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ABSTRACT

Background: Sudden changes (increases and decreases) in training load have been suggested to play a key role in the development of running-related injuries. However, the compiled evidence for an association between change in training load and running-related injury does not exist.

Purpose: The purpose of the present systematic review was to compile the evidence from original articles examining the association between changes in training load and running-related injuries.

Study Design: Systematic review.

Methods: Four databases (Pubmed/Medline, SPORTDiscus, Embase, and Scopus) were systematically searched. Two reviewers screened titles, abstracts, and full-text articles independently. Articles were included if i) the study design was a randomized trial, a prospective cohort study, a cross-sectional study or a case-control study, ii) participants were runners between 18-65 years, and iii) specific information on changes in training load was provided. Methodological quality of included articles was assessed using the Newcastle Ottawa Scale and the PEDro rating scale.

Results: Four articles fulfilled the eligibility criteria of which three found an association between increases in training load and an increased risk of running-related injuries: This association was shown by an increased injury risk amongst runners: i) if they recently had performed one or more changes in either velocity and/or distance and/or frequency compared with the non-injured runners (p=0.037), ii) increasing their average weekly running distance by more than 30% compared to an increase less than 10% (Hazard Ratio = 1.59 (95% Confidence Interval: 0.96; 2.66)), iii) increasing their total running distance significantly more the week before the injury origin compared with other weeks (mean difference: 86%; 95% Confidence Interval: 12%; 159%, p=0.026). However, no difference was found between a 10% and a 24% average increase in weekly volume (HR=0.8, 95% CI: 0.6; 1.3).

Conclusion: Very limited evidence exists supporting that a sudden change in training load is associated with increased risk of running-related injury.

Level of evidence: 2

Keywords: Etiology, running-related injuries, training load.
INTRODUCTION
Unravelling the etiology of running-related injury (RRI) has received extensive scientific attention throughout the past decades. A vast number of different risk factors for injury have been proposed, such as foot strike patterns, age, gender, body mass index (BMI), anthropometrics, footwear properties and anatomical factors, with absence of clear support for many of them.1 A history of previous injury is consistently reported in the literature as a strong risk factor for injury development; however, owing to its non-modifiable nature, the relevance of including it as a factor in an effective injury prevention intervention strategy is minor. Conversely, focusing on readily modifiable and causal plausible factors, such as scheduling of training load, has been suggested to have greater impact on RRI development.

Therefore, investigation of the role of training load as the main exposure of interest is essential to succeed with developing effective injury prevention strategies. Within sports injury research, the phenomenon “training too much, too soon”, or a sudden increase in training load, has been acknowledged to play a key role on injury development.2-6 This phenomenon also seems to resonate within RRI research,9,10 and furthermore, is being highlighted by runners and coaches as especially important in relation to injury development.11 From a theoretical viewpoint, injury occurs when the cumulative training load, over one or several running sessions exceeds the body's load capacity for adaptive tissue repair;2,9 training load comprises several variables (e.g. running distance, number of steps or strides, running pace or speed, and time spent running). Consequently, running data should be analyzed using changes in training load between each running session (or short period of time), as training load continuously changes over time and therefore should be considered as a time-dependent variable.12 This approach seems more appropriate to illuminate RRI etiology compared with examining running data as fixed, absolute, weekly mean values, or with investigating non-training-related risk factors for injury that simply identify sub-populations at higher or lower risk of injury.

In a previous systematic review13 aiming to investigate the association between training characteristic (i.e. volume, duration, intensity, and frequency of running) and RRI, training error in a specific training characteristic could not be identified. However, considerations about sudden changes in the training load were not considered as a potential injury mechanism.2-7,14 With the current high focus on sudden changes in training load, as well as the use of more complex statistical approaches in sports medicine,12 new evidence might be available. Therefore, the purpose of the present systematic review was to compile the evidence from original articles examining the association between changes in training load and running-related injuries.

METHODS

Literature Search
The first and the second author (CD and SG) performed an electronic literature search in four databases (Pubmed/Medline, SPORTDiscus, Embase, Scopus) from their inception to April 31st 2017. Database limits were set to published articles or articles in press written in English. A certified research librarian at Aarhus University Library, Denmark supervised the building of the search string through using the PICOS approach.15 The complete search strategy for all four databases are provided in Appendix 1.

Study selection
All articles were systematically and independently screened for eligibility by three reviewers (CD, SG and LM). All titles and abstracts were screened by CD and SG, and eligible articles retrieved in full text were carefully read by CD and LM. To be eligible for inclusion, the articles had to fulfill the following criteria:

Inclusion criteria:
1) The research of interest was specifically focused on changes in training load in relation to RRI;
2) the study design was a randomized trial, a prospective cohort study, a cross-sectional study or a case-control study;
3) the study participants were between the age of 18 and 65 years;
4) participants were runners (novice runners, recreational runners, elite runners, distance
runners, long-distance runners, road runners, trail runners, marathoners, ultra-marathon runners, extreme runners, track athletes, cross-country runners or orienteers);

Exclusion criteria:

1) running was not the participants' primary sport activity, e.g. football players, soccer players;

2) the RRI was not a musculoskeletal injury (i.e. blisters, skin abrasions, delayed onset muscle soreness or superficial bruises);

3) study subjects were military or army recruits;

In cases of disagreements between the reviewers regarding inclusion or exclusion of an article, a consensus meeting was held and if no consensus was reached, a fourth reviewer (RON) made the final decision.

Quality Assessment

The methodological quality assessment of the included full text articles was performed by three authors (CD, SG and LM) in an independent and blinded manner. The Newcastle Ottawa Scale (NOS) was chosen for assessing the quality of the included non-randomized studies due to its previous use within RRI. Furthermore, the NOS is reported as one of two most useful tools by the Cochrane Handbook for Systematic Reviews of Interventions and allows customization to the review question of interest. The original NOS contains 11 criteria designed to assess the risk of bias, and uses a star rating system to indicate the quality of a study. The 11 criteria are as follows: 1) description of runners or type of runners; 2) definition of the running-related injury; 3) representativeness of the exposed cohort; 4) selection of the non-exposed cohort; 5) ascertainment of exposure; 6) demonstration that outcome of interest was not present at the start of the study; 7) comparability of cohorts on the basis of the design or analysis; 8) assessment of outcome; 9) was follow-up long enough for outcomes to occur; 10) adequacy of follow-up of cohorts; and 11) statistic measurement of risk association.

The highest possible quality score in the original version is 12 stars (it is possible to award Criterion 7 with two stars). However, the tool was modified for the present review by excluding two of the 11 criteria; Criterion 4 was excluded because an exposed versus non-exposed cohort was irrelevant as long as the total study population was exposed to running, and Criterion 7 was excluded because it was linked to Criterion 4 comparing the exposed with the non-exposed cohort. These modifications decreased the highest possible quality score to 9 stars.

The methodological quality of the included, randomized trial was rated using the PEDro rating scale, which is based on the Delphi list developed by Verhagen and colleagues. The PEDro scale also contains 11 criteria to assess the risk of bias, which are as follows: 1) eligibility criteria were specified; 2) participants were randomly allocated to groups; 3) allocation was concealed; 4) groups were similar at baseline; 5) blinding of all participants; 6) blinding of all therapists who administered the intervention; 7) blinding of all assessors who measured at least one key outcome; 8) measures of at least one key outcome were obtained for more than 85% of participants initially allocated to groups; 9) data for at least one key outcome was analyzed by “intention-to-treat”; 10) results of between-group statistical comparisons reported for at least one key outcome; 11) study provided both point measures and measures of variability for at least one key outcome. In a recently published study by Yamato et al. 2017, the use of the PEDro scale demonstrated both high validity and inter-rater reliability when compared to the Cochrane back and neck risk of bias tool.

The total methodological quality of each included article was expressed in percent by calculating the number of criteria being fulfilled divided by the total number of possible ratings. All disagreements between the researchers in relation to the methodological quality assessment were resolved by a consensus meeting between the assessors (CD, SG, LM).

Data Extraction

Two authors (CD and LM) independently extracted the following information and data from the included studies; 1) first author and date, 2) injury type, 3) definition of exposure, 4) specification of exposure and 5) results. In case of any doubts about the extracted data, a meeting was held between the three authors (RON, CD, LM) to clarify the accuracy.
of the data. The interpretation of results included the proportion of injured and non-injured runners, the mean difference between them, measures of associations, and the corresponding level of statistical significance.

**RESULTS**

**Literature Search**

A total of 8,242 articles were identified through searching the four databases. Of those, 2,399 were duplicates, leaving 5,843 articles for screening of the title and abstract.

Primary screening resulted in exclusion of 5,779 articles, leaving 64 articles eligible for full assessment one of which was not available in full text. While assessing the remaining 63 full texts in accordance with the eligibility criteria, the reference list within each article were screened to identify potential new articles that were not found in the primary literature search. By this process, two additional articles were identified as eligible, and thus included in the assessment of full text articles. Out of the total 65 articles assessed in full text, 61 were excluded primarily due to no available information about changes in training load. The remaining four articles were included in the quality assessment. The selection process of the literature is presented in the PRISMA diagram (Figure 1).

**Description of the included articles**

In Table 1, the included studies are described according to: 1) year of publication; 2) country of origin; 3) study design; 4) study population; 5) sample size of participants; 6) baseline characteristics including injury history; 7) the collection method for the running data; 8) the collection method for the injury status; 9) injury definition. In three studies, all participants were injury free prior to baseline, whereas in one study, a group of injured runners was compared to a group of non-injured runners. In the study by Cantidio et al. the proportion of runners who reported recent variations in one or more of the running variables among the two groups (the injured and the non-injured runners) was presented, whereas no result for statistical comparison was provided. Therefore, as all data were available to run a Chi-square test this was performed by the present authors in order to compare the two proportions.

**Risk of Bias Assessment**

Information on potential risk of bias for the included studies is shown in Table 2. Among the non-randomized studies, the most frequent reasons for decreased quality scores were: low external validity, a follow-up period shorter than 12 weeks, and lack of reporting a measure of association, while the risk of bias was more related to the absence of blinding procedures in the included randomized trial.

**Changes in Training Load and RRI**

An overview of the existing evidence for the association between a change in training load and RRI is presented in Table 3. Overall, a tendency toward an increased injury risk following a sudden increase in training load was identified in three out of the four studies included. Cantidio et al. (22% methodological quality assessment score) showed that a significantly higher proportion of the injured runners had recently changed one or more of the running variables (velocity, distance, volume or frequency) compared with the non-injured runners (p=0.037). In Nielsen et al. (67% methodological quality assessment score), two different analyses related to an increase in running distance were reported. First, the runners who developed an injury during follow-up had increased their average weekly running distance with 31.6±3.1%, while the average for the runners that stayed injury free was 22.1±2.1% (p=0.07). Second, the mean difference between the increase in the running distance the week before the onset of an injury and the average weekly increase during other weeks was found to be 86% (95% confidence interval (95% CI): 12.9; 159.9, p=0.026). In the other study by Nielsen et al. (100% methodological quality assessment score), an increased Hazard Ratio (HR)=1.59 (95% CI: 0.96; 2.66) for distance-related injuries (i.e. patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, gluteus medius injury, greater trochanteric bursitis, injury to the tensor fascia latae and patellar tendinopathy) was found when increasing the weekly running distance by more than 30% compared to a less than 10% change (increase or decrease).

In contrast with the three studies above, the randomized trial by Buist et al. (73% methodological quality assessment score) showed that a significantly higher proportion of the injured runners had recently changed one or more of the running variables (velocity, distance, volume or frequency) compared with the non-injured runners (p=0.003). The interpretation of results included the proportion of injured and non-injured runners, the mean difference between them, measures of associations, and the corresponding level of statistical significance.
quality assessment score) found that the novice runners who followed the graded training program characterized by a 10% average increase in weekly volume were not at a lower injury risk (HR = 0.8, 95% CI: 0.6; 1.3) when compared to the novice runners who followed the standard training program (24% average increase in weekly volume).

**DISCUSSION**

**Main Findings**

The aim of the present systematic review was to search the literature for articles examining the association between changes (progressions and regressions) in training load and RRI. Four articles were included and of these, three studies found an
increased risk of injury development following either a sudden increase in running distance between two weeks \[10,23\], or a non-specific recent change in one or more of the training variables velocity, distance, volume or frequency during the past weeks (no available data on the timing of this sudden change)\[24\]. In contrast, in the fourth included study, Buist et al.\[22\], found no difference was found in injury risk when comparing two intervention groups (a graded training program with 10% average increase in weekly volume vs. a standard training program with 24% average increase in weekly volume). Thus, very limited evidence exists supporting that sudden changes are associated with increased injury risk among runners. As it may be plausible to assume that excessive progression in training load is associated with

### Table 1.

<table>
<thead>
<tr>
<th>References, Country of origin</th>
<th>Study design (follow-up)</th>
<th>Study population</th>
<th>Baseline characteristics</th>
<th>Data collection method</th>
<th>Musculoskeletal injury definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buist et al. 2008[22], The Netherlands</td>
<td>Randomized Controlled Trial (8 and 13 weeks for the standard and the graded training group, respectively)</td>
<td>532 novice runners (306 females). No running history the previous 12 months</td>
<td>Age range 18-65 years. No injury of the lower extremity within the preceding 3 months</td>
<td>Internet-based running log for both main exposure and outcome</td>
<td>Any self-reported running-related musculoskeletal pain of the lower extremity or back causing a restriction of running for at least 1 week (three scheduled trainings)</td>
</tr>
<tr>
<td>Cantidio Ferreira et al. 2012[24], Brazil</td>
<td>Cross-sectional study</td>
<td>100 leisure-time runners (27 females). Running history: minimum 3 months. Weekly frequency: 3-4 times. Mean distance per session: 5-7 kilometers</td>
<td>Age range 18-60 years with no history of previous trauma in lower limbs</td>
<td>Information about recently training variations and injury status was covered using a questionnaire</td>
<td>Injury, pain or aggravation which had limited or prohibited participation of the athletes in training and/or competitions for one or more days in the prior 6 months</td>
</tr>
<tr>
<td>Nielsen et al. 2013[22], Denmark</td>
<td>Prospective study (10 weeks)</td>
<td>58 novice runners (28 females). Running history: below 10 kilometers in total in all training sessions in the previous 12 months</td>
<td>Healthy novice runners age range 18-65 years with no injury in the lower extremities or back 3 months preceding baseline investigation</td>
<td>GPS watch data uploaded on an internet-based training diary and examination of injured runners by a physiotherapist</td>
<td>Any musculoskeletal complaint of the lower extremity or back causing a restriction of running for at least 1 week</td>
</tr>
<tr>
<td>Nielsen et al. 2014[10], Denmark</td>
<td>Prospective study (1 year)</td>
<td>873 novice runners (432 females). Running history: below 10 kilometers in total in all training sessions in the previous 12 months</td>
<td>Healthy novice runners age range 18-65 years with no injury in the lower extremities or back 3 months preceding baseline investigation</td>
<td>GPS watch data uploaded on an internet-based training diary and examination of injured runners by a physiotherapist</td>
<td>Any musculoskeletal complaint of the lower extremity or back causing a restriction of running for at least 1 week</td>
</tr>
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### Table 2.

**Newcastle Ottawa Scale (Adapted)**

<table>
<thead>
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<th>References</th>
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</tbody>
</table>

**Pedro Scale**

<table>
<thead>
<tr>
<th>References</th>
<th>Study design</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buist et al. 2008[22]</td>
<td>RCT</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0</td>
<td>0</td>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>8/11</td>
<td>73%</td>
</tr>
</tbody>
</table>
The overall methodological quality of the studies included in the present systematic review is varied. The study populations and RRI were accurately defined in all four studies, but failure to report measures of association, short follow-up periods, and lack of generalizability were observed in two of the prospective cohort studies.\textsuperscript{23,24} Also, the randomized trial did not include any blinding procedure.\textsuperscript{22}

### Table 3. Results

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study population</th>
<th>Injury</th>
<th>Definition of exposure</th>
<th>Specification of exposure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buist 2008\textsuperscript{22}</td>
<td>532 novice runners (306 females). No running history the previous 12 months</td>
<td>Overall RRI</td>
<td>Increase in weekly volume on average (%)</td>
<td>GTG: 10% increase in volume, STG: 24% increase in volume</td>
<td>Incidence of RRI: GTG: 20.8%, STG: 20.3%, (p-value: 0.9), HR: 0.8 [0.6; 1.3]</td>
</tr>
<tr>
<td>Cantidio Ferreira 2012\textsuperscript{24}</td>
<td>100 leisure-time runners (27 females). Running history: minimum 3 months. Weekly frequency: 3-4 times. Mean distance per session: 5-7 kilometers</td>
<td>Overall RRI</td>
<td>Recent training variation</td>
<td>Variation in velocity, distance, volume or frequency during the past couple of weeks</td>
<td>Recent training variation: Injured group: 52.5%, Non-injured group: 31.7%, (p-value: 0.037)</td>
</tr>
<tr>
<td>Nielsen 2013\textsuperscript{23}</td>
<td>58 novice runners (28 females). Running history: below 10 kilometers in total in all training sessions in the previous 12 months</td>
<td>Overall RRI</td>
<td>Increase in running distance (%)</td>
<td>Average weekly progression in running distance (%)</td>
<td>Injured: 31.6±3.1%, Injury free: 22.1±2.1%, (p-value: 0.07)</td>
</tr>
<tr>
<td>Nielsen 2014\textsuperscript{10}</td>
<td>873 novice runners (432 females). Running history: below 10 kilometers in total in all training sessions in the previous 12 months</td>
<td>Overall RRI</td>
<td>Weekly progression in running distance (%)</td>
<td>&lt;10% (ref) 10% - 30% &gt;30%</td>
<td>HR: 0.99 [0.55; 1.82], (p-value: 0.99), HR: 1.17 [0.84; 1.63], (p-value: 0.36)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distance-related injuries</td>
<td>&lt;10% (ref) 10% - 30% &gt;30%</td>
<td>HR: 1.03 [0.37; 2.90], (p-value: 0.96), HR: 1.59 [0.96; 2.66], (p-value: 0.07)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pace-related injuries</td>
<td>&lt;10% (ref) 10% - 30% &gt;30%</td>
<td>HR: 0.91 [0.32; 2.63], (p-value: 0.86), HR: 0.83 [0.44; 1.57], (p-value: 0.56)</td>
<td></td>
</tr>
</tbody>
</table>

RRI: Running-related injuries as defined in table 1; GTG: Graded Training Group; STG: Standard Training Group; HR: Hazard Ratio [and its 95% confidence interval]; Ref: Reference group; a Cox regression analysis; bChi-square test; c-t-test; dpaired t-test.

Increased injury risk, it is emphasized that future studies are highly needed to better define the role of sudden changes on RRI occurrence in a causal perspective.\textsuperscript{25}

### Study Quality Assessment

The overall methodological quality of the studies included in the present systematic review is varied. The study populations and RRI were accurately defined in all four studies, but failure to report measures of association, short follow-up periods, and lack of generalizability were observed in two of the prospective cohort studies.\textsuperscript{23,24} Also, the randomized trial did not include any blinding procedure.\textsuperscript{22}

### Definition of Change

In the articles in the current systematic review a change was defined as the change in running...
Independent of the way changes have been defined and the statistical approaches used, the main scientific aim is to shed light upon: What defines a change? Which magnitude of sudden changes has clinical relevance in relation to injury risk? Despite the substantial attention that these questions have paid, no clear consensus has been reached yet.

This demonstrates the need for identifying which definition of change(s) appears to have the strongest association with injury development in order to explore if one definition turns out to be more relevant compared to others, bearing in mind that one definition might be clinically relevant for a specific sports discipline or population while less valuable in another contexts.

Defining an Upper Limit for Sudden Increases

When examined from a practical and clinical perspective, the results from the present systematic review reveal that no evidence exists for the use of the so-called “10% rule”, which is commonly used by runners, coaches and clinicians as a guideline for a maximum increase in training load per week. Buist et al. 2008 compared injury risk based on an average increase in weekly volume of 10% and 24%, but did not find any difference between the two groups. An average weekly increase in training load of 24% may not be sufficiently large to reflect the mechanism of running too much, too soon in novice runners. This interpretation is in accordance with the findings by Nielsen et al. who found that the injurious mechanism of sudden increase happened for the novice runners increasing their average weekly distance more than 30% compared with the reference group increasing less than 10% while no difference was found for the group increasing by 10%-29% compared with the reference group. However, it should be noted that in the study by Buist et al., an average increase in weekly volume was used (13 weeks and eight weeks for the study group increasing 10% and 24%, respectively). In the study by Nielsen et al., the examination of the association between training characteristics and RRI focused on the comparison between one week and the next, but multiple changes over time were not accounted for. In the study by Cantidio et al., a higher proportion of runners with recent training changes were found among the injured group compared to the non-injured group. However, it was neither specified to which extend nor direction the training load changed, and thus, it is not possible to quantify the size of a potentially injurious sudden change in training load based on the results. Therefore, based on the four included studies, no evidence was found to support a well-defined threshold for hazardous sudden changes in training load above which the risk of injury development is significantly increased. Such a threshold might be specific to the definition and the method used to assess sudden changes, and above all, to the population of runners investigated. Given that the absolute training load was low in the populations investigated so far (e.g. total distance over a full year period less than 10 kilometers), a small increase in training load might result in a large relative sudden increase (e.g. increasing from 2 to 3 km per week represents an absolute difference of 1 km but a relative sudden increase of 50%). These runners’ profiles cannot be compared to other populations of runners with larger training load (e.g. a competitive runner running 100 km per week would only observe a 3% sudden increase in training load with an absolute increase of 3 km from one week to the next, and he would have to increase training load by 50 km per week to observe a 50% sudden change).

Limitations

The main limitations of the present study include: 1) the number of relevant databases that were searched: 2) the screening of articles for eligibility and 3) the limited generalizability of the findings. Regarding the databases the four largest (PubMed/
Medline, SPORTDiscus, Embase, Scopus) and most relevant for the specific research question in the present systematic review were searched. However, other databases such as PEDro and Web of Science could also have been relevant. In relation to the screening of articles for provision of information about changes in training load, this was performed on an abstract level in order to screen out articles just reporting the difference in injury risk between different subgroups of runners having performed a different weekly average. However, it is unknown if some articles deemed ineligible at this stage may have contained information about training load and injury that would have been evident if evaluated in full-text. Considering the generalizability of the findings, this is an important issue to address as all the studies included in the present systematic review only involved “novice” and “amateur” runners, which limits the applicability of the findings to other populations of runners. Finally, due to the heterogeneity observed in the study designs, the runners’ profiles, as well as the methods used for data collection and analysis of changes in training load, comparison of the results of the four included studies in the present systematic review must be performed with caution.

CONCLUSIONS

Very limited evidence exists supporting that changes (increases and decreases) in training load are associated with injury development. Specifically, no evidence was found to support the use of the so-called “10% rule”, which is commonly used by runners, coaches and clinicians as a guideline for a maximum increase in training load per week. Actually, a well-defined threshold for hazardous or sudden changes in training load above which the risk of injury development is significantly increased is still unknown. Future studies in runners of varied abilities are needed to better define the role of changes on RRI occurrence in a causal perspective using methodological approaches that take into account the time-varying nature of changes in training load.

REFERENCES


APPENDIX 1

SEARCH TERMS FOR PUBMED

(running[Majr] OR running)
AND
(exercise OR exposure OR "Exercise Therapy"[MeSH] OR "physical education and training/methods"[MeSH] OR "Healthy People Programs"[MeSH] OR (training method) OR regime OR program OR programme OR marathon OR training OR (training characteristics) OR (running patterns) OR volume OR intensity OR frequency OR speed OR pace OR distance OR mileage OR (number of strides) OR (number of steps) OR duration OR (number of running sessions) OR (cumulated stress) OR cadence OR (time spent running) OR progression* OR change OR alterations OR transition*)
AND
("Athletic Injuries"[MeSH] OR "running/injuries"[MeSH] OR injury OR (running injur*) OR (running-related injur*) OR injur* OR (overuse injur*)) OR "patellofemoral pain syndrome"[MeSH] OR "compartment syndromes"[MeSH] OR "iliotibial band syndrome"[MeSH] OR inflammation OR (cartilage injuries) OR tendin* OR fractur* OR fasciitis OR bursitis OR splint* OR tear* OR sprain* OR strain* OR entrapment* OR rupture* OR split* OR tenosynovitis)
NOT
("addresses"[Publication Type] OR "bibliography"[Publication Type] OR "biography"[Publication Type] OR "case reports"[Publication Type] OR "clinical conference"[Publication Type] OR "comment"[Publication Type] OR "congresses"[Publication Type] OR "dictionary"[Publication Type] OR "directory"[Publication Type] OR "editorial"[Publication Type] OR "festschrift"[Publication Type] OR "government publications"[Publication Type] OR "interview"[Publication Type] OR "lectures"[Publication Type] OR "legal cases"[Publication Type] OR "legislation"[Publication Type] OR "letter"[Publication Type] OR "news"[Publication Type] OR "newspaper article"[Publication Type] OR "retracted publication"[Publication Type] OR "retraction of publication"[Publication Type] OR "review"[Publication Type] OR "scientific integrity review"[Publication Type] OR "technical report"[Publication Type] OR "twin study"[Publication Type] OR "validation studies"[Publication Type] OR football OR basketball OR triathlon OR pregnancy OR rugby OR soccer OR rheumatoid* OR baseball OR military OR army OR combat OR animal* OR mice OR (case series) OR hockey OR rats)

SEARCH TERMS FOR SPORTDISCUS

(DE ‘RUNNING’ OR running)
AND
(exercise OR exposure OR DE “Exercise Therapy” OR DE “physical education” OR DE “PHYSICAL training & conditioning” OR DE “PHYSICAL activity” OR (training method) OR regim* OR program OR programme OR marathon OR training OR (training characteristics) OR (running patterns) OR volume OR intensity OR frequency OR pace OR distance OR mileage OR (number of strides) OR (number of steps) OR duration OR (number of running sessions) OR (cumulated stress) OR cadence OR (time spent running) OR progression* OR change OR alterations OR transition*)
AND
(DE ‘SPORTS injuries’ OR DE “RUNNING injuries” OR DE “OVERUSE injuries” OR DE “PLICA syndrome” OR DE “COMPARTMENT syndrome” OR DE “ILIOTIBIAL band syndrome” OR injury OR (running injur*) OR (running-related injur*) OR injur* OR inflammation OR (cartilage injuries) OR tendin* OR fractur* OR fasciitis OR bursitis OR splint* OR tear* OR sprain* OR strain* OR entrapment* OR rupture* OR split* OR tenosynovitis)
APPENDIX 1 (continued)

NOT
(football OR basketball OR triathlon OR 'pregnancy' OR rugby OR soccer OR rheumatoid* OR baseball OR military OR animal* OR mice OR (case reports) OR (case series) OR hockey OR rats)

SEARCH TERMS FOR EMBASE

('running'/exp OR running)

AND
(exercise OR exposure OR 'kinesiotherapy'/exp OR 'training'/exp OR 'health promotion'/exp OR (training method) OR regimen* OR program OR programme OR marathon OR training OR (training characteristics) OR (running patterns) OR volume OR intensity OR frequency OR pace OR distance OR mileage OR (number of strides) OR (number of steps) OR duration OR (number of running sessions) OR (cumulated stress) OR cadence OR (time spent running) OR progression* OR change OR alterations OR transition*)

AND
('sport injury'/exp OR 'patellofemoral pain syndrome'/exp OR 'iliotibial band friction syndrome'/exp OR 'compartment syndrome'/exp OR injury OR (running injur*) OR (running-related injur*) OR injur* OR inflammation OR (cartilage injuries) OR tendin* OR fractur* OR fasciitis OR bursitis OR splint* OR tear* OR sprain* OR strain* OR entrapment* OR rupture* OR split* OR tenosynovitis)

NOT
(football OR basketball OR triathlon OR pregnancy OR rugby OR soccer OR rheumatoid* OR baseball OR military OR army OR combat OR animal* OR mice OR (case series) OR (case report) OR (cross sectional) OR hockey OR rats)

SEARCH TERMS FOR SCOPUS

running

AND
(exercise OR training method OR program

AND
injury OR sports injuries
ABSTRACT

**Background/Purpose:** High body mass index is associated with an increased risk of running-related injury among novice runners. However, the amount of running participation plays a fundamental explanatory role in regards to running-related injury development. Therefore, the purpose of the present study was to investigate if the risk of running-related injury among obese novice runners (BMI 30-35) was different when the start-to-run distance was 3km per week instead of 6km per week.

**Hypothesis:** A start-to-run distance of 3km per week is associated with 20% fewer running-related injuries and significantly fewer symptoms of overuse injury than a start-to-run distance of 6km per week among obese novice runners.

**Study design:** Randomized trial

**Methods:** Fifty-six obese novice runners with a body mass index between 30-35 were enrolled and randomized to receive one of the two following Interventions: (i) a 4-week running program with a start-to-run distance of 3km per week including three sessions with 1km running per session (n=29), or (ii) a 4-week running program with a start-to-run distance of 6km per week including three sessions with 2km running per session (reference group, n=27). In both programs, the weekly running distance was increased by 10% each week throughout the follow-up.

**Results:** The intention-to-treat analysis revealed a protective cumulative risk difference of -16.3% (95%CI: -43.8%; 11.3%, p=0.25) after four weeks. Importantly, some participants completed much more running than prescribed (n=5) and some never uploaded any training (n=15). Therefore, a supplementary per-protocol analysis was performed revealing a cumulative risk difference of -31.2% (95%CI: -57.0%; -5.2%, p=0.02) after four weeks. Furthermore, in the per-protocol analysis, the cumulative risk difference of overuse-injury symptoms was -47.8% (95%CI: -81.0%; -14.6%, p=0.01) after four weeks of running.

**Conclusions:** A 3km reduction from 6km per week to 3km per week in the start-to-run distance appears to be associated with fewer running-related injuries and significantly fewer symptoms of overuse injury.

**Key words:** Movement System, Novice runner, Obese, Running, Running-related injury, Training dose

**Level of evidence:** 2b
INTRODUCTION

Running is highly effective at promoting numerous health-related benefits related to body mass, body fat, resting heart rate, VO2max, triglycerides, and HDL cholesterol in physically inactive adults.1 Furthermore, running is associated with a 30% lower risk of all-cause mortality and a 50% lower risk of cardiovascular mortality.2 Notwithstanding the many health benefits, running-related injuries are a well-known problem to runners and clinicians. The yearly cumulative injury risk of running-related injury is 19.4% to 79.3% depending on the population and the injury definition used.3-5 In this regard, obese novice runners seem particularly at risk of injury. Three large-scale prospective cohort studies among novice runners all found an association between higher body mass index (BMI) and increased risk of running-related injury.6-8 Running-related injury can lead to long periods of absence from running or even a permanent stop.9-12 Hence, injury prevention specifically targeted obese novice runners is important to ensure their successful inclusion and long-term commitment to running.

The amount of participation plays a fundamental explanatory role in regards to the risk of sustaining a running-related injury.13-15 This has been visualized by a framework for the etiology of running-related injuries.13 This framework builds on the premise that running-related injury occurs because of a mismatch between the cumulative load of one or more running sessions and the structures capacity to handle that load (the former surpasses the latter). Based on the outlined framework, the explanatory mechanism could be: (i) Obese novice runners are at an enhanced risk owing to a higher load magnitude per stride. Because of the higher body weight, fewer strides are potentially needed to accumulate an injurious amount of load when obese individuals take up running. (ii) Obese individuals may have a lower structure-specific load capacity than normal-weight novice runners when running is initiated owing to the sedentary lifestyle, which is associated with obesity.16 Consequently, the obese novice runner is less prepared to handle the load during running compared with the normal-weight novice runner who may have adapted in advance by being physical active in other weight-bearing sport activities. Fortunately, both mechanisms can be defused by reducing the number of strides/distance accordingly and thereby control the cumulative load at a non-injurious level. This would allow positive adaptations to take place to enhance the structure-specific load capacity before the distance is increased.13

Nielsen et al have recently investigated whether the risk of running-related injury differed in obese (BMI >30 kg/m2) and non-obese (BMI <30 kg/m2) novice runners that initiated running with different weekly start-to-run distances.17 They found obese novice runners to have a 10.8% greater cumulative risk of running-related injury after 20km when the start-to-run distance was >6km the first week compared with <3km.17 In comparison, non-obese novice runners had -1.0% lower cumulative risk of running-related injury after 20km when the start-to-run distance was >6km the first week compared with <3km.17 Nielsen et al concluded that novice runners with BMI >30 kg/m2 should be recommended a cumulative dose of running of <3km the first week. However, owing to the limitations of their study design, randomized trials are needed to further explore the effect of these recommendations.17 More knowledge on the appropriate start-to-run distance for obese novice runners can potentially allow a greater number of persons with obesity to take up running and harvest the many health-benefits running has to offer, without sustaining running-related injury.

Therefore, the purpose of the present study was to investigate if the cumulative incidence proportion of running-related injury among obese novice runners with BMI 30-35 was different when the start-to-run distance was 3km per week instead of 6km per week. It was hypothesized that a start-to-run distance of 3km per week would be associated with 20% fewer running-related injuries and significantly fewer symptoms of overuse injury.

METHODS

Study design

The study was a randomized trial (unblinded) with a 4-week follow-up. Reporting of the study followed the CONSORT statement.18 The study was conducted in Denmark and the Ethics Committee of Northern...
Denmark Region (N-20160031) approved the design, procedures, and informed consent procedures. The study was accepted by the Danish Data Protection Agency. All participants provided written informed consent.

Participants
The recruitment took place from May 2016 to September 2016 and was assisted by video material and written information posted on social media (Facebook). Furthermore, recruitment material was distributed to the employees and students of large public institutions in central Jutland (Via University College, Aarhus University and Central Denmark Region) through their professional e-mail or intranet account. Individuals who were interested in participating completed an online questionnaire, which contained questions about gender, age, running experience, health, previous running-related injuries and non-running-related injuries. Individuals with BMI 30-35, age 18-65 years, no previous running experience (less than 10km combined the last year) and less than one hour of other sports activity per week within the past year were eligible to participate. Individuals were excluded prior to baseline if they had absolute contraindications for vigorous physical activities, a new injury or symptoms from an older injury in the lower extremities within the last two years, or were unwilling to monitor their running training using a GPS-watch or a smartphone application. Persons eligible for inclusion were contacted by phone to verify their eligibility, give verbal information about the purpose and the content of the study, and to make a baseline appointment. Ineligible persons received an e-mail explaining why they were excluded.

Baseline assessment and randomization procedure
The baseline assessment took place at Aarhus University, Department of Public Health, Section for Sports Science, Dalgas Avenue 4, 8000 Aarhus C, Denmark from June 2016 to September 2016. At baseline, eligibility was confirmed once again using a checklist on in- and exclusion criteria. The height of the participants was measured by a ruler and the weight by a calibrated personal scale (SC 330; Tanita Corporation, Tokyo, Japan). BMI was calculated based on these baseline-measurements (kg/m²). Finally, the blood pressure was measured and assessed according to the guidelines from the Danish Hypertension Society to ensure the safety of the participants before final inclusion in the study. After the baseline measurements were completed, the participants were randomly assigned to one of two possible interventions following simple randomization procedures by selecting a sealed envelope containing one of two possible running programs. The participants were not told which intervention they were assigned. However, they were aware that the purpose of the study was to compare injury risk difference between a “standard” and a “reduced distance” program. Thus, they were probably able to identify the intervention by viewing the cumulative start-to-run distance the first week and compare it to other “standard” running programs. All enrollment and assignment procedures were carried out by the same principal investigator (MLB).

Interventions
Three kilometer (3km): Running program with a cumulative running distance of 3km the first week (1km per session). The program consisted of four weeks with three weekly training sessions. The running distance was increased by ~10% per week. The specific details of the running program are shown in Table 1.

Six kilometer (6km): Running program with a cumulative running distance of 6km the first week (2km per session). The program consisted of four weeks with three weekly training sessions. The running distance was increased by ~10% per week. The specific details of the running programs are shown in Table 1.

All participants were instructed to have at least one day with no running between each session and to run with a moderate intensity i.e. being able to converse without breathlessness. The running distance in both programs was split up into shorter intervals with walking at an easy/comfortable pace in the pauses between each interval. The running was conducted on a self-chosen route. Each week participants received a link to an online questionnaire via e-mail. In the weekly questionnaire, they reported their running training on a session level.
the past week, their injury status, and overuse symptoms status. The distance of each training session was reported in meters. The participants were instructed to measure their running distance with a smartphone application or a running-watch, of their choice, using Global Positioning System (GPS). GPS measurement of the distance is recommended in scientific studies because runners are unable to subjectively evaluate their running distance in a valid manner.\textsuperscript{20} The measurement error of commercial GPS running watches (≤6.2%) is acceptable in terms of identifying relevant differences in running distances in scientific studies on running-related injuries.\textsuperscript{21} The participants automatically received a reminder e-mail if they failed to complete the weekly questionnaire within five days after receiving it. They were contacted by phone if they did not respond to the reminder e-mail within one week.

<table>
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<tr>
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<tr>
<td>600m run</td>
<td>600m run</td>
<td>600m run</td>
<td>600m run</td>
</tr>
<tr>
<td>200m walk</td>
<td>200m walk</td>
<td>200m walk</td>
<td>200m walk</td>
</tr>
<tr>
<td>600m run</td>
<td>600m run</td>
<td>600m run</td>
<td>600m run</td>
</tr>
</tbody>
</table>

The 3km intervention program had a total running distance of 3km the first week. The 6km intervention program had a total running distance of 6km the first week. All runners were instructed to have at least one day between each session and run with a moderate intensity i.e. being able to converse without breathlessness. The running distance was increased by approximately 10% per week in both programs.
Outcome measures

Running-related injury (primary outcome)

Running-related injury was operationally defined for this study as: *An injury sustained on muscles, joints, tendons and / or bones as a result of running. The injury must have caused the runner to reduce the intended training (reduced distance, intensity or frequency).* This injury definition was a modified version of the one-day training-reduction injury (TR-day) and one-day time-loss injury (TL-day) definition used by Kluitenberg et al.22 Each week, in connection with their training registration, participants were asked if they had to reduce the training (reduced distance, intensity) owing to a running-related injury. This was reported for each of the weekly training sessions. If participants skipped entire training sessions, they had to report if it was because of a running-related injury (reduced frequency) or another reason.

Symptoms of overuse injury (secondary outcome)

Symptoms of overuse injury were operationally defined for this study as: *A physical problem perceived as pain, tenderness, stiffness, aching, looseness, locking or instability in any part of the body, caused by running.* This definition was adapted from the Oslo Sports Trauma Research Center questionnaire on overuse injury (OSTRC-O).23 At the end of each week, in connection with their training registration, participants were asked to report any symptoms of overuse injury they had during the past week. Participants that reported to have had “a physical problem perceived as pain, tenderness, stiffness, aching, looseness, locking or instability in any part of the body, caused by running” in the past week were asked to complete the OSTRC-O questionnaire.23 The OSTRC-O questionnaire was a validated Danish translation of the original questionnaire.24 The symptoms were reported on anatomical location level (ankle, knee, hip etc.). The severity of the symptoms was described using the OSTRC-O questionnaire severity score.23,24 The severity score was regarded as a rank score and further categorized according to the approach used by the Oslo sports trauma research center in other studies 23,25,26: No problem (severity score of 0), problem (severity score above 0) and substantial problem (OSTRC severity score of 13 or above in question 2 and/or question 3) were operationally defined.

Power calculation

An observational prospective cohort study found a running-related injury risk of 11.9% and 22.7% among obese runners running less than 3km the first week, and more than 6km the first week, respectively.17 Therefore, an expected running-related injury risk difference of minimum 10% between the 3km and 6km interventions seemed reasonable. A superiority power equation, with a minimal important difference of 10%, an alpha set to (0.05) and 62 participants in each exposure group, estimated the study power to 80%. We aimed to recruit and enroll n = 140 participants to take a dropout into account.

