running and other sport-specific tasks. Progression should be in a planned and organized manner, so the athlete has specific stages to progress through with the goal of returning to the field of play. Activities should start with planned non-reactive drills (cone drills, set passing drills) and progress to unplanned reactive drills. While extra precautions should be taken for contact sports during this phase, play on the field may be initiated with non-contact scrimmage, progressing to contact scrimmage, and lastly, controlled live play. When these steps are completed and proper loading and confidence is seen in the athlete, along with no signs of deleterious effects on the knee joint, the athlete can progress to full game play.

Overall load management should be monitored as the athlete starts to participate in full game play activity. A re-
striction on minutes played during a game may have to be instituted in order to progress to long game play situations. Athletes should be educated in this phase that as they start to progress with on field or on court activities, they will inherently be loading their joint more. Excessive running or jump training should be avoided since increased load is placed on the joint with a return to athletic activities. It is the surgeon and rehabilitation professionals’ responsibility at this point to not only provide proper education to the athlete regarding load management, but to be the one to decide if the athlete can handle more activity and are cleared for return to sport. This last phase is a fluid process and is dependent on the overall gains that the athlete has made up to this point. It requires a conversation between the physical therapist, surgeon, team and athlete regarding when this phase is finished. Emphasis should be placed on criteria achieved for full contact return to sport and not just a time frame of biological healing.

RETURN TO PLAY CONSIDERATIONS AFTER OCA

The literature on return to play rates after OCA in professional athletes is sparse. In our series of collegiate and professional basketball players, we found a median return to competitive play at 14 months and an overall rate of return to play at the same level of competition at 80%. Other studies that include high level athletes report return to sport rates ranging between 75-88% (Table 2). In professional athletes, the decision to return to play requires a multidisciplinary team approach with frequent communication between the surgical and rehabilitation teams (physical therapists, athletic trainers, coaching staff). The rehabilitation team needs to make sure that aspects of strength, movement and fitness are achieved. It is pertinent to note that not all athletes are built the same, and not all sports have the same physical demands. The physical demand for a baseball pitcher is different from a guard in basketball. Similarly, the efficiency of kinetic linking is different among sports as well. Athlete-specific care has to be integrated, and factors such as the specific sport and specific position played are ultimately considerations that the rehabilitation team need to consider. Isokinetic or general strength testing should show at least 90% limb symmetry between both legs before a return to sport is considered. More importantly, movement symmetry must also be present in which symmetry between sides is noted. Movement screens, functional sport testing, and jump testing are all quantitative elements that should be used in the return to sport process to safely and effectively return an athlete to their particular sport. As with any progression back to sport, athletes may experience soreness or persistent joint inflammation as progressive load is placed on the joint. A distinction needs to be made in athletes in this phase of when the soreness is happening. Is the overload happening with overtraining with plyometrics, or happening with progression of sports-specific activities? Throughout the rehabilitation process, the athlete had been taught and progressed through proper kinetic linking strengthening and progressions so that they understand that it is the job of the entire body to dissipate forces and not just the knee joint. Keeping these principles in mind during higher level strength and training activities can reduce the overall force that is placed on the knee complex but can also reduce further injury to other parts of the body. Joint inflammation after OCA can also be related to a low-level immunoreactivity of the host to the allograft tissue. Although articular cartilage is traditionally thought to be "immunoprivileged," antigenic material in the allograft bone, as well as exposed allogeneic chondrocytes, which express class I and II major histocompatibility (MHC) antigens, can potentially elicit immune responses in the host intra-articular environment. These persistent joint effusions can be particularly vexing for athletes during their recovery. Anti-inflammatory treatment modalities and limiting joint loads until complete resolution of the effusion are recommended. Future investigation into therapies that optimize the biologic milieu of the knee after transplantation are much needed.