Statistical analyses

Descriptive data for the demographic characteristics were presented as counts and percentage for dichotomous data. Continuous data were presented as mean, standard deviation (SD) or median and (25th percentile, 75th percentile) for normal and non-normal distributed data, respectively. The risk of running-related injury and risk of symptoms of overuse injury were assessed using a time-to-event analysis with weeks as the time scale. The pseudo-observation method 27 was applied to determine the cumulative risk difference (CRD) between the two interventions at week two and four (time-points were predefined in the study protocol). CRD is an absolute measure of association and a negative CRD indicates a protective effect (percentage point decrease in risk). In addition, a supplementary analysis with distance in km as the time scale and CRD estimated at 10km and 20km was performed in order to compare the results with the study from Nielsen et al. 17 All participants randomized were included in the analysis. Participants were censored when the outcome of interest occurred or they had no additional training uploads for the remainder of the follow-up. Importantly, censoring is not similar to exclusion. All censored participants are included in the analysis but they were only at risk until the censoring occurred.27 Only the first injury and symptom was included in the main and secondary outcome analysis, respectively. All estimates were presented with a 95% confidence interval and a p-value. Differences were considered statistically significant at p < 0.05.

A supplementary per-protocol analysis was performed. In the per-protocol analysis, participants
were excluded if they did not upload any running during the follow-up. Participants were censored if their training exceeded 130% of the scheduled distance in a training session, the outcome of interest occurred, or they had no additional training uploads for the remainder of the follow-up.

RESULTS

Participant flow
A total of 140 persons signed up for the study by answering the online inclusion questionnaire. Of these, 56 eligible persons were contacted for baseline assessment and randomization after excluding 84 persons. The specific reasons for exclusion are presented in the flow diagram (Figure 1). The recruitment ended before reaching the intended sample size of 140 subjects because it was exceedingly difficult to find additional eligible participants, within a reasonable timeframe, without the need for additional funding.

The randomization procedure assigned 29 participants to the 3km intervention and 27 participants to the 6km intervention. All participants who underwent randomization were included in the main time-to-event analysis (intention-to-treat). Figure 1 presents the flow of the participants from enrollment to the time point they were injured or censored.

Baseline data
The demographic characteristics of the participants are presented in Table 2 according to intervention allocation.

Compliance
Non-injured participants in the 3km intervention group completed half of the scheduled sessions 169 of 324 (52%). The proportion of completed sessions in the 6km intervention group was 120 of 264 (45%). The total distance (both running and walking) completed by the non-injured participants compared with the total distance scheduled was 309 of 603km (51%) in the 3km intervention and 404 of 902km (45%) in the 6km intervention. The reasons for discontinuing the interventions before end follow-up are presented in Figure 1. A total of four participants in the 3km intervention and one participant in the 6km intervention did not report why they discontinued the intervention and did not answer their phone or e-mail. None of the participants who discontinued the 3km intervention for unknown reason reported any symptoms the week prior to leaving the intervention. The participant in the 6km intervention reported symptoms the week before discontinuing the intervention (OSTRC Severity score = 31).

A small group of participants deviated severely from their scheduled training and trained much more than prescribed. Collectively, five participants completed 16 sessions that each exceeded 130% of the scheduled distance. All participants who trained excessively had been allocated to the 3km intervention. Two of the five participants sustained an injury subsequently to exceeding the prescribed distance, and all five developed symptoms of overuse injury during the follow-up.

Running-related injury
An injury was sustained by seven participants (12.5%) during the 4-week follow-up. Two participants were injured in the 3km intervention (6.9%). Five participants were injured in the 6km intervention (18.5%). The results of the time-to-event analysis are presented in Table 3 and Kaplan Meier plots of the injury-free proportion are presented with weeks and kilometers as timescale in Figure 2. Assuming a causal relationship, the number of obese novice runners who need to change from the 6km intervention to the 3km intervention to avoid one running-related injury (equivalent to numbers needed to treat) is six runners (based on the Intention-to-treat analysis with weeks as time scale).

Symptoms of overuse injury
Symptoms of overuse injury were observed in 21 participants (37.5%) during the follow-up. Eight participants reported symptoms in the 3km group (27.6%). Thirteen participants reported symptoms in the 6km group (48.1%). The results of the time to event analysis are presented in Table 3 and Kaplan Meier plots of the symptom-free proportion are presented with weeks and kilometers as timescale in Figure 2. The anatomical location, severity and proportion of symptoms in the 3km and 6km intervention groups during follow-up are presented in Table 4. Assuming a causal relationship, the number of
obese novice runners who need to change from the 6km intervention to the 3km intervention to avoid symptoms (equivalent to numbers needed to treat) is seven runners (based on the intention-to-treat analysis with weeks as time scale).

**DISCUSSION**

This is the first randomized trial to provide insight into the start-to-run distance and the risk of running-related injury specifically among obese novice runners. A start-to-run distance of 6km per week...
Table 2. Demographic characteristics of the participants randomized to the 3km and 6km intervention.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit/Qualifier</th>
<th>Total (n=56)</th>
<th>3km (n=29)</th>
<th>6km (n=27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female/Male</td>
<td>42/11 (79/21%)</td>
<td>23/6 (79/21%)</td>
<td>22/5 (81/19%)</td>
</tr>
<tr>
<td>Age</td>
<td>Years</td>
<td>39.2 (±9.5)</td>
<td>38.3 (±10.2)</td>
<td>39.3 (±9.2)</td>
</tr>
<tr>
<td>BMI</td>
<td>Kg/m²</td>
<td>32.7 (31.3, 34.3)</td>
<td>32.0 (31.2, 33.4)</td>
<td>33.3 (31.5, 34.6)</td>
</tr>
<tr>
<td>Activity level at home</td>
<td>Range 0-10²</td>
<td>3.6 (±1.4)</td>
<td>3.6 (±1.6)</td>
<td>3.7 (±1.3)</td>
</tr>
<tr>
<td>Activity level at work²</td>
<td>Range 0-10²</td>
<td>3 (2, 5)</td>
<td>3 (2, 4)</td>
<td>3 (2, 5)</td>
</tr>
</tbody>
</table>

Participants with 0 training reported

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit/Qualifier</th>
<th>Total (n=15)</th>
<th>3km (n=7)</th>
<th>6km (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female/Male</td>
<td>12/2 (87/13%)</td>
<td>6/1 (86/14%)</td>
<td>7 (87/13%)</td>
</tr>
<tr>
<td>Age</td>
<td>Years</td>
<td>38.8 (±7.6)</td>
<td>34.7 (±8.2)</td>
<td>38.8 (±8.6)</td>
</tr>
<tr>
<td>BMI</td>
<td>Kg/m²</td>
<td>32.2 (31.2, 34)</td>
<td>31.4 (31.2, 32.7)</td>
<td>32.4 (31.1, 34.3)</td>
</tr>
<tr>
<td>Activity level at home²</td>
<td>Range 0-10²</td>
<td>3 (2, 5, 4, 5)</td>
<td>3 (2, 4)</td>
<td>3.5 (3, 5, 5)</td>
</tr>
<tr>
<td>Activity level at work²</td>
<td>Range 0-10²</td>
<td>4 (2, 7)</td>
<td>2 (1, 6)</td>
<td>4 (2, 5, 7)</td>
</tr>
</tbody>
</table>

All participants randomized were included in the intention-to-treat analysis (n=56). A total of 15 participants reported no training sessions.

Abbreviations: BMI, Body mass index; SD, Standard deviation; Values are reported as: * Number (%), † means (SD) and ‡ Median (25th percentile, 75th percentile). § Numerical rank scale from 0 (sedentary) to 10 (highest possible activity level).

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Table 3. CRD of injury and symptoms between the 3 km (n=29) and 6 km (n=27) intervention group week 2 and week 4 and after 10 km and 20 km.

**Weeks as time scale**

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Week 2</th>
<th>CRD</th>
<th>95% CI</th>
<th>p value</th>
<th>Week 4</th>
<th>CRD</th>
<th>95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITT</td>
<td>Ref 6 km²</td>
<td>-14.5%</td>
<td>(-32.5; 3.4)</td>
<td>0.11</td>
<td>Ref 6 km²</td>
<td>-16.3%</td>
<td>(-43.8; 11.3)</td>
<td>0.25</td>
</tr>
<tr>
<td>PP</td>
<td>Ref 6 km²</td>
<td>-22.3%</td>
<td>(-42.6; -2.0)</td>
<td>0.03</td>
<td>Ref 6 km²</td>
<td>-31.2%</td>
<td>(-57.0; -5.2)</td>
<td>0.02</td>
</tr>
<tr>
<td>ITT</td>
<td>Ref 6 km²</td>
<td>-37.6%</td>
<td>(-67.2; -7.9)</td>
<td>0.01</td>
<td>Ref 6 km²</td>
<td>-13.9%</td>
<td>(-50.3; 22.5)</td>
<td>0.46</td>
</tr>
<tr>
<td>PP</td>
<td>Ref 6 km²</td>
<td>-59.3%</td>
<td>(-87.5; -31.0)</td>
<td>0.00</td>
<td>Ref 6 km²</td>
<td>-47.8%</td>
<td>(-81.0; -14.6)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Kilometers as time scale**

<table>
<thead>
<tr>
<th>Analysis</th>
<th>10km</th>
<th>CRD</th>
<th>95% CI</th>
<th>p value</th>
<th>20km</th>
<th>CRD</th>
<th>95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITT</td>
<td>Ref 6 km²</td>
<td>-19.1%</td>
<td>(-42.7; 4.5)</td>
<td>0.11</td>
<td>Ref 6 km²</td>
<td>-25.7%</td>
<td>(-51.8; 0.5)</td>
<td>0.05</td>
</tr>
<tr>
<td>PP</td>
<td>Ref 6 km²</td>
<td>-23.1%</td>
<td>(-46.7; 0.5)</td>
<td>0.05</td>
<td>Ref 6 km²</td>
<td>-29.2%</td>
<td>(-56.0; -2.4)</td>
<td>0.03</td>
</tr>
<tr>
<td>ITT</td>
<td>Ref 6 km²</td>
<td>-35.2%</td>
<td>(-65.7; -4.6)</td>
<td>0.02</td>
<td>Ref 6 km²</td>
<td>-34.0%</td>
<td>(-68.1; 0.1)</td>
<td>0.05</td>
</tr>
<tr>
<td>PP</td>
<td>Ref 6 km²</td>
<td>-47.3%</td>
<td>(-76.2; -18.5)</td>
<td>0.00</td>
<td>Ref 6 km²</td>
<td>-50.5%</td>
<td>(-85.0; -15.9)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*Reference group was the runners randomized to the 6 km intervention. †Values are absolute percentage points (95% confidence interval). ‡ Participants were excluded if they uploaded no running sessions (3 km n=7; 6 km n=8) and right censored if their running exceeded 130% of the scheduled distance in a training session. Abbreviations: ITT= intention-to-treat; PP= Per-protocol; CRD, cumulative risk difference. A negative CRD indicates fewer injuries/symptoms (percentage point decrease in risk).
Figure 2. Injury-free proportion (y-axis) among runners allocated to the 3km and 6km intervention, visualized as a function of time scale (x-axis): (A) Weeks at Risk, (B) Distance, km. Symptom-free proportion (y-axis) in runners allocated to the 3km and 6km intervention, visualized as a function of time scale (x-axis): (C) Weeks at Risk, (D) Distance, km.

Table 4. Anatomical location, severity and proportion of symptoms in the 3km and 6km intervention groups during follow-up.

<table>
<thead>
<tr>
<th>Location</th>
<th>3km</th>
<th>6km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 1 2 3 4</td>
<td>1 2 3 4 1 2 3 4</td>
</tr>
<tr>
<td>Foot</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Ankle</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Front of lower leg</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Back of lower leg</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Knee</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Groin</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Hip</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Lower back</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Ankle and knee</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Groin and knee</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Lower back and knee</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Proportion of participants</td>
<td>3/29 2/17 3/13 1/9</td>
<td>1/29 0/17 0/13 0/9</td>
</tr>
</tbody>
</table>

*aProblem was defined as an Oslo Sports Trauma Research Center questionnaire (OSTRC) severity score above 0.
*bSubstantial problem was defined as a problem leading to moderate or severe reduction in training volume, or moderate or severe reduction in sports performance, or complete inability to participate in sport (OSTRC severity score of 13 or above in question 2 and/or question 3).
*cProportion of the uncensored participants with problem/substantial problem during follow-up.
is common in running programs targeted novice runners. Nevertheless, the results of the present study indicate that a 6km per week start-to-run distance is associated with more running-related injuries compared to a more moderate distance of 3km per week. The cumulative risk of running-related injury was 26.8% with a start-to-run distance of 6km per week (3 x 2km per week and a 10% increase in distance the following 3 weeks) after four weeks of running. In comparison, the cumulative risk of running-related injury was only 10.5% with a start-to-run distance of 3km per week (3 x 1km per week and a 10% increase in distance the following 3 weeks) after four weeks of running. However, it should be emphasized that these results were affected by low compliance. Some participants completed much more running than prescribed and some never uploaded any training. In the supplementary per-protocol analysis, participants who ran excessively (130% of the prescribed distance in their program) were censored and participants who never uploaded any training were excluded. Based on the per-protocol analysis, the CRD of running-related injury was -31.2 % (95%CI: -57.0%; -5.2%, p=0.02) after four weeks of running. Furthermore, the CRD of overuse-injury symptoms was -47.8% (95%CI: -81.0%; -14.6%, p=0.01) after four weeks of running. These findings further support the supposition that obese novice runners need to be cautious in relation to their start-to-run distance and potential for running-related injury. Even a small difference seems to have a substantial impact on the risk of running-related injury the first four weeks of running (3km vs. 6km per week).

Only one other study has previously has looked into the association between the start-to-run distance and running-related injuries among obese novice runners. The study was an observational 3-week prospective cohort study (n = 749) based on the DANO-RUN study. In the DANO-RUN study, the CRD after 20km was -10.8% when the initial running distance the first week was ≤3km compared with >6km (reference). This is similar to the present study showing that obese novice runners reduce their injury risk substantially if the start-to-run distance is 3km instead of 6km per week. The considerably larger CRD after 20km found in the present study (-25.7%) compared with the DANO-RUN may possibly be explained by the difference in study design. Plausibly, novice runners choose their start-to-run distance based on their susceptibility to injury, knowingly or unknowingly. In an observational prospective cohort study, such as the DANO-RUN study, this self-selection of the exposure could cause an overrepresentation of participants with specific characteristics associated with increased/decreased injury risk in one of the exposure groups. Most likely, the more injury-susceptible novice runners would select a shorter start-to-run distance and the less injury-susceptible novice runners a longer start-to-run distance. This source of bias is somewhat accommodated by the randomized design used in the present study. However, importantly, the results from the present study may still be biased because of the low compliance with the running programs. Essentially, the low compliance may cause a “self-selection issue” similar to that of the observational study design. Another explanation for the larger risk difference found in the present study is the running-related injury definition. In the present study, an injury was defined as a one-day training restriction or time-loss (reduced distance/intensity/frequency) whereas the definition in the DANO-RUN study was a seven-day training restriction or time-loss (reduced distance/intensity/frequency). Nevertheless, all injured participants in the present study were restricted more than seven days and could, therefore, have been classified as injured according to the DANO-RUN definition.

The substantial compliance problem in the present study illustrates the limitations in using training guidance as an injury prevention strategy. It doesn’t work if the advice is ignored. Running-related injury in the 3km intervention group occurred only in participants who chose to run more than prescribed by the program. In addition, those who ran more than prescribed all developed symptoms of overuse injury. Therefore, the importance of motivating and educating obese novice runners to follow injury preventive training advice must be acknowledged. Future research, investigating how this is effectively achieved, is essential if injury preventive training guidance should have an effect. The Systems Theoretic Accident Mapping and Processes (STAMP) model is a promising tool in this endeavor and has
recently been adapted to a running-related injury context for distance runners in Australia.\textsuperscript{28,29} This model visualizes the complex system that includes control and feedback mechanisms between multiple hierarchical levels of determination, which can then be used to guide strategies for implementing novel injury prevention interventions.\textsuperscript{28,29} A similar model for running-related injury prevention in obese novice runners is not yet available.

**Limitations of the study**

The low compliance to the interventions must be acknowledged as a major limitation of the study. The intervention groups reported fewer completed training sessions than prescribed by the programs. The non-injured participants in the 3km and 6km group completed only 52\% and 45\% of the training session planned, respectively. Thus, the difference in the cumulative distance was lower than prescribed by the protocol. Consequently, the CRD found in the intention-to-treat analysis (CRD after four weeks = -16.3\%, 95\%CI: -43.8; 11.3, \( p=0.25 \)) might have been underestimated compared with a scenario where all sessions were completed as prescribed. In addition, five participants in the 3km intervention ran longer distances than prescribed. As a result, they had almost comparable running exposure as had they followed the program received by the 6km intervention. Furthermore, seven of the participants in the 3km intervention and eight participants in the 6km intervention never uploaded any reports of running. Consequently, the difference in running exposure was less extreme than prescribed by the study-protocol. For this reason, the CRD might have been underestimated in the intention-to-treat analysis (CRD after four weeks = -16.3\%, 95\%CI: -43.8; 11.3, \( p=0.25 \)) compared with a scenario where the training was completed as prescribed in the protocol.

Another major limitation that must be acknowledged is that five participants left the study without reporting a reason why (3km n = 4, 6km n = 1). This could potentially have biased the results dramatically if all had unreported running-related injuries. However, the four participants in the 3km intervention reported no symptoms the week before discontinuing the intervention, which suggests that injury was not the reason for leaving the study. The participant in the 6km intervention reported symptoms the week before discontinuing the intervention (OSTRC Severity score = 31). The risk difference may have been underestimated if the participant in the 6km intervention left with an unreported running-related injury.

Finally, in the present study, the sample size was small. Consequently, the risk of a random difference between intervention groups was high. Nevertheless, Table 2 suggests that the intervention groups were equally distributed on the measured baseline characteristics. Still, other unobserved risk factors for running-related injury could have been unequally distributed. Another limitation of the small sample size is only seven running-related injuries occurred during the follow-up. The recommended minimum number of events per explanatory variable (EPV) is 10 in an analysis on CRD.\textsuperscript{30} Ideally, 20 injuries were needed to meet the recommended minimum EPV. For this reason, caution is advised when interpreting the results of the analysis.

Other limitations of the study were the absence of blinding, absences of clinical assessment of injury, and the short follow-up period.

**Generalizability**

A large proportion of the population was women (42/56). This is in contrast to, a more equal distribution of men and women in previous studies.\textsuperscript{6,7} However, there is no consistent evidence that suggests women have different injury risk than men.\textsuperscript{31-33}

Only obese novice runners with no lower extremity injury the past two years were included in the present study. Obese novice runners with a more recent injury could potentially be at high risk of injury even when the start-to-run distance is 3km per week or less. In addition, only persons with less than one hour of sports activity experience per week were included. Obese novice runners with >one-hour sports experience per week from other activities might tolerate a start-to-run distance of more than 3km per week without substantial risk of injury.

In the present study, the distance was cumulated over three weekly running sessions. Imaginably, the risk of running-related injury could have been different if the weekly cumulative running distance had been distributed over more or fewer sessions...
or the distance was unevenly distributed between sessions (e.g. 1km, 2km, 3km compared with 2km, 2km, 2km). Also, the “within session” cumulation of the running distance could have an influence on the risk of running-related injury. In the present study, the participants were instructed to run 500m as the shortest interval.

CONCLUSIONS
A 3km reduction from 6km per week to 3km per week in the start-to-run distance appears associated with fewer running-related injuries. Based on this, obese novice runners (BMI 30-35) are recommended a total start-to-run distance of ≤3km the first week. Still, this advice should be considered with caution. Importantly, sub-groups of obese novice runners could potentially have a high risk of running-related injury even with a start-to-run distance less than 3km per week (e.g. obese individuals with a previous injury). Conversely, other sub-groups may possibly tolerate a start-to-run distance of more than 6km per week while remaining at low risk of running-related injury (e.g. obese individuals with previous sports experience). Further studies are needed to address the appropriate start-to-run distance in sub-groups of obese novice runners.

REFERENCES


ABSTRACT

Background: The increased incidence of lower extremity injury in runners compared to the general population is well documented. The amount of passive hip rotation and the position of hip flexion or extension at which it occurs may be factors related to injury incidence.

Purpose: The purpose of the current study was to measure and compare hip rotation passive range of motion in male and female runners and non-runners at 0 and 90 degrees (°) of hip flexion.

Study Design: Descriptive Laboratory Study.

Methods: Eighteen Division II collegiate distance runners (9 female, 9 male, mean age = 19.1, +/- 1.1 years) who had run for an average of 7.1 (SD = 1.7) years participated in the study. Twenty non-runners (10 female, 10 male, mean age = 19.6, +/- 1.1 years) from the same institution were also recruited. Passive hip internal rotation (IR) and external rotation (ER) were measured with a universal goniometer in 90° of hip flexion in a seated position, and in 0° of hip flexion in prone position.

Results: There was a significant difference in IR measured in 0° of hip flexion, between runners and non-runners (F(1,37) = 8.04, p = .007). Additionally, the difference in IR between males (36.68 +/- 9.19 degrees) and females (45.99 +/- 9.12) was significantly different (F(1,37) = 20.79, p = .001). There were no other statistically significant differences in measurements between groups.

Conclusions: Collegiate runners had significantly greater passive hip IR when measured at 0° of hip flexion compared to the non-runners. Female runners had significantly greater passive hip IR compared to the male participants across both runners and non-runners.

Level of Evidence: 3

Key Words: Hip rotation, injury, lower extremity, running

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INTRODUCTION
The increase in stride rate, stride frequency and center of gravity vertical displacement with running as compared to walking may increase the risk of injury.² Participation in running has continued to grow and has resulted in an overall increase in the number of runners injured.²,³ Depending on injury definition and the length of follow-up period, the injury incidence among runners varies between 19-79%.⁴

During walking and running, the overall translation is along the sagittal plane, even though there are significant frontal and transverse plane contributions to this sagittal movement. In the weight-bearing phase, hip IR is functionally linked with hip adduction and hip flexion. During running, the increase in ground reaction forces due to vertical displacement of center of mass creates a significant increase in hip adduction and IR range of motion compared to walking.⁵ Recently, the literature has identified risk factors for the increased incidence of patellofemoral knee pain proximally at the hip and trunk.⁶,⁷ Recent research has linked aberrant frontal plane mechanics of the lower extremity, specifically excessive hip adduction, to increased knee injuries.⁸ Relevant studies have also utilized proximal strengthening of hip abductors and external rotators in runners in order to decrease patellofemoral symptoms.⁹ It is unclear if this strategy is successful based predominantly on the runner’s foundational weakness of these muscles or excessive amounts of hip adduction and IR.¹⁰ Therefore, excessive amounts of passive hip IR could result in range of motion that might need to be limited and/or controlled, eccentrically or isometrically via hip external rotators and abductors, possibly contributing to the risk of increased knee injuries.

The literature regarding assessment of and normative values for hip rotation are quite consistent.¹¹,¹² The majority of standard examination normative values for passive hip IR, however, identify hip IR as being equal to or less than ER across all populations with hip ER in the range of 40-45°.¹¹ The majority of normative data for hip ER and IR has been gathered using the position of 90° of flexion of the hip joint in the sagittal plane, in a seated position.¹¹,¹² Neither of the two previously published normative data sets nor the APTA (American Physical Therapy Association) Hip Pain and Mobility Deficits Clinical Practice Guidelines or American Academy Orthopedic Surgeons guidelines indicate a hip IR gender bias. There has been limited evidence of static lower limb alignment at knee and forefoot as well as range of motion measures at ankle being associated with injury in runners.¹³

The purpose of the current study was to measure and compare hip rotation passive range of motion in male and female runners and non-runners at 0° and 90° of hip flexion. The authors hypothesized that runners would have increased passive hip IR in 0° of hip flexion compared to non-runners and that female runners would have greater passive hip IR in 0° of hip flexion than male runners.

METHODS
Participants
Eighteen Division II collegiate distance runners (9 female, 9 male, mean age =19.1, +/- 1.1 years) who had run for an average of 7.1 (SD=1.7) years participated in the study (see Table 1). Subjects were a sample of convenience recruited from the cross country and track teams. To be included the runners had to compete in middle and/or long distance events, have trained for a minimum of three years (part or full time) and have trained for at least ten hours/week for the six months prior to the study. Runners were excluded from the study if they had an injury or pain that could be exacerbated by range of motion testing, could preclude them from running at the time of the range of motion testing, or precluded them from consistent training for the preceding twelve months.

An age and gender matched group of twenty non-runners (10 female, 10 male, mean age =19.6, +/- 1.1 years), a sample of convenience, were recruited. Participants were healthy, recreationally active men

<table>
<thead>
<tr>
<th>Table 1. Demographic Data for Participants</th>
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<tr>
<td></td>
</tr>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>Mean Age (years)</td>
</tr>
<tr>
<td>Mean Duration of Running (years)</td>
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</tbody>
</table>

The International Journal of Sports Physical Therapy | Volume 13, Number 6 | December 2018 | Page 957
and women aged 18-22 years majoring in health sciences at the same institution. Recreationally active for this comparison group was defined as participating in intramural sports on campus, fitness center based cardiovascular activity, or general strength training and flexibility. Non-runners were excluded if they had a history of lower extremity injury or pain, which was defined as having any previous hip, knee, foot or ankle injury in the prior twelve months that prevented them from participating in their chosen physical activity or if they ran more than one mile, three times per week in the past twelve months. Each participant was required to report to the Health Sciences Human Performance Laboratory on one occasion. An information sheet explaining the aims of the study was provided and an informed consent was signed. Approval for the study was obtained from the College’s Institutional Review Board.

Data Collection
All participants completed a treadmill warm up that included walking for one minute at a comfortable speed followed by running at six miles per hour for five minutes. After the warm up, the participants sat on the edge of an exam table in a neutral lumbar spine position and passive hip IR and ER in 90° of hip flexion was measured with a flexible hand held Baseline 360 universal goniometer. The same two examiners measured all participants. Examiner one used both hands to stabilize the distal thigh at the table edge and examiner two measured range of motion by bringing the lower leg to the firm end point of both IR and ER (Figure 1). The participants then lay prone on table and passive hip IR and ER was measured with the same hand held universal goniometer. The thigh was carefully positioned in 0° of hip abduction or adduction, with the contralateral limb in approximately 20° of abduction. Examiner one stabilized the pelvis and examiner two measured range of motion by bringing the leg to a firm end point of both IR and ER (Figure 2). Each single measurement was taken on the left then the right for the odd numbered participants and right then left for the even numbered participants. A single measurement was chosen because it has been shown to be as reliable as the average of multiple measurements within the same session and is more consistent with clinical practice.14

Data Analysis
Data were analyzed using SPSS (version 21.0). In order to examine the differences of hip rotation under different condition between runner and non-runners, a 2 (gender; male vs. female) X 2 (athlete vs. non-athlete) X 2 hip flexion degree (90 vs. 0 degree) X 2 side (left vs. right) X 2 rotation (IR vs. ER) repeated measures ANOVA was implemented. All alpha values were adjusted to 0.0125 for simple effect tests.
RESULTS

There was a significant interaction between runners and non-runners for degrees of hip flexion and hip rotation \((F(1,35) = 4.56, p = .039, (\text{Table 2})\). Simple effect tests showed the differences in IR between runners and non-runners in 90° of hip flexion was not significantly different \((F(1,37) = 5.36, p = 0.028)\). In 90° of hip flexion, the difference in ER between runners and non-runners was not significantly different \((F(1,37) = 3.89, p = .061)\). In 0° of hip flexion, the difference in IR between runners and non-runners was significantly different \((F(1,37) = 8.04, p = .007)\), however, the ER differences between runners and non-runners was not significantly different \((F(1,37) = 6.22, p = 0.017)\).

There was also a significant interaction between hip rotation and gender (Figure 3) \((F(1, 35) = 9.55, p = .003)\). Simple effect tests showed that the difference of IR between males and females was significantly different \((F(1,37) = 20.79, p = 0.00001)\) with males demonstrating a mean of 36.68° \((SD = 9.19)\) and females demonstrating a mean of 45.99° \((SD = 9.12)\). The difference in ER between males and females was not significantly different \((F(1,37) = 0, p = .75)\) with males demonstrating a mean of 35.75° \((SD = 7.79)\) and females demonstrating a mean of 35.75° \((SD = 7.46)\). Finally, there was not a significant main effect for \((F(1, 35) = 1.79, p = 0.19)\) indicating that there were no differences between left and right legs for IR or ER in either 0° or 90° of hip flexion for both runners and non-runners.

DISCUSSION

The results of this pilot study demonstrated that collegiate runners have significantly greater hip IR at 0° of hip flexion compared to the non-runners. Prior research has identified a hip IR difference of 8° or less as a threshold to separate injured from uninjured athletes.\(^{15,8}\) Specifically, Li found a subset of baseball players with hip injuries compared to the no injury group had decreased passive hip IR on the right IR 29° versus 35°.\(^{8}\) Sousa, found runners with patellofemoral pain demonstrated significantly greater average dynamic hip internal rotation (8.2° versus 0.3°).\(^{15}\) In addition to this statistical difference it is the authors’ opinion that an 8° difference in hip rotation is clinically significant as well.

The mean standard deviation of repeated ROM measurement of extremity joints taken by one examiner using a universal goniometer has been found to range from 4 to 5°.\(^{16,17}\) Therefore, to show improvement or worsening of joint motion measured by the same examiner, a difference of 5° \((\pm 1°)\) to 10° \((\pm 2°)\) is necessary. Therefore, the 8° of difference in IR measurements between runners and non-runners, while statistically significant, also falls within the range that clinicians should notice and is likely clinically significant.

Current literature focuses on the role of increased dynamic hip IR with weight-bearing in running as

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**Table 2. Hip rotation measurements (in degrees) at different flexion degree between runners and non-runners, presented as mean (SD).**

<table>
<thead>
<tr>
<th></th>
<th>Runners ((n=18))</th>
<th>Non-runners ((n=20))</th>
<th>F value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD 90°</td>
<td>IR 38.95 (7.00)</td>
<td>34.30 (5.61)</td>
<td>5.36</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>ER 30.84 (4.78)</td>
<td>33.58 (3.84)</td>
<td>3.89</td>
<td>0.06</td>
</tr>
<tr>
<td>FD 0°</td>
<td>IR 50.82 (10.92)</td>
<td>42.58 (6.88)**</td>
<td>8.04</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>ER 36.32 (7.83)</td>
<td>42.05 (6.50)</td>
<td>6.22</td>
<td>0.017</td>
</tr>
</tbody>
</table>

**Figure 3. Internal and external hip rotation comparison between males and females.**

***Indicates significant difference at the \(p < .0125\) level (note: adjusted alpha value used to determine statistical differences was \(p < .0125\)). FD= degree of hip flexion during measurement.
being potentially causative of distal symptoms and able to be successfully treated with hip abduction and ER strengthening. The current findings of the presence of increased passive hip IR in non-weight bearing in runners may indicate that greater available hip dynamic IR may need to be controlled by dynamic proximal stabilizers in weight bearing. Though the process of clinically-based video assessment of running continues to improve with regard to time required and cost, it still exceeds the time and fiscal constraints of many clinicians and settings, not to mention patient confidentiality. In settings where these hurdles can be overcome, the current findings may be a valuable adjunct to allow clinicians to focus their video assessment on hip internal rotation as well as internal rotation eccentric control. In this study, the statistically significant finding of greater passive hip IR in the sample of runners compared to non-runners should inform clinicians to consider this simple, clinically perceptible measurement, in combination with available complimentary assessments, including video, when treating the running population.

An unexpected finding that was not part of the original purpose of the study was that the historical notion that hip ER is greater than or equal to IR is not supported when runners were measured at 0° of hip flexion. The two most commonly utilized textbooks for the education of athletic trainers and physical therapists in the clinical skill of goniometry do not identify the need for measuring hip rotation solely in 0° of hip flexion or at 0° and 90° of hip flexion and none indicate that greater hip IR may occur in any position. Both references places normal ER at 45°-50° with IR equal to or slightly less at 45°. What has been considered to be normal hip rotation should be reassessed in this specific population and testing motion within the functional range that it is pertinent to the chosen activity should be considered. The hip position during running is much closer to 0° of hip flexion than 90°. The finding that there was no difference in rotation between runners and non-runners at 90° of hip flexion, the traditional and “convenient” position to test these motions, indicates that a statistically and possibly clinically significant difference in hip rotation may be missed by measuring hip rotation at 90° of flexion versus 0°. Finally, the lack of any difference right to left is consistent with no significant side dominance typical of distance runners overall.

The second hypothesis that female runners would have greater passive hip IR in 0° of hip flexion than male runners was supported as significantly greater passive hip IR was seen in female compared to male participants across both runners and non-runners. Previous literature has reported mixed findings on the gender differences. An additional goniometric reference, though offering data on a gender bias covering the 18-22 age range regarding hip IR, does not offer this gender bias for hip IR in their normative data section for clinicians. However, anecdotally, most clinicians would indicate that females have greater passive hip IR and some researchers have agreed. There is current literature linking dynamic knee valgus, which is mechanically linked to hip IR range of motion, as greater in females than males upon jump landing. The findings from the current study provide additional insight on the gender differences in passive hip IR and ER measurements between runners and non-runners.

Both of the hypotheses being supported is consistent with the patterns seen in the literature to date regarding an increased risk of injury being greater at the knee for runners versus non-runners and for females versus males. Prior research has demonstrated increased dynamic hip adduction and IR in females while running being correlated to patellofemoral injury. Our study did not directly attempt to investigate running related injury nor the risk of it. Further investigation may support a correlation between these mentioned dynamic measures, lower extremity injury and simple goniometric measurements of passive hip IR as prior studies have linked passive and active hip rotation variations to low back pain, shoulder and elbow injuries.

LIMITATIONS
Some limitations of the current study include a relatively low sample size and the convenience sample of both runners and non-runners, a single examiner, and a single simple measure. As the non-runners were students majoring in health sciences, they may have been more physically active than the general population. This may limit the measurement
differences between runners and non-runners. The choice of a single examiner was intentional to maximize the reliability during this initial investigation of a single measurement of joint passive range of motion. Clinicians should consider that the researchers found disparate results in passive hip rotation ROM from past literature when evaluating these subjects and that future evaluation is warranted. Future studies should include a larger sample size and a more representative sample of participants, multiple examiners and the measurement of both active and passive range of motion.

CONCLUSIONS
The results of this study suggest that there may be differences in passive hip IR between males and females and between runners and non-runners, when measured in 0 degrees of hip flexion (in prone). Based on these results, clinicians may consider that passive hip IR can be dependent upon the angle of hip flexion at which it is measured. The traditional assumption that hip IR is less than or equal to hip ER is not consistent with the current findings. The results of this study warrant the consideration of assessment of hip IR in 0° of hip flexion as a clinical tool when working with females, both runners and those in the general population.

REFERENCES


ABSTRACT

Background: Male collegiate basketball (BB) players are at risk for musculoskeletal injury. The rate of time-loss injury in men’s collegiate BB, for all levels of National Collegiate Athletic Association (NCAA) competition, ranges from 2.8 to 4.3 per 1000 athletic exposures (AE) during practices and 4.56 to 9.9 per 1000 AE during games. The aforementioned injury rates provide valuable information for sports medicine professionals and coaching staffs. However, many of the aforementioned studies do not provide injury rates based on injury mechanism, region of the body, or player demographics.

Hypothesis/ Purpose: The purpose of this study is two-fold. The first purpose of this study was to report lower quadrant (LQ = lower extremities and low back region) injury rates, per contact and non-contact mechanism of injury, for a cohort of male collegiate basketball (BB) players. The second purpose was to report injury risk based on prior history of injury, player position, and starter status.

Study Design: Prospective, descriptive, observational cohort

Methods: A total of 95 male collegiate BB players (mean age 20.02 ± 1.68 years) from 7 teams (NCAA Division II = 14, NCAA Division III = 43, NAIA = 21, community college = 17) from the Portland, Oregon region were recruited during the 2016-2017 season to participate in this study. Each athlete was asked to complete an injury history questionnaire. The primary investigator collected the following information each week from each team’s athletic trainer: athletic exposures (AE; 1 AE = game or practice) and injury updates.

Results: Thirty-three time-loss LQ injuries occurred during the study period. The overall time-loss injury rate was 3.4 per 1000 AE. Division III BB players had the highest rates of injury. There was no difference in injury rates between those with or without prior injury history. Guards had a significantly greater rate of non-contact time-loss injuries \((p = 0.04)\).

Conclusions: Guards experienced a greater rate of LQ injury than their forward/center counterparts. Starters and athletes with a prior history of injury were no more likely to experience a non-contact time-loss injury than nonstarters or those without a prior history of injury. These preliminary results are a novel presentation of injury rates and risk for this population and warrant continued investigation.

Level of Evidence: 2

Keywords: basketball, college, epidemiology, prior history of injury
INTRODUCTION
Male collegiate basketball (BB) players are at risk for musculoskeletal injury.1-4 The rate of time-loss injury in men's collegiate BB, for all levels of National Collegiate Athletic Association (NCAA) competition, ranges from 2.8 to 4.3 per 1000 athletic exposures (AE) during practices and 4.56 to 9.9 per 1000 AE during games.1,2 Men's basketball ranks fourth; only behind football, wrestling, and soccer in overall time-loss injury rates at the collegiate level.3 Lateral ankle sprains, internal derangement at the knee, patellar tendinopathy, and muscular strains are the most common injuries experienced by BB players during either practices or games.1,2,4-9

The majority of injuries experienced by male collegiate BB players involve the lower extremities and the low back region.1 Dick et al reported 60.6 percent of injuries that happen during practice and 57.9 percent of injuries happen during games occurred in the lower extremities.1 Another 11.4 and 13.5 percent of all injuries (occurring during practices and games respectively) involved the trunk/back region.1

Many of the aforementioned epidemiological studies do not provide injury rates based on sport-related demographics (e.g., player position or starter status), injury mechanism (MOI), prior history of injury, and/or region of the body.1,9 Calculating injury rates based on demographics, prior injury history, or MOI may provide insights that may help with the development of injury reduction programs and/or off-season training regimens.10-13

There is a gap in literature regarding specific injury rates in male collegiate BB players. Therefore, the purpose of this study is two-fold. The first purpose of this study was to report lower quadrant (LQ = lower extremities and low back region) injury rates, per contact and non-contact MOI, for a cohort of male collegiate BB players. It was hypothesized that BB players with a prior history of injury, or who were a forward or center, or who were starters would have a greater risk of LQ injury than those without prior injury history, or who were a guard, or who were a non-starter. The second purpose was to report injury risk based on prior history of injury, player position, and starter status. It was hypothesized that athletes with a prior history of injury or who were a forward/center or who were a starter would have a significantly greater risk of LQ injury than their counterparts.

METHODS
Participants
A total of 95 male collegiate BB players (mean age 20.02 ± 1.68 years) from seven teams (NCAA Division II = 14, NCAA Division III = 43, NAIA = 21, community college = 17) from the Portland, Oregon region were recruited during the 2016-2017 season to participate in this study. The data presented in this study is part of a larger, ongoing, multi-year epidemiologic study of risk factors associated with men's collegiate basketball. An athlete was excluded from participation in this study if he was under the age 18 at the start of the season. The Institutional Review Board of George Fox University approved this study. Informed consent was provided by each athlete prior to study participation.

Procedures
Injury History Questionnaire
Each athlete was asked to complete an injury history questionnaire providing the following information: prior sport-related injury history (yes/no), injury location (e.g., right ankle), diagnosis (e.g., sprain, strain, etc.), and if the injury resulted in time-loss from sport.

Player Position and Starter Status
Team statistics were reviewed at the end of the season in order to identify primary player position and starter status. Players were categorized into two player position groups: guards and forwards/centers. Centers were combined with forwards in this study due to the overall low number of centers available for this study [note: some teams did not even designate one player as a center]. BB players were also categorized by starter status: starters and non-starters. A review of team records identified the athletes from each team who were the primary starters. Only 34 players (instead of 35; 5 starters per 7 teams) were identified as starters because a starter from one NAIA team did not complete preseason testing.
**Injury Surveillance**

The primary investigator collected the following information each week from the team’s athletic trainer: athletic exposures (AE; 1 AE = game or practice) and injury updates. Injured athletes were evaluated by their team’s athletic trainer. The operational definition of an injury was any musculoskeletal injury of the low back or the lower extremity that occurred either during practice or during a game that required the athlete to be removed from that day’s event or to miss a subsequent practice or competition.\textsuperscript{14,15} If an athlete was injured the following information was collected: mechanism of injury (contact or non-contact), location (e.g., body part and side of body), diagnosis (e.g., sprain, strain, etc.), and days missed from competition.

**Statistical Analyses**

Initial, subsequent, and total injury rates were calculated per level of competition. An “initial” injury was defined as the first musculoskeletal injury experienced by an athlete involving the LQ region. A “subsequent” injury was defined as any musculoskeletal injury to the LQ region experienced after an athlete’s initial injury (note: a subsequent injury could be any injury and not a recurrence of the initial injury). Injury rates based on MOI (e.g., contact or non-contact) were calculated per level of play based on prior history of sport-related injury. Initial and subsequent injury rates were also calculated based on player position and starter status. Injury rates and rate ratios (RR) were calculated using OpenEpi. Univariate logistic regression analysis was performed to calculate odds ratios (OR) and 95% confidence intervals (CIs). The authors utilized a previously reported sample size estimation of 67 subjects to determine statistically significant associations between LQ injury and potential risk factors.\textsuperscript{5} For each logistic regression model athletes were categorized into the following groups: 1) prior history of injury [at risk]/no prior history history [reference]; 2) prior history of ankle sprain [at risk]/no prior history of ankle sprain [reference]; 3) guard [reference] / forwards/centers [at risk]; 4) starter [at risk] / non-starter [reference]. Logistic regression analysis was performed using SPSS 24 (Chicago, IL) with alpha level set at 0.05.

**RESULTS**

A total of 29 initial and four subsequent LQ injuries were experienced by male collegiate BB players during the course of this study (Table 1). Injury mechanisms were categorized as either contact (e.g., injury occurring due to contact/collision with another player) or non-contact (e.g., injury mechanism not related to contact/collision with another player). Fifteen of the 29 initial LQ injuries occurred during practice (51.7%). The majority of time-loss injuries (73.3%) that occurred during practice had a non-contact mechanism. A non-contact injury mechanism was also responsible for a majority of LQ time-loss injuries (77%) occurring during games. The four subsequent LQ time-loss injuries occurred in practice with three of the four injuries (75%) due to a non-contact mechanism.

Table 2 presents the injury rates (initial and subsequent) for the total population (n = 95) and per level of competition. The overall LQ time-loss injury rate (including injuries from both contact and non-contact mechanisms) for the entire population was 3.4 (95% CI: 2.3, 4.7) per 1000 AE. Division III athletes had the highest rates of initial and subsequent injuries.

Table 3 presents lower quadrant (LQ) time-loss injury rates for non-contact, contact, and “all injury mechanisms” categorized by prior history of sport-related injury. Division III BB players had the highest rates of non-contact time-loss LQ injury based on prior history of injury. There was no difference in non-contact time-loss LQ injury rates between players with prior injury history [2.6 (95% CI: 1.7, 3.9) per 1000 AE] and players with no prior history [1.3 (95% CI: 0.2, 4.4) per 1000 AE] for the total population [RR = 2.0 (95% CI: 0.5, 12.5) p = 0.3].

Table 4 compares injury rates between player positions categorized as either: guards or forwards/centers. Guards experienced a significantly greater overall rate of non-contact time-loss LQ injury than their forward/center counterparts [(RR = 0.4 (0.1, 1.0) p = 0.04). Note: the aforementioned RR is based on forwards/centers having been designated as “at risk”. If guards were designated as “at risk” the RR would be 2.6 (1.0, 7.6)]. No differences in injury rates based on contact MOI or the combined MOI category “all injuries” were observed between player positions.
Table 5 compares injury rates between starters and non-starters. There was no difference in injury rates between starters and non-starters for non-contact, contact, or all injury mechanisms categories.

Table 6 presents odds ratios (OR) associated with prior injury history, player position, and starter status. Prior injury history (either all prior injuries or prior ankle sprain injuries) was not associated with greater risk of either a non-contact LQ injury or a non-contact ankle sprain. Player position was not associated with an increased risk of injury; however, there was a trend towards guards having a significantly greater risk of injury [OR = 2.9 (95% CI: 0.9, 9.5) \( p = 0.08 \)].

**DISCUSSION**

As mentioned previously the purpose of this study was two-fold. The first purpose was to report injury
rates, categorized by MOI, per prior injury history, player position, and starter status. The overall LQ injury (e.g., “all injury mechanisms”) rate of 3.4 (95% CI: 2.3, 4.7) per 1000 AE was below previously reported rates; however, this likely due to the exclusion of upper quadrant related musculoskeletal injuries, concussions, and other non-musculoskeletal time-loss injuries. A unique aspect of this study is the reporting of non-contact time-loss LQ injury rates. The injury rate associated with time-loss LQ injury due to a non-contact MOI was 2.4 (95% CI: 1.6, 3.6) per 1000 AE.

The second purpose of this study was to report injury risk based on prior injury history, player position, and starter status. It was hypothesized that BB players with a prior history of injury would be at a greater risk of LQ injury during the season. In this study BB players with a prior sport-related injury were no more likely to be injured during the course of the study when compared with BB players with no prior injury history. This is an interesting finding that warrants discussion. Prior history of sport injury has been identified as a risk factor for subsequent injury; however, it appears that this relationship is specific to injury type.16-23 For example, a prior hamstring strain, or ankle sprain, or anterior cruciate ligament (ACL) sprain are risk factors for a recurring hamstring strain, recurring ankle sprain, or secondary ACL sprain respectively.16-23 It can be argued that prior injury, if not optimally rehabilitated, may leave the athlete with deficits of

| Table 3. Lower Quadrant Injury Rates (Non-Contact, Contact, and All Injury Mechanisms) in Male Collegiate Basketball Players based on Prior History of Sport-Related Injury. |
|----------------|----------------|----------------|----------------|----------------|
| Injury Mechanism | Total | Prior History Injury | No History Injury | Rate Ratio† (95% CI) |
|                 | No. AEs | Rate (95% CI) | No. AEs | Rate (95% CI) | No. AEs | Rate (95% CI) | Rate Ratio† (95% CI) |
| Injury Rates: Non-Contact | | | | | | | |
| Division II (n = 14) | 1404 | 0.7 (0.0, 3.5) | 1303 | 0.8 (0.0, 3.8) | 101 | 0.0 | 1.4 (0.3, 29.0) p = 0.9 |
| Division III (n = 43) | 4033 | 4.7 (2.9, 7.2) | 3747 | 4.8 (2.9, 7.4) | 286 | 3.5 (0.2, 17.2) | 1.1 (0.1, 32.5) p = 0.9 |
| NAIA (n = 21) | 2187 | 0.5 (0.0, 2.3) | 1858 | 0.5 (0.0, 2.7) | 329 | 0.0 | |
| Community College (n = 17) | 2213 | 1.4 (0.0, 3.7) | 1427 | 1.4 (0.2, 4.6) | 786 | 1.3 (0.1, 6.3) | |
| Total Population (n = 95) | 9837 | 2.4 (1.6, 3.6) | 8335 | 2.6 (1.7, 3.9) | 1502 | 1.3 (0.2, 4.4) | 2.0 (0.5, 12.5) p = 0.3 |
| Injury Rates: Contact | | | | | | | |
| Division II (n = 14) | 1404 | 0.0 | 1303 | 0.0 | 101 | 0.0 | |
| Division III (n = 43) | 4033 | 0.5 (0.1, 1.6) | 3747 | 0.5 (0.1, 13.2) | 286 | 0.0 | |
| NAIA (n = 21) | 2187 | 1.8 (0.6, 4.4) | 1858 | 2.2 (0.7, 5.2) | 329 | 0.0 | |
| Community College (n = 17) | 2213 | 1.4 (0.0, 3.7) | 1427 | 1.4 (0.2, 4.6) | 786 | 1.3 (0.1, 6.3) | 1.1 (0.1, 32.5) p = 0.9 |
| Total Population (n = 95) | 9837 | 0.9 (0.4, 1.7) | 8335 | 1.0 (0.4, 1.8) | 1502 | 0.7 (0.0, 3.3) | 0.1 (0.2, 3.2) p = 0.8 |
| Injury Rates: All | | | | | | | |
| Division II (n = 14) | 1404 | 0.7 (0.0, 3.5) | 1303 | 0.8 (0.0, 3.8) | 101 | 0.0 | |
| Division III (n = 43) | 4033 | 5.2 (3.3, 7.8) | 3747 | 5.3 (3.4, 8.1) | 286 | 3.5 (0.2, 17.2) | 1.5 (0.3, 32.0) p = 0.8 |
| NAIA (n = 21) | 2187 | 2.3 (0.8, 5.1) | 1858 | 2.7 (1.0, 6.0) | 329 | 0.0 | |
| Community College (n = 17) | 2213 | 2.7 (1.1, 5.6) | 1427 | 2.8 (0.9, 6.8) | 786 | 2.5 (0.4, 8.4) | 1.1 (0.2, 8.6) p = 0.9 |
| Total Population (n = 95) | 9837 | 3.4 (2.3, 4.7) | 8335 | 3.6 (2.4, 5.1) | 1502 | 2.0 (0.4, 5.8) | 1.8 (0.6, 7.4) p = 0.3 |

CI = confidence interval
AE = athletic exposure
Rate: Injury rate per 1000 athletic exposures
†Rate Ratio: comparison between 2 rates; comparison between athletes with prior injury history and those with no prior history of injury.
Table 4. Lower Quadrant Injury Rates (Non-Contact, Contact, and All Injury Mechanisms) in Male Collegiate Basketball Players per Player Position: Guards vs. Forwards/Centers.

<table>
<thead>
<tr>
<th>Injury Mechanism</th>
<th>Total</th>
<th>Guards</th>
<th>Forwards/Centers</th>
<th>Rate Ratio† (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>AEs</td>
<td>Rate (95% CI)</td>
<td>No.</td>
</tr>
<tr>
<td>Injury Rates: Non-Contact Onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>21</td>
<td>8375</td>
<td>2.5 (1.6, 3.8)</td>
<td>16</td>
</tr>
<tr>
<td>Subsequent</td>
<td>3</td>
<td>1462</td>
<td>2.1 (0.5, 5.6)</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>9837</td>
<td>2.4 (1.6, 3.6)</td>
<td>23</td>
</tr>
<tr>
<td>Injury Rates: Contact Onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>8</td>
<td>8375</td>
<td>1.0 (0.4, 1.8)</td>
<td>5</td>
</tr>
<tr>
<td>Subsequent</td>
<td>1</td>
<td>1462</td>
<td>0.7 (0.0, 3.3)</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>9837</td>
<td>0.9 (0.4, 1.7)</td>
<td>5</td>
</tr>
<tr>
<td>Injury Rates: All Onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>28</td>
<td>8375</td>
<td>3.3 (2.3, 4.8)</td>
<td>21</td>
</tr>
<tr>
<td>Subsequent</td>
<td>4</td>
<td>1462</td>
<td>2.7 (0.9, 6.6)</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>9837</td>
<td>3.4 (2.3, 4.7)</td>
<td>25</td>
</tr>
</tbody>
</table>

CI = confidence interval
AE = athletic exposure
Rate: Injury rate per 1000 athletic exposures
†Rate Ratio: comparison between 2 rates; comparison between guards (reference) versus forwards/centers (at-risk)

Table 5. Lower Quadrant Injury Rates (Non-Contact, Contact, and All Injury Mechanisms) in Male Collegiate Basketball Players per Playing Status: Starters vs. Non-Starters.

<table>
<thead>
<tr>
<th>Injury Mechanism</th>
<th>Total</th>
<th>Starters</th>
<th>Non-Starters</th>
<th>Rate Ratio† (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>AEs</td>
<td>Rate (95% CI)</td>
<td>No.</td>
</tr>
<tr>
<td>Injury Rates: Non-Contact Onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>21</td>
<td>8375</td>
<td>2.5 (1.6, 3.8)</td>
<td>7</td>
</tr>
<tr>
<td>Subsequent</td>
<td>3</td>
<td>1462</td>
<td>2.1 (0.5, 5.6)</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>9837</td>
<td>2.4 (1.6, 3.6)</td>
<td>7</td>
</tr>
<tr>
<td>Injury Rates: Contact Onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>8</td>
<td>8375</td>
<td>1.0 (0.4, 1.8)</td>
<td>4</td>
</tr>
<tr>
<td>Subsequent</td>
<td>0</td>
<td>1462</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>9837</td>
<td>0.9 (0.4, 1.7)</td>
<td>4</td>
</tr>
<tr>
<td>Injury Rates: All Onset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>29</td>
<td>8375</td>
<td>3.5 (2.4, 4.9)</td>
<td>11</td>
</tr>
<tr>
<td>Subsequent</td>
<td>4</td>
<td>1462</td>
<td>2.7 (0.9, 6.6)</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>9837</td>
<td>3.4 (2.3, 4.7)</td>
<td>11</td>
</tr>
</tbody>
</table>

CI = confidence interval
AE = athletic exposure
Rate: Injury rate per 1000 athletic exposures
†Rate Ratio: comparison between 2 rates; comparison between starters (at-risk) and non-starters (reference)
muscular strength, flexibility, and/or other domains that would increase that athlete’s risk for future injury. For example, lower extremity strength deficits, represented by shorter triple hop distance and side-to-side limb asymmetry during the triple jump, are components of a clinical profile associated with one having a higher risk of a second ACL injury. However, having had a prior LQ sport-related injury does not increase the likelihood for any type of sport-related LQ injury in a sample of male collegiate BB players. Prior history of ankle sprain (regardless of side) was also not associated with a sport-related non-contact ankle sprain in this study. This was an interesting finding because prior studies have identified a prior history of an ankle sprain as a risk factor for recurrent ankle sprains in basketball players. It is possible that a lack of relationship between prior ankle sprain injury and subsequent ankle sprain injury was due to one or more factors. First, analysis of subsequent ankle sprain injury was restricted to those with a noncontact MOI. Second, it is possible that athletes with a prior history of lateral ankle sprains may have been utilizing prophylactic measures (e.g., bracing or taping) therefore reducing their risk of reinjury. Third, it is possible that no relationship was found due to the limited sample size in this preliminary report (type II error).

It was hypothesized that forwards/centers would be at greater risk for injury than guards. This hypothesis was based on prior reports and positional requirements. For example, forwards and centers may spend more time playing in and around the key region. As a result, there may be a greater chance for repeated physical contact (e.g., blocking out for rebounds) and there may be greater exposure to certain injuries due to repetitive jumping (e.g., jumper’s knee or bone stress injuries). Starkey reported National Basketball Association (NBA) forwards had the highest game-related injury rate of 21.7 per 1000 AEs, followed closely by NBA guards at 21.3 per 1000 AEs, and finally NBA centers at 21.0 per 1000 AEs. However, it is important to note that this injury rate was for games only, included injuries for the entire body, and did not differentiate injuries based on MOI. Meeuwise et al reported injury rates for male collegiate BB players from Canada. In that study centers experienced the highest injury rates per mechanism: contact (27.12 per 1000 AEs) and non-contact (36.16 per 1000 AEs). Centers also experienced a significantly greater rate of injury per knee, ankle, and foot regions when compared to forwards. In addition, there was no discrimination based on other player demographics.

In this study guards had a significantly greater rate of non-contact injury when compared to their forward/center counterparts. This finding is opposite of a previous report that centers had the highest injury rate regardless of MOI. There are a couple

### Table 6. Odds Ratios Associated with Prior Injury History, Player Position, or Starter Status.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N at risk</th>
<th>All Non-Contact Injuries (%) per Category</th>
<th>Odds Ratio (95% CI)</th>
<th>Non-Contact Ankle Sprain (%) per Category</th>
<th>Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior History of Sport-Related Time Loss Injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>81</td>
<td>(24)</td>
<td>1.9 (0.4, 9.0)</td>
<td>(7)</td>
<td>1.0 (0.1, 9.4)</td>
</tr>
<tr>
<td>No</td>
<td>14</td>
<td>(10)</td>
<td>1.0 (Reference)</td>
<td>(7)</td>
<td>1.0 (Reference)</td>
</tr>
<tr>
<td>Prior History of Ankle Sprain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>33</td>
<td>(24)</td>
<td>1.2 (0.4, 3.3)</td>
<td>(12)</td>
<td>2.7 (0.6, 12.9)</td>
</tr>
<tr>
<td>No</td>
<td>62</td>
<td>(21)</td>
<td>1.0 (Reference)</td>
<td>(5)</td>
<td>1.0 (Reference)</td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guard</td>
<td>61</td>
<td>(28)</td>
<td>2.9 (0.9, 9.5)</td>
<td>(8)</td>
<td>1.4 (0.3, 7.8)</td>
</tr>
<tr>
<td>Forward/Center</td>
<td>34</td>
<td>(12)</td>
<td>1.0 (Reference)</td>
<td>(6)</td>
<td>1.0 (Reference)</td>
</tr>
<tr>
<td>Starter Status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter</td>
<td>34</td>
<td>(21)</td>
<td>0.8 (0.3, 2.3)</td>
<td>(9)</td>
<td>1.4 (0.2, 7.1)</td>
</tr>
<tr>
<td>Non-Starter</td>
<td>61</td>
<td>(23)</td>
<td>1.0 (Reference)</td>
<td>(7)</td>
<td>1.0 (Reference)</td>
</tr>
</tbody>
</table>
potential explanations for this finding. First, the centers studied in Meeuwise et al\textsuperscript{4} were members of collegiate teams in Canada. There may be regional differences in game strategy that increased injury risk in that population. For example, the Meeuwise et al\textsuperscript{4} study (which was published 2003) may have reflected offensive and defensive strategies emphasizing play involving the center. Reported injury rates by court location found “the key” region had the highest rates of injury: 0.34/1000 AEs for injuries causing \( \geq 7 \) missed AEs and 1.86/1000 AEs for injuries causing < 7 missed AEs (the region with the second highest injury rate for injuries causing < 7 days of time-loss was the midcourt at 0.28/1000 AEs).\textsuperscript{4} A second potential reason may be due to the combining of centers and forwards into one category in the current study. This was done due to the overall low numbers of centers enrolled in the study. It can be argued that many forwards and centers have similar roles on the court, on both the offensive and defensive ends, and therefore may have a similar risk profile. Since this is a preliminary study, the inclusion of additional team data over the three or more year study period may allow for eventual comparison between guards and forwards/center as well as comparisons between guards, forwards, and centers. A third potential reason for injury rate differences between guards and forward/centers may have to do with off-season/preseason training habits, although this only speculative. For example, it is possible that the training programs performed by centers (who were observed during the Meeuwise et al study\textsuperscript{4}) were not adequate to reduce injury risk. However, there is limited data in the literature detailing off-season training habits and future risk of injury in various BB populations. One study has reported off-season training habits based on level of competition and per player position.\textsuperscript{31} NAIA forwards/centers devoted significantly greater amounts of time to cardiovascular exercise and plyometric exercise than those who competed at the NCAA Division III level during the six-week period prior to the start of the official preseason.\textsuperscript{31} NAIA forwards/centers also devoted significantly greater amounts of time to plyometric training than their guard counterparts.\textsuperscript{31} This study however did not evaluate risk of injury based on off-season training habits.\textsuperscript{31}

It was hypothesized that starters would be at a greater risk for injury compared to their non-starter counterparts. This relationship was hypothesized because starters may have greater exposure to injury due to playing more minutes per game. However, starters were no more likely to experience a time-loss injury (contact or noncontact) than their non-starter counterparts. This finding is consistent with a prior report that found no greater risk of injury based on starter status.\textsuperscript{5} While it might be assumed that starters would be at a greater risk based on having a greater exposure to injury due to minutes played in games; the overall time spent playing during games is only a small fraction of the total time spent playing basketball during practices and games during the course of a season.

**Limitations of this Study and Recommendations for Future Investigations**

There are some limitations to this study that warrant discussion. First, the sample size utilized in this study is relatively small; especially in relation to previously published multi-year studies.\textsuperscript{1-3} Previous multi-year studies presented injury rates based on populations consisting of tens to hundreds of thousands of AE. For example, Dick et al reported injury rates based on over 45,000 game-related AEs and over 140,000 practice-related exposures.\textsuperscript{1} To provide perspective, the total number of AE in the current study near 10,000. Despite the large difference in total AE, this study presents rates that are either novel or that differ from prior reports. As previously mentioned, this is a preliminary report that is part of an on-going multi-year investigation. A second limitation to this study relates to the proportion of athletes represented per level of competition. The largest population of athletes based on level of competition were from Division III teams. Athletes from the Division III level had the highest rates for time-loss LQ injury and thus may have skewed overall injury rates higher. Recruiting additional athletes from other levels of competition may result in different overall non-contact time-loss injuries of the LQ. Finally, this study explored relationships between prior injury history, player position, and starter status. While some significant relationships between rates and risk profiles were identified, other potential risk factors were not able to be
assessed. For example, in this study all guards were combined in one category. It is possible that point guards, because of their position requirements, have a greater risk of injury than shooting guards; however, this is currently unknown. Future research should focus on the potential relationship between specific player positions and injury.

CONCLUSIONS
The results of the current study indicate that guards experienced a greater rate of LQ injury than their forward/center counterparts. Starters and athletes with prior history of injury were no more likely to be injured when compared to nonstarters or to those with no prior history of injury. Athletic trainers and other sports medicine professionals should consider this data when developing injury prevention programs for their athletes.

REFERENCES


ABSTRACT

Background: Modifiable risk factors associated with non-contact anterior cruciate ligament (ACL) injuries are highly debated, yet the incidence rate of ACL injury continues to increase. Measures of movement quality may be an effective method for identifying individuals who are at a high risk of injury.

Purpose: The purpose of this study was to investigate whether a movement screen and/or a drop-jump landing (DJL) task identifies female individuals at a higher risk for sustaining non-contact lower extremity (LE) injuries, particularly ACL injuries.

Study Design: Cohort study

Methods: 187 women (mean age 19.5 ± 1.21 years) who played collegiate soccer, volleyball, or basketball completed the Functional Movement Screen (FMS™) and a drop-jump landing task. Weekly injury reports of participants who sustained a non-contact LE injury were collected. FMS™ scores (both total score and individual screens) and Knee Abduction Moment (KAM) values from the DJL task, were compared between injured and uninjured sample populations.

Results: A statistically significant difference ($t = 1.98, p = 0.049$) was observed in the FMS™ scores between the injured (ACL and LE injury) and uninjured groups. Prior ACL injury was also a significant predictor of LE injury (OR = 4.4, $p = 0.01$).

Conclusions: The FMS™ can be used to identify collegiate female athletes who are at an increased risk of sustaining a non-contact ACL or LE injury. Female collegiate athletes that score 14 or less on the FMS™ have a greater chance of sustaining a non-contact LE injury than those who score above 14.

Level of Evidence: 3b

Key Words: anterior cruciate ligament, functional movement screen, knee abduction moment
INTRODUCTION

Sport and policy committees of the National Collegiate Athletics Association (NCAA) report that more and more individuals are participating in athletics at the collegiate level.1,2 Subsequently, anterior cruciate ligament (ACL) injuries are increasing every year. Researchers claim an annual increase in ACL injury of 1.3%.3 Female collegiate-level athletes may be two to eight times more likely to sustain an ACL injury than males collegiate-level athletes.4,5

Investigators generally agree that ACL injuries most commonly occur as a result of non-contact mechanisms.6–8 The rate for non-contact ACL injuries ranges from 70 to 84% in both male and female athletes.9–11 Debate exists, however, over internal/external and modifiable/non-modifiable risk factors that influence non-contact ACL injury mechanisms.

Preventative programs may decrease the rate of non-contact ACL injuries.12–14 These programs were created by injury prevention experts who attempted to address apparently deficient and prevalent modifiable risk factors. Current programs include the Prevent Injury and Enhance Performance program (PEP, Santa Monica Orthopedic and Sports Medicine Foundation, Santa Monica, CA), FIFA 11 and FIFA 11+ (International Association Football Federation Medical Assessment and Research Center, Schultess Clinic, Zurich, Switzerland), and the Knee Ligament Injury Prevention (KLIP, Irmischer, Harris, Pfeiffer, DeBeliso, Adams, and Shea, Center for Orthopaedic and Biomechanics Research, Boise, ID) programs. Current research indicates that the PEP and FIFA 11 + programs may decrease the incidence rate of ACL injuries and lower extremity injuries.12–14 Mandelbaum et al13 and Steffen et al14 concluded that preventative program adherence rate among participants is the primary determinant of a successful injury prevention program. Additionally, addressing global deficits using a prevention program may not be sufficient in specific populations with increased risk factors outside the norm. Hewett et al15 believe that faulty movement patterns need to be identified and corrected before preventative interventions occur, so undesirable movement patterns are not used during prevention programs.

Investigators have suggested that among females, a high knee abduction moment (KAM) as observed in landing mechanics may be associated with an increased risk of ACL injury.16–18 Myer et al19 attempted to validate a clinician-based prediction tool (KAM nomogram) that was designed to establish a probability of individuals to demonstrate high knee load (KAM) landing mechanics. Clinical measures, including knee valgus motion, body mass, tibia length, knee flexion range of motion, and quadriceps-hamstrings (quad/ham) ratio were used to quantify the probability that participants who demonstrate high KAM (21.74 Nm) during a drop-jump landing (DJL) task possess a higher risk of ACL injury.20

The Functional Movement Screen (FMS™) is a ranking and grading system that uses seven fundamental movement patterns to observe an individual's movement competency.21 Each of the seven FMS™ movements is graded separately and assigned a specific movement score. The sum of the FMS™ movement scores comprises the FMS™ composite score. While the FMS™ screen has not been established to be used as an injury-risk-screening tool, researchers have used FMS™ composite scores as baselines in research designs with intervention programs that are intended to improve the FMS™ composite score after implementation.22 Researchers claim that increasing the composite FMS™ score may reduce the risk of injury.22–24

The purpose of this study was to investigate whether a movement screen and/or a drop-jump landing (DJL) task identifies female individuals at a higher risk for sustaining non-contact lower extremity (LE) injuries, particularly ACL injuries. Movement screens (e.g., FMS™) combined with a risk assessment measure (e.g., KAM probability) may improve clinicians' ability to identify individuals at an increased risk of non-contact ACL and/or lower extremity (LE) injury.

METHODS

Participants

The study was conducted at five National Association of Intercollegiate Athletics (NAIA) institutions. The research design and study were approved by the University of Idaho Institutional Review Board. For this study, 217 female NAIA varsity-level collegiate athletes who either played soccer (n = 63), basketball
(n = 92), or volleyball (n = 62) were recruited as participants. Among the student-athletes who volunteered to participate in the study (88% participation rate), 191 were eligible, given the age criterion of 18-25 years old; however, four of the 191 volunteers (2%) were eliminated from the study, based on the following exclusion criteria:

- Any injury status not allowing participation in sport
- A request from a physician not to engage in activity or exercise
- Any reason given by the participant or the primary investigator (PI) that is seen as potentially harmful to the participant were she to engage in the study (e.g., a temporary illness that affected the participant's ability to move, or a disease or illness that caused pain in the participant during the screen).

Written consent was received the day of data collection. Each participant also completed a pre-participation survey to establish eligibility for the investigation, and identify prior ACL injury and/or prior knee surgery. All eligible participants (n = 187) performed the DJL task. Five participants began the FMS™ but did not complete all of the movements, due to time constraints. Partial data collected from the five participants were included in the statistical analyses.

**Instrumentation**

Functional Movement Screen movements were rated by the PI using the FMS™ test kit (Functional Movement Systems, Inc., Chatham, Virginia). The FMS™ movements included the hurdle step, inline lunge, shoulder mobility test, active straight-leg raise, trunk stability push-up, rotary stability test, and deep squat which comprise the FMS™. Each movement was graded on quality and ability to produce optimal movement. The movements were scored using an ordinal scale from one to three. Pain that was reported by the participants during any movement pattern resulted in a score of zero. Three pain provocation screens were also conducted as a part of the FMS™.

In order to identify clinical measures necessary to determine each participants' probability of demonstrating high KAM, participants completed the DJL task. The DJL task involved performing a sports-specific jumping task three times from a 31 cm wooden box constructed by the PI (Figure 1). The participants dropped down, and, upon landing, immediately jumped as high as possible. Tape lines were applied 35 cm apart on top of the wooden box to allow for the minimum foot/ankle separation necessary to enable adequate observation of knee valgus motion.

Using a previously validated clinic-based nomogram, the probability of demonstrating high KAM (>21.74 Nm) was determined by measuring knee flexion and valgus motion during the DJL task. The participants' DJLs were recorded using two off-the-shelf camcorders (Panasonic V550) in frontal and sagittal planes. Virtualdub video analysis software, version 1.10.4 (Free Software Foundation, Inc., Cambridge, Massachusetts), was used to capture still images of knee flexion angles and knee valgus motion from the recordings. ImageJ software, version 1.48 (U.S. National Institute of Health, Bethesda, Maryland), was used to measure knee flexion angles and knee valgus motion from the still images at specifically designated time points (see description below). Participant body mass was measured with a Health-o-Meter® weight scale, called The Doctor's
The body mass measures were used in the nomogram to help identify participants’ KAM probability. Although, quad/ham ratio is traditionally captured using an isokinetic testing device, the investigators used a surrogate measure as suggested by Myer et al²⁴ (participant’s mass is multiplied by 0.01 and the resultant value added to 1.10).

**Procedures**

Participants were grouped with their respective athletic teams for FMS™ and KAM data collection and were measured in the athletic training clinic or in the gym of their institution. For the sake of participants' privacy, measures were collected behind a tri-fold screen. The PI measured and recorded all participant data. Tibia length, from the lateral knee joint line to the center of the lateral malleolus, was measured in centimeters, using a standard measuring tape.

Functional Movement Screen instruction and demonstrations were conducted in groups (teams). At the completion of the FMS™ screen, groups were provided an introduction to the DJL task. The PI demonstrated the DJL task to each group but did not offer instruction regarding DJL mechanics. If desired, participants could perform one to two practice DJL tasks. When ready, the participants dropped directly down from the box, landed, and immediately performed a maximal jump. The participants were encouraged to mimic the jump they would perform in their sport. For example, jumping for a rebound was suggested to basketball participants, jumping to block a hit was suggested to volleyball participants, and jumping to head a ball was suggested to soccer participants. Mimicking sport activity may help participants to be less concerned that they are being evaluated,²⁵ leading to more natural jump and landing biomechanics.

The PI then watched the video-recorded DJL tasks and identified which of each participant’s jumps produced the greatest knee valgus position. The knee flexion angle was measured from the same DJL attempt that produced the greatest knee valgus position. Knee flexion angle one (F1) was measured from the sagittal view at the video frame just prior to foot contact with the ground (Figure 2). Knee flexion angle two (F2) was measured from the video frame demonstrating greatest knee flexion motion (Figure 3). The knee flexion range of motion (ROM) value was determined by subtracting F2 from F1 (F1-F2 = knee flexion ROM value). Knee valgus position one (V1) was measured from the frontal view at the video frame just prior to foot contact with the ground (Figure 4). Knee valgus position two (V2) was identified at the video frame with maximal medial position of the knee joint center (Figure 5). Knee valgus motion value was determined by subtracting V2 from V1 (V1-V2 = knee valgus motion value). The knee flexion and

---

**Figure 2. Knee flexion angle 1**
The frame rate prior to initial contact with the ground was used to identify the position of knee flexion angle 1 (F1). The knee flexion range of motion (ROM) value was determined by subtracting F2 from F1 (F1-F2 = knee flexion ROM value). The knee flexion value was used in the KAM (Knee Abduction Moment) nomogram to determine each participant's probability of demonstrating high KAM (21.74 Nm) during the drop jump landing task.
valgus motion values were used in the nomogram to determine each participant’s probability of demonstrating high KAM (21.74 Nm) during the DJL task.

The PI contacted each institution’s head athletic trainer weekly, through email, requesting that he/she refer to the PI any female participants who sustained an apparent ACL or non-contact LE injury. An apparent ACL injury was defined as any knee injury that a medical professional clinically assessed and diagnosed as a possible ACL injury. A non-contact LE injury was defined as any injury that a medical professional clinically assessed and diagnosed at or below the hip which was not caused by a physical external force (i.e., an opposing player, a ball, or referee) and which resulted in the participant’s inability to participate in her sport for at least 48 hours.

Participants who sustained an apparent ACL injury (n = 6) were sent an online survey via email (Appendix A). The survey questionnaire sought to determine the nature of the injury and whether or not the athlete’s hormone levels based on self-reported onset of most recent menstrual cycle, could have affected her susceptibility to injury. Additionally, the survey helped the investigators to confirm that the sustained ACL injury was, in fact, non-contact.

RESULTS

Data Analysis
Data analyses were conducted using International Business Machines (IBM) SPSS statistics, version 21.0
SPSS Inc., Chicago, IL) and SAS/STAT software, version 9.3 (SAS Institute Inc., Cary, NC). The descriptive statistics (found in the following section) were compiled from data on both injured and non-injured groups. In order to identify potential relationships within each group, independent variables (i.e., KAM probability, KAM clinical measures, FMS™ composite score, and FMS™ specific movement scores) were observed using univariate analyses (i.e., frequency, central tendency, and dispersion). Independent samples t-test were used to compare mean data sets between participants who sustained a non-contact ACL or LE injury and those who did not. The variables in this test include the following:

- FMS™ composite score
- FMS™ specific movement scores (i.e., lunge, deep squat, straight leg raise, shoulder mobility, rotary stability, push-up, and hurdle step)
- KAM probability as calculated from the nomogram
- KAM clinical measures (i.e., knee valgus motion, knee flexion motion, tibia length, body mass, and quad/ham ratio)

The researchers used exact logistic regression analyses to identify whether the FMS™ composite score and/or the KAM probability best predicted non-contact LE and ACL injury. Standard logistic regression analyses were used to determine which combination of FMS™ specific scores and KAM clinical measures best predicted non-contact ACL and LE injury. The \( \alpha \) was set at 0.05.

**Descriptive Statistics**

Table 1 provides descriptive statistics for FMS™ composite and specific movement scores. Descriptive statistics for the clinical measures used to determine the KAM probability are found in Table 2.

Seventeen participants (9%) sustained a non-contact LE injury during the observation period. The injured participants’ FMS™ mean composite score (14 ± 3.46) was statistically significantly lower when compared to the non-injured participants (15.35 ± 2.58, \( t = 1.98, p = 0.049, 95\% CI = 0.01, 2.69 \)). The average probability of KAM (high knee load) of injured participants (0.892 ± 0.11) was not statistically

![Figure 5. Knee valgus position 2](image)

The frame rate with maximal medial position of knee joint center was used to identify the position for knee valgus position 2 (V2). Knee valgus motion value was determined by subtracting V2 from V1 (V1-V2 = knee valgus motion value). The knee valgus motion value was used in the KAM (Knee Abduction Moment) nomogram to determine each participant’s probability of demonstrating high KAM (21.74 Nm) during the drop jump landing task.
significantly higher when compared to the non-injured participants (0.852 ± 0.16, $t = -1.084, p = 0.28$, 95% CI = -0.112, 0.03) (Table 3 and Table 4).

Of the six ACL injuries that were reported during this study, two resulted from contact initiated by a separate individual (teammate or opposing player) and four were non-contact ACL injuries. The researchers’ data analyses only considered the ACL and LE injuries that were non-contact in nature. The FMS™ composite score was statistically significantly different in ACL injured versus non-ACL injured subjects ($p = 0.015$; KAM probability, $p = 0.7$) (Table 4). The average FMS™ composite score of ACL injured participants ($12 ± 4.83$) was lower when compared to the uninjured ACL participants ($15.3 ± 2.61, t = 2.452, p = 0.015, 95% CI = 0.644, 5.948$). The average KAM probability was unexpectedly higher in the uninjured ACL participants ($0.857 ± 0.15$) compared to the ACL injured group ($0.827 ± 0.16, p = 0.7$). The KAM probability and clinical measures of KAM were reviewed for outlier cases within the sample population. All data points were within three standard deviations from the mean.

The clinical measures used to identify the KAM probability that demonstrated poorer scores among the injured participants (body mass, quad/ham ratio, and valgus motion) are found in Table 5.

The components of the FMS™ screen that demonstrated poorer movements among the injured participants observationally include the lunge, straight leg raise, push-up, trunk rotation stability, and deep squat (Table 6).

Participants who reported sustaining ACL injuries prior to the investigation (n = 27) demonstrated
poorer FMS™ composite scores in the FMS™ movement screen (13.84 ± 3.611) when compared to participants who did not report a prior ACL injury (15.30 ± 2.732, t = 2.03, p = 0.04). There was no significant difference between FMS™ composite scores in participants who reported having undergone one or more knee surgeries (n = 29) (14.45 ± 2.84) when compared to participants who did not report a prior knee surgery (15.37 ± 2.65, t = 1.7, p = 0.09).

The independent samples t-test of FMS™ composite score and LE injury demonstrated a statistically significant difference (t = 1.98, p = 0.049) between the injured and uninjured groups. The independent samples t-test of KAM probability was not associated with a statistically significant difference (t = -1.084, p = 0.28) between the injured and uninjured groups.

Using an exact logistic regression model, previous ACL injury and FMS™ composite score were demonstrated to be the strongest predictors of non-contact LE injury (Table 7). Exact logistic regression was used due to the small sizes of the non-contact LE and ACL injured groups (n = 17 and 4).

The results from Model Set 1 (effect of movement scores on LE injury) indicated that the effect of FMS™ composite score on the logistic odds of sustaining an LE injury was trending towards statistically significant (p = 0.06) (Table 7). With every one standard deviation increase (improvement) in FMS™ composite score (2.69 points), the odds of sustaining an LE injury decreased by more than 35% (OR = 0.64). The PI categorized the participants’ KAM probability into high- and low-risk groups, based on a cut point of ≥ 0.80. The investigators' results indicated that probability of high KAM, using a threshold cut point of 0.80 as “high-risk,” did not predict non-contact LE injury (p = 0.284).

Model Set 2 (Table 7) contains the effect of FMS™ composite score on the log-odds of sustaining an LE injury when controlling for prior knee surgery and pain reported during the FMS™ screen. When pain during the FMS™ screen and prior knee surgery were controlled (p = 0.52 and 0.35), neither FMS™ composite score nor KAM probability predicted non-contact LE injury.

Table 5. Clinical Measures of KAM Nomogram and Lower Extremity Injuries.

<table>
<thead>
<tr>
<th>KAM Probability</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No injury</td>
<td>0.852 (0.156)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>0.892 (0.109)</td>
</tr>
<tr>
<td>Tibia*</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>41.68 (2.41)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>41.4 (1.7)</td>
</tr>
<tr>
<td>Body mass*</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>69.51 (13.08)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>70.08 (8.09)</td>
</tr>
<tr>
<td>Quad/ham ratio*</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>1.79 (0.13)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>1.8 (0.08)</td>
</tr>
<tr>
<td>Flexion*</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>65.99 (13.81)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>66.18 (14.45)</td>
</tr>
<tr>
<td>Valgus*</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>4.12 (3.05)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>4.99 (2.31)</td>
</tr>
</tbody>
</table>

* Measured in centimeters
* Measured in kg
* Measured by participant’s body mass multiplied by 0.01 and the resultant value added to 1.10
* Measured in degrees
KAM = Knee Abduction Moment

Table 6. FMS™ Movements (Point Based) and Lower Extremity Injuries.

<table>
<thead>
<tr>
<th>FMS™ Composite Score</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No injury</td>
<td>15.35 (2.58)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>14 (3.46)</td>
</tr>
<tr>
<td>Hurdle</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>2.24 (0.61)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>2.24 (0.56)</td>
</tr>
<tr>
<td>Lunge</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>2.49 (0.7)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>2.06 (1.14)</td>
</tr>
<tr>
<td>SLR</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>2.29 (1)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>2.24 (1.15)</td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>2.7 (0.73)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>2.59 (0.87)</td>
</tr>
<tr>
<td>Pushup</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>2.31 (0.96)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>2 (1.06)</td>
</tr>
<tr>
<td>Rotational</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>1.77 (0.78)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>1.47 (0.87)</td>
</tr>
<tr>
<td>Deep squat</td>
<td></td>
</tr>
<tr>
<td>No injury</td>
<td>1.7 (0.74)</td>
</tr>
<tr>
<td>Sustained an injury</td>
<td>1.41 (1.07)</td>
</tr>
</tbody>
</table>

FMS™ = Functional Movement Screen
SLR = straight leg raise

Table 7. Non-contact Lower Extremity Injury Logistic Regression.