Management of expectations of both the athlete and coaches will prevent overtraining. As athletes continue to progress, they may feel that they can do all the strengthening and plyometric activities that their teammates do. An understanding must take place that they are continuing to progress through the rehabilitation process and that patience has to be shown in order to continue to progress. Proper fitness gains finally have to be made in order for the athlete to be in "game shape" as well. Many athletes feel that as the rehabilitation process ends, they are automatically cleared for returning to full game play. Per our experience, athletes typically need 3-4 months of fitness training before being able to return to preinjury performance. Some of this involves continued strength training with the help of a strength and conditioning specialist as well as progress-
Table 2: Return to Sport After Osteochondral Allograft Transplantation

<table>
<thead>
<tr>
<th>Study Author (Year Published)</th>
<th>Number of Patients (Average Age in years)</th>
<th>Level of Activity</th>
<th>Average Time to Return to Sport (in months)*</th>
<th>Percentage that Returned to Sport</th>
<th>IKDC prior to OCA **</th>
<th>IKDC after OCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nielsen, E. Scott, et al. (2017)</td>
<td>142 (31.2)</td>
<td>Self-reported: 45% &quot;highly competitive athlete&quot;; 55% &quot;well-trained and frequently sporting&quot;</td>
<td>4 to 6 per protocol</td>
<td>75.2%</td>
<td>42.0 ± 16.5</td>
<td>74.5 ± 19.8</td>
</tr>
<tr>
<td>Frank, Rachel M., et al. (2017)</td>
<td>180 (32.7)</td>
<td>33% Self-reported athletes</td>
<td>4 to 6 (8 to 12 for combined surgeries) per protocol</td>
<td>63% not requiring reoperation, 87% graft survival ****</td>
<td>33.8 ± 13</td>
<td>59.2 ± 21.4</td>
</tr>
<tr>
<td>Balazs, George C., et al. (2018)</td>
<td>11 (22.8)</td>
<td>64% NCAA, 36% NBA</td>
<td>NBA median 20, NCAA median 8</td>
<td>80%</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Krych, Aaron J., et al. (2012)</td>
<td>43 (32.9)</td>
<td>74% recreation, 23% NCAA, 2% professional</td>
<td>Average 9.6 months ± 3.0 months</td>
<td>88% limited participation, 79% full participation</td>
<td>46.27 ± 14.86</td>
<td>79.29 ± 15.53</td>
</tr>
<tr>
<td>McCarthy, Mark A., et al. (2017)</td>
<td>13 (Unreported)</td>
<td>69% Highschool, 31% NCAA</td>
<td>7.9 ± 3.5 months</td>
<td>77%***</td>
<td>38 ± 12</td>
<td>63 ± 22</td>
</tr>
<tr>
<td>Marmon, Niv et al. (2019)</td>
<td>1</td>
<td>100% Professional</td>
<td>7</td>
<td>100%</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
</tbody>
</table>

* If time to return to sport data not provided, rehabilitation guidelines per protocol were listed
** IKDC=International Knee Documentation Committee Score; All IKDC improvements significant to p < 0.014
*** 77% when adjusted for patients who graduated from high school sport
**** Individual RTS data not provided for athletes, statistics represent entire cohort

As OCA becomes more widely utilized to treat focal cartilage defects of the knee in high-level and professional athletes, post-operative rehabilitation is an essential component of the treatment plan in permitting athletes to return to play. The aforementioned five-phase approach to progressive rehabilitation takes into account the biological processes of healing and optimization of neuromuscular recovery required for high-level sport. Even after proper progressive rehabilitation, persistent joint inflammation and reactivity remain a vexing issue for athletes after OCA. The principles of early ROM, proper progression through the kinetic chain, avoidance of pain and effusion, optimization of movement, regimen individuation, and integration of sports-specific activities underlie proper recovery.

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Expertise, which can be developed through specialization in sports physiotherapy, has evolved as part of lifelong learning to improve patient care.\(^1\)\(^,\)\(^2\) Specialization is described as having in-depth knowledge, skills and competence in a specific area of practice.\(^3\)\(^,\)\(^5\) The International Federation of Sports Physical Therapy (IFSP) provides a specialist recognition process through certification by member organizations, which includes masters level knowledge and skills mapped to competencies, while also demonstrating situational and contextual awareness.\(^2\) The process acknowledges and promotes that becoming a specialist involves more than merely successfully completing a course of study, rather, it requires a longer period of reflective practice in the sports physiotherapy field.

Typically, professional expertise is considered a gradual transition, often starting with formal (university) education and then specializing through (clinical) experience and ongoing informal learning, which builds upon this academic foundation.\(^4\) Experts in a specialized field demonstrate ongoing regular deliberate practice and consistently successful superior performance in complex situations.\(^5\) Not all specialists will become ‘experts’ but a suitable specialization process can facilitate developing expertise characteristics. In this international perspective the authors are encouraging the reader to consider how you are developing or maintaining your own, and others’ level of expertise, which will in turn enhance the practice of sports physiotherapy.