<table>
<thead>
<tr>
<th></th>
<th>Model Set 1 Movement Only</th>
<th>Model Set 2 Controlling for Prior Injury and Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>p</td>
</tr>
<tr>
<td>KAM</td>
<td>1.12 (0.68-1.83)</td>
<td>0.65</td>
</tr>
<tr>
<td>FMS™</td>
<td>0.64 (0.41-1.03)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Results are based on exact logistic regression models.
OR = odds-ratio
FMS™ = Functional Movement Screen
LE injury. However, the odds of participants who reported sustaining a prior ACL injury and/or knee surgery sustaining a subsequent non-contact LE injury were 4.4 times greater than participants without prior ACL injury and/or knee surgery (OR = 4.40, 95% CI: 1.32, 14.47, p = 0.01). Pain reported during the FMS™ screen did not predict LE injury (p = 0.39). Thirty-four percent of the participants (n = 64) reported pain during one or more of the FMS™ specific movements. Participants reported pain during 94 movements (8.51%) when considering all FMS™ specific movements observed (1,105).

Given the small incidence of non-contact ACL injury (n = 4), the model set for non-contact ACL injury (Table 8) was more exploratory than confirmatory. The results from the exact logistic regression models indicated that FMS™ composite score was a significant predictor of ACL injury. Additionally, with every one standard deviation increase (improvement) in the FMS™ composite score, the odds of sustaining a non-contact ACL injury decreased by 60% (OR = 0.40, p = 0.03). The investigators’ results indicate that the KAM probability (high-risk cut point of ≥ 0.80) did not predict non-contact ACL injury (p = 0.64).

When considering all combinations of the FMS™ specific movement scores and KAM clinical measures, there were no statistically significant predictors of ACL or LE injury (p > 0.05 for all). The effect of FMS™ lunge on LE injury approached statistical significance (p = 0.08), such that increased lunge scores were associated with decreased odds of sustaining a non-contact LE injury (OR = 4.40, 95% CI: 1.32, 14.47). When all FMS™ movements and KAM clinical measures were considered, the combined effect of the valgus (KAM) clinical measure and the FMS™ lunge on LE injury was the strongest predictor (p = 0.11).

**DISCUSSION**

This study was conducted to determine if movement screens (FMS™ and KAM) could be used to predict non-contact LE injury in female participants and to identify the combination of movement scores that best predicts injury. The identified cut-off for the FMS™ composite score that best predicted non-contact LE injury in the current study was 14. A cut-off score of 14 or less is congruent with recent literature that also identified individuals at a higher risk of sustaining an injury.24,26–28

Previous authors have suggested that ≥ 74 Nm of knee abduction represents high KAM, and ≤ 7.6 Nm of knee abduction represents low KAM.19 Myer et al identified females with knee abduction > 25.3 Nm at a greater risk of sustaining an ACL injury.29 It is important to note that the KAM nomogram indicates the probability that individuals will demonstrate 21.74 Nm of undesired knee load during landing mechanics. Some of the participants likely possessed knee loads greater than 21.74 Nm as predicted from the nomogram; however, actual knee loads were not measured.

Hewett et al18 determined that the average female athlete has about a 4.4% risk of suffering a non-contact ACL injury when the high-risk sport (basketball, soccer, or volleyball) is played year round (169 activity exposures). Participants in this study were observed only while “in season” (about 90 activity exposures over a 12-16-week period). Activity exposures included pre-season and in-season practices, games, scrimmages, and any other athletic activity specific to participants’ sport. Thus, the adjusted average risk of suffering an ACL injury was 2.7%. The participant sample size (N = 187) was expected to produce five ACL injuries (rounded down from 5.1). The sample population from this investigation sustained the anticipated ACL injury rate when considering all confirmed contact and non-contact ACL injuries (n = 6).

The injured groups’ FMS™ specific movement scores were numerically lower (poorer) in six out of the
seven movements; however, differences between the injured and uninjured groups were not statistically significant \((p > 0.05)\). Although the statistical analyses for KAM probability did not indicate significant differences between the injured and uninjured groups, there was a trend that indicates that poorer clinical measures in KAM (i.e., higher knee valgus motion, body mass, quad/ham ratio, and/or KAM probability) may help to identify participants who are more at risk of non-contact LE injuries.

The investigators believe that the FMS™ demonstrated significant differences between the injured and uninjured groups, because seven fundamental movement patterns that operate as a basis for more complex sport related movements were observed; whereas the KAM nomogram quantifies a risk-assessment value using a single dynamic movement (DJL) and anatomic measures. The investigators found that the FMS™ composite score demonstrated differences between injured and uninjured groups are similar to the result of several recent studies.\(^{26–28,30,31}\) Further, the findings using the KAM nomogram to identify differences between the two groups cannot be compared, feasibly, with current literature, due to limited and conflicting research.\(^{32,33}\)

**Limitations**

Data were collected and injury observation occurred throughout the participants’ regular athletic season (12-16-week period). A longer observation period (i.e., more activity exposures) may be necessary in order to determine whether or not there is a statistically significant difference in movement scores between injured and uninjured participants.

Participation in recreational and high-risk activity outside of the participants’ sport may have occurred. The post-ACL injury questionnaire (Appendix A) asked injured participants if the apparent ACL injury occurred while playing their sport. Complete participant honesty when reporting or not reporting pain was assumed throughout FMS™ screening and DJL testing.

**Future Research**

Future research regarding FMS™ composite score and KAM probability should be conducted to further investigate whether individuals with low movement scores possess a greater likelihood to sustain a non-contact ACL and/or LE injury. Previously known injury risk factors (e.g. previous injury, pain, and body mass index) and movement screens (e.g. FMS™, Lower Quarter Y-Balance Test, and Star Excursion Balance Test) may provide investigators with an individualized injury risk assessment and improved identification of individuals who possess a greater risk of injury. Investigators should consider observing a larger sample size, which may result in a higher number of reported injuries. Increasing the length of time in which injury surveillance occurs may also result in a higher number of non-contact LE injuries.

**CONCLUSIONS**

The FMS™ screen and KAM probability algorithm (nomogram) are easily implemented into clinical settings that include collegiate female athletes. The results of the current study indicate that the KAM probability (high-risk cut point of \(\geq 0.80\)) does not predict non-contact ACL injury \((p = 0.64)\). However, the FMS™ composite score can be used to help identify collegiate female athletes at a higher risk of sustaining a non-contact ACL and/or LE injury. A statistically significant difference \((t = 1.98, p = 0.049)\) was observed in the FMS™ scores between the injured (ACL and LE injury) and uninjured groups. Female athletes in this investigation who scored 14 or less on the FMS™ screen had a greater chance of sustaining a non-contact LE injury.

**REFERENCES**


4. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament


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**Appendix A.** The questionnaire sent to participants (via online survey, Qualtrics) who sustained an ACL injury during the observation period.

Please answer the following questions to the best of your ability. However, you are free to not answer any question you do not want to. The survey should take 2-3 minutes.

1. Did your knee injury occur while participating in your collegiate sport (during practice, training, scrimmage, or game)?
   - a. If no, in your own words, where did the knee injury occur? (You may write ‘Not Sure’)

2. Was anyone else physically in contact with you when the knee injury occurred (teammate, opponent, or referee)?

3. Did you have a menstrual cycle within the last 15 days from your injury date?
   - a. If yes, to the best of your memory, what was the start and end date?

4. Are you currently using any contraceptives (birth control)?
   - a. If yes, have you been using birth control for at least 30 days?
   - b. If so, what contraceptive are you using?

5. Not including your current knee injury, have you ever been diagnosed with an ACL tear?
   - a. If yes, did you have surgery to repair the ACL?

6. Were you using an ACL prevention program prior to your ACL injury?
ABSTRACT

Background: Cryotherapy is commonly used in sport for the management of injury or during recovery, however the effects on concentric isokinetic strength appear unclear when considering the effect of joint cooling distal to the anterior thigh.

Purpose: The purpose of this study was to investigate the effect of cooling of the knee joint on quadriceps concentric isokinetic torque production. The results will inform the use of cryotherapy in practice.

Study Design: Observational cohort, Repeated Measures

Methods: Fourteen healthy male participants volunteered to take part in the study, all of whom regularly played competitive sports (mean age 20.24 ± 1.51 years; body mass 80.34 ± 11.34 kg and height 179.45 ± 6.59 cm). 800 g of crushed ice was applied over the anterior knee joint for 20 minutes. Concentric quadriceps strength was measured using an isokinetic dynamometer (IKD) by measuring concentric peak (Pkt) and average torque (AvT) outputs at pre-, immediately post and 20 minutes post cooling intervention. Additionally, skin surface temperature (Tsk), was measured using a hand-held thermometer at the patella at the same time intervals. Measurement was taken at the mid-point of each participant’s patella, which was ascertained by measuring between the base and apex.

Results: Significant main effects reported for Pkt, for time post-ice application (p = 0.02, η² = 0.161). Post-hoc analysis revealed pre-ice application Pkt to be significantly higher (p ≤ 0.003) than all other timepoints. Quadratic regression analysis revealed a strong correlation between reductions in quadriceps torque production and time post application (r = 0.82). The quadratic pattern of recovery displays a minima of 17.28-minutes and maxima of 34.56-minutes post ice application. AvT post-ice application demonstrated significant main effects for time post-ice application (p = 0.03, η² = 0.152). Post-hoc analysis revealed pre-ice application AvT to be significantly higher (p ≤ 0.005) than at all other timepoints. Quadratic regression analysis revealed a strong correlation between reductions in quadriceps torque production and time post application (r = 0.80). The quadratic pattern of recovery displays a minima of 18.38-minutes and maxima of 36.76-minutes post ice application. Tsk reduced significantly, immediately post intervention (p ≤ 0.05) without returning to baseline measures at 20-minutes post (p ≤ 0.05).

Conclusions: Isokinetic peak torque values of the quadriceps diminish after cryotherapy application to the knee joint and are not fully recovered at 20 minutes post application on the knee. These findings could have potential implications for participation in activity immediately following ice application.

Level of Evidence: 2b

Keywords: Cryotherapy, Isokinetic Dynamometry, Knee, Quadriceps

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The authors declare no conflict of interest within or related to the present work.
INTRODUCTION
Cryotherapy, commonly utilized within sporting populations post injury, initiates multiple physiological changes, including reductions in edema, nerve conduction velocity (NCV), and tissue metabolism,\(^1,2\) while concurrently inducing an analgesic effect. With regard to muscle strength, changes in cold-induced NCV presents no consensus in current literature\(^3\) indicating a detriment to muscle performance through reductions in receptor firing rate and muscle spindle activity. Authors suggest that variance in myotatic stretch reflex and ion (\(\text{Na}^+, \text{K}^+, \text{Ca}^+\)) diffusion at the motor end plate causes the known reduction in enzymatic activity at lower temperatures,\(^4,5\) with previous research suggesting that cooling impairs \(\text{Ca}^+\) release therefore ensuing adenosine triphosphate decline altering cross bridge function. Current literature\(^6,7\) provides evidence of increased muscle stiffness post cooling, suggesting inability to monitor stretch limit within the muscle, potentially increasing the risk of tissue injury. The emerging evidence also suggests that joint cooling also affects joint position sense (JPS).\(^8,9\) Altered mechanoreceptor feedback caused by reductions in proprioceptive control\(^9\) following cooling at the knee, could make a heightened risk of injury to the anterior cruciate ligament (ACL) and medial complex. The effect of cooling on muscle strength around the knee may also have implications deleterious to athletes returning to functional activities immediately following cryotherapy. Although reported widely on in current literature, there are variations across studies and conflicting magnitudes of change in muscle strength following local applications of cold.\(^7,12,13,24,32\) This thought to be due to differences in research design, with some studies failing to analyze muscle strength in conjunction with tissue temperature.\(^27\) Study outcomes are consequently difficult to compare.

Decreases in recorded \(T_{sk}\) following local cooling correlates to reductions in muscle function.\(^5\) Deterioration in both extension torque and power by around 5% for every \(1\) °C decrease in intramuscular temperature has been previously reported.\(^10\) Colder intramuscular temperatures (\(\sim 30\) °C) reported in research were associated with lower concentric isokinetic torque production, at varying speeds from fast to slow.\(^11\) However, Thornley et al., describe moderate or contradictory changes such as, reporting increases in isometric quadriceps strength after 30-minutes of thigh cooling.\(^12\) Recent suggestions imply that an increase in muscle stiffness occurs post cryotherapy application, lowering the available sustained stretch in muscle tissue therefore increasing potential injury risk.\(^7\) Variability in duration of application of cryotherapy modalities noted in published literature recently considers realistic applications (10 minutes) of local cooling in sport, compared to traditional clinical protocols of 20-minute durations.\(^5\) Cryotherapy modality type, duration, and method of application also vary throughout the available studies, including cold-water immersion and crushed ice via local applications, reflecting further difficulty in comparison ability and outcome implications within literature.

Isokinetic Dynamometry (IKD) commonly used in research\(^17\) to evaluate torque production as a measurement of muscle strength, due to its high test-retest reliability.\(^18\) Suggestions for the use of isokinetic dynamometry include measurements of both peak torque (\(\text{PkT}\)) and average peak torque (\(\text{AvT}\)) in order to describe muscle function and has been utilized to assess reductions in strength post fatigue protocols.\(^19\) Quadriceps strength or a potential strength deficit is important to consider during the evaluation of knee joint function,\(^20\) as this can have implications on knee function, including stability during performance.\(^21\) When considering muscle strength deficits post cooling\(^11\) (indicative of potential changes in quadriceps strength), awareness must be paid to of possible effects on neuromuscular parameters, which may be related to knee injury risk. Impact on joint control and stabilization may be a result of decreased capability of muscle tension regulation\(^16\) impairing knee extensor control of the quadriceps through reduced sensitivity of receptors following cooling. When considering knee injuries in sport, decreases in quadriceps function may prevent reductions in the ability to prevent abnormal or excessive movement when performing functional movement patterns.\(^22\) Decreases in quadriceps function and control during performance, alongside other neuromuscular considerations, are highly relevant during acceleration and deceleration, and...
may increase the risk of non-contact musculoskeletal injuries.\textsuperscript{22}

Skin surface temperature ($T_{sk}$) and intramuscular temperature ($T_{im}$) post cooling presents a highly significant quadratic association.\textsuperscript{14} Although fluctuations in the rate of temperature change between various applications of modalities have been reported, research presents consensus on the relationship between superficial and deeper intramuscular cooling.\textsuperscript{2} A change in temperature during post-cooling phases occurs as heat from deeper tissue structures transfers to superficial tissues.\textsuperscript{14,15} Since muscle continues to cool following removal of cold, while skin re-warms,\textsuperscript{14} the delayed effects this may induce in respect to muscle strength and joint control should be considered. Data appears contradictory when considering the effect of cooling distal to the anterior thigh on strength of the quadriceps.\textsuperscript{16,23,24} The purpose of the present study was to investigate the effect of cooling of the knee joint on quadriceps concentric isokinetic torque production. The results will inform the use of cryotherapy in practice.

**METHODS**

**Participants**

A priori power calculation was conducted to determine a sample size of fourteen healthy male participants (statistical power > 0.8, $p < 0.05$). Subjects participating in the study regularly took part in competitive sports (age 20.24±1.51 years; body mass 80.34±11.34Kg and height 179.45±6.59cm). All participants provided written consent to take part in the study. The study was conducted according to the Declaration of Helsinki\textsuperscript{25} and approved by University of Central Lancashire Ethics Committee. To increase sample homogeneity all-male participants were used due to gender differences found in response to local cooling.\textsuperscript{26} Exclusion criteria contained; any contraindications to cryotherapy\textsuperscript{27} previous knee joint surgery, lower limb injury in the prior six months, and/or referred pain either to or from the knee.

**Intervention Protocol**

Testing took place in a movement analysis laboratory. Kinematic data (PKT and AVT) was collected pre- and post- intervention using a Cybex IKD (Cybex, division of Lumex Inc., Ronkonkoma, NY, USA) chosen due to its high reliability (0.9 – 0.98).\textsuperscript{18,19,21} Superficial skin temperature was measured using a hand-held digital thermometer (Fora, Gallen, Switzerland, IR19). The digital thermometer meets the required standard in ASTM E1965-98 and EC directive 93/42/EEC. Prior to testing participants acclimatized to a steady thermal state for 15 minutes prior to intervention. Following the acclimatization phase, three measures of $T_{sk}$ were recorded at the center of participants’ patella for average baseline data.

Concentric isokinetic torque measurements of the quadriceps were performed. Subjects performed three repetitions of knee extension to at 60°s\textsuperscript{-1} on the dominant leg, passively moving into flexion at 10°s\textsuperscript{-1} between repetitions. The participant’s dominant leg was determined by which leg they would normally kick a ball with.\textsuperscript{30} The researcher recorded participants’ position settings, and the same settings were utilized during each measurement (pre, immediately post-, and 20-minutes post- crushed ice intervention). During isokinetic testing, participants sat in the IKD with straps applied across the chest, pelvis and mid-thigh to minimize extraneous body movements during testing. The rotational axis of the dynamometer aligned with the lateral femoral epicondyle and the tibial strap placed distally at three-quarters of the length of the tibia. Participants were instructed to position their arms across the chest to isolate the quadriceps during torque production.\textsuperscript{28} Participants completed each repetition throughout every set to their maximum and were encouraged to do so throughout with verbal and visual feedback.\textsuperscript{29} A total of three maximal repetitions were completed at 60°s\textsuperscript{-1} and an average of two consistent repetitions were taken for PKT\textsubscript{conc} and AVT\textsubscript{conc} measures. Researchers observed each repetition completed on the IKD ensuring that smooth and consistent effort was exerted, throughout the subject’s performance.

Following the collection of baseline data, the researcher applied 800g of crushed ice contained in a clear plastic bag held in place by cling film wrap, following previous protocols\textsuperscript{31} over the anterior aspect of the knee, on the dominant leg, for a period of 20 minutes.\textsuperscript{5} Post the 20-minute cryotherapy application, the ice was removed from the limb and concentric torque data was collected. This was then repeated.
at 20-minutes post removal of the ice after the subject had been exposed to a period of rewarming.

**Statistical Analysis**

A one-way repeated measures ANOVA was used to investigate a within factors main effect for time. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardized residuals. Scatterplots of the stacked unstandardized and standardized residuals were also utilized to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Where significant main effects were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Measures of significance were supplemented with partial eta squared (η²) values calculated to estimate effect sizes for each dependent variable, and provide a measure of meaningfulness. As recommended by Cohen (1988), partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138).

The temporal pattern of changes in each isokinetic variable over the time collection period was examined using regression analyses. Quadratic polynomial models were applied, with the optimum fit determined by the strength of the correlation coefficient (r). Where a quadratic regression analysis represented the best fit, the regression equation was differentiated with respect to time to elicit the time (torque values post-exercise) at which the data reached maxima (or minima). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at  

\[ p \leq 0.05 \]

and all data are presented as mean ± standard deviation.

**RESULTS**

**Peak Torque**

Figure 1 displays the effects of a 20 minute ice application on PkT immediately post ice application and 20 minutes post ice application. There was a significant main effect for time post ice application

\[ (p = 0.02, \eta^2 = 0.161) \]

Post hoc testing revealed that pre ice application PkT was significantly higher (\( p \leq 0.003 \)) than at all other time points. The quadratic regression revealed a strong correlation (\( r = 0.82 \), displaying a minima of 17.28 minutes and maxima of 34.56 minutes post ice application.

**Average Peak Torque**

The acute influence of ice application and the subsequent recovery of AvT post ice application are

![Figure 1. Mean PkT (Peak Torque Concentric Quadriceps) Values for Pre, Post and 20 Minutes Post Crushed Ice Application for Isokinetic Speed of 60°/s⁻¹.](image)
displayed in Figure 2. There was a significant main effect for time post ice application ($p = 0.03, \eta^2 = 0.152$).

Post hoc testing revealed that pre ice application PkT was significantly higher ($p \leq 0.005$) than at all other time points. The quadratic regression revealed a strong correlation ($r = 0.80$), displaying a minima of 18.38 minutes and maxima of 36.76 minutes post ice application.

**Skin Surface Temperature**

$T_{sk}$ (measured at the center or the patella) demonstrated significant reductions post cryotherapy intervention ($p \leq 0.05$). Average $T_{sk}$ immediately post cryotherapy application was $13.9 \pm 1.9^\circ C$, representing a skin surface temperature response to within therapeutic range, resulting in a percentage change reduction in $T_{sk}$ of 51%. At 20-minutes post removal of the intervention average $T_{sk}$ was reported to be $24.0 \pm 2.9^\circ C$, supporting the known re-warming curve for $T_{sk}$ but not yet having returned to baseline measures (Figure 3). $T_{sk}$ displayed a 16% reduction at 20-minutes post removal when compared to baseline.

**DISCUSSION**

Cryotherapy applications are common in sport for the management of injury, however the effects on strength of the thigh when cold is applied to the knee and surrounding soft tissue continues to lack consensus. Musculature at the knee provides feedback for joint stability, with reductions in quadriceps strength known to increase the risk of non-contact injury around the knee. The purpose of the current study was to investigate the effect of cryotherapy on the torque production ability of the quadriceps immediately and 20-minutes post cryotherapy application at the knee. Significant reductions in strength were reported in PkT and AvT when compared to baseline to both immediately post and 20-minutes post. Large effect sizes ($\eta^2 = 0.161$ and $\eta^2 = 0.152$) were reported for both PkT and AvT, indicating that cryotherapy application had a large immediate effect on strength following removal of the ice and up to 20 minutes post application. Quadratic regression analysis indicated that isokinetic strength measures reached a minima at 18.38 minutes post ice application and returned at a predicted 36.76 minutes post icing. These findings support the findings of previous research describing reductions in muscle strength following cryotherapeutic applications but differ in the conclusion that even when the quadriceps are not directly cooled, and cooling occurred distal to the muscle belly at the knee joint, reductions in quadriceps strength still occurs. These findings suggest a need for awareness of the effects on surrounding soft tissue structures that may be affected post cooling of

![Figure 2. Mean AvTconcQ (Average Torque Concentric Quadriceps) Values for Pre, Post and 20 Minutes Post Crushed Ice Application for Isokinetic Speed of 60°/s⁻¹.](image-url)
The implications of reduced muscle strength of the quadriceps may include increased risk of non-contact injury at the knee complex.\(^{22}\) Strength reductions in the current study were still evident at 20-minutes post removal of the intervention displaying a 16% reduction in PkT and AvT respectively. Although perhaps a poor comparison due to a difference in location of cryotherapy application and protocol, these findings contrast with an earlier study that observed no delayed reductions in isokinetic concentric strength at 20-minutes post ice application.\(^{32}\)

The amount of ice and location of application differs between studies, with 5lb directly over the quadriceps\(^{33}\) compared to 800g in the current study. Both studies tested concentric isokinetic strength at 60°s\(^{-1}\). It may be postulated that cooling at the knee joint disrupted feedback mechanisms affecting strength capability more than cooling directly over the muscle belly alone. This is only an assumption in consideration of previous research as the current study only had a single placement of cooling. Current literature highlights increases in muscle stiffness post ice application attributing the increases in stiffness to alterations to the mechanical properties of the tissue and desensitization of the mechanoreceptors in the tissue. This may lead to reduced PkT due to alterations in the ability to sense tissue stretch to the point of sustainability prior to consequent injury, postulating a guarding mechanism resulting in reduced strength output on concentric quad activation.

\(T_{sk}\) met therapeutic range, therefore thought to induce an analgesic effect and did not return to baseline measures at 20-minutes post. A quadratic relationship exists between \(T_{sk}\) and \(T_{im}\) suggesting as \(T_{sk}\) re-warms, \(T_{im}\) continues to cool.\(^{14}\) This may be the reason as to why PkT and AvT values did not return to baseline concentric strength at 20-minutes post removal of the intervention. It would however have been useful to measure \(T_{sk}\) over the quadriceps as well as over the patella in order to investigate potential distribution of cooling dispersed away from the site of application. Although the cryotherapy modality was placed over the anterior aspect of the knee, it is suggested that involvement of the quadriceps tendon insertion as a feedback mechanism for knee stability may be affected by cold application, although

### Table 1. Average + SD data for all measures of PkT, AvT and \(T_{sk}\)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Time Point</th>
<th>Pre</th>
<th>Post</th>
<th>20 Minutes Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{sk}) (°C)</td>
<td>28.9±2.5</td>
<td>13.9±1.9</td>
<td>24.6±2.9</td>
<td></td>
</tr>
<tr>
<td>PkT</td>
<td>225.5±30.99</td>
<td>189.90±36.20</td>
<td>203.29±38.30</td>
<td></td>
</tr>
<tr>
<td>AvT</td>
<td>164.51±26.73</td>
<td>138.45±25.33</td>
<td>148.36±26.54</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 3. Mean Skin Surface Temperature (\(T_{sk}\)) for baseline, Immediately Post and 20 Minutes Post Crushed Ice Cryotherapy Intervention.](image-url)
not quantified in the current study. Accurate indication of the required force the muscle needs to exert to stabilize the knee may not have occurred resulting in a decrease in PkT and AvT output compared to baseline following cooling. In consideration of the decreases in NCV\(^1\) following cryotherapy, it is thought that the combination of physiological change occurring within soft tissue muscle structures and desensitization of superficial mechanoreceptors disrupting neuromuscular response may be also responsible for the reported reduction in muscle strength occurring at the quadriceps. Although contradictory to these considerations, a review on the effects of joint cryotherapy on muscle function reports increases in muscle activation (Electromyography) and strength (isokinetic), but decreases in reflexive reactions in patients with joint effusion.\(^3\)

In consideration of the contribution to the role reflexive behaviour on motoneuron recruitment and force production this may provide implications following joint cooling on proximal muscle concentric strength, as noted in the current study.

Specific mechanisms through which cryotherapy altered quadriceps strength in this study may include the additional involvement of deeper joint structures. It is suggested that structures within the joint continued to remain cool after removal of the crushed ice intervention, although this outcome was not measured in the current study. Desensitization of deep joint mechanoreceptors may have affected neuromuscular response; supporting earlier literature proposing a change in proprioceptive feedback following cooling occurs.\(^3^4\) This however may not be isolated to the effects on JPS but also could affect the muscular strength of associated musculature proximal or distal to the cooling site.

**LIMITATIONS**
The current results cannot be generalized to other peripheral joints and muscles, weight-bearing joints in the lower limb, or females. Other limitations include variations in cryotherapy durations and modalities applied in the current study that may not be comparable to other cryotherapeutic modalities used in sport. Eccentric muscle strength was not considered in the current study however should be examined in future protocols.

Future studies should investigate combined dynamic stability following similar protocols and involve myoelectrical activity and JPS assessment to support the proposed physiological mechanisms in the current study. It would be useful to observe a longer period of delayed response to determine a suggested timescale for when muscle strength actually returns post removal of the intervention. This may help establish boundaries regarding safe return to functional activity following cooling exposures of the lower limb, and consideration by sports medicine practitioners regarding the possible strength changes following cryotherapy.

**CONCLUSIONS**
A 20-minute cryotherapy application at the knee induces immediate and longer-term reductions in concentric quadriceps strength. Concentric isokinetic torque production of the quadriceps does not fully recover 20-minutes post ice application to the knee. This is in support of previous findings.\(^3^2\) Current findings have potential implications for injury management and athlete participation in activity immediately following and up to 20- minutes post cryotherapy application at the knee.

**REFERENCES**


ABSTRACT

Background: Ankle sprains frequently result in persistent sensorimotor deficits. Sufficient evidence of effects of sensorimotor training using unstable devices on physical functions is lacking. There is no insight as to whether simultaneous tactile stimulation of plantar foot mechanoreceptors using textured surfaces may influence outcomes in people with a history of ankle sprain.

Purpose: The purpose of this study was to investigate the potential effects of sensorimotor training using unstable textured surfaces on balance, strength, joint function, and plantar sensitivity in recreational athletes with a history of ankle sprain.

Participants: Nineteen recreational athletes (6 females, 13 males; mean age: 29 ± 7 years) with a history of ankle sprain and self-reported sensation of instability participated.

Methods: Self-reported function of the ankle joint, plantar cutaneous detection threshold to light touch, balance during single-leg stance as well as maximal isometric strength of the ankle joint in eversion and inversion were measured. Participants were randomly allocated to either a training group using unstable textured surfaces or a training group using unstable smooth surfaces or a control group. Outcome measurements were repeated after six weeks of training and at follow-up after 10 weeks. Within and between group differences were analyzed using ANOVA, Friedman tests, or Kruskal Wallis tests (p<0.05) and post-hoc tests with Bonferroni correction. Correlations between outcome-parameters from baseline measurements were analyzed using Spearman's rho (p<0.05).

Results: No significant between-group differences in all outcome measures were detected. However, a significant increase of strength in eversion was found for the training group using textured surfaces after 10 weeks (p=0.01). A moderate correlation existed between plantar detection threshold of metatarsal head (MT) I and strength of inversion (r = 0.51, p<0.05) before training across all groups. There were moderate negative correlations between balance parameters and strength in eversion (r = -0.57 – -0.64, p≤0.01) as well as plantar detection thresholds at MT V (r = -0.48 – -0.62, p<0.05) at baseline across all groups.

Conclusion: A six-week sensorimotor training using unstable smooth and textured surfaces demonstrated no significant differences in balance, strength in eversion and inversion, plantar foot sensitivity, and self-reported ankle instability between training groups and the control group in recreational athletes with a history of ankle sprain. A better score on balance testing seems to correlate with an increase in eversion ankle strength and a decreased plantar sensitivity at MT V.

Keywords: ankle; balance training; movement system; sensorimotor deficits; textured surface

Level of Evidence: Level IIb
INTRODUCTION
In the United States of America, 628,000 ankle injuries, including sprains and fractures, occur each year representing 20% of all treated joint injuries. Seventy-nine percent of these injuries are lateral ankle sprains, 4% are medial ankle sprains. In 17% of all cases, the syndesmosis is damaged. About 74% of athletes suffer from at least one re-injury, and 22% sustain even five or more recurrent ankle sprains.

Frequently, ankle sprains are considered to heal spontaneously. However, symptoms, such as pain, swelling, muscle weakness, or instability remain many years after the initial injury in 74% of athletes. Nineteen to seventy-two percent of individuals develop chronic instability. Chronic instability is categorized as either functional or mechanical instability. Mechanical instability is considered as a loss of mechanical support. Functional instability is characterized by subjective sensation of a weak, painful and lower functioning ankle joint. Furthermore, a feeling of “giving way” is representative of this kind of instability. Therefore, chronic instability incorporates recurrent injury including mechanical or functional instability and may lead to a number of deficits. However, why and how affected persons develop chronic instability remains incompletely understood. Delayed stabilizing reflexes or prolonged reaction time of lower extremity muscles, deficits of kinesthesia and proprioception, or impaired postural control have been suggested as contributory factors.

Sefton et al. considered variables of static balance, such as anterior-posterior and medial-lateral center of pressure (CoP) displacement as well as CoP velocity as those which clearly differentiate between persons with and without chronic ankle instability. Strength deficits of lower leg muscles seem to be associated with chronic instability, however, several studies do not support this assumption.

Moreover, there are conflicting results with respect to eversion and inversion strength deficits as related to ankle instability. Altered myoelectric activity of lower extremity muscles is considered as a possible cause of those strength deficits. In addition to a loss of sensory input by articular mechanoreceptors, a reduction of plantar foot sensitivity has been discussed. This may be related to deficits in sensorimotor function as shown in a study on the effects of repetitive electrical stimulation on the control of force output at the ankle joint.

Balance training is effective in the prevention of recurrent ankle sprains. However, based on the findings related to the functional adaptations, treatment of patients with chronic instability differs. David et al. suggest a rehabilitation focused on control of eccentric muscle contraction of involved muscles. Kaminski et al. advise to additionally target joint proprioception in the treatment of chronic ankle instability. Sefton et al., postulated that static balance plays a major role in the rehabilitation of patients, however, they could not find an improvement after six weeks of balance training. In contrast, Kidgell et al. reported improved anterior-posterior and medial-lateral sway after six weeks of balance training using unstable devices. Overall, evidence regarding methods to improve postural control, perceived function of the ankle joint and other symptoms in patients with ankle instability is scant and further investigation is needed.

Sensorimotor training seems to slightly influence components of muscle strength and stimulation of the foot sole using textured insoles may assist in improving gait and balance in people with impairments of gait and balance. However, long-term effects of plantar cutaneous stimulation using unstable devices with textured surfaces during balance training on functions of the ankle joint in people with an ankle instability are unclear.

The purpose of this study was to investigate the potential effects of sensorimotor training using unstable textured surfaces on balance, strength, joint function, and plantar sensitivity in recreational athletes with a history of ankle sprain. Moreover, correlations between the outcome variables were examined across all groups before onset of intervention. It was hypothesized that outcome variables would significantly improve after balance training using unstable devices with a textured surface compared to balance training using unstable devices with a smooth surface and no treatment.
METHODS

Participants
Twenty-one recreationally active participants between the ages 18 to 50 years volunteered for the study. They were recruited from the local university and local sport clubs. Further inclusion criteria predominantly followed the recommendations of the International Ankle Consortium and were:

- At least one ankle sprain with the initial injury at least 12 months prior to study enrollment related with inflammatory symptoms (pain, swelling etc.)
- At least one interrupted day of preferred physical activity
- The most recent sprain happened more than three months prior to study enrollment
- At least two episodes of “giving way” of the previously injured ankle joint within six months prior to study enrollment and/or at least two sprains to the same ankle
- Self-reported feeling of ankle joint instability

Prior to enrollment participants completed the German version of the Cumberland Ankle Instability Tool (CAIT) as previously recommended. The CAIT is a reliable and valid questionnaire that detects the severity of ankle instability. In the present study a cutoff-score of ≤27 was used. For bilaterally affected participants the ankle with the lower CAIT score was considered in the final data analysis.

Exclusion criteria were an ankle injury and/or other injuries of the lower extremity within the three months prior to enrollment, a CAIT score >27 in both ankles as well as neurological and rheumatological diseases and disorders that could have influenced outcomes. People with a history of fracture of the foot, ankle or leg are often excluded in studies dealing with chronic ankle instability, however, these participants were included in the present study, because they also can show functional instability involving “giving way”. Therefore, the term “history of ankle sprain with a self-reported feeling of instability” was used for the description of included participants rather than the term “chronic ankle instability.” Furthermore, the study was a pilot study to replicate, in miniature, a planned full-sized RCT. All of the participants provided written informed consent prior to participation and were able to withdraw from the study at any time. The study was approved by the “Ethikkommission an der Physio-Akademie des Deutschen Verbands für Physiotherapie” (2014 – 04). This study was not registered as a clinical trial.

PROCEDURES

In each participant the sensitivity of the sole of the foot, balance in single-leg stance, the maximal voluntary isometric strength of ankle eversion and inversion as well as self-reported function of both ankles using the CAIT score were measured before and after six weeks of sensorimotor training as well as after 10 weeks (follow-up). The tested foot, the sites of the foot sole and the direction of strength measurement were selected at random using concealed envelopes at baseline to avoid systematic effects of learning. All measurements during the study were completed by the same tester (SD) who was blinded to the group allocation. After baseline measurements, participants were allocated at random to one of three groups: training group textured surface (TS), training group smooth surface (SMS) and a control group (CG that received no training) (Figure 1). For randomization, a computer-generated table of random numbers was created using MS-Excel. The assessor (SD) kept the assignment order and provided the assignment to the treating physical therapist (MA) in a sequence of consecutively numbered opaque envelopes. Allocation was concealed from the tester at all times and from the participants and the treating physical therapist (MA) until the start of treatment.

Sensorimotor training began at least one week after baseline measurements. The participants of the training groups completed a six-week progressive exercise program two days per week that lasted 20 to 30 minutes. The program was supervised and intervention adherence documented by a physical therapist (MA) with 12 years of experience in the arena of sports physical therapy. Exercises included double- and single-leg stance (both legs) on unstable devices [wobble board, rocker board, and a soft balance
A textured balance pad [Thera-Band®, ARTZT vitality, Dornburg, Germany] was used in the TS group, while the SMS group used a smooth surfacemed. This pad had a textured surface (diameter: 41 cm; height: 8.8 cm; material: plastic) and was used in single-leg stance. During the first two weeks, exercises were carried out three times for 20 seconds with a resting period of 30 seconds between the sets and one minute between the exercises. Balance on the wobble board and the balance pad was performed in single-leg stance. The textured surface of the wobble board (diameter: 41 cm; height: 8.8 cm; material: plastic) consisted of small pyramids (height: 3 mm). The wobble board with smooth surface (Therapy Balancing Tops, Sport-Thieme GmbH, Grasleben, Germany) was made of beechwood and had a diameter of 37 cm and a height of 9.5 cm. The rocker board with smooth surface (Pedalo® Rocking Board, Sport-Thieme GmbH, Grasleben, Germany) consisted of beechwood with a length of 45 cm, a width of 30 cm and a height of 9.5 cm. One side of the foam surface of the balance pad (Thera-Band®, ARTZT vitality, Dornburg, Germany; dimension: 40 x 50 x 6 cm; material: polyethylene) had broad horizontal grooves and this was used with the TS group. The SMS group used the same balance pad, however, it was turned over such that the smooth surface was on the top (under the surface of the foot).

During the first two weeks, exercises were carried out three times for 20 seconds with a resting period of 30 seconds between the sets and one minute between the exercises. Balance on the rocker board was performed in double-leg stance, while balance on the wobble board and the balance pad was carried out in single-leg stance. During the weeks three
to six all exercises were performed in single-leg stance. Sets were progressively increased to four during the weeks three and four, and to five sets during weeks five and six. The number of training sessions (12), the training frequency (two days per week), the duration of training sessions (about 20 minutes), and the duration of each balance task (20 seconds) was based on previous studies. The control group received no sensorimotor training; however, participants were allowed to continue their usual sport activities.

Outcome measurements

Plantar foot sensitivity

Plantar cutaneous detection thresholds to light touch were measured at four locations of the foot sole of both feet using a set of 20 Semmes-Weinstein Monofilaments (SWM; Rehaforum MEDICAL GmbH, Elmshorn), which were considered reliable by Snyder et al. with ICC values ranging from 0.61 to 0.85 for the intrarater reliability and 0.62 to 0.92 for the interrater reliability. The following locations were tested in a random order:

- Center of the big toe
- Head of the metatarsal I (MT I)
- Head of the metatarsal V (MT V)
- Center of the heel

Participants were tested in a well-lit quiet laboratory within the university. They were assessed in a prone position on a treatment bench with their feet off the end of the bench and were blinded to measurements. Locations were determined using the procedure reported by Perry (Figure 3) at each measurement (baseline, post 6 weeks, follow-up) to ensure testing of the same points at the different measurements. Additionally, they were marked with a waterproof pen to avoid deviations from the test localization during testing. The calibrated monofilaments vary in diameter and provide a known target force [filament size = log (10 x force in milligrams)]. They were applied perpendicular to the skin surface and pressed until bending to a C-shape. Plantar detection threshold to light touch at each location was determined using the 4-2-1 stepping algorithm. It was started with an intermediate level (4.17 = 1.48 g). Either the level was increased if the stimulus was not felt or decreased if the stimulus was felt by four steps until a turnaround point was reached. A level was considered valid when the participant detected at least two out of three trials. Then the level was increased or decreased by two steps until the next turnaround point was attained. Finally, the filaments were applied in single steps. If a level was not detected correctly for three times, then the next detected level above was accepted as the detection threshold for the tested localization. Randomized null-stimuli were included in the test to increase accuracy. Foot sole temperature was measured at each location using a calibrated infrared thermometer (Braun NTF 3000, no touch + forehead thermometer, Lausanne, Switzerland) before and after sensory testing. Furthermore, room temperature was controlled using a calibrated commercial thermometer.
**Balance (single-leg stance)**

Participants balanced in single-leg stance on their involved and uninvolved leg for 30 seconds on a force plate [Bertec Force Plate, Version 1.0.0. Bertec Corporation Columbus, Ohio (USA)]. Three-Dimensional ground reactions forces were sampled at 1000 Hz including an anti-aliasing filter of 500 Hz. Participants' eyes were open focusing on a spot on the wall that was about five meters in front of them. Their knee was slightly bent and their hands were resting on their iliac crests. They were not allowed to touch the ground with their contralateral foot or to touch the supporting lower extremity with any part of their contralateral lower extremity. Balance was measured by mean amplitudes of center of pressure (CoP), i.e. the average value over all data points recorded in a trial.\(^{42}\) Thereby, CoP displacements in anterior-posterior and medial-lateral directions were determined by summing the actual distance (m) between consecutive CoP locations in the respective direction.\(^{43}\) Total CoP displacements (m) were determined by means of the Pythagorean theorem. Furthermore, the mean of center of pressure excursion velocity (CoPV) was calculated by dividing total CoP displacement by the total time of trial duration.\(^{42}\)

CoP measurements were completed using the software Bertec Digital Acquire 4, (Version 4.0.11. Bertec Corporation Columbus, Ohio, USA). For each participant, data from second five to second 25 (20 seconds) out of one trial were used for further analysis.

**Maximal isometric inversion and eversion muscle strength**

Maximal isometric foot inversion and eversion forces of both feet were assessed using a belt-stabilized hand-held dynamometer (HHD; Commander™ Muscle Tester, JTECH Medical, Salt Lake City, USA) with participants lying on their side, with the measured foot off the end of the treatment bench and with the tibia of the tested leg secured with a non-elastic belt.\(^{44}\) The participant's head and neck were supported by a foam therapy half roll. The knee was supported by a rolled towel at the medial side when measuring eversion force. The assessor stood close to the participant's tested foot. The treatment bench was adjusted to be level with the assessor's anterior iliac spine. The HHD was stabilized using a non-elastic belt that was vertically applied around the forefoot of the participant and the foot of the tester. The belt was used for stabilization because of the probability that the forces produced by participants' would surpass the resisting force of the assessor, which is required to perform “make” tests accurately.\(^{45}\)

The foot was positioned at \(10^\circ\) of plantarflexion.\(^{46}\) For testing foot eversion strength, the transducer of the hand-held dynamometer was placed at the lateral border of the forefoot directly below the fifth metatarsal head. For measuring foot inversion strength, the transducer of the hand-held dynamometer was positioned at the medial border of the forefoot directly below the first metatarsal head. The recorded force in Newton (N) was converted to torque and expressed as Newton-meters (Nm) by multiplying it by the corresponding lever arm (in meters).\(^{47}\) The functional axis of rotation for eversion and inversion enters the front superior part of the talus on the medial side and crosses downwards to the lateral rearfoot.\(^{48,49}\) For testing inversion strength, the lever arm was defined as the distance between the first metatarsal head (dynamometer location) and the superior part of the sustentaculum tali, and for eversion strength between the fifth metatarsal head (dynamometer location) and the superior part of the cuboid.

Isometric “make” tests were performed.\(^{50}\) During the make test, the participant exerts a maximal force against the HHD, that is stabilized by the examiner or a belt. In contrast, the break test is performed by the examiner pushing the HHD against the participant's limb until the participant's maximal muscular exertion is exceeded and the joint gives way. The participant held the contraction for three seconds.\(^{51}\) After one trial of a submaximal contraction was used to familiarize the participant with the task, three consecutive maximal contractions were completed by the participant and recorded by the assessor. The resting period between trials was about 10 sec. The participant was blinded to the results from all measurements. The mean of the three trials was used for further analysis.\(^{47}\) The assessor and the participant were blinded to the results from previous measurements when performing the retests. All participants were measured barefoot. The foot (right/left) of the participant and the foot movement (inversion/
eversion) were assessed in a random order to avoid any effects of fatigue and learning. This testing procedure was preserved for the retests.

**Functional instability of the ankle joint**
Additionally to the CAIT score that was described before, the German version of the Foot and Ankle Outcome Score (FAOS) was used to assess the functional status of the ankle joint, according to the recommendations of the International Ankle Consortium.

**Statistical analysis**
Data were examined for normal distribution using Shapiro-Wilk-tests and using histograms. The parametric distribution of data was confirmed. For continuous variables, within [pre vs. post 6 weeks vs. post 10 weeks] and between group differences [group TS vs. group SMS vs. control] were analyzed using repeated measures analysis of variance (ANOVA, p<0.05). Greenhouse-Geisser correction was used, if the assumption of sphericity assessed by Mauchly's test was violated. For discrete variables, Friedman tests (p<0.05) were used to test for differences within groups and Kruskal Wallis tests (p<0.05) were performed to test for differences between groups. Post-hoc tests (t-tests for continuous variables and Wilcoxon signed-rank tests for discrete variables, p<0.05) with Bonferroni correction were used for pairwise comparisons, respectively. The effect size was calculated using eta squared ($\eta^2$) and interpreted according to Cohen's approach, where $\eta^2=0.01$ represents a small effect, $\eta^2=0.06$ a moderate effect and $\eta^2=0.12$ a large effect. Correlations between outcome-parameters from baseline measurements were analyzed using Spearman's rho (p<0.05). Statistical analysis was conducted with commercial software (IBM SPSS Statistics 23.0).

**Results**

**Participants included in the study**
Nineteen participants (six females and 13 males) met the inclusion criteria and were included. Their mean age was 29 (± SD 7) years, their mean height was 174 (± SD 12) cm, their mean body mass was 76 (± SD 12) kg, and their mean body mass index was 24 (± SD 3) kg/m². Moreover, they regularly performed at least one session of sport per week at study enrollment. Sport activities they carried out before initial injury and/or continued after initial injury are presented in Table 1.

**Group characteristics**
There were no differences between groups with respect to age, height, body mass and BMI at baseline measurement (p≥0.05). The distribution of females and males differed between groups (Table 1). The mean CAIT score in the control group was increased compared to the training groups, however, this was not statistically significant (p≥0.05).

**Training effects**
All participants in both training groups completed the intervention as planned. No significant between-group differences in all outcome measures were detected. However, a significant increase of strength in eversion was found for the training group using textured surfaces after 10 weeks (p=0.01, $\eta^2=0.46$) (Figure 4).

**Correlations between outcome measurements at baseline**
A moderate correlation existed between plantar detection threshold of metatarsal head (MT) I and strength in inversion ($r = 0.51$, p<0.05) before training across all groups. There were moderate negative correlations between balance parameters and strength in eversion [rs (range) = -0.57 to -0.64 (anterior-posterior displacement), p≤0.01] as well as plantar detection thresholds at MT V [rs (range) = -0.48 to -0.62 (anterior-posterior displacement), p<0.05]. Descriptive statistics are presented in Table 2.

**Foot sole temperature**
Mean foot sole temperature of each location and measurement is demonstrated in Table 3. Mean room temperature during measurements was 23.8 (±1.1) °C at baseline, 23.9 (±1.2) °C after six weeks and 23.4 (±1.0) °C after 10 weeks. No significant differences were found between groups at each measurement for foot sole temperature as well as for room temperature (p>0.05).

**Post hoc power analysis**
A post hoc power analysis (G*Power 3.1.9.2.) on the basis of $\alpha < 0.05$, the identified effect size for ankle...
Table 1. Demographic data of the participants of the current study. Age, height, body mass and BMI are demonstrated as means (± SD). CAIT-scores are presented as medians (1st quartile; 3rd quartile). Sport activities participants carried out before initial injury (pre) and/or continued after initial injury (post) are shown as numbers (n), multiple nominations were allowed.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Group SMS</th>
<th>Group TS</th>
<th>Control group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Male</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Age (years)</td>
<td>30.0 (6.83)</td>
<td>29.83 (8.18)</td>
<td>26.67 (6.22)</td>
<td>28.89 (6.88)</td>
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<tr>
<td>Height (m)</td>
<td>1.70 (0.15)</td>
<td>1.79 (0.04)</td>
<td>1.75 (0.12)</td>
<td>1.74 (0.12)</td>
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<tr>
<td>Body mass (kg)</td>
<td>74.86 (17.02)</td>
<td>78.5 (9.29)</td>
<td>73.67 (9.27)</td>
<td>75.63 (12.19)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.9 (4.49)</td>
<td>24.39 (2.59)</td>
<td>24.36 (3.98)</td>
<td>24.44 (3.0)</td>
</tr>
<tr>
<td>CAIT-score</td>
<td>19 (11; 21)</td>
<td>18 (15; 22)</td>
<td>22 (19; 24)</td>
<td>19 (16; 23)</td>
</tr>
</tbody>
</table>

**Sport activities**

- Badminton (pre/post) n=9/ n=8
- Football/soccer (pre/post) n=4/ n=2
- Fitness (pre/post) n=4/ n=7
- Running (pre/post) n=2/ n=3
- Volleyball (pre/post) n=1/ n=1
- Table tennis (pre/post) n=1/ n=1

**Figure 4.** Differences (p < 0.05) in mean eversion muscle strength within- and between- groups pre, post 6 and post 10 weeks of sensorimotor training. Error bars represent standard deviations (SD). SMS: Smooth surface; TS: Textured surface.
eversion strength ($\eta^2 = 0.46$, i.e., $f = 0.92$) from repeated measures ANOVA (within factors), and a sample size of $n = 19$, revealed a test power of 100%.

**DISCUSSION**

To the best of the authors' knowledge, this was the first study exploring the influence of sensorimotor training on unstable textured surfaces on balance, strength, joint function and plantar foot sensitivity in participants with a history of ankle sprain and a self-reported feeling of ankle instability. The main finding was that no significant between-group differences in all outcome measures existed after six weeks of training. However, eversion muscle strength significantly increased after sensorimotor training using unstable textured surfaces at the 10-week follow-up. Furthermore, increased eversion muscle strength was related to a better score on balance testing and decreased plantar cutaneous sensation to light touch before intervention.

**Muscle strength**

Authors have noted that balance training might have immediate effects on eversion and inversion muscle strength.54 In the present study, eversion and inversion muscle strength did not differ between groups after the intervention and at follow-up, which was consistent with previously reported findings.30 However, the significant increase of eversion muscle strength at the 10-week follow-up, but not at six weeks, in the group TS might indicate that a sensorimotor training on unstable textured surfaces potentially leads to a prolonged neuromuscular adaptation resulting in increased peroneal muscle strength. Accordingly,
it has been shown that cutaneous touch/pressure sensation is important for isometric ankle force control.\textsuperscript{25} Furthermore, an acute local pressure at the lateral border of the foot using a sensorimotor insole increased muscle activity of the peroneus longus in loading response and mid-stance phases of walking.\textsuperscript{55} A textured insert decreased muscular activation of the soleus and tibialis anterior during locomotion.\textsuperscript{56} Therefore, pressures applied to the foot sole may alter sensory feedback\textsuperscript{56} or even increase afferent information.\textsuperscript{55} Thereby, firing of the most sensitive fast adapting receptors is responsible for the transmission of afferent information during balance and locomotor tasks.\textsuperscript{57} A slight non-significant improvement was also detected for the other groups that might have been explained by a learning effect due to the repetition of the strength measurements after six and 10 weeks. However, previous authors have not reported significantly different values of eversion and inversion muscle strength using an HHD when measurements were repeated at the following day.\textsuperscript{44,58} Moreover, participants in the control group may have been increasingly motivated to achieve high force values.

Eversion and inversion isometric muscle strength values found in the subjects of the present study are comparable to those from patients with chronic ankle instability reported by Hall et al.\textsuperscript{59} They measured 157.2 to 187.5 N for inversion as well as 141.2 to 175.5 N for eversion using an HHD with participants lying on their side. The original values of the present study without consideration of the lever arm in the calculation ranged from 155 to 219 N for eversion and from 142 N to 211 N for inversion. The higher values above 210 N compared to those from Hall et al.\textsuperscript{59} may be explained by the belt-stabilization of the HHD. Hall et al.\textsuperscript{59} provided manual resistance to the ankle. In HHD measurements, the strength of the assessor to withstand the force generated by the tested person is a decisive factor. When forces above 120 N are applied, the tester’s strength seems to regulate the extent of the forces assessed with the HHD.\textsuperscript{60} This may lead to an underestimation of muscle strength.

**Postural control**

No statistically significant differences were found within and between groups for all balance outcomes. However, the SMS and TS groups showed a slight non-significant improvement of the total CoP displacement, the medial-lateral and anterior-posterior displacement as well as the mean CoP velocity after six and after 10 weeks. As the control group demonstrated a slight improvement as well and the changes were within the range of measurement error, a causal relationship between intervention and these improvements could not be concluded. Moreover, a learning effect rather than a training effect was more likely here.\textsuperscript{30} It was previously hypothesized, that wearing textured insoles during single-leg stance results in a reduced ability of the sensorimotor system to reweight sensory feedback available to keep single-leg stance.\textsuperscript{61} This is potentially caused by changed information from cutaneous receptors of the foot sole due to the textured surface. Furthermore, individuals with chronic ankle instability seem to increasingly rely on sensory information, i.e. plantar cutaneous receptors, during single-leg stance. Although not assessed within the current study, it may be possible, that weekly repetitions of plantar stimulation during sensorimotor training in those with a feeling of ankle instability using a textured surface may lead to an increase of the ability of the sensorimotor system to reweight sensory input available to maintain balance.

The results of the present study are difficult to compare with previous study results, because different study designs, training regimes and parameters of CoP measurements were used. Sefton et al.\textsuperscript{28} found no significant changes in total CoP path length and average CoP displacement after a six-week sensorimotor training, where participants with chronic ankle instability completed three sessions per week. Mettler et al.\textsuperscript{62} demonstrated that the CoP location under the foot shifted posteriorly after four weeks of balance training, that was performed three times per week, in those with chronic ankle instability compared to affected controls. They concluded that there is a recovery of impaired sensorimotor pathways that is induced by the balance training.

In the study by Freyler et al.\textsuperscript{63} mean medial-lateral CoP displacements ranged from 94.6 (± 25.6) cm to 118.6 (± 24.4) cm compared to 0.76 ± 0.15 m (76 ± 15
cm) to 0.9 ± 0.14 m (90 ± 14 cm) in the present study. Freyler et al.\textsuperscript{63} reported mean anterior-posterior CoP displacements ranging from 82.5 (± 11.7) cm to 102.1 (± 21.4) cm compared to 1.01 ± 0.11 m (101 ± 11 cm) to 1.13 ± 0.19 m (113 ± 19 cm) in the present study. The values for anterior-posterior CoP displacement were remarkably higher in the present study compared with those of Freyler et al.,\textsuperscript{63} although the time of single-leg stance was 10 seconds less. However, it was not reported by the authors, from where healthy participants were recruited. Furthermore, no information about the participants’ level of performance (e.g. elite, non-elite) was provided. Linens et al.\textsuperscript{64} investigated the mean CoP excursions in medial-lateral and anterior-posterior directions as well as the mean CoP anterior-posterior and medial-lateral velocity using a force plate in people with chronic ankle instability and healthy controls. Their values were considerably decreased compared with the values found in the present study, although the time of single-leg stance was the same. Reasons for these differences might have been, that in the present study one trial was used for analysis compared to Linens et al.,\textsuperscript{64} who used the mean out of three trials for their analysis. A learning effect between trials and previous balance tests performed in their study might have led to significantly reduced excursions. Additionally, settings at which force data were collected might have differed.

**Plantar foot sensitivity**

No significant changes of plantar cutaneous thresholds were found within and between groups after the intervention. The thresholds are mainly comparable to those of participants classified as copers and participants with chronic ankle instability, except for the measurement at the heel.\textsuperscript{65} Copers are those who have sprained their ankle but have no perception of instability or repeated episodes of giving way and had continued activities without restriction for at least 12 months.\textsuperscript{65,66} Furthermore, copers are considered to demonstrate a CAIT score >24.\textsuperscript{67} The 4-2-1 stepping algorithm for sensation testing was also used by Burcal & Wikstrom,\textsuperscript{65} however, a median threshold of 4.17 at the heel at baseline for those with chronic ankle instability was reported compared to 3.61/3.73 in the current study. Accordingly, two participants in the present study had a CAIT score >24 (27 and 26) before intervention and may be classified as copers according to previously reported classifications.\textsuperscript{67,68} Powell et al.\textsuperscript{24} found higher thresholds in participants with chronic ankle instability, ranging from a median of 4.08 for MT I to 4.56 for the heel. Interestingly, the thresholds of not affected participants in their study were similar to those of the participants in the present study. Furthermore, the thresholds in the current study were slightly lower as compared to those of healthy 20 to 30 year old people.\textsuperscript{40} However, Perry\textsuperscript{40} used a set of six monofilaments which is considered less sensitive compared to the set containing 20 monofilaments. There may have been other factors, such as time of day and gait activity\textsuperscript{69} that could have influenced results of sensory testing. Although, Semmes-Weinstein monofilament testing is considered reliable and valid,\textsuperscript{70} it may be questionable, whether it is sensitive enough to detect small differences and changes of plantar sensation in people with a history of ankle sprain and a feeling of instability.

**Grade of severity of functional instability and foot function**

No significant changes within and between groups were found for CAIT scores as well as for FAOS-scores. However, the greatest positive change of CAIT scores was observed in the group TS (three scores improved after six weeks and six scores after 10 weeks). As previously reported, four or six weeks of balance training resulted in improved CAIT scores, other activities of daily living related questionnaires and functional tests in people with chronic ankle instability.\textsuperscript{71,72} The sample size was considerably higher in both studies (n = 40\textsuperscript{72} and n = 70\textsuperscript{71}). Wright et al.\textsuperscript{72} and Cruz-Diaz et al.\textsuperscript{71} performed the training sessions three times per week. Cruz-Diaz et al.\textsuperscript{71} used a multi-station program with a variety of exercises. This may indicate, that the number of sessions per week and the variety of exercises might have been too low in the present study.

**Correlations between outcome parameters**

Moderate correlations between plantar detection thresholds at MT I, MT V and the heel and muscle strength in eversion and inversion may indicate that a decreased sensitivity was related to an increased muscle strength. Usually it may be expected that
a higher sensitivity to light touch is correlated to a higher muscle strength. However, the findings here indicate the opposite or a negative correlation. A decreased sensitivity with a reduced feedback of cutaneous afferents may lead to an increased eversion and inversion muscle strength needed to compensate for the reduced cutaneous feedback in people with a history of ankle sprain and a feeling of instability in order to protect the ankle in situations of sudden ankle perturbations. However, reflex reaction to sudden inversion was not investigated in this study. Furthermore, reflex reaction to sudden ankle inversion is considered to be too slow to protect the ankle. Therefore, the correlation between plantar sensory feedback and the change of motoneuron pool excitability as well as rate of force development in a maximal voluntary muscle contraction need to be explored more in a future study comparing the effects of sensorimotor training using different unstable surfaces in this population.

The moderate negative correlations between muscle strength in eversion and the CoP- parameters indicate that the higher eversion muscle strength the smaller the CoP displacement and velocity, i.e. the better balance ability. It appears, that participants with chronic ankle instability and copers use balance control strategies, where eversion muscle strength is primarily involved. Accordingly, the high relevance of eversion muscles in postural control has been confirmed previously. Participants with chronic ankle instability and copers showed an increased muscle activation of the peroneus longus and tibialis anterior during the star excursion balance test compared with healthy controls. Thereby, muscle activation was even higher in copers than in participants with chronic ankle instability, indicating, that they use a fully developed strategy of increased muscle activation to compensate for loss of stability, usually provided by capsule and ligaments.

The negative correlation between plantar cutaneous threshold at MT V and balance parameters indicated that a decreased sensitivity was related to an increased balance ability. These findings were contrary to findings from the literature and difficult to explain. However, the mean of time-to-boundary minima in anterior-posterior direction was measured and moderately correlated to plantar cutaneous sensitivity. The results of the present study may suggest that decreased plantar sensitivity at MT V may lead to decreased CoP displacements as a result of increased muscle activation that may result in higher eversion and inversion strength.

**Limitations of the study**
There are limitations of the study that need to be addressed. As this was a pilot study, the sample was small and the group sizes were partially unequal. Therefore, the groups might not have been as comparable and generalizability of the results cannot be concluded. Furthermore, results should be considered with caution because two participants demonstrated a CAIT score >24, four participants had a history of ankle or foot fracture with surgery within two years and one participant had sustained a medial ankle sprain. The sensorimotor training might have led to adaptations of the central nervous system that could not be assessed with the measurement instruments used in the current study. In a previous study was found that balance training was able to restore the ability to modulate the excitability of motoneuron pools, which is necessary to adjust to a changing environment. The restoration process may need time and may become visible only after more than six weeks of training, because established control strategies have to change or new compensation strategies have to develop. Accordingly, it has been shown that CoP displacements in single-leg stance even slightly increased after six weeks of balance training. Therefore, the period and intensity of sensorimotor training may have to be increased in future studies.

**CONCLUSION**
A six-week sensorimotor training using unstable smooth and textured surfaces demonstrated no significant differences in balance, strength in eversion and inversion, plantar foot sensitivity and self-reported ankle instability between training groups and the control group in recreational athletes with a history of ankle sprain. However, a better score on balance testing seems to correlate with an increase in eversion ankle strength and a decreased plantar sensitivity at MT V before a sensorimotor training. Future studies incorporating inclusion criteria of the CAIT score ≤24 used by Gribble et al., no fracture
with or without surgery, and only lateral ankle sprain should be considered for a robust controlled trial of homogenous participants.

REFERENCES


ABSTRACT

**Background:** Upper extremity injuries commonly occur in baseball players, and can often necessitate surgical interventions. Athletes recovering from previous surgeries may be at greater risk of a secondary injury due to potential residual deficits in global movement. Identifying individuals with residual movement dysfunction following surgery during a pre-participation examination may help health care professionals identify baseball players who may be at a greater risk of re-injury in their throwing arms so that appropriate interventions can be developed.

**Purpose:** The purpose of this study was to assess relationships between history of shoulder or elbow surgeries and Functional Movement Screen™ (FMS™) shoulder mobility scores or Selective Functional Movement Assessment (SFMA) upper extremity patterns in collegiate baseball players.

**Study Design:** Cohort study.

**Methods:** One hundred seventy-six healthy, male, Division III collegiate baseball players (mean age = 19.65 ± 1.52 years) underwent preseason screening using the FMS™ shoulder mobility screen, and SFMA upper extremity patterns. Total FMS™ scores were dichotomized into “good” and “poor” groups (good = 2 or 3, poor = 0 or 1). SFMA scores were dichotomized into “good” and “poor” groups (good = functional non-painful (FN), poor = dysfunctional painful (DP), dysfunctional non-painful (DN), and functional painful (FP). Dichotomized FMS™ and SFMA scores were compared to questionnaire data regarding history of shoulder or elbow surgeries.

**Results:** Thirty participants (17%) reported a previous shoulder or elbow surgery in their dominant arms. Past surgeries in the shoulder or elbow were not related to FMS™ (odds ratio [OR]=0.74, 95% confidence interval [CI]=0.30, 1.82, p=0.52) or SFMA performance (OR=0.93, 95%CI=0.38, 2.27, p=0.88) independent of grade and playing position.

**Conclusion:** History of shoulder or elbow surgery was not related to performance on the FMS™ shoulder mobility test or SFMA upper extremity patterns. Differences in the dates of surgery at the time of testing, and sport-specific adaptations of the upper extremities that are common in baseball players due to the cumulative tissue stress from years of throwing at the collegiate level, may explain these insignificant findings.

**Level of Evidence:** Level 3

**Keywords:** Baseball, Functional Movement Screen™, elbow surgery, movement system, Selective Functional Movement Assessment, shoulder surgery
INTRODUCTION

Upper extremity injuries are a common occurrence in baseball players at almost all levels of competition, as the repetitive throwing motion produces large forces in the soft tissues of the shoulder and elbow.\(^1,2,3,4\) Such overuse injuries often require surgical interventions. Pitching is the primary position to experience upper extremity injuries that result in greater time loss and surgical interventions when compared to other position players.\(^5\) Of injuries requiring surgery, the elbow is the most commonly injured site, with ulnar collateral ligament (UCL) reconstruction (aka Tommy John surgery) being the most common procedure, followed by labrum repairs of the shoulder.\(^6,7\) Across all ranks of professional baseball, it is estimated that overall UCL reconstruction prevalence is roughly 10% in active players, with an increased percentage in Major League Baseball (MLB) pitchers (25%) compared to minor league pitchers (15%).\(^8\)

UCL reconstruction has shown to have very favorable outcomes in terms of recovery, as MLB pitchers are able to return to play (RTP) in the MLB at a rate of 83%, or a combined rate of 97.2% when also including the minor leagues.\(^7\) Surgeries in the shoulder do not seem to be as successful. Outcomes in baseball players returning to throw after undergoing arthroscopic repair of a superior labrum anterior-posterior (SLAP) tear seems to vary within the literature ranging between 68-84%.\(^9,10,11\) Research tracking RTP rates after SLAP tears in professional players also varies between 32%\(^12\) to 40%, where the RTP criteria not only required athletes reach the pre-injury competitive level, but also return to the statistical quality of performance pre-injury.\(^13\) In a review of shoulder surgeries in professional and collegiate players, Harris et al. noted only 68% of pitchers were able to resume pitching at their pre-injury level of competition.\(^14\) The discrepancy in shoulder and elbow RTP rates post surgery may be due to minor changes in accuracy, velocity, or endurance that perhaps occur more often with the shoulder compared to the elbow. These differences can therefore affect the success of a player's career, which may be undetectable by physical examination of the shoulder and elbow, clinical outcome scores, or imaging studies.\(^7,11\)

In terms of athletes' risk of sustaining another injury upon RTP, several authors have examined the association of past injuries with future injuries. Knowles et al. noted that among high school athletes, the biggest predictor for injury was a previous injury.\(^15\) Relationships between previous and future injury may be explained by residual deficits following initial injury. Upper extremity re-injury research is somewhat limited but several studies have investigated lower extremity re-injury risk factors. Previous research in lower extremity injuries requiring surgery, such as anterior cruciate ligament reconstruction (ACLR) have shown residual deficits in neuromuscular factors such as proprioception, peak torque, intra-muscular forces, altered gait mechanics, and functional movement patterns following injury.\(^16,17\) It has also been demonstrated that changes in neuroplasticity and brain activation occur during knee flexion and extension tasks in athletes after ACL surgery, potentially increasing the risk of recurrent ACL tears.\(^18,19\) Secondary injury rates in ACLR athletes have been shown to occur in 6-13% of reconstructed knees, and 2-6% sustain an ACL injury to the opposite leg.\(^20\)

In baseball players experiencing rotator cuff-related pathologies, alterations in scapular orientation can occur during normal movements, such as increased elevation of the shoulder complex during elevation in the scapular plane, potentially increasing risk of future shoulder injuries.\(^21\) Therefore it would not be unlikely for injured athletes requiring surgery to experience similar alterations in shoulder kinematics. Previous authors have also shown that collegiate athletes who experienced past injuries or shoulder surgeries demonstrated worse overall performance in composite FMS™ scores, and specifically lower shoulder mobility scores, although baseball players were not included in that particular study.\(^22\)

Performing movement-based assessments as part of a pre-participation screening protocol can help identify individualized movement dysfunctions.\(^23\) The Functional Movement Screen™ (FMS™) and Selective Functional Movement Assessment (SFMA) specifically, may help identify any asymmetries, imbalances or musculoskeletal dysfunctions that exist in the upper extremity of baseball players. Sports medicine professionals commonly use these...
screens to quickly and accurately assess quantity and quality of movement, and these screens have high inter- and intra-rater reliability when administered by individuals experienced with the assessments.\textsuperscript{24,25} Identifying individuals with residual movement dysfunction following surgery may help health care professionals identify baseball players who may be at a greater risk of re-injury in their throwing arms. However, to date there are no studies assessing relationships between FMSTM and SFMA upper extremity screens and history of elbow or shoulder surgeries in collegiate baseball players.

The purpose of this study was to assess relationships between history of shoulder or elbow surgeries and FMSTM shoulder mobility scores or SFMA upper extremity patterns in collegiate baseball players. It was hypothesized that players with a previous history of shoulder or elbow surgeries would have poor FMSTM and SFMA scores when compared to individuals with no prior history of shoulder or elbow surgeries.

**METHODS**

**Participants**

National Collegiate Athletic Association Division III male collegiate baseball players (n=176, age = 19.65 ± 1.52 years) were recruited from four local universities to participate in this study. Among those recruited were 37 seniors, 33 juniors, 48 sophomores, and 58 freshmen. Participants were included if they had been cleared to fully participate in team activities by a medical practitioner by the date of testing each year. Participants were excluded if they were being treated for a shoulder or elbow injury, or reported any current upper extremity injuries at the time of testing. A university institutional review board approved this study and written informed consent was obtained from all participants before beginning the study.

**Data Collection**

Testing was completed before the start of official team practices during the spring season. The examiner for all data collection was a certified FMSTM and SFMA practitioner, with over five years of experience screening individuals. Intra-rater reliability during pilot testing demonstrated excellent agreement on both the FMSTM shoulder mobility (100%), and SFMA upper extremity patterns (92.5%). All participants completed a questionnaire regarding position, eligibility, surgical history of their shoulder or elbow, and history of time-loss (games and practice) due to a shoulder or elbow injury within the previous two years. All participants were individually screened in both the FMSTM shoulder mobility, and upper extremity patterns of the SFMA in randomized order, along with the clearing tests for rotator cuff impingement and acromioclavicular (AC) joint impingement as described by Cook et al\textsuperscript{26} (Figure 1). Total FMSTM scores were dichotomized into “good” and “poor” groups (good = 2 or 3, poor = 0 or 1). SFMA scores were dichotomized into “good” and “poor” (good = functional non-painful [FN], poor = dysfunctional painful [DP], dysfunctional non-painful [DN], and functional painful [FP]).

**Figure 1.** The different movement screens utilized (a) FMSTM shoulder mobility reciprocal pattern of both arms (b) SFMA upper extremity patterns 1 (left) and 2 (right). Both SFMA patterns 1 and 2 were repeated on the opposite arm as well.
Statistical Analysis
Data analyses were conducted using the Statistical Package for the Social Sciences version 23.0 (SPSS, Inc., Chicago, IL). Initial chi-square analyses were performed to assess relationships between history of shoulder or elbow surgeries and FMSTM or SFMA performance category. Logistic regression analyses were used to assess relationships between history of shoulder or elbow surgeries and FMSTM or SFMA performance category while controlling for effects of grade and position. Statistical significance was determined a priori at \( p < 0.05 \). According to power analyses, 88 subjects were needed for chi-square analyses to identify a moderate effect size of 0.30 at an alpha level of 0.05 and an achieved power of 0.80. For logistic regression analyses, 113 subjects were needed to achieve an odds ratio of 2.0 at an alpha level of 0.05 and an achieved power of 0.80.

RESULTS
Distribution of the 176 participants by position were: pitchers (\( n = 72, 40.91\% \)), catchers (\( n = 17, 9.66\% \)), middle infielders (\( n = 36, 20.45\% \)), corner infielders (\( n = 28, 15.91\% \)), and outfielders (\( n = 23, 13.07\% \)). History of previous elbow or shoulder surgery was reported by 30 (17.05\%) participants. Of the dichotomized FMSTM scores, 57 (32.39\%) were classified as poor performers and 119 (67.61\%) were classified as good performers. Of the dichotomized SFMA scores, 125 (71.02\%) were classified as poor performers and 51 (28.97\%) were classified as good performers. Distribution of FMSTM and SFMA scores by history of surgery category are presented in Table 1. Results from chi-square and logistic regression analyses are presented in Table 2. History of elbow or shoulder injuries was not related to FMSTM or SFMA performance with or without controlling for grade and position (\( p \)-value range: 0.52 – 0.59).

DISCUSSION
The primary finding of this research was that baseball players with a history of shoulder or elbow surgeries performed no differently on the FMSTM shoulder mobility screen or the SFMA upper extremity patterns compared to uninjured players; regardless of grade or position. These findings suggest that upper extremity movement screens may not differentiate players with a history of shoulder or elbow surgery from those with no history of surgery. Although no measures of rehabilitative outcomes were assessed in this study, the lack of significant findings could be due to improved rehabilitation strategies among practitioners. A growing trend in rehabilitation is to avoid focusing on single pathological structures of injured sites, which often results in poor patient outcomes. Rehabilitation has focused on expanding the identification and screening of other influencing regions above and below the area of primary complaint or dysfunction.27,28 Another possible explanation for the lack of significant findings could be that the surgeries did not occur close enough to the time of testing to show any residual deficits, as the surgery date for each individual was not collected. The findings of this study differs from that of Chimera et al.22 who observed worse FMSTM performance in a variety of Division I collegiate athletes with prior

| Table 1. Counts of FMSTM and SFMA scores by history of surgery. |
|---------------------------------|-----------------|-----------------|-----------------|
|                                 | Previous Surgery | No Previous Surgery | Total           |
| **FMS™ Performance**<sup>a</sup> |                  |                  |                 |
| Poor (score of 0 or 1)          | 9 (15.79%)       | 48 (84.21%)      | 57 (100%)       |
| Good (score of 2 or 3)          | 21 (17.65%)      | 98 (82.35%)      | 119 (100%)      |
| **SFMA Performance**<sup>a</sup> |                  |                  |                 |
| Poor (FP, DN, DP)               | 21 (16.80%)      | 104 (83.20%)     | 125 (100%)      |
| Good (FN)                       | 9 (17.65%)       | 42 (82.35%)      | 51 (100%)       |

*Note: FMSTM = Functional Movement Screen™ shoulder mobility scores; SFMA = Selective Functional Movement Assessment of dominant arm only; FP = functional painful; DN = dysfunctional non-painful; DP = dysfunctional painful; FN = functional non-painful.*

*Values are counts (%)
shoulder surgeries and injuries, however none of those athletes in the Chimera study were baseball players, which may explain these differences in performance.

In the sample of 176 collegiate baseball players, 119 were considered good performers in the FMS™, while only 51 were considered good performers in the SFMA. Upon observation of the players during testing, there were only 20 players who scored poorly in the SFMA pattern two movement of their dominant arms, while 105 scored poorly in pattern one. Pattern two includes shoulder flexion, abduction, and external rotation as the subject reaches overhead (and behind the head) toward the opposite scapula. Therefore, the majority of players classified as dysfunctional by the SFMA standards were classified so because of their pattern one performance, which is an inability to reach behind their back through shoulder extension, adduction, and internal rotation of the glenohumeral joint to touch the inferior angle of the opposite scapula. Poor pattern one performance may be partially explained by sport-specific adaptations that often occur in the dominant shoulders of baseball players, specifically glenohumeral internal rotation deficits (GIRD). GIRD is characterized by the loss of internal rotation of the glenohumeral joint, accompanied by an increase in external rotation and is likely a result of soft-tissue adaptations and osseous changes in anatomy due to the chronic repetitive stress of throwing. The amount of shoulder abduction and external rotation demonstrated during throwing can alter soft tissues such as ligaments and capsular structures within the shoulder, causing a laxity or weakness in the anterior shoulder capsule, and tightening of the posterior shoulder capsule.

The numbers of good SFMA scores were drastically different from the number of good FMS™ scores, which may be explained by differences in scoring criteria. The margin for asymmetry to exist within each arm while still receiving a good FMS™ score is greater since the arms are tested reciprocally (together) rather than separately. If an individual reaches their top arm overhead relatively farther than the bottom arm can reach behind their back, a player could still receive a good score even though they lack the motion necessary for a good SFMA score. An inability to reach the opposite scapula in the SFMA may be a better mobility threshold that is more sensitive to discrepancies in global movement.

In collegiate baseball players, sport-specific adaptations may be too great in the dominant-arm range of motion to discern between players with or without a history of shoulder or elbow surgeries. These screens do provide a quick and accurate identification of individuals with limited or painful mobility, which has been shown to increase the likelihood of

<table>
<thead>
<tr>
<th>Table 2. Relationship between history of surgery and FMS™ or SFMA performance categories.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS™ Performance a</td>
</tr>
<tr>
<td>Poor (score of 0 or 1)</td>
</tr>
<tr>
<td>Good (score of 2 or 3)</td>
</tr>
<tr>
<td>SFMA Performance a</td>
</tr>
<tr>
<td>Poor (FP, DN, DP)</td>
</tr>
<tr>
<td>Good (FN)</td>
</tr>
</tbody>
</table>

Note: CI = Confidence Interval; FMS = Functional Movement Screen; SFMA = Selective Functional Movement Assessment; FP= functional painful; DN= dysfunctional non-painful; DP= dysfunctional painful; FN= functional non-painful.

aGood performance is reference group

bUnadjusted OR and p-value calculated from 2x2 contingency table

cAdjusted OR calculated from binomial logistic regression
overuse symptoms throughout a collegiate baseball season.34

This study does have limitations when interpreting the data. The sample included was a convenience sample of four colleges, with data collection over a two-year period. Surgery dates were not collected, which could have factored into the lack of significant findings. Strength and conditioning practices were not investigated in terms of common exercises, or lack-therof which could play an important part in contributing to muscle imbalances in the upper extremity. Pitch counts, throwing velocity, and throwing volumes encountered in the previous season were also not recorded, which have all been associated as risk factors for shoulder and elbow injuries6 and therefore not taken into account when assessing the relationship between movement screen performance and past shoulder or elbow surgeries.

CONCLUSIONS
This study attempted to identify relationships between previous shoulder or elbow surgeries with FMS™ and SFMA performance in collegiate baseball players. There were no statistically significant relationships between history of surgery and FMS™ or SFMA performance. Implementing the FMS™ shoulder mobility and SFMA upper extremity patterns into pre-participation baseball movement screens may be beneficial for identifying individuals who exhibit movement dysfunctions, but those screens may not distinguish individuals with a previous history of shoulder or elbow surgeries.

REFERENCES


ORIGINAL RESEARCH

COMPARISON OF CORE STABILITY AND BALANCE IN ATHLETES WITH AND WITHOUT SHOULDER INJURIES

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Courtney M. Butowicz, PhD, CSCS⁶
Charles Thigpen, PT, PhD, ATC⁴
Brian Sennett, MD⁵
David Ebaugh, PT, PhD⁶

ABSTRACT

Background: Relationships between core stability and lower extremity injuries have been described in the literature; however, evidence of the relationship between upper extremity injuries and core stability and balance is limited.

Hypothesis/Purpose: The purpose of this study was to compare clinical measures of core stability and balance between athletes with and without non-traumatic shoulder injuries.

Study Design: Cross sectional.

Methods: Eighty athletes (54 males, age: 21.2 ± 3.3 years) participated in this study. Forty athletes with a current shoulder injury were matched to healthy athletes by age, gender, BMI, and sport. Athletes completed clinical core stability tests including flexor and extensor endurance tests, double leg lower test (°) and balance tests including single leg stance under eyes open and eyes closed conditions, and the Y-balance test. MANOVAs were used to assess group differences.

Results: No statistically significant differences existed between athletes with and without shoulder injuries for clinical tests of core stability, F(1,78) = 0.97, p = 0.41; η² = 0.04. No statistically significant differences existed between injured athletes with and without shoulder injuries for static and dynamic balance measures, F(1,78) = 0.86, p = 0.53; η² = 0.07.

Conclusions: Although core stability is widely incorporated in rehabilitation of athletes with shoulder injuries, performance on these clinical tests did not differ in the group of athletes assessed in this study.

Level of evidence: 3.

Key words: Core stability, kinetic chain, shoulder injuries

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INTRODUCTION
Shoulder injuries account for up to 40% of athletic injuries at the high school, collegiate, and elite levels. It is difficult to determine the percentage of injuries that result from a single traumatic episode. However, it is reasonable to believe that a large number are due to overuse caused by repetitive loads through the joint, and are affected by proximal movement patterns and/or the inability to properly transmit force.

The kinetic chain theory states that optimal shoulder function requires contribution from the legs and core (trunk and pelvis) to maximize performance while minimizing potentially harmful forces from being applied to the shoulder. Optimal core stability requires muscle capacity (strength and endurance) and neuromuscular control of trunk and pelvic musculature to produce, transfer, and control forces during activity. Pelvic musculature is often considered to be important for core stability as these muscles maintain pelvic position and are the link between the trunk and lower extremities. Likewise, the scapula is the link responsible for transferring energy from the lower extremities and trunk to the upper extremity. This theory is used in clinical and research settings as a rationale for inclusion of core stability training after injury, or for extremity injury prevention; however, a paucity of literature exists to support this approach. Deficits in lower extremity dynamic balance (the ability to maintain lower extremity stability whilst moving) are thought to be a proxy for core stability and to impair upper extremity function.

Direct relationships between core stability and lower extremity injuries have been described in the literature. However, literature to support evidence of the relationship between upper extremity injuries and poor core stability and balance is limited. Elucidating this relationship is important to improve athletic shoulder injury prevention and performance programs. The purpose of this study was to determine if differences exist in clinical measures of core stability and balance between athletes with and without a current non-traumatic shoulder injury. The hypothesis was that athletes with a current injury would have poorer performance on clinical measures of core stability and balance than athletes without injury.