The authors have previously proposed a model of expertise development in sports physiotherapy.\(^6\) In this model, learning is categorized into technical (scientific and skill-based), creative (adapting decision-making and techniques to clinical situation) and contextual (self-awareness and ability to adapt behaviors within wider cultural and situational circumstances).\(^6\) Creative and contextual learning both improve with informal practical/experiential learning. Novices typically have the technical knowledge to support evidence-based practice but lack the depth of experience on which to base their practice decisions, especially in complex situations.\(^7\) Individuals then continue to critically appraise available evidence and reflect on patient outcomes to further modify their practice while on a specialist pathway. Sports related examples of different characteristics across novice to expert, to illustrate this, can be seen in Figure 1.

Formal learning is typically planned, ‘teacher’ led and explicit, while informal learning is usually unplanned, experiential, reactive and implicit in nature.\(^8\) Physiotherapists use both, with the limited available evidence suggesting that they seem to prefer formal learning, but it is not clear why.\(^9\) In contrast to these preferences, learning has been shown to be more effective when it happens in a supportive learning community and within practice environments, which suggests more implicit learning.\(^5\)

Developing this implicit learning style enhances skill retention and the ability to transfer to novel circumstances but it can take longer initially.\(^10\) The authors feel that this time constraint may be why busy practitioners typically prefer explicit learning opportunities when asked about preferred methods of learning. Not all experiences trigger the same amount of reflection with expected outcomes tending to confirm existing knowledge, thereby triggering less reflection than an unexpected outcome where reflection generates new learning and knowledge.\(^2,\)\(^4,\)\(^8\) As reflection encourages creative and contextual learning, the authors suggest that a deliberate strategy to encourage evidencing reflective practice would address the perceived value of informal implicit learning. Experience alone does not appear to be enough to generate expertise, rather the development of expertise depends on the nature and frequency of reflection. Being able to question areas of practice while being exposed to different ways of thinking within a community of practice takes commitment to accruing both experience and feedback.\(^5\) The authors suggest that a strategy to encourage developing practitioners to more readily share unexpected, potentially suboptimal outcomes, would more effectively facilitate learning, but this requires a change in attitudes.

<table>
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<tr>
<th>LEARNING, REFLECTION AND KNOWLEDGE</th>
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<td>It is clear that expertise is more than isolated formal learning and requires additional deliberate practice and informal learning. From the authors’ experiences, the challenge of using deliberate practice is to balance the need for mistakes to happen to facilitate implicit learning through reflection and problem solving, while attending to athlete safety. This is where mentoring and supervision becomes so important, especially in the competitive world of sport, where...</td>
</tr>
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</table>
performance is key and there is often little tolerance for errors. Thus, working with colleagues who possess greater expertise provides an element of protection to both the developing practitioner and the athlete. The specialist workforce scarcity and budget limitations mean that sports teams will readily recruit novice practitioners, who often find themselves in a sole practitioner role very early in their careers. As a profession sports physiotherapy needs to develop a more effective community of practice, so that a platform can be created for future specialists to develop their expertise. This can be done virtually as well as through direct supervision but must reflect the local cultural and economic environments in order to be effective. Easily accessible mentoring also helps keep the athlete safe, as well as benefiting both the mentor and mentee. The IFSPT and National member organizations can play an important role in changing attitudes towards using deliberate practice and presenting reflections on informal learning to include a breadth of experiences, both positive and negative.

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REFERENCES


Blood Flow Restriction: Cause for Optimism, But Let’s Not Abandon The Fundamentals

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Keywords: bfr, sports physical therapy, strength training

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One of the most popular modalities in sports physical therapy in recent memory is blood flow restriction (BFR) training. The concept of BFR dates back to the 1960's, and BFR-related studies published in the literature started increasing in the early 2000's. Its close relative, ischemic preconditioning, had been used even earlier than the 2000's in non-traditional sports physical therapy populations, like cardiac disease, but is now being used as a recovery tool in sports medicine settings. As sports physical therapy professionals, we have a good reason to be excited about this modality. Many interventions we use or have used have little to no scientific basis or clinical research to support them. There are numerous trends that have a theoretical basis for use. Thus, it seems we tend to put practice before the scientific and/or clinical research support. BFR training has not only been supported scientifically regarding mechanisms of action in the literature, but also has support from clinical studies indicating that BFR helps to relieve pain,1,2 improve aerobic capacity,3–6 reduce the deleterious effects of immobilization,7,8 improve bone healing,9–11 and assist in the care of impairments in specific diagnoses like ACL reconstruction.12,13