MATERIALS AND METHODS
Eighty athletes were recruited from two Division I universities and athletic organizations in the area through flyers, athletic trainers, coaches, and team physicians. Athletes between the ages of 18 and 35 years old were included. Inclusion criteria were athletes who participated in any sport at an elite, varsity, or club level, with a minimum participation of 10 hours per week in practice and/or strength and conditioning workouts. Exclusion criteria were current cervical or lumbar spine injury, or any previous injury that affected the ability to play their sport. Subjects with a shoulder injury had additional inclusion criteria: shoulder injury that was non-traumatic in nature, affected their ability to perform their usual sport, and injury onset within the prior six months. Non-traumatic shoulder injury was defined as any episode which did not result from a single incident of the athlete in contact with the ground, equipment, or another player. If the subject was currently undergoing intervention for a shoulder injury, additional core training could not be part of the rehabilitation program. Forty control subjects were matched by age within five years, gender, sport group [1) overhead athletes; 2) non-overhead athletes], and body mass index (BMI) within 5 kg/m².

Subjects attended one testing session lasting approximately two hours. All subjects read and signed a written informed consent approved by the Human Research Protection Program of the university. Demographic and morphological data were collected: age, sex, height, weight, leg length, hand dominance/leg dominance, sport, if they were in season, and a description of current strength and conditioning workouts, including core stabilization exercises (Table 1). Following this, the subject was given a survey (Baecke questionnaire) regarding activity level and the Penn Shoulder Score to determine their self-reported level of shoulder disability. A shoulder screen was completed for all subjects, including range of motion (ROM; flexion, abduction, external rotation at 90 degrees of abduction, and functional internal rotation), manual muscle testing of the shoulder musculature (flexion, abduction, and internal and external rotation at neutral abduction; strength and presence/absence of pain noted), and provocative testing (anterior and posterior...
apprehension, biceps load I and II, Jerk, empty can, external rotation lag, and Neers tests). The shoulder screen was performed by the primary author (a licensed physical therapist) for all subjects. Subjects with shoulder pain were classified into one of the following primary diagnoses (n): rotator cuff tendinopathy (15), rotator cuff tear (2), anterior instability (9), posterior instability (1), multidirectional instability (1), and labral pathology (12).

Overhead athletes were operationally defined as athletes who performed repetitive overhead motion during practice and competition, and included throwing, racquet, and swimming sports. Athletes who participated in strength and conditioning training (79/80) reported performing core stability exercises as part of their usual regimen (indicated on the intake questionnaire; included: bridges, back extension, planks, side planks, sit-ups/crunches). Out of forty athletes with a shoulder injury, 26 were currently attending formal physical therapy.

None reported performing additional core stability exercises as part of their physical therapy intervention.

**DATA COLLECTION**

Testing of core stability focused on the muscle capacity component. Static and dynamic standing balance assessment was also performed. Test descriptions are included in Table 2.

These clinical tests were chosen based upon prior test performance in athletes. The extensor endurance test correlates with trunk and hip extensor muscle activity. Additionally, normative values have been established, and this test has also been shown to be able to discriminate between subjects with and without low back pain. The flexor endurance test correlates with trunk flexor muscle activity, and reference values have been established. The double leg lowering test (DLLT) is a test of abdominal muscle performance, activating rectus abdominis.

### Table 1. Subject Demographics and Group Differences, presented as Mean (SD), unless otherwise indicated.

<table>
<thead>
<tr>
<th></th>
<th>Control (n=40)</th>
<th>Shoulder Injury (n=40)</th>
<th>Group Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>21.0 (3.4)</td>
<td>21.4 (3.2)</td>
<td>t(78) = 0.51, p = 0.61, d = 0.11</td>
</tr>
<tr>
<td>Sex (M/F, n)</td>
<td>27/13</td>
<td>27/13</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.5 (9.5)</td>
<td>176.2 (9.9)</td>
<td>t(78) = 0.11, p = 0.92, d = 0.02</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>84.9 (18.5)</td>
<td>84.6 (20.5)</td>
<td>t(78) = 0.083, p = 0.93, d = 0.02</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.0 (4.1)</td>
<td>26.9 (4.5)</td>
<td>t(78) = 0.13, p = 0.90, d = 0.03</td>
</tr>
<tr>
<td>Penn Shoulder Score</td>
<td>97.5 (3.8)</td>
<td>78.2 (11.7)</td>
<td>t(78) = 10.0, p &lt; 0.001*, d = 2.2</td>
</tr>
<tr>
<td>Baecke Sports Score</td>
<td>6.2 (1.0)</td>
<td>6.1 (1.1)</td>
<td>t(78) = 0.33, p = 0.74, d = 0.07</td>
</tr>
<tr>
<td>Sport Type</td>
<td>14/26</td>
<td>14/26</td>
<td></td>
</tr>
<tr>
<td>Currently in season</td>
<td>18</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Participation in</td>
<td>40</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Strength and</td>
<td></td>
<td></td>
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<tr>
<td>Conditioning (n)</td>
<td></td>
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</tbody>
</table>

*statistically significantly different
### Table 2. Clinical Tests Descriptions and Metrics

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensor Endurance Test&lt;sup&gt;15&lt;/sup&gt;</td>
<td>The subject was positioned prone on a treatment table with their iliac crests at the edge of the table and upper trunk hanging down from the edge of the table. Mobilization belts were used to secure the subject across the buttocks, posterior thigh above the knee, and ankles. The subject was instructed to cross their arms across their chest and extend their back until their torso was parallel to the floor. The examiner used an inclinometer on the thoracic spine to determine when the subject could no longer maintain the test position (indicated by a 10 degree change in trunk alignment).</td>
<td>1 trial, measured in seconds.</td>
</tr>
<tr>
<td>Flexor Endurance Test&lt;sup&gt;15&lt;/sup&gt;</td>
<td>This test required the subject to sit in hooklying with a custom built 60 degree wedge placed behind their back. The subject was asked to cross their hands across their chest, the wedge was removed, and they were asked to maintain that position for as long as possible. The test was terminated when the subject changed their hip flexion angle, indicated by pressing into or coming off the wedge. Figure 2?</td>
<td>1 trial, measured in seconds.</td>
</tr>
<tr>
<td>Double-leg lowering test&lt;sup&gt;16&lt;/sup&gt;</td>
<td>Subjects lie on their back with their legs straight and their hips flexed to 90°. From this position, subjects slowly lower their legs towards the floor without changing the pressure in the blood pressure cuff under their lumbar spine. Once the pressure changes 10 mm Hg, the angle of the legs relative to the horizontal is recorded. Figure 3?</td>
<td>Measured in degrees with wall display goniometer.</td>
</tr>
</tbody>
</table>
Table 2.  *Clinical Tests Descriptions and Metrics. (continued)*

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static balance (SLS in EO and EC)⁰⁷</td>
<td>Single leg stance (SLS) was assessed under eyes open (EO) and closed (EC) conditions, consisting of one practice trial and 2 trials on each leg for each condition, with a rest period of 30 seconds between trials. This was performed by having the subject stand in bare feet, and lift their right leg until the toes cleared the floor by approximately 15 cm. Subjects kept their arms crossed across their chest during the trial, and stayed as still as possible. This was repeated with the right leg.</td>
<td>The Balance Error Scoring System (BESS), which provides criteria for scoring the SLS test related to the quality of performance, was used to score the SLS test by counting the number of errors.</td>
</tr>
<tr>
<td>Y-Balance Test Composite⁰⁸,⁰⁹</td>
<td>The Y-balance test was used as the measure of dynamic balance, using a custom-built PVC frame. Following six practice trials, the subject was asked to perform three consecutive trials of reaching in anterior, posteromedial, and posterolateral directions for each lower extremity. Subjects were instructed to keep their hands on their hips for the duration of each trial, pick the opposite foot up, and in a controlled manner, place their toes on the end of the box and push it as far as possible, then. Subjects were instructed to return to the start position, without putting their foot down. Following successful completion of the anterior reach, they then completed three trials of the posteromedial and posterolateral directions were completed. Trials were repeated if any of the following occurred during the trial: 1) the non-stance leg touched the floor; 2) the subject stepped off the testing platform; 3) the subject removed their hands from their hips; and 4) the subject put weight on the plastic box while sliding it forward.</td>
<td>Reach distances were recorded by noting the distance the box was pushed; measurements were averaged across trials and normalized to leg length, and a composite score was calculated as the sum of the three directions.</td>
</tr>
</tbody>
</table>
obliquus internus abdominis, and obliquus externus abdominis muscles, and reference values have been published for collegiate athletes. The Y-balance test (YBT) is a commonly utilized test of lower extremity postural stability, and normative values have been established for collegiate athletes.

After each test, exertion was assessed by the Borg scale. If any test(s) resulted in a rating of > 13/20, the subject was allowed additional rest until the rating reached < 8/20 before the subject continued. If any test caused a two point increase (out of 10 points) on a pain rating scale, the session was terminated. All subjects completed the entire testing protocol without any reported increased pain.

**DATA ANALYSIS**

Data were collected for all variables on 80 athletes. SPSS Statistics software (SPSS 23, IBM, Armonk NY), was used for assessing normality and descriptive statistics. Independent T-tests examined group differences for all demographics, with significance set to \( p = 0.05 \). Group differences were assessed with 2 MANOVAs: 1. core stability tests (FLEX, EXT, DLLT) and 2. balance tests (BESS EO and EC left and right; YBT, normalized composite score, left and right). Significance was set to \( p = 0.05 \).

A logistic regression was used to determine if group differences could be detected based upon a battery of tests. In order to determine which clinical tests would be included in the logistic regression, univariate tests were used to assess for group differences for each variable, with \( p = 0.10 \). Variables that reached statistical significance were used in the logistic regression. For the logistic regression, significance was set to \( p = 0.05 \).

**Sample Size**

An a priori power analysis using G*Power 3, for a large effect size (\( f^2 = 0.15 \)), \( \alpha = 0.10 \), \( \beta = 0.80 \), two groups, and a maximum of six response variables, a sample size of 80 was suggested to find a difference between groups. A more liberal \( \alpha \) was used for the initial analysis, and then variables that were found to differ significantly between groups would be looked at separately by univariate analysis. Recruitment of a total sample size of 80 allowed us to use up to four predictors in our regression equation.

**RESULTS**

Eighty subjects (40 with a current shoulder injury, 40 control) completed this study. Outliers were removed on a case-wise basis. Less than 5% of data were removed; thereafter, data were found to be normally distributed for all variables. Means and standard deviations of all measures are presented in Table 3.

There were no statistically significant differences between athletes with and without shoulder non-traumatic injuries for the clinical core stability measures, \( F(3,76) = 0.97, p = 0.41; \eta^2 = 0.05 \), or for standing balance measures, \( F(6,73) = 0.86, p = .53; \eta^2 = 0.07 \).

In this study, 28/80 athletes were overhead athletes. Analyses on this subgroup (comparing overhead athletes with and without a current shoulder injury) revealed no significant differences between the overhead athlete subgroup for any of our measures (core tests; \( F(3,21) = 0.69, p = .57; \eta^2 = 0.09 \); balance tests; \( F(6,18) = 1.3, p = .32, \eta^2 = 0.29 \)).

No single variable was found to differ between groups; therefore, for the logistic regression, the following predictor variables were used: 1. DLLT; 2. FLEX; 3. EXT; 4. YBT COMP. DLLT was used as better performance on this is associated with better performance on an upper extremity functional test and the univariate test approached significance (\( p = 0.13 \)). FLEX and EXT were included to ensure both anterior and posterior trunk musculature was represented in the regression equation. The YBT was included as there is an association between decreased test performance and UCL tears in baseball. Only one side (right side) was included since there was no significant difference between sides. The logistic regression was not significant, \( \chi^2 = 4.4, df = 4, p = 0.36 \) indicating that none of the variables differentiated between the injured and uninjured groups.

**DISCUSSION**

The surprising results of this study show that clinical measures of core stability utilized in this study were not different between athletes with and without a current non-traumatic shoulder injury. This was the first study to compare core muscle endurance
testing, DLLT, and YBT between groups of injured and uninjured athletes. The findings can be attributed to several factors. First, the sample tested in this study was homogeneous in training and groups were matched on age, gender, and sport. All subjects were high-level athletes, participating at the collegiate or elite level of competition. Over, ninety-eight percent (79/80) of the athletes participated in practice and strength and conditioning workouts, all of which included core muscle training. The most commonly reported core exercises were planks, side planks, bridges, and abdominal curls, which involve the same core musculature as the FLEX, EXT, and DLLT tests. Second, there were no group differences found in the Baecke Sports Score between groups. The Sports Score captures information regarding whether an athlete is in season, the level at which they compete, and the number of hours/week and months/year they participate in their sport(s). Training volume was similar across athletes; thus, the lack of group differences cannot be attributed to training load. Other potential confounding factors (e.g., pain, fatigue) were controlled and did not differentiate groups. Therefore, the subjects were well matched and relevant confounding factors were accounted for in the design and analysis.

The clinical tests of core stability used in this study (FLEX, EXT, DLLT) all have been shown to correlate with trunk muscle activity and have established reference values.\textsuperscript{16} For the DLLT, the athletes performed better (as indicated by a lower score) than previously published reference values, indicating that the athletes in this study did not exhibit poor core stability, as measured by this test. The subjects in this study exhibited similar performance on FLEX, EXT, and YBT, compared to reference values reported in previous literature, indicating that poor core stability cannot be suspected in the population tested.\textsuperscript{16,19}

There were no observed differences in static balance (EO and EC conditions) between athletes with and without shoulder injuries. This is in contrast with findings from Baierle and colleagues,\textsuperscript{10} who reported that patients with shoulder pain demonstrated decreased balance control in double leg stance compared to a healthy cohort; however, these patients did not represent an athletic population. Radwan and colleagues\textsuperscript{13} found that Division III overhead athletes with shoulder dysfunction demonstrated decreased performance with SLS versus their healthy peers; however, this difference was only significant with the right

<table>
<thead>
<tr>
<th>Clinical Test</th>
<th>Controls (n=40) Mean (SD)</th>
<th>Shoulder Injury (n=40) Mean (SD)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLEX (s)</td>
<td>95.0 (47.0)</td>
<td>102.8 (47.8)</td>
<td>F(3,76) = 0.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>p = .41</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$\eta^2 = 0.05$</td>
</tr>
<tr>
<td>EXT (s)</td>
<td>83.5 (37.9)</td>
<td>79.5 (36.0)</td>
<td></td>
</tr>
<tr>
<td>DLLT (°)</td>
<td>19.1 (14.0)</td>
<td>24.6 (18.6)</td>
<td></td>
</tr>
<tr>
<td>BESS EO L</td>
<td>0.1 (0.5)</td>
<td>0.1 (0.4)</td>
<td>F(6,73) = 0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>p = .53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\eta^2 = 0.07$</td>
</tr>
<tr>
<td>BESS EO R</td>
<td>0.1 (0.3)</td>
<td>0.2 (0.5)</td>
<td></td>
</tr>
<tr>
<td>BESS EC L</td>
<td>3.2 (2.1)</td>
<td>3.3 (2.1)</td>
<td></td>
</tr>
<tr>
<td>BESS EC R</td>
<td>2.8 (1.8)</td>
<td>3.3 (2.2)</td>
<td></td>
</tr>
<tr>
<td>YBT COMP L</td>
<td>1.35 (0.2)</td>
<td>1.33 (0.2)</td>
<td></td>
</tr>
<tr>
<td>YBT COMP R</td>
<td>1.34 (0.2)</td>
<td>1.36 (0.3)</td>
<td></td>
</tr>
</tbody>
</table>

FLEX = flexor endurance test; EXT = extensor endurance test; DLLT = double leg lowering test; BESS: Balance Error Scoring System, EO and EC, left (L) and right (R), recorded in number of errors; YBT COMP L/R = Y Balance test, composite score normalized to leg length, left and right.
As subjects in their study were not matched, the reported differences could potentially have been due to confounding factors such as sex, BMI, activity level, sport type, or limb dominance. The BESS score was used for the clinical measure of static balance in this study. Most athletes achieved a score of zero errors for the eyes open condition, indicating that this test condition was not challenging enough for this population. A systematic review of the BESS stated that the scoring system had better reliability and validity where large differences in balance existed (for example, after an injury such as concussion compared to healthy controls), but validity should be questioned when subtler differences exist. The eyes closed condition was only somewhat more difficult. It is possible that the clinical static balance test used in this study was not difficult enough for an athletic population to be able to discriminate between those athletes with good and poor static balance.

Similarly, differences in dynamic balance test results were not observed in this study, contrasting Garrison et al. who saw differences in standing dynamic balance between baseball players with and without a current ulnar collateral ligament (UCL) injury. However, Garrison's study investigated only UCL injuries, and there was no mention as to how recently the UCL injury occurred. Thus, the difference in YBT scores between injured and uninjured baseball players could potentially be explained by a change in the activity level in the injured players (i.e., if they participated less in practice and/or strength and conditioning), which may have caused the observed dynamic balance deficits. This is plausible since both the lead and stance limbs showed decreased YBT scores versus their uninjured counterparts. In this study, subjects were captured as close to the time of injury as possible, minimizing the potential effects of deconditioning from non-participation in practice and/or strength and conditioning. Often, strength and conditioning exercises and athletic tasks require the athlete to be in single leg stance for part of the activity. Thus, single leg stance performance was expected to be similar across the athletic population tested, in the absence of a deconditioning effect secondary to injury. Future work should consider the utilization of more advanced athletic tasks, such as advanced dynamic stabilization or unilateral plyometric activities to potentially discern differences in athletic performance.

The results show that no test combination among the DLLT, FLEX, EXT, and YBT tests differentiated injured and uninjured athletes. Additionally, none of the individual tests differentiated between groups (shoulder injury versus control). Furthermore, both the MANOVS and logistic regression had small effect sizes, indicating that a larger sample would very likely reveal similar results.

Previous work examining the kinetic chain theory has focused on overhead athletes, most commonly baseball players. In this study, the overhead athlete subgroup revealed no significant differences between the overhead athlete subgroup for any of measures tested; furthermore, the small effect size for the core measures suggests that if more overhead athletes participated in this study, we would still be unlikely to find group differences. Since balance test score differences had a large effect size, future work may examine balance differences in this subset of athletes. The rationale for including other athletes (e.g., lacrosse, crew) was that all athletes who participated in this study used their upper extremity in some manner to perform their sport tasks. Additionally, the kinetic chain theory does not state that its premises are only applicable to specific athletes.

The current results do not support the premise that highly trained athletes with a current shoulder injury differ in clinical measures of strength or endurance of the core muscles nor standing balance compared to an uninjured cohort. Although core stability is widely incorporated in rehabilitation of athletes with shoulder injuries, limited evidence has demonstrated differences in core stability in athletes with shoulder injuries versus their uninjured peers. The clinical tests of core stability used in this study were geared towards assessing the muscle capacity aspect of core stability and while these tests are widely used and have documented reliability, they may not be sensitive enough, to detect deficits in highly trained athletes. Additionally, clinical tests that focus on the neuromuscular control aspect of core stability may, in isolation or combined with tests used in this study, may be able to identify group differences in core stability. Not including
clinical tests of neuromuscular control, or the transference of forces through the lower extremities, core, and upper extremities are limitations of this study. Investigating all aspects of core stability as well as other intrinsic and extrinsic risk factors for shoulder injuries in an athletic population should be the focus of future research.

CONCLUSION
No differences in clinical measures of core stability or balance were found between athletes with and without a non-traumatic shoulder injury. Although core stability is widely incorporated in rehabilitation of athletes with shoulder injuries, athletes who develop non-traumatic shoulder injuries may not have significant impairments in core stability or balance that are contributing to their injuries.

REFERENCES
ABSTRACT

**Background:** Posterior shoulder tightness (PST), defined as limited glenohumeral (GH) horizontal adduction and internal rotation motion, is a common occurrence in overhead athletes, particularly baseball and softball players, as a result of the extreme forces on the GH joint and the high number of throwing repetitions. Despite clinical evidence suggesting the use of joint mobilizations and muscle energy techniques (MET) for treating PST, there currently are no data examining the overall effectiveness of joint mobilizations and MET to determine optimal treatment for posterior shoulder tightness.

**Purpose:** To compare the acute effectiveness of MET and joint mobilizations for reducing posterior shoulder tightness, as measured by passive GH horizontal adduction and internal rotation ROM, among high school baseball and softball players.

**Study Design:** Randomized controlled study

**Methods:** Forty-two asymptomatic high school baseball and softball players were randomly assigned to one of three groups (14 MET, 14 joint mobilization, 14 control). Glenohumeral passive adduction and internal rotation ROM were measured in all participants in a pre-test post-test fashion. Between testing, the joint mobilization group received one application of GH posterior joint mobilizations. The MET group received one cycle of MET applied to the GH horizontal abductors. The control group received no intervention. Posttests measures were completed immediately following intervention or a similar amount of time resting for the control group and then again 15 minutes later.

**Results:** One-way analyses of covariance showed that the MET group had significantly more horizontal adduction ROM post-treatment compared to the control group ($p = 0.04$). No significant differences existed between groups in horizontal adduction ($p > 0.16$) or internal rotation ($p > .28$) or at the 15-minute posttests ($p > 0.70$).

**Conclusion:** The results of this study indicate the application of MET to the horizontal abductors provides acute improvements to GH horizontal adduction ROM in high school baseball and softball players, while joint mobilizations provide no improvements.

**Level of Evidence:** 1

**Keywords:** Baseball, glenohumeral joint, manual therapy, softball.
INTRODUCTION

Due to the extreme ranges of motion (ROM) and high arm velocities that occur during the throwing motion, the glenohumeral (GH) joint is subjected to tremendous amounts of force. As a result of the repetitive application of such large loads, specific adaptions commonly occur to the osseous and soft tissue components of the GH joint. A combination of these structural adaptations has been shown to modify the normative ROM of the throwing shoulder, resulting in increased external rotation and decreased internal rotation ROM. An increase in humeral retroversion typically leads to an equal shift in the total arc of motion, such that the gain in external rotation equals the loss in internal rotation. However, soft tissue tightness of the posterior shoulder can result in decreased GH internal rotation, without a concomitant increase in external rotation, as well as decreased horizontal adduction and an increased risk for injury.

Researchers have implicated posterior shoulder tightness (PST) as a potential cause of muscular dysfunction, superior labral anterior to posterior lesions, subacromial impingement and pathological internal impingement. Many of the studies pertaining to shoulder ROM changes and PST focus on the loss of internal rotation, but decreased horizontal adduction has also been observed. PST may be managed effectively with different types of conservative treatment options. Muscle energy techniques (MET) applied to the GH joint have been shown to aid in improving shoulder ROM. Moore et al. explored the effects of a MET treatment applied to the GH external rotators compared to the horizontal abductors. These authors determined that treatment to the horizontal abductor muscle group yielded a greater improvement in both internal rotation and horizontal adduction motions when compared to a control group. Joint mobilizations are another form of manual therapy and have been clinically shown to improve joint motion and kinematics.

Pathological implications of PST often only become prevalent once significant losses in ROM have occurred. However, it is difficult to determine if the loss of motion led to injury or if the injury was the cause of the lost ROM. Regardless, due to the potential negative effects of PST, determining optimal treatment options for improving GH internal rotation and horizontal adduction ROM in asymptomatic throwing athletes could aid in decreasing the incidence and severity of shoulder injury. The purpose of this study was to compare the acute effectiveness of MET and joint mobilizations for reducing posterior shoulder tightness, as measured by passive GH horizontal adduction and internal rotation ROM, among high school baseball and softball players. The secondary purpose was to determine if any changes in ROM persisted over a 15-minute time period. It was hypothesized that the application of the joint mobilizations would yield the greatest acute restorative results in shoulder ROM.

METHODS

The participants who volunteered for this study consisted of youth throwing athletes recruited from two high schools. A university institutional review board approved this study prior to all data collection. All participants 18 years or older provided informed consent. All participants under the age of 18 years provided written assent, and their parents or guardians provided written permission for their daughter or son to participate. Inclusion criteria required participants to be a current member of a competitive high school baseball or softball team (pitchers and position players). Participants were excluded from the study if they had any recent history (prior three months) of upper extremity injury that prevented participation in their respective sport or any history of upper extremity surgery. The total number of participants for this study was 42 (24 baseball, 18 softball) based on a sample of convenience. Thirty-six participants were right-hand dominant throwing athletes, while six were left hand dominant throwing athletes. Participant demographics are presented in Table 1.

Participant demographic information was recorded and included age, height (cm), body mass (kg), injury history, and throwing arm preference. Group allocation (control, MET, joint mobilizations) was determined, by the principal investigator, prior to subject participation, such that an equal number of participants were randomly assigned to each group. Multiple high schools participated in this study, so testing of each team was conducted in their respective...
sports medicine facility. All participants completed three testing sessions (pre-test, immediate post-test, 15 minutes posttest). The immediate posttest measurements were recorded directly following the treatment application for the experimental groups and after following a one minute waiting period for the control group. All participants then waited an additional 15 minutes for a second round of post-tests. All pre- and posttest measurements were performed in an identical manner. The order of the passive ROM measurements was not randomized and the investigators were not blinded to the group of each participant. All measurements and interventions were performed by the principal investigator.

Data collection occurred during the midpoint of the competitive season for all participants. Prior to data collection, participants completed their team’s specific standard warm-up. This warm up consisted of mild jogging, static and dynamic total body stretches, and low velocity overhead/throwing motions. The warm up for this study was not standardized in order to mimic the normal playing conditions and regular training regimen for each specific participant. After completing the warm up, each participant was assessed for a baseline measurement of horizontal adduction and internal rotation ROM of their throwing shoulder.

A Pro 3600 digital inclinometer (SPI-Tronic, Garden Grove, CA, USA) was used to record ROM measurements for GH horizontal adduction and internal rotation. To assess GH horizontal adduction ROM, each participant was positioned supine with both shoulders flush against a standard examination table. An examiner stood at the top of the examination table towards the participant's head and stabilized the lateral border of the scapula by providing a posterior force. The participant’s arm was placed in a position of 90 degrees of GH abduction with 90 degrees of elbow flexion. The opposite hand of the clinician held just distal to the participant's elbow and passively horizontally adducted the arm (Figure 1). At the first point of resistance a second examiner recorded the amount of motion present by aligning the digital inclinometer with the shaft of the humerus.

Passive GH internal rotation ROM was measured with the participant lying supine on an examination table, with the shoulder abducted to 90 degrees (frontal plane) and the elbow in 90 degrees of flexion. The examiner applied a posterior stabilizing

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET (n=14)</td>
<td>17.07±1.0</td>
<td>176.17±14.7</td>
<td>69.81±12.9</td>
</tr>
<tr>
<td>Joint mobs (n=14)</td>
<td>16.43±0.8</td>
<td>172.72±11.4</td>
<td>71.88±17.4</td>
</tr>
<tr>
<td>Controls (n=14)</td>
<td>16.50±1.2</td>
<td>174.46±11.4</td>
<td>72.23±26.6</td>
</tr>
</tbody>
</table>

There were no significant differences between groups for any characteristics ($p > 0.07$).

MET = muscle energy technique; joint mobs = joint mobilizations

Figure 1. Horizontal adduction range of motion measurement.
force to the acromion processes of the scapula, and internally rotated the arm until the first point of resistance. The second examiner then recorded the amount of motion by aligning the digital inclinometer with the shaft of the ulna.

A pilot test consisting of 16 subjects (separate from those used in the current study) was completed a priori to determine intraclass correlation coefficients (ICC), standard error of measurements (SEM), and minimum detectable change (MDC) for all ROM tests. Each subject had their throwing shoulder ROM measured resulting in 32 total limbs tested. Subjects were initially tested and then follow-up tests were collected at least 24 hours later. All measurements showed excellent intra-rater reliability and SEM (horizontal adduction: ICC = .85, SEM = 2.3°, MDC = 6.4°; internal rotation: ICC = .87, SEM = 4.2°, MDC = 11.6°).

The principal investigator, who performed all ROM testing and performed all treatments is a certified athletic trainer with extensive training in manual therapy. The participants that received the joint mobilization intervention were positioned supine along the edge of an examination table, so that the humeral head did not have any support in a posterior direction, but so that the table provided scapular stabilization. The participant's shoulder was abducted to 90 degrees and internally rotated to the first barrier of resistance, with the elbow flexed and relaxed (Figure 2). The participant's distal forearm was braced on the examiner's hip as a support, with the clinician's hand applying overpressure to the GH joint in the posterior direction. The examiner then applied fifteen, one second, grade III posterior oscillations to the humeral head parallel to the glenoid treatment plane. There was also a one second rest period between oscillations, resulting in a 30 second total treatment period. Grade III posterior GH mobilizations were chosen based on the clinical experiences of the investigators and from the findings of previous research.24

The participants in the muscle energy technique (MET) treatment group were positioned supine on the examination table with the examiner stabilizing the lateral border of the scapula. The examiner passively horizontally adducted the arm until the first barrier to motion by applying pressure to the distal humerus. This passive stretch was applied for three seconds. The examiner then instructed the participant to attempt to horizontally abduct the test arm at 25% of their maximal effort while the examiner applied manual resistance at the distal humerus to create an isometric contraction lasting five seconds. The examiner then brought the participant's arm back into horizontal adduction, for a three second active assistive stretch. Four of these application cycles were completed in totaling approximately 60 seconds. The control group rested in a supine position for one minute in between pre and post-tests.

**STATISTICAL METHODS**

SPSS Statistical software (IBM SPSS Statistics for Windows, version 22.0; IBM Corp, Armonk, NY) was used to analyze all data. Statistical analyses were conducted via separate one-way analyses of covariance (ANCOVA) for horizontal adduction and internal rotation ROM. The dependent variables consisted of posttest ROM and the covariates were pretest ROM. Fisher's least significant difference post hoc analysis was used when appropriate. All analyses were considered significant at the 0.05 alpha level. Effect sizes were used to provide impression of clinical significance and were calculated as: experimental group mean – control group mean / largest standard deviation.

**RESULTS**

There were no significant differences between groups for age (p > 0.07), height (p > 0.49), or mass.
There was a significant between group difference for post-intervention horizontal adduction ROM \( (F(2,38) = 8.7; p = 0.001) \). Post hoc analysis showed that the shoulders treated with MET had significantly more passive horizontal adduction ROM post-treatment compared with the control group \( (p = 0.04) \) (Table 2). There were no significant differences between joint mobilizations and MET \( (p = 0.16) \) or joint mobilizations and control \( (p = 0.48) \) for post-intervention horizontal adduction passive ROM (Table 2). There was no significant between group difference in internal rotation PROM post-intervention \( (F(2,38) = 1.3; p = 0.28) \) (Table 3). When analyzing the results of measurements collected 15 minutes post intervention, there was no significance between groups differences for either horizontal adduction \( (F(2,38) = 0.4; p = 0.70) \) or internal rotation \( (F(2,38) = 0.1; p = 0.91) \) (Tables 2 & 3).

**DISCUSSION**

Due to the extreme velocities and high repetitions sustained by the throwing shoulders of baseball and softball players, these athletes often present with PST.1,3,25 This tightness has been repeatedly shown to alter shoulder ROM,2,3,10 kinematics,26,27 and kinetics.26,27 Alterations to GH ROM in the overhead athlete have been linked to various pathologies including muscular dysfunction,12,13 labral lesions, 11,13-15 and impingement syndromes.4,6,12,13,16 In order to prevent and treat various pathologies related to this tightness, it is essential to implement techniques that lengthen both the contractile and non-contractile tissues of the posterior shoulder. The results of this study demonstrate that the application of MET to the horizontal abductors provides acute improvements in GH horizontal adduction ROM in high school baseball and softball players. The MET application to the horizontal abductor group yielded significant improvements in horizontal adduction when compared to the control group. This result revealed a moderate-to-large effect size as evaluated by Cohen's \( d \) (0.73). The difference between the pre and posttest values (8.3 degrees) was also larger than the SEM (2.3 degrees), which may indicate clinical significance. These findings did not support the author’s hypothesis that joint mobilizations would produce greater improvements in ROM compared to the use of MET. These results demonstrate that MET applied to the horizontal abductors may be beneficial in treating athletes with PST due to muscular limitations amenable to MET versus joint mobilizations which targets the joint capsule. MET should be considered in the prevention and treatment of injuries associated with PST tightness.

**Table 2. Means and Standard Deviations for Horizontal Adduction Range of Motion.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre test (°)</th>
<th>Acute post test (°)</th>
<th>Difference (°)</th>
<th>Effect size</th>
<th>15 Minutes post test (°)</th>
<th>Difference (°)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET*</td>
<td>15.6±7.7</td>
<td>24.0±7.4</td>
<td>8.3±7.6</td>
<td>0.73</td>
<td>17.8±5.7</td>
<td>2.2±5.7</td>
<td>0.02</td>
</tr>
<tr>
<td>Joint mobs</td>
<td>18.5±5.8</td>
<td>19.9±6.9</td>
<td>1.4±4.0</td>
<td>0.24</td>
<td>19.1±7.4</td>
<td>0.6±5.4</td>
<td>0.13</td>
</tr>
<tr>
<td>Control</td>
<td>18.6±9.7</td>
<td>17.9±8.4</td>
<td>-0.7±5.0</td>
<td>0.07</td>
<td>18.0±8.2</td>
<td>-0.6±7.1</td>
<td>0.06</td>
</tr>
</tbody>
</table>
| MET= muscle energy technique; Joint mobs= joint mobilizations * = significant post-intervention acute difference between MET and control groups \( (p = 0.04) \)

**Table 3. Means and Standard Deviations for Internal Rotation Range of Motion.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre test (°)</th>
<th>Acute post test (°)</th>
<th>Difference (°)</th>
<th>Effect size</th>
<th>15 Minutes post test (°)</th>
<th>Difference (°)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET</td>
<td>53.2±8.9</td>
<td>58.2±9.4</td>
<td>5.0±5.5</td>
<td>0.04</td>
<td>54.6±10.0</td>
<td>1.4±6.8</td>
<td>0.28</td>
</tr>
<tr>
<td>Joint mobs</td>
<td>55.4±11.5</td>
<td>57.9±11.8</td>
<td>2.5±4.1</td>
<td>0.02</td>
<td>57.3±10.6</td>
<td>1.9±4.6</td>
<td>0.06</td>
</tr>
<tr>
<td>Control</td>
<td>55.2±9.8</td>
<td>57.7±10.5</td>
<td>2.5±3.6</td>
<td>0.24</td>
<td>58.0±12.1</td>
<td>2.9±6.2</td>
<td>0.23</td>
</tr>
<tr>
<td>There was no significant between group acute differences post-intervention ( (p=0.28) ). MET= muscle energy technique; Joint Mobs= joint mobilizations</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
therapy provides the most significant reductions in PST. Previous literature has determined that a variety of stretching techniques targeting the musculature of the posterior shoulder are effective methods for reducing the ROM discrepancies associated with PST.1,4,10,18,19,28,29 Most commonly, studies have demonstrated that the sleeper stretch4,18,29 and the cross body stretch19 are beneficial. Both stretches have been shown to be effective for increasing horizontal adduction and internal rotation, with the largest increases in both motions occurring when the scapula is stabilized.19,28 This research focused on stretching techniques targeting the soft tissue components of the GH joint. Because the application of MET targeted several muscles of the GH joint these results would support these previous findings. However, not everyone can tolerate the cross-body stretch or the sleeper stretch, especially throwing athletes because these stretches place the shoulder in an impingement prone position, which can be uncomfortable or painful and result in muscle guarding.

In addition to the use of stretching techniques to improve range of motion, MET has also been explored as a treatment targeting the soft tissue extensibility issues behind motion restrictions. A series of studies have validated the use of MET for increasing ROM by observing the effects on different segments and directions of trunk motion30-32 and hamstring extensibility.31 Relatively few studies have applied this technique to the upper extremity,17,34 however these past studies have shown evidence that support MET for improving GH ROM. Moore et al.17 examined the effects of a MET application to the shoulder external rotators and horizontal abductors with a similar technique as used in this study. This previous research demonstrated that the horizontal abductors responded well to an acute MET treatment, creating significant improvements in horizontal adduction and internal rotation ROM. The results of this study support those of Moore17 as the current MET technique was also able to induce a significant increase in horizontal adduction. However, Moore also reported a significant improvement in internal rotation. This could be due to several factors, such as Moore’s use of a larger sample size and a longer stretch phase (30 seconds) during the MET intervention. Moore et al.17 discussed that at the time of their publication that it was unknown if muscular or capsular tightness was a larger contributor to PST and the associated ROM changes. Further research is necessary to determine the anatomical contribution to PST.

Conversely, previous research has postulated that capsular tightness contributes significantly to PST.4,12 Several studies have shown that joint mobilizations are an effective method for treating conditions such as adhesive capsulitis, by targeting the motion restrictions created secondary to capsular tightening and effectively increasing motion.21,22 However, the literature surrounding the use of joint mobilizations to decrease PST has not yet examined the isolated effects of joint mobilizations, but rather paired the mobilizations with a series of different stretching and therapeutic exercise protocols.24,35,36 The findings of this study support previous studies that have focused on treatments directed at improving muscular extensibility.4,10,17,18,28,29,34 The findings of this study may suggest that the contributions of the GH capsule in the development of PST is limited, especially in high school baseball and softball players. As such, youth athletes may have not experienced the same degree of posterior capsular tightening as an adult overhead athlete. However, further research is needed to confirm this topic.

The effects of the MET treatment were transient, lasting less than 15 minutes. The principles of soft tissue extensibility emphasize the clinical importance of preventative treatments that may reduce the prevalence of shoulder pathologies over time. The results of this study indicate the effectiveness of MET for short term changes in improving GH ROM and decreasing PST. Similarly, previous research has shown that repeated static and MET treatments applied to the soft tissue components of the GH joint are effective in creating improvements to GH ROM among non-athletes and swimmers.19,34 Unfortunately, there is little research determining the length of time this improvement in GH ROM lasts. Furthermore, athletes who perform MET prior to sport participation may see longer lasting results when immediately followed by their sport activity, as opposed to being static, as during our study. However, future research is needed to validate this hypothesis.
Several limitations of this work are worth noting. First, there was a relatively small sample size for each group (n=14). The authors conducted a power analysis based on an alpha level of 0.05 and a power of 0.80 and found that the joint mobilization group would have required 191 participants to see a statistically significant improvement in horizontal adduction ROM, which is not feasible. The population of this study consisted of youth athletes, limiting the application of these results to older athletic populations. The subjects were also limited to participation in baseball and softball, limiting the generalizability of these results to other overhead sports such as volleyball and tennis that also often present with PST. This study evaluated the effects of these treatments in asymptomatic subjects who were not previously identified with PST. Unfortunately, the methodology used in this study cannot confirm that the subjects who received joint mobilizations had significant capsular stiffness. Therefore, these participants may not have had significant PST prior to the intervention. Similarly, those with injury may respond to MET and joint mobilizations in a different manner. The results of this study indicate that a single application of MET is an effective method of acutely decreasing passive horizontal adduction ROM. Future research should be directed toward observing any potential lasting changes in GH ROM following a course of multiple MET applications.

CONCLUSIONS

The findings of this study indicate that a single application of MET to the GH horizontal abductors significantly increases horizontal adduction ROM among asymptomatic high school baseball and softball players. However, the effects of the treatment were transient, lasting less than 15 minutes. The application of MET did not have any significant effect on internal rotation motion. These findings also indicate that the results created by the application of joint mobilizations were negligible at both the immediate posttest and 15 minutes posttest for both horizontal adduction and internal rotation measures. Therefore, the application of MET to the horizontal abductors may assist in treating PST in youth baseball and softball players.

REFERENCES


CASE SERIES

CONSERVATIVE TREATMENT CONTINUUM FOR MANAGING FEMOROACETABULAR IMPINGEMENT SYNDROME AND ACETABULAR LABRAL TEARS IN SURGICAL CANDIDATES: A CASE SERIES

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Matthew D. Haberl, PT, DPT, OCS, FAAOMPT2,4
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Daniel I. Rhon, PT, DPT, DSc, OCS, FAAOMPT3

ABSTRACT

Background/Purpose: Femoroacetabular impingement Syndrome (FAIS) and the often-associated acetabular labral tears (ALTs) are challenging to treat and consensus to guide effective management is lacking. Recent guidelines suggest physical therapy is beneficial, yet the guidance for specific interventions is unclear. The purpose of highlighting these cases was to describe the outcomes and the clinical reasoning process driving conservative management of subjects with FAIS and ALTs that were deemed surgical candidates.

Study Design: Case Series

Case Descriptions: Six subjects (20 - 65 years old) with confirmed FAIS and/or ALTs were included. Subjects were assigned to different treatment pathways based on their individual presentation. Three subjects were categorized as having primary mobility impairments and three were categorized with primary neuromuscular control impairments. Treatment intensity was adjusted according to the individual nature of symptoms, and on average lasted 81 days.

Outcomes: Clinically important improvements were seen on all self-reported outcome measures (International Hip Outcome Tool – 33, Numeric Pain Rating Scale, Patient Specific Functional Scale, and Global Rating of Change). At two years, none of the subjects had elected surgical management.

Discussion: These cases illustrate the clinical reasoning process utilized to prioritize subjects' treatment along a continuum of neuromuscular control and mobility. The treatment approach also illustrates successful management of potential surgical candidates that elected to forego surgery after satisfactory completion of conservative management.

Level of Evidence: Level 4

Key Words: Clinical reasoning, femoroacetabular impingement syndrome, hip pain, mobility, neuromuscular control, physical therapy

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BACKGROUND AND PURPOSE

Femoroacetabular impingement Syndrome (FAIS) is a movement disorder of the hip resulting in aberrant contact between the femur and acetabulum.\textsuperscript{1} This often co-exists with acetabular labral tears (ALTs), and their clinical presentations continue to challenge healthcare providers.\textsuperscript{2} Evidence for preeminent interventions is lacking and diagnostic criteria remain elusive.\textsuperscript{1-3} This is demonstrated by the average cost to diagnose FAIS ($2,456 USD) over a typical timeframe of one to three years after hip symptoms first occur.\textsuperscript{4-6} Despite inconclusive evidence for optimal interventions with proven long-term benefit, surgical rates for FAIS are rising.\textsuperscript{6-13} Similarly, evidence is emerging to support successful outcomes with non-surgical management.\textsuperscript{14-19} The majority of studies to date reflect short-term outcomes with little understanding regarding the downstream effects of treatment choices. The goal of treatment for FAIS is to ameliorate symptoms and prevent progression of intra-articular joint disease.\textsuperscript{7,9,15,20}

Recent guidelines have been published to help optimize management of FAIS and ALTs.\textsuperscript{1,13,21} The guideline authors appropriately recognized that evidence to guide optimal management is lacking, but still recommend a conservative-first approach. Although physical therapy is increasingly being recommended,\textsuperscript{1,9,13,22} guidelines regarding optimal physical therapy interventions remain ambiguous.\textsuperscript{1,13} Various treatment approaches exist, but a clear rationale for treatment selection is lacking.\textsuperscript{14,17,18} The scope of evidence is broad, often contradictory, and varies regarding the importance of range of motion (ROM), strength, neuromuscular control, and functional movement in regard to the development of symptomatic FAIS and ALTs.\textsuperscript{7,15,23-28} This variability likely represents the wide range of morphological and movement related abnormalities contributing to FAIS and ALTs (Figure 1).\textsuperscript{3,29,30} This may suggest that a multifarious population exists, amenable to various treatment approaches.\textsuperscript{14,16-18,22,23,30,31} Thus, outcomes are likely optimized when treatment is individualized. This requires thorough clinical examination and sound reasoning in order to guide the treatment plan and is based on addressing neuromuscular control and mobility deficits that align with a proposed treatment process (Table 1).\textsuperscript{16,20,22,23,32} The purpose of highlighting these cases was to describe the outcomes and the clinical reasoning process driving conservative management of subjects with FAIS and ALTs that were deemed surgical candidates.

Clinical Setting, Cohort Selection, and Objective Examination Components

Surgical candidates between the ages of 18-65 with a diagnosis of FAIS or ALTs were prospectively recruited from a multidisciplinary hospital institution between October of 2014 and December of 2015 (Figure 2). Institutional review board approval was received from Gundersen Clinic, Ltd. (#2-14-11-001) and subjects provided consent prior to the collection of data. Six subjects from the ages of 20 to 65 agreed to participate in this case series. Diagnosis was confirmed through the presence of: anterior hip or groin pain, symptoms reproduced with hip flexion and FADIR test, positive radiographic signs, and greater than 50% relief of symptoms after intra-articular injection.\textsuperscript{1,2} Subjects were excluded if their hip symptoms were reproduced with lumbar segmental movement, had pending litigation, were involved in a workmen’s compensation case, were pregnant, had prior surgery on the involved hip, were unable to give informed consent or speak, read or write in English, and had already undergone a prior supervised regimen of physical therapy for this condition in the prior six months.

Baseline demographics were recorded (Table 2), and all subjects completed the Medical Screening Questionnaire (MSQ), International Hip Outcome Tool – 33 (IHOT-33),\textsuperscript{33} pain body diagram,\textsuperscript{34,35} Numeric Pain Rating Scale (NPRS),\textsuperscript{36} Patient Specific Functional Scale (PSFS),\textsuperscript{37} and Pain Catastrophizing Scale at baseline (PCS) (Table 3).\textsuperscript{38,39} These outcome measures, with the addition of the Global Rating of Change (GROC), were also reassessed at six weeks or discharge, and six months.\textsuperscript{40-42}
movement screening (multi-segmental flexion, extension, and rotation). Kinesthetic awareness was assessed with single limb balance tests (eyes open and closed), dynamic functional control was assessed with dynamic single limb balance test, double leg squat test (bubble goniometer was used to measure tibial and femoral angles), and the lateral step-down test. 

ROM was measured with a universal goniometer in supine for hip flexion, and in both supine (hip flexed to 90 degrees) and prone (0 degrees hip
### Table 1. Description of treatment algorithm used in the study

<table>
<thead>
<tr>
<th>Examination and Evaluation Components</th>
<th>Component One-Medical Screening</th>
<th>Component Two-Differential evaluation of clinical findings according to body function and the associated pathology</th>
<th>Component Three-Diagnosis of tissue irritability level and match with appropriate dosage of examination and interventions</th>
<th>Component Four-Interventions strategies to address clinical findings of restriction in joint, soft tissue, and/or pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate for PT evaluation and intervention</td>
<td>Appropriate for PT evaluation and intervention with consultation of another medical provider</td>
<td>Not appropriate for PT evaluation &amp; intervention requiring consultation with healthcare provider</td>
<td>Diagnosis to be Low, Moderate, or Severe</td>
<td></td>
</tr>
<tr>
<td>Intra-Articular Pathology Clinical Findings:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Anterior hip or Groin</td>
<td>- Symptoms with hip flexion</td>
<td>- &gt;50% relief w/intra-articular injection</td>
<td>- Imaging consistent with femoroacetabular impingement and/or labral pathology</td>
<td></td>
</tr>
<tr>
<td>Component Three-Diagnosis of tissue irritability level and match with appropriate dosage of examination and interventions.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low: Low pain with activity (NPRS &lt;3/10) relieved as fast as aggravated. Higher level activities aggravate. Low disability levels: IHOT-33 &gt;65%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate: Moderate pain (NPRS 4-7/10) that lingers longer than aggravation time. Moderate level activities aggravate. Moderate disability levels: IHOT-33 “64.36%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe: Significant pain (NPRS &gt;8/10) and difficulty to relieve symptoms. Low level activities such as ADL’s aggravate. High disability levels: IHOT-33 &lt;35%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component Four-Interventions strategies to address clinical findings of restriction in joint, soft tissue, and/or pain</td>
<td>Joint</td>
<td>Soft Tissue</td>
<td>Pain</td>
<td></td>
</tr>
<tr>
<td>Lack of Mobility</td>
<td>Interventions: Low to high grade joint mobilizations (Accessory &amp; Physiological)</td>
<td>Interventions: Instrumented assisted and hands on soft tissue mobilization to specific structures</td>
<td>Interventions: Therapeutic neuroscience education</td>
<td></td>
</tr>
<tr>
<td>- Lumbo-pelvic Rotation C/R &amp; thrust mobilization</td>
<td>- Posterior Lumbo-pelvic Complex</td>
<td>- PRICE principles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Long Axis Hip Traction/Thrust</td>
<td>- Lateral Hip/Thigh Complex</td>
<td>- Joint Motion/Pain free movement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Lateral Distraction MWM</td>
<td>- Anterior Hip/Thigh Complex</td>
<td>- PROM→AAROM→AROM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- AP Mobilization</td>
<td>- Medial Hip/Thigh complex</td>
<td>Low Grade soft tissue and joint mobilizations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- PA Mobilization</td>
<td>Contract-relax AROM→stretching</td>
<td>- Same as previous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Mobilizations:</td>
<td>Anterior: ½ Stand quad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Anterior hip: ½ Stand Hip extension mobilization</td>
<td>- Posterior: Piriformis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Posterior hip: Seated or standing piriformis mobilization</td>
<td>- Lateral: Side lying Ober’s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Medical hip: Prone Figure 4</td>
<td>- Medial: Prone Figure 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Neuromuscular Control</td>
<td>Interventions: Kinesthetic awareness:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- ½ kneeling balance EO wide to narrow stance→ EC→Dynamic arm movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- SL balance EO→EC→Dynamic arm and leg movements→Star reach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interventions: Muscle Activation→Endurance→Strength→Power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Therapist applied assistance→Resistance function</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Isometric→Eccentric→Concentric contractions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Therapeutic Neuroscience Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Patient specific</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neural desensitization:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Neurodynamic gliders→tensioners</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
flexion) for hip internal rotation (IR) and external rotation (ER). Hip extension was estimated visually using a categorical scale of less than 0 degrees, less than 15 degrees, and greater than 15 degrees. Hip abduction, IR and ER strength were assessed, dependent on symptom irritability, using a handheld dynamometer (MicroFET2, Hoggan Health Industries, Salt Lake City, UT). The average of three trials was recorded. Positioning for abduction was in sidelying, and IR and ER in sitting. Muscle length and flexibility assessment included Ely’s, modified Ober’s, piriformis, and FABER tests, which were scored as either positive or negative. A positive test was defined as asymmetry compared to the contralateral side or reproduction of comparable symptoms. Finally, joint provocation testing (FADIR, Scour, and log roll) were performed only when symptoms were not exacerbated during single plane ROM or flexibility testing. If symptoms were already provoked during single plane ROM or flexibility testing, it was reasoned that provocative tests would also replicate symptoms. As these tests demonstrate higher sensitivity than specificity, further provocation would have added no additional diagnostic information.

Clinical Reasoning for Categorization and Treatment Components

By considering individual impairments and movement dysfunctions, treatment selection was matched to classification along the continuum. This allowed prioritization of interventions directed at mobility or neuromuscular control components, while simultaneously considering joint, soft tissue, or pain as primary contributors to the subjects’ movement dysfunction. The fundamental component guiding examination and interventions was tissue irritability and its relationship to movement barriers (joint, soft tissue, or pain). Irritability has been previously described as the real time pain response, determined by the intensity of a physical activity required to produce comparable symptoms, and then the amount of time elapsed before those symptoms resolve. For these subjects, pain was not the only component of irritability but consideration was also given to how tissue irritability might impair muscle function and/or kinesthetic awareness during functional movement. Multiple subjective factors were considered when determining the level of irritability, including the subjective examination and self-reported outcome scores. Furthermore, irritability
guided the vigor of the objective examination, and was continually refined based upon the patient’s response to the physical examination. For example, if irritability was low, and active ROM (AROM) was relatively asymptomatic, then joint overpressure was applied in order to ascertain the qualitative barrier to movement, such as soft tissue or joint. However, if irritability was high, and AROM reproduced

**Figure 2. Study Flow Chart**

*Abbreviations: PT - Physical Therapy*

**Table 2. Demographic data.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (# Female/total sample)</td>
<td>5/6</td>
</tr>
<tr>
<td>Age (years)</td>
<td>37.8 ± 15.4</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>23.2 ± 6.86</td>
</tr>
<tr>
<td>Duration of current episode (months)</td>
<td>26.0 ± 3.6</td>
</tr>
<tr>
<td>Symptom factors (positive results/total sample)</td>
<td></td>
</tr>
<tr>
<td>Clicking/popping</td>
<td>2/6</td>
</tr>
<tr>
<td>Pain with twisting</td>
<td>2/6</td>
</tr>
<tr>
<td>Pain with adduction</td>
<td>3/6</td>
</tr>
<tr>
<td>Pain with internal rotation</td>
<td>3/6</td>
</tr>
<tr>
<td>Pain with flexion</td>
<td>5/6</td>
</tr>
<tr>
<td>Imaging (positive results/total sample)</td>
<td></td>
</tr>
<tr>
<td>CAM morphology</td>
<td>3/6</td>
</tr>
<tr>
<td>Pincer morphology</td>
<td>2/6</td>
</tr>
<tr>
<td>Labral tear</td>
<td>2/6</td>
</tr>
</tbody>
</table>

Age, Body mass index, duration of current episode, and prior episodes of hip pain are presented as mean values ± standard deviation.
symptoms, then overpressure was not applied, and ROM was deemed limited by pain. Similarly, if pain was elicited with muscle activation, formal strength testing was not performed.

As previously mentioned, the vigor of examination was matched with symptom provocation and irritability. The key elements guiding the decision to progress or hold on further objective testing were as follows:

- **Movement Assessment**: Individuals with a symptomatic double limb squat, who then failed single leg balance tests, were not asked to perform a lateral step-down test.
  - Rationale: With the inability to perform double limb dynamic squat task without pain, and insufficient control with static single limb task, it is highly unlikely the prerequisite neuromuscular control for a single leg dynamic task was present.
- **ROM assessment**: If passive single plane ROM reproduced symptoms, then multi-plane assessment and provocative tests were not performed.

### Table 3. Descriptions of outcome measures used in the current study.

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Description</th>
<th>Psychometric Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical Screening Questionnaire (MSQ)</td>
<td>Includes questions to explore medical problems that may pose a contraindication to treatment or medical referral.</td>
<td>None</td>
</tr>
<tr>
<td>International Hip Outcome Tool – 33 (iHOT-33)</td>
<td>Designed for young or active patients with hip pathology, consists of four sections including: symptoms and functional limitations, sports function and recreational activities, job related concerns, and social, emotional and lifestyle concerns. The 33 questions each use a visual analog scale to quantify the individuals function where the highest score of 100 represents full function.</td>
<td>Construct validity (correlation coefficient = 0.81)</td>
</tr>
<tr>
<td></td>
<td>Rationale: With the inability to perform double limb dynamic squat task without pain, and insufficient control with static single limb task, it is highly unlikely the prerequisite neuromuscular control for a single leg dynamic task was present.</td>
<td>Reliability (ICC = 0.78, Cronbach α = .99)</td>
</tr>
<tr>
<td></td>
<td>Rationale: With the inability to perform double limb dynamic squat task without pain, and insufficient control with static single limb task, it is highly unlikely the prerequisite neuromuscular control for a single leg dynamic task was present.</td>
<td>MCID 6.1 points</td>
</tr>
<tr>
<td>Numeric Pain Rating Scale (NPRS)</td>
<td>Utilized to quantify subjective pain intensity. A 0-10 numeric pain rating scale ('0' indicating no pain, and '10' worst imaginable pain).</td>
<td>Test-retest reliability</td>
</tr>
<tr>
<td></td>
<td>Rationale: With the inability to perform double limb dynamic squat task without pain, and insufficient control with static single limb task, it is highly unlikely the prerequisite neuromuscular control for a single leg dynamic task was present.</td>
<td>MCID 2 points</td>
</tr>
<tr>
<td>Pain Catastrophizing Scale (PCS)</td>
<td>Measures the extent to which people catastrophize in response to pain. 13-item patient-report scale, with three sub-scales (rumination, magnification and helplessness), each item is scored from 0 ('not at all') to 4 ('all the time'). Higher scores indicating greater catastrophizing.</td>
<td>Internal consistency and Construct validity</td>
</tr>
<tr>
<td></td>
<td>Rationale: With the inability to perform double limb dynamic squat task without pain, and insufficient control with static single limb task, it is highly unlikely the prerequisite neuromuscular control for a single leg dynamic task was present.</td>
<td>MDC 9.1 points</td>
</tr>
<tr>
<td>Pain Diagram</td>
<td>A body diagram will be completed to identify the location and nature of symptoms.</td>
<td>None</td>
</tr>
<tr>
<td>Global Rating of Change (GROC)</td>
<td>The GROC questionnaire is utilized to assess short term changes in quality of life. The GROC has a 15-point scale with high scores representing greater improvement in a patient's perception of quality of life.</td>
<td>MCID more than 3 points</td>
</tr>
<tr>
<td>Patient Specific Functional Scale (PSFS)</td>
<td>The PSFS was used to quantify subjective improvements in the patient’s functional goals. Validation of this tool has not been specifically performed for the hip, however, validity and reliability has been demonstrated in musculoskeletal conditions such as the knee, lumbar spine, and cervical spine.</td>
<td>MCID 2.3 points</td>
</tr>
</tbody>
</table>

Abbreviations: ICC – intra-class correlation coefficient; MCID – minimum clinically important difference; MDC – minimal detectable change
### Table 4. Individual subject presentations along a continuum of neuromuscular control and mobility impairments.

<table>
<thead>
<tr>
<th>Description</th>
<th>Mobility Patient 1</th>
<th>Mobility Patient 2</th>
<th>Mobility Patient 3</th>
<th>Neuromotor Control Patient 1</th>
<th>Neuromotor Control Patient 2</th>
<th>Neuromotor Control Patient 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Irritability Level:</strong></td>
<td>Moderate to low</td>
<td>Low</td>
<td>Low-Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Pain</strong></td>
<td>0/10 at rest</td>
<td>0/10 at rest</td>
<td>0/10 at rest</td>
<td>1/10 at rest</td>
<td>0/10 at rest</td>
<td>0/10 at rest</td>
</tr>
<tr>
<td><strong>Outcome Measures</strong></td>
<td>IHO: 33: 54%</td>
<td>IHO: 33: 32%</td>
<td>IHO: 33: 41%</td>
<td>IHO: 33: 46%</td>
<td>IHO: 33: 63%</td>
<td>IHO: 33: 73%</td>
</tr>
<tr>
<td>Lumbar Clearing</td>
<td>Unremarkable</td>
<td>Unremarkable</td>
<td>*Restricted multi-</td>
<td>*Excessive motion</td>
<td>*Aberrant movement</td>
<td>*Multiple movement</td>
</tr>
<tr>
<td></td>
<td>examination</td>
<td>examination</td>
<td>segmental flexion  with multi-segmental</td>
<td>with multi-segmental</td>
<td>with multi-segmental</td>
<td>with multi-segmental</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with inability</td>
<td>flexion</td>
<td>extension</td>
<td>extension</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>to touch test</td>
<td></td>
<td></td>
<td>extension</td>
</tr>
<tr>
<td><strong>Kinesthetic Awareness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Single Leg balance EO</strong></td>
<td>&gt;30 seconds</td>
<td>&gt;30 seconds</td>
<td>&gt;30 seconds</td>
<td>&gt;30 seconds</td>
<td>&gt;30 seconds</td>
<td>&gt;30 seconds</td>
</tr>
<tr>
<td><strong>Single Leg balance EC</strong></td>
<td>&gt;30 seconds</td>
<td>*&lt;10 seconds</td>
<td>*&lt; 10 seconds</td>
<td>*&lt; 10 seconds</td>
<td>*&lt; 10 seconds</td>
<td>*&lt; 10 seconds</td>
</tr>
<tr>
<td><strong>Dynamic balance</strong></td>
<td>&gt;30 seconds</td>
<td>*Unstable</td>
<td>*Unsteady</td>
<td>*Unsteady</td>
<td>*Unsteady</td>
<td>*Unsteady</td>
</tr>
<tr>
<td><strong>Squat test</strong></td>
<td>*- 25° tibial angle - 90° femoral angle Full pain free squat</td>
<td>*- 25° tibial angle -110° femoral angle</td>
<td>*- 2° tibial angle -40° femoral angle Full pain free squat</td>
<td>*- 2° tibial angle -40° femoral angle Full pain free squat</td>
<td>*- 2° tibial angle -40° femoral angle Full pain free squat</td>
<td>*- 2° tibial angle -40° femoral angle Full pain free squat</td>
</tr>
<tr>
<td><strong>Hip Range of Motion (degrees)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>-Flexion</strong></td>
<td>Inv. 105 Uninvolved 120</td>
<td>Inv. 110 Uninvolved 120</td>
<td>Inv. 110 Uninvolved 130</td>
<td>Inv. 110 Uninvolved 130</td>
<td>Inv. 110 Uninvolved 130</td>
<td>Inv. 110 Uninvolved 130</td>
</tr>
<tr>
<td><strong>-IR at 90° hip flexion</strong></td>
<td>*15 45 *48 55 48 50 42 40 55 50 45 45</td>
<td>*15 45 *48 55 48 50 42 40 55 50 45 45</td>
<td>*15 45 *48 55 48 50 42 40 55 50 45 45</td>
<td>*15 45 *48 55 48 50 42 40 55 50 45 45</td>
<td>*15 45 *48 55 48 50 42 40 55 50 45 45</td>
<td>*15 45 *48 55 48 50 42 40 55 50 45 45</td>
</tr>
<tr>
<td><strong>-ER at 90° hip flexion</strong></td>
<td>*50 60 *58 45 *47 72 *70 55 *65 60 65 65</td>
<td>*50 60 *58 45 *47 72 *70 55 *65 60 65 65</td>
<td>*50 60 *58 45 *47 72 *70 55 *65 60 65 65</td>
<td>*50 60 *58 45 *47 72 *70 55 *65 60 65 65</td>
<td>*50 60 *58 45 *47 72 *70 55 *65 60 65 65</td>
<td>*50 60 *58 45 *47 72 *70 55 *65 60 65 65</td>
</tr>
<tr>
<td><strong>-IR 90°</strong></td>
<td>55 50 40 40 *30 55 45 50 *40 55 full full</td>
<td>55 50 40 40 *30 55 45 50 *40 55 full full</td>
<td>55 50 40 40 *30 55 45 50 *40 55 full full</td>
<td>55 50 40 40 *30 55 45 50 *40 55 full full</td>
<td>55 50 40 40 *30 55 45 50 *40 55 full full</td>
<td>55 50 40 40 *30 55 45 50 *40 55 full full</td>
</tr>
<tr>
<td>Flexibility Testing</td>
<td><em>Ely’s &amp; Thomas</em></td>
<td><em>Ely’s &amp; Thomas</em></td>
<td><em>Ely’s &amp; Thomas</em></td>
<td><em>Ely’s &amp; Thomas</em></td>
<td><em>Ely’s &amp; Thomas</em></td>
<td><em>Ely’s &amp; Thomas</em></td>
</tr>
<tr>
<td><strong>Anterior Ely’s &amp; Thomas</strong></td>
<td>Pain-free &amp; equal limitation</td>
<td>*Pain &amp; limited with Ely’s testing</td>
<td>Pain-free &amp; equal limitation</td>
<td>*Ely’s non-painful &amp; limited. *Thomas painful &amp; limited</td>
<td>Pain-free &amp; limited</td>
<td>Normal</td>
</tr>
<tr>
<td><strong>Lateral Ober’s Test</strong></td>
<td>Pain-free &amp; equal</td>
<td>Not tested due to</td>
<td>Pain-free &amp; equal</td>
<td>Pain-free &amp; limited</td>
<td>*Painful &amp; limited</td>
<td>*Painful &amp; limited</td>
</tr>
<tr>
<td><strong>Posterior Piriformis test</strong></td>
<td>limitation</td>
<td>Ely’s test</td>
<td>limitation</td>
<td>Pain-free &amp; limited</td>
<td>*Painful &amp; limited</td>
<td>*Painful &amp; limited</td>
</tr>
<tr>
<td><strong>Medial Hip FABER test</strong></td>
<td>Not tested due to</td>
<td>Not tested due to</td>
<td>*Pain with excessive</td>
<td>Not tested due to limited hip ER at 90°</td>
<td>Non-painful &amp; bilateral</td>
<td>Non-painful &amp; bilateral</td>
</tr>
<tr>
<td><strong>Hand Held Dynamometer</strong></td>
<td>limited hip ER at 90° already</td>
<td>limited hip ER at 90° already</td>
<td>limited hip ER at 90° already</td>
<td>limited hip ER at 90° already</td>
<td>limited hip ER at 90° already</td>
<td>limited hip ER at 90° already</td>
</tr>
<tr>
<td><strong>Imaging</strong></td>
<td>Mixed CAM &amp; pincer impingement</td>
<td>Mixed CAM &amp; pincer impingement</td>
<td>Mixed CAM &amp; pincer impingement</td>
<td>Mixed CAM &amp; pincer impingement</td>
<td>Mixed CAM &amp; pincer impingement</td>
<td>Mixed CAM &amp; pincer impingement</td>
</tr>
<tr>
<td><strong>Intervention focus</strong></td>
<td>-Global Moderate to high grade joint mobilizations -Frontal plane hip strengthening</td>
<td>-Anterior &amp; medial Moderate to high grade joint mobilizations</td>
<td>-Soft tissue mobilizations to anterior hip &amp; hip abduction</td>
<td>Posterior Moderate to hip &amp; hip</td>
<td>Posterior Moderate to hip &amp; hip</td>
<td>Posterior Moderate to hip &amp; hip</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>high grade joint mobilizations</td>
<td>high grade joint mobilizations</td>
<td>high grade joint mobilizations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Soft tissue mobilizations to posterior hip &amp; hip</td>
<td>-Soft tissue mobilizations to posterior hip &amp; hip</td>
<td>-Soft tissue mobilizations to posterior hip &amp; hip</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Kinesthetic awareness</td>
<td>-Kinesthetic awareness</td>
<td>-Kinesthetic awareness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Transverse plane re-education using</td>
<td>-Transverse plane re-education using</td>
<td>-Transverse plane re-education using</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mobilization with movement mops &amp; exercise for pain-free activation</td>
<td>Mobilization with movement mops &amp; exercise for pain-free activation</td>
<td>Mobilization with movement mops &amp; exercise for pain-free activation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Soft tissue techniques to anterior hip &amp; high</td>
<td>-Kinesthetic awareness</td>
<td>-Kinesthetic awareness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Transverse plane re-education using</td>
<td>-Transverse plane re-education using</td>
<td>-Transverse plane re-education using</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mobilization with movement mops &amp; exercise for pain-free activation</td>
<td>Mobilization with movement mops &amp; exercise for pain-free activation</td>
<td>Mobilization with movement mops &amp; exercise for pain-free activation</td>
</tr>
</tbody>
</table>

*Irritability Level:

- **Low:** Low pain with activity (NPRS <3/10) relieved as fast as aggravated. Higher level activities aggravate. Low disability levels: IHO:33 >65%
- **Moderate:** Moderate pain (NPRS 4-7/10) that lingers longer than aggravation time. Moderate level activities aggravate. Moderate disability levels: IHO:33 >44-65%
- **Severe:** Significant pain (NPRS >8/10) and difficulty to relieve symptoms. Low level activities such as ADL’s aggravates. High disability levels: IHO:33 >33%

*Indicates clinical sign used for reassessment and clinical decision making for classification throughout patient care.

IHO-33 = International Hip Outcome Tool – 33; PSFS = Patient Specific Functional Scale; IR = Internal Rotation; ER = External Rotation; Inv. = Involved; EO = Eyes Open; EC = Eyes Closed; NPRS = Numeric Pain Rating Scale
Rationale: Increasing PROM into multiple planes increases tissue strain and the potential for further aggravation of symptoms without providing additional information. Moreover, in order to optimize treatment, aggravation of symptoms was minimized. Provocative tests of the hip include multi-plane joint assessments as demonstrated by the FADIR (Flexion, Adduction and IR planes), Scour (Dynamic overpressure applied to FADIR positioning) and FABER (Flexion, Abduction, and ER).

Flexibility Testing: If Ely's test in prone (assessing predominately anterior hip and thigh structures) was positive, a progression to Thomas and modified Ober's tests were not performed.

Rationale: The progression to Thomas would be the same as with Ely's, with the addition of hip extension, to further stress anterior hip and thigh structures. Similarly, modified Ober's test includes the components of Thomas and then further stresses the structures of the lateral thigh with adduction.

Strength Assessment: If AROM was provocative formal strength assessment was not performed.

Rationale: If symptoms were provoked with gravity dependent AROM then additional resistance is not indicated as this would potentially invalidate further strength assessment.

As the examination was guided by the level of symptom irritability, the clinician would simultaneously distinguish the foremost limiting factor for normal movement as either joint, soft tissue, or pain. For ROM, this was achieved by appreciating reproduction of symptoms and the qualitative barrier to movement with passive overpressure. For example, a hard, bony, end feel with overpressure was associated with potential alterations in joint morphology. Additionally, if the quality was more compliant and elastic, soft tissue (muscular or capsular) was reasoned to be the limiting factor. Interventions could include mobilizations or stretching for joint and soft tissue respectively. On the contrary, pain was considered the primary restriction to movement if symptoms limited the ability to reach an end feel.

Limitations due to pain would be treated with AROM exercises and gentle joint mobilizations (grade I - II) for pain modulation. Both nociceptive and biopsychosocial inputs were recognized as influential on the pain presentation. Skilled interventions require the recognition of all contributing biomedical and biopsychosocial components, discussion of which is beyond the scope of this paper. However, a recent study suggested examining five relevant “drivers” of pain to appropriately direct treatments (nociceptive, nervous system dysfunction, comorbidity, cognitive-emotional, and contextual).

Finally, comprehensive assessment of objective examination findings helped determine whether movement dysfunctions were predominately due to lack of mobility/tissue extensibility or a lack of neuromuscular control. For instance, if squat depth was limited by pain, but isolated joint ROM was full and asymptomatic, neuromotor control was considered the limiting factor and the movement dysfunction would be categorized under neuromuscular control. If the greatest number of impairments were related to ROM, subjects were placed on the mobility end of the continuum and treatment was prioritized to address those primary limitations. If during functional movement tasks, alterations were observed in dynamic control or postural stability, subjects were placed toward the neuromuscular control end of the continuum and treatment prioritized neuromuscular control. In individuals with elevated pain and high irritability, it may be difficult to determine best placement along the neuromuscular control or mobility spectrum. Thus, treatment of pain (whether primarily influenced by nociceptive input and/or psychosocial factors) was the first priority. Thus, continual reassessment was performed through plan of care, during each visit.

CASE SERIES DESCRIPTION AND TREATMENT
Three of the six subjects were classified with primary mobility limitations based upon interpretation of examination findings. Clinical presentation in these subjects suggested a primary mobility dysfunction, based on limited ROM either at the joint or limited extensibility of surrounding soft tissues, with contributing weakness and poor neuromuscular control.
Similarly, three subjects had primarily neuromuscular control dysfunctions, based on aberrant lumbo-pelvic movement, impaired kinesthetic awareness and poor control with functional testing. Furthermore, these subjects presented with normal or even excessive joint ROM in most planes of movement. Despite relatively normal joint ROM, flexibility was variably limited, suggesting other structures in the lumbosacral region or extra-articular structures of the hip might be involved.

Treatment prioritization was then matched with patient categorization on the treatment continuum, as well as directing interventions towards the primary movement barrier being either joint, soft tissue or pain. The first goal of treatment was to restore pain free AROM followed by full PROM and over-pressure in a single plane then moving to multiple planes. Treatment choice was determined by the therapist’s appreciation of which structures were predominately influencing nociceptive input, as described above.

When predominant joint mobility restrictions were identified, joint mobilization and self-mobilizations techniques were utilized to address specific, directional impairments. The vigor of treatment was matched to the patient’s tissue irritability. Low grade (I or II) mobilizations were implemented for pain reduction in subjects with higher tissue irritability, while high grade (III - V) mobilizations, to improve full pain free ROM, in those with lower tissue irritability. If the barrier to movement was soft tissue, techniques included both hands on and instrumented assisted soft tissue mobilizations and were complimented with contract-relax stretching in order to improve pain free soft tissue mobility.

In subjects with primary neuromuscular control deficits the initial goals were to restore normal kinesthetic awareness to the joint. If pain was provoked with mid to end range functional movements, and/or isolated joint ROM was normal, yet, symptomatic with overpressure, then mobilizations with movement were utilized to gain full, pain free ROM. Exercise selection was determined by best matching the exercise to the patient and their ability to successfully complete the task without provoking lasting symptoms. Modification was made via patient positioning and visual assistance. Progression was then made to dynamic control and functional movements. If subjects were symptomatic with activities of daily living, such as sit to stand, education on activity modification was provided to alter/limit activities until asymptomatic. For example, using hands to assist with sit to stand, or to avoid sitting on low surfaces. When objective loss of strength was present, exercise selection was determined by a subject’s ability to complete pain-free muscle specific contractions starting with isometric to eccentric then concentric. When indicated by pain-free strength testing and functional movement, progression to power and plyometric exercises were implemented. Tissue irritability was a guiding factor for appropriate selection, frequency, duration, and intensity of interventions.

**OUTCOMES**

From initial visit to discharge, iHOT-33, NPRS, PSFS, and GROC all improved, exceeding the MCIDs (Table 5). This improvement correlated with changes noted in each patient's objective data at discharge. Single limb balance with eyes closed, dynamic single limb balance, and lateral step-down tests (consistent...
findings in the neuromuscular control impaired subjects) were all improved after treatment. By the final visit, all functional tests were symmetrical and did not reproduce symptoms. ROM and strength improved on the involved side in all directions. Finally, a two-year review of patient records indicated that no patient had elected surgical management during this time.

On average subjects improved over the course of 8.6 visits (range: 5 - 11 visits) and duration of 81.4 days (range: 68 – 91 days). Median healthcare costs associated with management of each patient was on $12,215 US dollars. Median expenditure was as follows: diagnostic measures consisted of 65% of the overall costs, imaging accounted for 43% ($5,199) and injection procedures accounted for 22% ($2,685) of the total. Patient management including physical therapy was 18% of the total cost ($2,242), with other medical office visits including primary care appointments associated with the hip diagnoses were 7% ($863) of the total. Other expenses included durable medical equipment, labs and chiropractic visits, which were less than 1% of total cost for each subject.

**DISCUSSION**

This clinical reasoning model and proposed intervention algorithm demonstrated meaningful improvement in pain, functional impairments, and perceived improvement in all six subjects. This approach relies on appropriate identification and placement of patient specific movement dysfunctions on a continuum to appropriately match specific treatment. Interventions were then directed to relevant factors limiting movement (pain, joint or soft tissue) and guided by tissue irritability. Although surgical criteria vary, the subjects described were all considered surgical candidates by their managing surgeon. The improvements seen corroborate recent guidelines suggesting value with a physical therapy first approach.

The precise etiology of intra-articular pathology in FAIS is still unclear, although it appears to be multifactorial. Because of this, emphasis should be placed on individualized treatment. There are, however, some common factors underlying intra-articular disease processes that can be targeted with conservative interventions. Mobility and neuromuscular control components will be discussed individually. First, consideration will be given to the evidence-based framework for this proposed continuum. Next, examining how patient presentations (impairments and functional movements) varied along the continuum. Finally, relevance of imaging/medical components will be considered.

**MOBILITY**

Abnormal joint mobility can contribute to symptoms. This could be due to congenital factors, microtrauma or macrotrauma, or an interactive process involving alterations in both mobility and neuromuscular control. Regardless, in subjects with imaging findings suggestive of FAIS/ALTs, abnormalities have been identified in sagittal, frontal and transverse plane ROM in those with symptoms compared to asymptomatic. Alterations in joint ROM and muscular recruitment patterns can ultimately lead to concentrated areas of abnormal stress along the capsuloligamentous and articular structures. Likewise, excessive joint mobility can lead to aberrant loading of joint structures. These findings might imply that mobility restrictions have multiple etiologies and contributing components, which need to be prioritized and addressed specific to the unique needs of the patient.

The subjects in this case series demonstrated joint ROM abnormalities in at least one plane of motion. The three subjects with primary impairments of mobility presented with more global reduction in joint ROM, with varying degrees of severity. As ROM decreased, the need for neuromuscular control to compensate also decreased, leading to less difficulty controlling single leg functional and kinesthetic awareness tasks. This was seen most notably in the first patient categorized with a hypo-mobility dysfunction (Table 4). In contrast, the neuromuscular control subjects presented with more complex ROM abnormalities. One had increased joint ROM into flexion and ER, another had decreased flexion and increased ER, while the final exhibited a mixed pattern of hypermobility in flexion and IR, with limited ER. Isometric strength in the mobility subjects varied, with mild deficits in abduction for one, and more diffuse weakness on the involved side for another. Poor functional movement and neuromuscular
control were a consistent finding in all subjects. The mobility subjects responded well to interventions targeting an increase in mobility with an eventual transition to neuromuscular control. Continual reassessment of the patient’s impairments is important to monitor the change in patient’s symptoms and continue to individualize treatment selection as they evolve over the course of care.

When considering symptomatic intra-articular dysfunctions, imaging should be put into context with information about joint mobility. It seems reasonable that imperfectly shaped joints may put individuals at risk for FAIS and ALTs, however, the presence of concomitant mobility dysfunctions may be necessary for symptom provocation. Two of the three subjects with primary impairments in hip mobility had imaging findings indicating elements of a mixed-type impingement. These morphological changes corroborated with the observed loss of ROM clinically. However, the third mobility patient had a pincer deformity which did not seem to align with the isolated ER ROM deficits observed clinically. Additionally, the patient with the greatest amount of mobility (considered hypermobile) had a cam deformity with a labral tear. These findings support prior evidence suggesting sole reliance on imaging is insufficient for valid identification of the nociceptive source. For example, radiographs demonstrating cam morphology combined with clinical loss of IR were more effective in predicting progression to OA than imaging alone. Furthermore, it was recently shown that lower mental health scores (Veterans RAND 12-item, mental component score) had a stronger association with symptoms than imaging in subjects with intra-articular pathology. Morphology should be considered but interpreted within the context of the clinical examination and patient presentation. It is possible that both a hypermobile and hypomobile joint will have underlying aberrant morphology and be at greater risk for producing symptoms.

NEUROMUSCULAR CONTROL
Joint movement is inextricably linked to the surrounding muscle activity. Additionally, the neuromuscular system functions as a critical source of central nervous system input, where a tremendous amount of information is processed, including joint proprioceptive information which determines motor output. When articular structures are damaged, neuromuscular control needed to stabilize the joint may increase. Articular damage could be a result of microtrauma or macrotrauma, or could involve the components of joint hyper- or hypo-mobility dysfunctions previously discussed. As joint damage occurs, the demand for muscular stability increases, while a concomitant reduction in neuromuscular control ensues as sensory input is altered. Other factors may also be responsible for reductions in neuromuscular control such as effusion, pain inhibition, muscle weakness, and poor central processing. Furthermore, the long duration of symptoms before an appropriate diagnosis can increase the likelihood of developing neuromuscular control dysfunction, with evidence suggesting that central nervous system changes such as motor cortex re-organization are typical with persistent symptoms. Although surgical interventions can improve symptoms and morphology, functional impairments can persist 18 to 24 months or longer after arthroscopy. Unless the neuromuscular control dysfunction is addressed and movement patterns corrected, it is possible that symptoms may become persistent and recurrent. Thus, individual symptoms could be primarily due to motor control dysfunctions, joint mobility dysfunctions, aberrant morphology, or perhaps are better conceptualized as an interactive combination of all three.

Subjects in this case series consistently demonstrated poor neuromuscular control, with all but one having poor kinesthetic awareness with single limb balance eyes closed tests, and all having poor control with the lateral step-down test (Table 4). Aberrant movement identified with multi-segmental screening was common and was increasingly prominent the more the subject presented with neuromuscular control dysfunctions. Strength deficits varied in both groups. However, normal strength did not seem to determine normal functional movement, as symmetrical strength was observed in some subjects, despite asymmetrical functional movements. Although functional movement was improved by the final visit in most subjects, some deficits were still noted with many of
the functional tasks. These differences were present despite improvements in ROM and strength, suggesting the presence of a complicated neuromuscular control dysfunction. The neuromuscular control subjects improved with interventions targeting muscle extensibility, muscle activation patterns, proprioceptive/kinesthetic training and eventual transition to more demanding functional neuromuscular control tasks. The question still remains as to whether well-developed movement interventions may prevent or assist in management of symptomatic intra-articular pathology long term.2,10 Perhaps, treatment components should consider a spectrum of both mobility and neuromuscular control dysfunctions among individual subjects.

Although more difficult to conceptualize based on morphology alone, all subjects demonstrated improvements in function, pain, and movement control regardless of cam/pincer morphology or presence of ALTs. Perhaps the improvements in joint ROM, muscular strength and control of functional movements helped to slow the progression of intra-articular damage. One key argument for surgical intervention is to prevent the onset of osteoarthritis (OA).3,10,78 However, exercise and joint movement can also slow down clinical progression of OA.8,12,64,71,76,79 If morphology predicts OA progression, yet OA responds well to conservative management, could FAIS also respond to conservative care?90 A better understanding of effective non-surgical treatments is needed, and the approach described in this case series should be validated for effectiveness in larger scale prospective trials.