Given that muscle weakness and atrophy are common impairments after musculoskeletal injury, BFR enables the sports physical therapist to mitigate atrophy and muscle weakness under low load conditions in order to minimize stress to healing tissues.14 The number of studies on the subject matter in peer-reviewed journals has exploded in the last six or seven years. The author of this viewpoint presented on the topic in 2015 and it was a novel concept to the audience and received with skepticism – for many of the current reasons. It can be overwhelming to wade through the science, the clinical studies, and the myriad of other considerations regarding BFR – safety/efficacy, indications/contraindications, cuff selection, etc. Complicating matters further is that whenever trendy interventions surface, it is tempting to use them for any and all populations – everyone wants the shiny new toy, so to speak. The danger of this approach, though, is that in lieu of using proven methods, it is enticing to utilize cutting edge approaches for any and all purposes. Therefore, the objective of this viewpoint is threefold. First, a review of physiologic responses to BFR compared to more traditional training methods will be discussed. Second, a summary of key considerations for BFR with particular emphasis on safety and risk of DVT’s will be reviewed. Last, a brief discussion about potential clinical usage and recommendations for implementing BFR.

It is beyond the scope of this clinical viewpoint to go into detail about the neural, mechanical, and metabolic mechanisms of increased strength and hypertrophy. There are several excellent review articles: Patterson et al.,15 Pearson et al.,16 and Hwang et al.17 for reviews on the mechanisms of BFR, and Schoenfeld et al.,18 Kraemer et al.,19 and Kraemer et al.20 for reviews on traditional loading, respectively. To summarize, both traditional loading for strength and hypertrophy as well as low-load training with BFR cause increases in muscle building materials – growth hormone, Insulin-like growth factors (IGF’s), Vascular Endothelial Growth Factor, mTORC1, and myogenic stem cells – all of which contribute to protein stimulus and muscle hypertrophy.21–25 When muscles are loaded up to 60% of one repetition maximum (1RM) or trained to failure, either could be an potent stimulus for muscle hypertrophy.18 Strength is best trained with high loads, typically >80% 1RM for 3–4 sets in the 1–8 repetition range with long rest periods. In cases of the recovering athlete, high loads may not be appropriate or contraindicated. The evidence to date has shown that many of the benefits of traditional higher load training methods are similar or enhanced with low-load environments while using BFR. This is an exciting and clinically meaningful outcome. If we can get strength gains with loads that are as low as 20% of 1RM, this is significant for just about anyone in practice.

Several concerns are frequently raised regarding the risk of deep venous thrombosis (DVT)/safety and legality. The reader is referred to the recent paper by Bond et al.24 discussed the risk of DVT’s when using BFR. Additionally, the Wells Criteria for DVT risk is a good reference for this topic.25 The fear of DVT is, at this time, more fear over facts. The author of this clinical viewpoint is not aware of any cases where a DVT was caused by BFR training. In a case study26 by Noto et al., a subject got an effort thrombosis in the upper extremity, but a review of the training in that study showed that the subject trained every day with oc-
clusion for about an hour. Time under occlusion is an aspect of BFR that is a topic of debate. Surgical tourniquets are inflated to well over 100 mmHg on average, applied for about 2 hours, and have a complication rate of 0.04%.27 Most studies maintain occlusion, while other studies have allowed reperfusion between exercises or sets.28 Patterson et al.15 suggest 5–10 minutes of occlusion per exercise and suggest continuous or intermittent pressure. Discomfort is typically the reason for the need for reperfusion, particularly if higher pressures are being utilized. It is possible that allowing reperfusion between sets may allow greater volume to be achieved due to less discomfort. Depending how many exercises are being performed, the tolerance to the pressure of the subject, and whether or not failure is achieved, the author suggests that occlusion time be for about 10 minutes for resistance exercises. The author is not aware of any studies saying one should not go over 10 minutes, but current studies seem to show benefits are realized in 10 minutes. It appears that an occlusion time around 10 minutes is the "minimum effective dose" to realize the benefits of BFR. However, we do not know at this time if longer times are more efficacious or warranted. For aerobic conditioning, about 20 minutes is suggested, but again, we do not know if longer times are warranted. Most of the side effects are short-lived, such as petechiae, numbness, and potentially abrasions if the BFR cuff isn’t appropriately applied. The most notable side effect is likely discomfort. It is professional duty and responsibility to educate oneself on the scientific reasoning of a modality or treatment, application, relative indications, contraindications, and side effects. It is the responsibility of sports physical therapists to appropriately educate our patients and obtain their consent to treatment. Finally, thorough documentation is imperative, with or without BFR. In summary, BFR is safe when used appropriately & under proper safety guidelines.

BFR is approved in the practice acts for both physical therapists and athletic trainers by the APTA29 and NATA,30 respectively. There is currently no requirement for certification, nor is there any one device that is required to be used in exclusivity. It is important for the sports physical therapist to check state practice acts and ensure that key stakeholders like physicians, administrators/supervisors, and legal counsel are educated on the science, application, risks, and benefits of using BFR. Ultimately, the decision may not be made by practicing clinicians, but being informed is the most pragmatic approach.

At this time, BFR is most recommended to attenuate losses in hypertrophy and strength in conditions when traditional, high loads are either not indicated nor appropriate given the pathology in question. In addition, post-operative conditions of the lower extremity or injuries requiring immobilization are ideal candidates for BFR. BFR has been shown to have an additive effect when used with neuromuscular electrical stimulation (NMES)31–33 and the sports physical therapist should consider using it as an adjunct to traditional use of NMES. BFR is helpful for reducing pain and increasing strength in those whose symptoms may be exacerbated by high loads, such as advanced osteoarthritis of the knee;34,35 however, it should be noted that the benefit of BFR in this particular population is in question in regards to clinical outcomes.36 In the upper extremity, the benefits of improved strength and hypertrophy37,38 may be realized in rotator cuff repairs, Bankart repairs, SLAP repairs, or biceps/pectoral tendon repairs, but there is a less data on diagnosis-specific benefits of BFR in the upper extremity. Regardless of diagnosis, BFR should be used as a supplement to or to augment traditional loading progressions rather than a replacement of these methods.

While it appears that higher arterial occlusion pressures (AOP) are more beneficial, a range of 40–80% of AOP could be used if greater pressures are not tolerated by the patient or athlete. AOP should be determined by either Doppler ultrasound or pulse oximetry in the absence of personalized systems. Loading should be anywhere from 20–40% of one repetition-maximum (1RM), and this could be determined by a 10RM estimate, using the uninvolved limb as reference, or a load equivalent to 2-3 on the RPE scale. Usually, a minimum of 2-3 sets but up to 5 sets per exercise are recommended with anywhere from 45–75 repetitions per exercise. The lower end of this repetition scheme is assuming at least 1-2 sets are performed to failure.39 One or two sets to failure is encouraged to maximize the hypertrophic effects.39,40 While the primary indications are listed above, there is evidence that BFR can be used to augment aerobic training at 30-50% of heart rate reserve (HRR) through either walking or use of other cardiovascular activities such as cycling or elliptical trainers.3–7 Additionally, studies have shown a benefit of BFR for improvements in VO2 Max.41–44 The benefits of BFR for performance training are likely indirect. Strength is the foundation of athletic performance and, therefore, increasing strength should improve power, but this may or may not transfer to actual improvements in sports performance. Thus, more power during strength training exercises may not transfer to improvements in batting average, shot percentage, or rushing yards, for example. It is not recommended that BFR be used prior to explosive activities due to BFR exercises being performed at or near volitional fatigue. While it is early to make any definitive conclusions, there is some early evidence that ischemic preconditioning may enhance recovery after athletic performance,45–49 but evidence to the contrary exists as well.50,51

While BFR appears to be a very promising and exciting innovation in our field, it is important to keep in mind that accepted, proven training practices and principles are not abandoned. Prior to incorporation of BFR training clinicians should ask themselves several questions. Why are more traditional methods not working? Has traditional exercise been dosed and loaded correctly? Has the clinician adhered to the principle of progressive overload? Is there an issue with programming that is prohibiting making the desired improvements? When an athlete is appropriate for higher loading, they should have higher loads. BFR should augment or be a supplement to traditional training methods when appropriate, not a replacement. While there a number of encouraging, positive studies on BFR, we still have so much to learn. The author encourages the reader to investigate the science, mechanisms, applications, clinical usage, and seek answers to clinical inquiries – but continue using proven, evidence supported methods for resistance training.

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Blood Flow Restriction: Cause for Optimism, But Let’s Not Abandon The Fundamentals
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