NUMBER OF VISITS AND COST ANALYSIS
With rising healthcare costs, it is relevant to ask if the proposed clinical reasoning and treatment continuum resulted in timely and cost-effective patient outcomes. Subjects improved on average over the course of 8.6 visits and 81.4 days, compared to five to 16 visits spanning 35 to 112 days in other reports.16–18,22,23,80,81 The median cost for each patient’s physical therapy was $2,242 in the present series. In contrast, this is far below the estimated $9,000 a recent study predicted would be necessary for the definitive management of FAIS.10 Similarly, the entire mean cost of physical therapy care was less than the typical $2,456 dollars required to make a diagnosis.5 With 65% of the costs being diagnostic in nature (i.e. imaging and diagnostic injection), perhaps physical therapy could be considered earlier in the treatment plan? Especially, as intra-articular injection is thought to have limited therapeutic benefit in isolation.82,83 Imaging and injections could potentially be postponed and utilized only if physical therapy management was unsuccessful.

FUTURE DIRECTIONS
Despite the large number of proposed contributors to intra-articular pathology, surgical management has been the predominating focus.7–9 Abnormal morphology provides a simple construct that lends itself well to the idea of surgical correction.15,17,19,26,29,31,69 However, the high prevalence of abnormal morphological findings in asymptomatic individuals suggests the problem is more complex.4,62,79,84–86 Similar patterns have been seen previously, aberrant shoulder and knee morphology lead to an exponential increase in invasive treatments which had not yet been established in the literature as more helpful than less invasive interventions.8,30 Therefore, providers must reason through how morphology, collectively with mobility and neuromuscular control impairments, can be addressed effectively with non-surgical treatment approaches.16,17,26,29

The goal of this case series was to present an intervention program that is pragmatic, and easy to conceptualize and implement in clinical practice. While only one clinical trial comparing surgical to non-surgical interventions exists,87 the results remain inconclusive. Several other trials are due to be completed in the near future, and will likely provide more insight.1,9 Regardless, more research is needed to guide clinical decision making, and until then, current evidence suggests conservative management may be effective in treating individuals with intra-articular pathology and should occur prior to surgical interventions.

LIMITATIONS
The small sample size in this case series limits the generalizability and conclusiveness of the intervention approach utilized. Patient follow up was limited to two years, and only two out of the five discharged subjects directly responded to a request for a six-month follow up. Finally, it is possible the benefits
may have been from a combination of therapy in addition to corticosteroid injection, or simply from the injection. However, evidence suggests injections are not long term solutions and unlikely to address the movement and control dysfunctions present in these subjects.

CONCLUSIONS
The etiology of symptomatic FAIS and ALTs is traditionally attributed to morphological abnormalities. However, based on the presence of these abnormalities in asymptomatic individuals, it appears the diagnosis and treatment of intra-articular pathology is more complicated. Treatment should focus on the individual patient, how their impairments may contribute to their symptoms and emphasize continual reassessment. Categorizing patients into initial treatment groups, based upon the proposed continuum of neuromuscular control and mobility deficits may help to facilitate treatment based clinical decision making.

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ABSTRACT

Background and Purpose: There have been few published studies regarding the treatment of patients with non-ossifying fibromas (NOFs), either conservatively or operatively. The purpose of this case report is to discuss the clinical presentation and conservative management of a teenage athlete diagnosed with a proximal humerus NOF.

Case Description: The subject was a 13-year-old male middle school student with a diagnosis of left shoulder pain over the prior year preventing him from participating in sports activities. The combination of radiological findings revealing a NOF and a thorough physical examination allowed for the development of a physical therapy plan of care to address impairments and functional limitations. The subject was seen for eight visits where a combination of manual therapy techniques, neural mobilizations, and therapeutic exercises were administered to the cervical and upper quarter regions. The subject’s progress was tracked by measuring pain-free shoulder active range of motion (AROM) and monitoring changes using the Numerical Pain Rating Scale (NRPS) values throughout sessions.

Outcomes: After four sessions, AROM shoulder flexion and abduction increased from 123º and 119º to 160º and 180º respectively, and worst NRPS decreased from 9/10 to 3/10. Upon discharge after the eighth visit, the subject’s DASH improved from 11.66 to 2.5. The subject remained pain free at an eight month follow up and returned to activity.

Discussion: Thorough assessment of both neuromechanical sensitivity and musculoskeletal impairments may provide for the utilization of conservative treatment options for individuals with symptomatic NOFs.

Level of Evidence: 4

Keywords: neural mobilizations, non-ossifying fibroma, shoulder, movement system

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BACKGROUND AND PURPOSE
Non-ossifying fibromas (NOFs) are benign, lytic bone lesions located within the metaphyseal region of long bones that extend into the medullary canal. This tumor differentiates itself from a focal cortical defect (FCD) based on the size and location of the lesion, requiring a length greater than 3 cm with some portion of the tumor being found within the medullary canal to be classified as a NOF. NOFs are more commonly seen in younger individuals, as it has been documented that upwards of 75% of NOFs occur within the second decade of life, but also may be common between the first and third decades. Males tend to have a higher incidence rate than females, and Abdelsayed et al. reported the prevalence of fibrous defects in cortices of long bones was greater than 35% in children. While NOFs can be found in most long bones, they are frequently found about the knee joint, most commonly at the distal femoral metaphyses, followed by the distal tibial metaphyses. Another well documented location is the mandible, but a case report regarding a NOF identified in a child's mandible found that only 10 isolated NOFs of the jaw have been reported since 1964.

The majority of NOFs are asymptomatic, but larger tumors may result in discomfort or potential pathological fractures. Arata et al. found that if NOFs involve more than 50% of the transverse diameter of the bone or measure more than 33 mm in length, there is an increased risk of pathological fracture. This finding has come into question recently as a more recent case series showed that 59% of cases of NOF exceeded these threshold measurements without fracturing.

There have been few published studies regarding the treatment of NOFs, either conservatively or operatively. Regarding a NOF of the mandible, Bailey et al. stated that curettage and resections were the primary form of treatment for symptomatic patients. Another group of authors who studied curettage and grafting in athletes with benign bone lesions found positive results and return to play in patients undergoing the respective procedures. While there have been several studies regarding surgical procedures and the management of patients with NOFs, there are limited published reports regarding conservative treatment of patients diagnosed with NOFs. The purpose of this case report is to discuss the clinical presentation and conservative management of a teenage athlete diagnosed with a proximal humerus NOF.

CASE DESCRIPTION: SUBJECT HISTORY AND SYSTEMS REVIEW.
A 13-year-old male middle school student was referred to physical therapy by an orthopedic specialist with a diagnosis of left shoulder pain. The subject reported an insidious onset of left shoulder pain over the past year, unchanged by positioning of the arm or with medications. He did not recall a specific injury that precipitated his symptoms, although he noted an increase in burning and tingling symptoms throughout the upper arm after he was pushed into the bleachers while playing floor hockey several weeks prior, striking his lateral shoulder. The subject stated that his symptoms radiated distally down his left arm to the level of the elbow intermittently, but were primarily isolated to the anterior shoulder. In addition to the pain, his primary complaints included significantly decreased range of motion and strength, limiting his ability to participate in extracurricular activities such as playing football, basketball, skeet shooting, and participating in physical education class. The subject's goals were to decrease pain, increase shoulder mobility, and return to the above-mentioned sport activities which were limited secondary to pain.

Information from the medical history questionnaire was used to initially screen for potential red flags that would suggest a serious underlying pathology that would necessitate referral. With regard to past medical history, the subject reported having sustained previous clavicle and elbow fractures three years prior (both on the left side), severe migraines, as well as a history of a non-ossifying fibroma located within the proximal humerus.

The Numeric Pain Rating Scale (NPRS) was used to measure pain intensity. The subject rated average pain, least pain, and worst pain over the last 24 hours on a 0 to 10 scale, 0 representing no pain and 10 representing the worst pain imaginable. The subject rated his pain as 6-6-9 (least, average, worst pain, respectively), the mean of these three scores was 7.0. The NPRS has demonstrated acceptable levels of
reliability and validity\textsuperscript{9,11} and a two-point change in the NPRS has been reported to be clinically meaningful.\textsuperscript{12} The Patient-Specific Functional Scale (PSFS) is a self-report measure that was used to measure the subject’s perceived level of disability.\textsuperscript{13} The subject is asked to choose and rate three activities that are difficult due to the subject’s condition, each on a 0 to 10 scale, with 0 representing inability to perform the activity and 10 representing the ability to perform the activity as well as he or she could prior to the onset of symptoms. The minimally clinically important change is two points.\textsuperscript{13} The subject in this case report only chose two activities, and rated playing basketball and skeet shooting as 6/10 and 5/10 respectively. The subject also completed the Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire (ICC = .90), which has been found to be a valid subject reported outcome measure for individuals with upper extremity pathologies.\textsuperscript{14} The subject scored 11.66 on the DASH and a 25 on the DASH sports module.

**CLINICAL IMPRESSION #1**

The subject’s initial symptoms were insidious in onset over the course of one year, although he reported an exacerbation in symptoms after striking his lateral shoulder against the bleachers while playing hockey. Differential diagnosis consists of a deltoid strain, rotator cuff strain, rotator cuff tear, subacromial impingement syndrome, acromioclavicular joint sprain, proximal physeal fracture, and cervical radiculopathy. Because MRA imaging ordered by the physician revealed a non-ossifying fibroma located in the proximity where the subject reported having pain, this was also considered in the differential diagnosis list. The examination included screening for cervical radiculopathy as a possible cause followed by examination including strength, flexibility, palpation, and special testing of the shoulder complex to further discern the underlying causes as well as the functional presentation and movement diagnosis.

**EXAMINATION**

The subject did have imaging performed which indicated the following plain radiographs that revealed no acute fracture or dislocation, however did reveal an eccentric area of rarefaction in the medial metaphysis of the left proximal humerus with a sharp zone of transition. Subsequently, a MRA was performed revealing “a 3.1 cm cephalocaudal expansile sharply circumscribed lesion in the medial cortex of the proximal metaphysis diaphysis of the humerus corresponding with the plain film findings consistent with a benign non-ossifying fibroma.” (Figures 1-2)
Postural observation of the subject revealed bilateral forward shoulder posture with slight forward head posturing, and anterior tilting of both scapulae at rest.\textsuperscript{15} Due to the subject's subjective reports of “burning and tingling” in the shoulder that occasionally radiated down the arm, a cervical screen including active range of motion and Spurling's Tests were performed without any reproduction or exacerbation of the subject's symptoms. Observation of gross glenohumeral motion revealed marked limitations in all planes due to pain. Scapular dyskinesis was demonstrated as an inability to control scapular internal rotation upon eccentric return from a flexed and abducted position, as well as marked forward head posturing during both overhead movements. Active range of motion measurements were performed using a standard goniometer with the subject able to reach 123\(^\circ\) of shoulder flexion and 119\(^\circ\) of shoulder abduction. Internal rotation was examined using the Apley Scratch Test, and the subject was able to reach one inch inferior to the inferior scapular angle. All active ranges of motion were limited secondary to reports of pain. The subject experienced hypoesthesia to light touch within C4 and C5 dermatomes on the left side, but no other abnormalities to sensation were noted.

The subject reported pain with both Hawkins-Kennedy and Empty Can tests, and had a negative Drop Arm Test.\textsuperscript{16} Passive shoulder mobility was not tolerated by the subject as he was apprehensive towards any shoulder movements, and reported pain upon testing all planes.

Due to the subject's subjective history which included intermittent sensations of burning and tingling that radiated from his shoulder to his elbow, further evaluation of neuromechanical sensitivity was warranted. Since the subject was unable to tolerate passive shoulder testing, this also prevented the examiner from assessing neurodynamics, particularly the Upper Limb Neural Tension Test A at initial examination. The subject also reported significant discomfort when assessing glenohumeral joint mobility; therefore, a thorough assessment of joint play was unable to be performed, and due to the subject's level of irritability, further joint mobility testing of the shoulder girdle was deferred.

A hand-held dynamometer was utilized during resisted testing of the glenohumeral joint, which was performed in the positions as described by Cyriax.\textsuperscript{17} The results of strength testing can be found in Table 1. Fieseler et al found high intra-rater reliability for the use of hand-held dynamometry on the shoulder with ICC values of 0.96-1.00.\textsuperscript{18} Manual muscle testing of the lower and middle trapezius muscles was performed in prone, as described by Kendall.\textsuperscript{19} The subject was unable to maintain any of the testing positions against gravity due to reports of global left shoulder pain. Thoracic mobility was assessed in prone via posterior-anterior joint mobilizations as described by Maitland et al,\textsuperscript{20} and no segmental hypomobility or pain was noted. Heiderscheit et al found the intra-examiner reliability of joint mobility testing to have a kappa value between 0.61-0.80 when a global assessment was made across more than one spinal level, while the reliability of pain provocation assessment was considered very good with a kappa value between 0.81–1.00.\textsuperscript{21}

While the subject presented with impairments that were appropriate for physical therapy treatment, no conclusive movement or pathological structural diagnosis had been made. Although initial cervical screening was inconclusive, further evaluation was performed with the subject in supine. In order to help the subject relax, gentle manual cervical traction was applied prior to assessing joint mobility. Upon applying the traction force, the subject reported an immediate reduction of pain from 6/10 to 1-2/10. The subject reported that this was the “best” his shoulder had felt within the past year, and his symptoms remained reduced after the traction force was released (4/10 after releasing manual traction). A similar response in symptoms was experienced with lateral glide assessment of the mid to lower cervical spine when mobilizing away from the involved extremity.

<table>
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<tr>
<th>Table 1. Shoulder Complex Isometric Testing, using Hand Held Dynamometry.</th>
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<td><strong>Motion</strong></td>
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<td>Shoulder Flexors</td>
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<td>Shoulder External Rotators</td>
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CLINICAL IMPRESSION #2
At this point in the evaluation, the examiner was able to make the following assessments:

- Persistent shoulder pain of an insidious onset for the past year with high irritability and severity (7/10 average NPRS)
- Reduction of shoulder pain occurred following both cervical traction and lateral glides from 6/10 to 1-2/10, despite full, symptom-free cervical AROM and a negative Spurling’s test. Reasoning behind this response has been speculated previously, with hypothetical rationales including activation of descending pain inhibitory systems through joint mechanoreceptors, decreasing stress on neural tissue, and improving neural mobility.22-24
- Limitations in shoulder motion (both active and passive) with high pain severity/irritability
- Weakness and impaired motor control of scapular stabilizing musculature during visual observation
- Weakness of shoulder musculature, demonstrated via HHD results
- Altered sensation to light touch along C4 and C5 dermatomes
- Inability to participate in sports related activities including football, skeet shooting, and physical education class

The uniqueness of the pathological presentation was quite evident following the evaluation, and although no formal movement diagnosis was generated, the subject was deemed appropriate for physical therapy based on the number of impairments that could be addressed through conservative treatment (high pain severity/irritability, range of motion, strength, etc.). The initial plan for treatment included addressing irritability of symptoms through manual therapy techniques directed at the cervicobrachial region in the form of mid to lower cervical lateral glides and cervical traction, and neuromuscular retraining of the upper quarter musculature. Outcomes that would be assessed related to mobility, strength without pain, as well the DASH, PSFS and NPRS scores.

INTERVENTION AND OUTCOMES
Initial treatment included educating the subject on performing neuromuscular re-education of the longus colli muscle in supine, as well as performing standing scapular retractions. Both of these exercises were chosen initially due to movement impairments observed during shoulder active range of motion assessments, including inability to control scapular internal rotation and forward head positioning during overhead movements. While no formal assessment of deep neck flexor strength or endurance was completed during the initial examination, it has been shown that individuals with persistent neck pain have a reduction in the feedforward activation of the neck musculature during active shoulder motions.25 That being said, there is limited evidence to support this treatment for the subject's overhead movement strategies, but addressing the motor coordination of the neck musculature appeared warranted.26 In addition, scapular retraction exercises were utilized to assist in retraining the periscapular muscles in a pain free manner to address the aforementioned movement coordination impairment. To assist in symptom management, the subject's mother was instructed on how to perform manual cervical traction in supine to be utilized as needed.

At the subsequent therapy session, the subject reported that his symptoms remained reduced since the initial evaluation, although he reported a return of 6/10 discomfort after performing manual labor including lifting boxes earlier in the day. The subject stated that he was able to perform typical activities of daily living without a reproducing his shoulder pain, and that he tolerated the home exercises without any difficulties. Treatment focus remained on pain control and neuromuscular re-education. Once again, cervical traction and lateral glides were performed to decrease the subject's pain level, but the subject's left shoulder was positioned at progressively increased ranges of shoulder abduction (90, 100, 120 degrees respectively) to preload neural structures during the mobilization techniques.23 The use of upper extremity pre-positioning with manual therapy to the cervical spine has been documented in previous cases for the treatment of cervical radiculopathies.22,23 The subject was able to tolerate each incremental increase in shoulder motion, although
After reducing the subject's symptoms to 2/10, the focus of the session shifted towards neuromuscular re-education. Manual resistance was provided to the subject's involved extremity in the form of rhythmic stabilization. Due to the subject's limited tolerance to activities above 90 degrees of shoulder flexion, stabilization was performed at approximately 30 degrees of flexion while in supine and tolerated well by the subject. The subject was also instructed in isometric shoulder extension in supine, as well as scapular push-ups against a table to promote serratus anterior activation. Exercises were attempted in quadruped, but the subject reported increased shoulder pain with upper extremity weight bearing, and they were not continued. Pending the subject's progress with home exercises, the plan was to begin introducing progressive resistive exercises for scapular stabilizing and rotator cuff muscle groups. Moezy et al found that scapular stabilization exercises have been successful in improving shoulder range of motion, decreasing forward head and shoulder postures in subject's with subacromial impingement syndrome, and while this subject did not have a true impingement presentation, the impairments with which he presented may have benefit from this type of intervention.

During the second follow-up appointment, the subject reported no increase in symptoms since the last therapy session (remained at a score of 2/10 on the pain scale). The subject also reported having an upcoming football combine within the next three weeks where he would be expected to perform exercises such as the bench press, back squat, and Farmer's walk, and was hoping to be able to participate. He was informed that these exercises would be introduced to his rehabilitation plan pending continued progress of his symptoms.

Due to the subject's minimal symptoms, no manual therapy was performed. A brief review of the subject's current home exercises was performed to ensure proper technique and execution. The following exercises were then performed and added to the subject's current home exercise plan (HEP): side lying external rotation, prone horizontal abduction with shoulder in external rotation, PNF pattern D2 shoulder flexion with a two-lb. dumbbell. Both the side lying external rotation and prone horizontal abduction with shoulder in external rotation have been shown to produce maximal muscle activity of the infraspinatus/teres minor and supraspinatus respectively. The subject was provided with verbal and tactile cueing for technique, as well as to facilitate scapular retraction during the exercises. The subject attempted supine serratus anterior presses with a dumbbell, but due to the reproduction of symptoms, was provided with an upper extremity proprioceptive neuromuscular facilitation pattern (D2 flexion) with a dumbbell in standing as an alternative exercise.

The subject returned to physical therapy for his third treatment session stating he had not required any manual traction to reduce his symptoms at home over the prior week, and that he had noticed improvements in shoulder range of motion. Upon measurement of gross shoulder motion, the subject was able to achieve 160 degrees of pain free shoulder flexion and shoulder abduction, without pain.

The fourth follow-up therapy session occurred one month after the initial examination, at which time a re-examination was performed in order to generate a progress note for the referring physician. The following objective measures from the re-examination are provided in Table 2.

The subject exhibited slight forward head posturing during active motion testing overhead, but a reduction of scapular dyskinesia was observed compared to the initial examination. The subject also stated that he was able to complete the football combine and...
several workouts without pain, noting only muscule fatigue.

At this point in the rehabilitation plan (treatment sessions 6-8) focus was shifted towards more sports-specific activities with the intention of completing a return to play progression. Included within this phase were more dynamic activities (medicine ball tosses, chest press against BOSU, closed kinetic chain plyometrics), progressions of stabilization exercises (physioball walkouts with focus on scapular stabilization, Turkish Getups), and sports specific drills (stiff arm/hitting practice against a heavy punching bag, catching drills). The subject was cleared by the referring physician to return to sports without any restrictions, and as the subject was independent with his HEP and had reached goals of therapy, and therefore was discharged from skilled therapy services. The subject was provided with the DASH questionnaire upon discharge, in which he scored a 2.5 on the DASH and a 6.25 on the DASH sports module. Table 3 displays an outline of the treatment plan of care for this subject.

The subject was contacted eight months following discharge in order to check on his symptoms and function, at which time the subject had no reports of shoulder pain and was participating in baseball and skeet shooting without restrictions.

**DISCUSSION**

Although it is known that NOFs are typically asymptomatic bone lesions, there are several documented cases in which they result in pain.1-3 As previously noted, there is little mention of the possible conservative treatments used with subject s with NOFs outside of a “wait and see” philosophy in which the lesion is simply observed.1,2,6 While the NOF in this particular case may not have been the only contributing factor towards the subject’s symptoms, it was an important component to take into consideration when establishing the treatment plan. The

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**Table 2. Left Shoulder objective findings at initial examination and re-examination.**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Initial Examination</th>
<th>Re-Examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>AROM-Flexion</td>
<td>123°*</td>
<td>160°</td>
</tr>
<tr>
<td>AROM-Abduction</td>
<td>119° painful</td>
<td>18° pain free</td>
</tr>
<tr>
<td>Strength of flexors</td>
<td>6lbs*</td>
<td>13lbs</td>
</tr>
<tr>
<td>Strength of internal rotators</td>
<td>18lbs*</td>
<td>23lbs</td>
</tr>
<tr>
<td>Strength of external rotators</td>
<td>9lbs*</td>
<td>12.7lbs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pain Score (0-10: least, average, worst)</th>
<th>Least</th>
<th>Average</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient Specific Functional Scale (basketball, Skeet Shooting)</th>
<th>Least</th>
<th>Average</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basketball</td>
<td>5</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Skeet Shooting</td>
<td>6</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

| DASH (0= no disability, 100 = fully disabled)                | 11.66|         | 2.5   |
| DASH Sports Module (0= no disability, 100 = fully disabled) | 25   |         | 6.25  |

* = pain with testing, AROM= active range of motion, DASH= Disabilities of the Arm, Shoulder, and Hand questionnaire
Table 3. Plan of Care Progression.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Goals</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase One</strong></td>
<td>• Pain Reduction</td>
<td><strong>Exercise</strong></td>
</tr>
<tr>
<td>(Pain Control)</td>
<td>• Cervicothoracic stabilization</td>
<td>• Supine longus colli neuromuscular re-education</td>
</tr>
<tr>
<td></td>
<td>• Improve range of motion of glenohumeral joint</td>
<td>○ 10 reps x 10 sec, 2x/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Seated Scapular Retraction (AROM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 10 reps x 5 sec, 2x/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Isometric lower trap activation (supine)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 10 reps x 5 sec, 2x/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Serratus Push-ups Against Table (45 degree incline)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 8-12 reps, 3 sets, 1x/day</td>
</tr>
<tr>
<td></td>
<td><strong>Manual therapies</strong></td>
<td><strong>Manual</strong></td>
</tr>
<tr>
<td></td>
<td>• Cervical Traction</td>
<td>• Cervical Traction</td>
</tr>
<tr>
<td></td>
<td>○ 20-30 seconds, 3-5 repetitions</td>
<td>○ With and without UE pre-positioning</td>
</tr>
<tr>
<td></td>
<td>• Cervical Lateral Glides</td>
<td>○ Contra-lateral grade III mobilizations for 30 seconds, 3-5 reps</td>
</tr>
<tr>
<td></td>
<td>○ 8-12 reps</td>
<td><strong>Glenohumeral Rhythmic Stabilization (supine)</strong></td>
</tr>
<tr>
<td></td>
<td>• Increase global scapulothoracic strength/endurance</td>
<td>○ 30 degrees of shoulder flexion, 15-20 seconds, 3-5 reps</td>
</tr>
<tr>
<td></td>
<td>• Improve rotator cuff activation</td>
<td><strong>Manual</strong></td>
</tr>
<tr>
<td></td>
<td>• Increase core stabilization</td>
<td>• Glenohumeral Rhythmic Stabilization (supine)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 90 degrees of shoulder flexion, 15-20 seconds, 3-5 reps</td>
</tr>
<tr>
<td><strong>Phase Two</strong></td>
<td>• Pain Reduction</td>
<td><strong>Exercise</strong></td>
</tr>
<tr>
<td>(Strengthening)</td>
<td>• Cervicothoracic stabilization</td>
<td>• Upper Body Ergometer (Forward/Backward)</td>
</tr>
<tr>
<td></td>
<td>• Improve range of motion of glenohumeral joint</td>
<td>○ 2 minutes each direction</td>
</tr>
<tr>
<td></td>
<td>• Increase core stabilization</td>
<td>• Prone Shoulder Extension/Horizontal Abduction/Scaption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 8-12 reps, 2-3 sets, 1x/day</td>
</tr>
<tr>
<td></td>
<td>• Increase global scapulothoracic strength/endurance</td>
<td>• Side Lying External Rotation</td>
</tr>
<tr>
<td></td>
<td>• Improve rotator cuff activation</td>
<td>○ 8-12 reps, 2-3 sets, 1x/day</td>
</tr>
<tr>
<td></td>
<td>• Increase core stabilization</td>
<td>• Push Up-Plus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 8-12 reps, 2-3 sets, 1x/day</td>
</tr>
<tr>
<td></td>
<td><strong>Manual</strong></td>
<td>• Dumbbell Resisted D2 Shoulder Flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 8-12 reps, 2-3 sets, 1x/day</td>
</tr>
<tr>
<td><strong>Phase Three</strong></td>
<td>• Improve dynamic stability of glenohumeral joint</td>
<td><strong>Manual</strong></td>
</tr>
<tr>
<td>(Return to Play)</td>
<td>• Increase joint loading of glenohumeral joint</td>
<td>• Glenohumeral Rhythmic Stabilization (supine)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ 90 degrees of shoulder flexion, 15-20 seconds, 3-5 reps</td>
</tr>
<tr>
<td></td>
<td><strong>Exercise</strong></td>
<td><strong>Exercise</strong></td>
</tr>
<tr>
<td></td>
<td>• Physioball Walkouts</td>
<td>• Physioball Walkouts</td>
</tr>
<tr>
<td></td>
<td>○ 10 reps, 2 sets</td>
<td>○ 10 reps, 2 sets</td>
</tr>
<tr>
<td></td>
<td>• Physioball Push Up Plus</td>
<td>• Physioball Push Up Plus</td>
</tr>
<tr>
<td></td>
<td>○ 8-12 reps, 2 sets</td>
<td>○ 8-12 reps, 2 sets</td>
</tr>
<tr>
<td></td>
<td>• Turkish Get-Up (15 lbs.)</td>
<td>• Turkish Get-Up (15 lbs.)</td>
</tr>
<tr>
<td></td>
<td>○ 8 reps, 3 sets</td>
<td>○ 8 reps, 3 sets</td>
</tr>
<tr>
<td></td>
<td>• Medicine Ball Toss against Rebounder (2-11 lbs.)</td>
<td>• Medicine Ball Toss against Rebounder (2-11 lbs.)</td>
</tr>
<tr>
<td></td>
<td>○ 5-8 reps, 2 sets (chest pass, diagonal chops)</td>
<td>○ 5-8 reps, 2 sets</td>
</tr>
<tr>
<td></td>
<td>• Dynamic Chest Press Against BOSU</td>
<td>• Dynamic Chest Press Against BOSU</td>
</tr>
<tr>
<td></td>
<td>○ 5-8 reps, 3 sets</td>
<td>○ 5-8 reps, 3 sets</td>
</tr>
<tr>
<td></td>
<td>• Closed Kinetic Chain Plyometrics</td>
<td>• Closed Kinetic Chain Upper Extremity Stability Tests</td>
</tr>
<tr>
<td></td>
<td>○ Closed Kinetic Chain Upper Extremity Stability Tests</td>
<td>▪ 15 seconds, 3 sets</td>
</tr>
<tr>
<td></td>
<td>▪ Plyometric Pushup</td>
<td>• Football Catching Drills</td>
</tr>
<tr>
<td></td>
<td>▪ 5-8 reps, 3-5 sets</td>
<td></td>
</tr>
</tbody>
</table>

Reps = repetitions, AROM = active range of motion
impairments discussed in this case, as well as their subsequent treatment plans, can be broken down into two primary areas of focus: the shoulder and the cervical spine. Since the subject was referred to physical therapy for shoulder pain, this was the initial focus during the physical assessment. Clinical examination revealed impairments that were appropriate for physical therapy rehabilitation, including pain, decreased range of motion, weakness of the shoulder complex musculature, impaired neuromuscular control, and decreased ability to participate in sports related activities. However, examination of the cervical spine revealed potential contributing factors including poor postural awareness, impaired neuromuscular control as demonstrated by forward head posturing with overhead motions, and suspected alterations in neuromechanical sensitivity evident through the effects of cervical traction and lateral glides on the subject's arm pain. Although formal upper limb neurodynamic testing was not performed, the subject presented with other factors several authors have described to be consistent with a neurogenic pain pattern, including high pain severity and irritability, burning and tingling symptoms throughout the upper arm, and pain generation without direct stimulus/response relationship.31-35 Based on these impairments, it was hypothesized that by improving the neuromuscular control and stability of both the cervical and scapulohumeral regions, the potential irritation of the neural structures would lessen and allow for improved shoulder function. Due to the inconclusive physical therapy examination in ruling in or out a pathoanatomical source of the subject's symptoms, it was deduced that the aforementioned hypothesis was plausible based on the subject's positive outcomes from the initial interventions. A similar approach has been utilized when treating individuals with highly irritable adhesive capsulitis that present with signs of neural irritation, and upon addressing the underlying neuromechanical sensitivity, a significant improvement in shoulder function has been observed.36

While there were musculoskeletal impairments that were appropriate for physical therapy intervention, the dramatic, immediate improvement in symptoms with manual therapy at the cervical spine remains an interesting component to the plan of care. One possible explanation for the positive effects elicited by this treatment may be due to the mobilization of neural tissue. It has been suggested that mechanical cervical traction can both widen the intervertebral foramen and separate the vertebral bodies,37 which would allow the surrounding neural structures to have less restriction to movement. Graham et al. also found that movements of the upper extremity have mobilized the cervical roots of the brachial plexus; therefore, it is hypothesized that movements of the cervical spine would cause resulting movements of the more peripheral neural structures of the plexus.38 Based on this hypothetical assumption, the use of both cervical traction and lateral glides would assist in a form of neural mobilization at the nerve root.39 Considering a recent systematic review that reported that studies investigating the effects of cervical lateral glide mobilizations consistently found significant improvements in pain in individuals with nerve-related neck and arm pain,40 the manual techniques described in this case report could have resulted in the same effect. McClatchie et al. also found that mobilizations of the cervical spine in individuals without neck pain has been beneficial in reducing shoulder impairments, once again supporting the various manual techniques utilized in this case report.41

A question remains: why would a subject with a NOF present with neurodynamic dysfunction? There are nociceptors within both the periosteum and marrow of bones, which would explain the possibility of having symptoms related to a NOF.42 Sensitization of the dorsal horn neurons has been also documented as a potential source for referred pain or secondary hyperalgesia in individuals with bone pathologies, which may be more pertinent to the subject in this case report.42 Considering the subject had hypoesthesia, reports of burning/tingling throughout the arm, and the chronicity of his symptoms, it would be reasonable to assume that alterations to the peripheral and/or central nervous system's processing had occurred, resulting in a sensitized state.43,32 Central sensitization can cause the following changes to occur within the dorsal horn: spontaneous activity within the neurons, a decrease in the required stimulus to reach threshold, an augmented response once threshold is reached, an
increased receptive field size, and a range of neuro-immunologic responses, leading to enhanced central excitability and/or diminished central inhibition.43-45 Central neuroimmunologic responses may lead to sensitize the dorsal root ganglia,45 which in combination with aberrant movement patterns, could contribute to sensitization of the peripheral nerves of the upper quarter.44 Based on the subject's presentation upon evaluation, it is plausible that his symptoms were due to a mix of peripheral and central pain mechanisms.49 When taking into consideration the previous information regarding the benefits of neural mobilizations and the nociceptor innervation of the periosteum, mobilizing the cervical spine may prove beneficial in subject s with non-mechanical pain associated with NOFs. Further investigation of the conservative physical therapy management of individuals with radiological evidence of a NOF is needed to enhance the body of knowledge regarding this pathology.

LIMITATIONS
While the outcomes of this case report were positive, there are several limitations. For instance, the subject in this case presented with increased neuromechanical sensitivity, but this finding may not be consistent amongst other individuals. Having only a single subject within the case prevents generalizability to be made amongst all individuals with NOFs, and further investigation of the presentation and treatment of symptomatic NOFs remains warranted.

CONCLUSION
This case report describes positive results after conservative treatment of a teenage athlete with a symptomatic NOF in the proximal humerus. He was able to return to full participation in his prior sports activities after a combined approach of manual therapy, neuromuscular re-education, and progressive resistance training. Physical therapists must take into consideration many factors that may be contributing to a subject's persistent pain. Alterations in neuromechanical sensitivity should be included as part of a differential diagnosis in subject s with persistent symptoms, particularly when there is evidence of a NOF. By incorporating neural mobilization techniques, along with addressing any pertinent underlying musculoskeletal impairments, utilization of conservative treatment options may be helpful in individuals with symptomatic NOFs.

REFERENCES


ABSTRACT

Background and Purpose: Brachial plexus neuropraxia (BPN), or “burners” and “stingers”, affect 50-65% of football players, with a high rate of recurrence and the potential, in rare cases, for catastrophic injury. Existing literature on rehabilitation of these athletes is limited. The purpose of this case report is to describe the successful and comprehensive rehabilitation of a subject with recurrent brachial plexus neuropraxia using range of motion exercises, cervical and periscapular strengthening, stabilization exercises, and activity modification.

Case Description: The subject was a 17-year-old high school linebacker with repeated BPN episodes. He presented with limited cervical extension, rounded shoulder posture, and weakness of the cervical and periscapular stabilizers, and was known to tackle using the crown of his helmet. Physical therapy intervention consisted of regaining full passive & active range of motion and strength in the neck, shoulders and periscapular region, including several novel stretches and exercises to address the subject's unique presentation. Dynamic stabilization, postural control, safe tackling form, and long-term maintenance exercises were also addressed to decrease risk of injury recurrence.

Outcomes: The subject regained full pain-free PROM, AROM, strength & stability throughout the upper body after ten treatment sessions over five weeks, and was able to return to full participation the next season with normal safe tackling form and no further episodes.

Discussion: Despite the prevalence, chronic nature, and potentially devastating effects of BPN, little has been written regarding comprehensive rehabilitation of the condition. Regaining full upper body range of motion, strength, and dynamic stability, as well as normalizing tackling form, is essential to resolving BPN and preventing recurrence.

Level of Evidence: Level 4, single case report

Key Words: Brachial plexus neuropraxia, burners, cervical, stingers, football
BACKGROUND AND PURPOSE
Brachial plexus neuropraxia (BPN), commonly called “burners” and “stingers”, affects 50-65% of football players,1,2,3 and has been reported in high school, collegiate (Div I-III) and professional athletes. BPN also been reported in Canadian football,2 rugby,4 wrestling, hockey, basketball, boxing and weightlifting.5 The rate of recurrence can be as high as 50-87%.1,2 Generally thought to occur in younger athletes by a blow to the head or shoulder forcing cervical sidebending in one direction and shoulder girdle depression in the other, the subsequent traction on the upper extremity neurovasculature causes transient upper extremity tingling, numbness, weakness, and/or pain.2,6,7,8,9,10,11,12,13 Other described mechanisms include a direct blow to Erb’s Point,14 and a compression-type injury to the nerve root, caused by ipsilateral cervical sidebending and/or hyperextension, thought to occur in older (collegiate or professional) athletes with degenerative cervical canal or neuroforaminal stenosis.10,12,14,15,16 Sixty-two to 83% of BPN injuries in football occur while tackling or blocking,2,3,17 and most commonly affect defensive linemen, linebackers, defensive backs, and offensive linemen, and to a lesser extent, running backs and wide receivers.1,2,3,17 The athlete may present on the sidelines slightly bent at the waist with the involved upper extremity lowered down, supported by the uninvolved side, and the neck flexed toward the side of the injury to reduce tension on the injured nerve. To relieve symptoms, athletes often shake their hands or bring their chin toward their chest.2 Acute symptoms typically last seconds to minutes,2 and the majority of injured athletes lose less than 24 hours of participation,17 or lose no time at all,2 but regaining full symptom-free function may take days or weeks, especially after repeated episodes. Injured athletes often do not report their symptoms2 and attempt to return to play once their symptoms partially subside, and sometimes suffer several neuropraxias before notifying medical staff. Return to play after brachial plexus neuropraxia is generally allowed once symptoms resolve and the clinical examination is normal,9,13,18,19,20 including within the same game,12,20,21 although there is no consensus on this topic.22 Athletes with chronic symptoms and/or episodes are typically sent for plain film radiographs and/or MRI to investigate for cervical pathology, and electromyography may also be considered for symptoms lasting several weeks.12,20,21,23

Central canal and neuroforaminal stenosis has been strongly associated with chronic BPN in professional and collegiate football players,10,15,24 and has been identified in athletes ages as young as 15-18 years old.25 Cervical intervertebral disc degeneration (CIDD) and decreased cervical extension ROM may also be related to BPN; in a recent study of 49 Japanese collegiate football players, of those with CIDD, 59% had sustained BPN injuries, compared to only 6% of those without CIDD.26 In the same study, significantly lower cervical extension ROM was found in athletes who had sustained BPN during the previous season (50.9°) than in those that hadn’t (60.2°).26

Continuing to play despite repeated BPN can be devastating. Several authors have reported cases of traumatic cervical nerve root avulsion in football players, leading to near complete loss of upper extremity function.27,28,29,30 At least one of these subjects had a documented history of repeated BPN episodes.28 The combination of congenital central canal stenosis, loss of cervical lordosis, and a tendency to lead with the crown of the head when tackling, called “Spear Tackler’s Spine”, is considered extremely dangerous due to the risk for catastrophic spinal cord injury from axial loading and possibility of fracture/dislocation of the cervical vertebrae. Spear Tackler’s Spine is generally considered to be an absolute contraindication to playing football,13,31,32 although there is debate on this topic.33

Literature on rehabilitation of brachial plexus neuropaxia is quite limited, and generally consists of cervical range of motion and isotonic strength exercises, and strengthening of the upper trapezius, deltoids and rotator cuff musculature.34,35,36 Described strength exercises for the cervical spine typically include isometrics or isotonics using manual resistance, exercise bands, and weight machines. Despite their direct influence on stability and posture of the cervicothoracic spine and shoulder complex,37,38,39,40,41 and their inclusion in published rehabilitation programs for cervical radiculopathy,42,43,44,45 strengthening of the periscapular muscles has been mentioned only occasionally as part of BPN rehab, and not in
any detail. No literature could be found describing any kind of dynamic spinal stabilization, neuromuscular re-education, postural control, or tackling replication exercise as part of BPN intervention.

Equipment adaptations such as cervical collars or augmented shoulder pads are sometimes used, but their success in preventing brachial plexus neuropaxia has not been firmly established beyond anecdotal or biomechanical studies. These collars have been shown to somewhat limit hyperextension but have little effect on controlling the cervical sidebending typically found with brachial plexus neuropaxia. There is no known literature on rehabilitation of Spear Tackler’s Spine syndrome and/or loss of normal cervical lordosis.

The purpose of this case report is to describe the successful and comprehensive rehabilitation of a subject with recurrent brachial plexus neuropaxia using range of motion exercises, cervical and periscapular strengthening, stabilization exercises, and activity modification. Some aspects of this group of interventions could be applied broadly to subjects with this condition, and others are unique to this particular subject.

**CASE DESCRIPTION: SUBJECT HISTORY AND SYSTEMS REVIEW**

The subject was a 17-year-old male high school football player (height 5'11”/1.80 m, weight 183 lbs/83 kg) seen 17 days following a football game in which he sustained two BPN episodes. Per his report, the first occurred while tackling another player, at which time his head was down and the other player ran directly into the superior aspect of the subject's shoulder. He felt immediate pain and weakness into the left arm and left the game, although he did not report his symptoms to the coaches or medical staff. He attempted to return to the game later but his acute symptoms returned when attempting to block another player, at which time he left the game and notified medical staff. The subject later admitted that similar episodes had occurred at least four times in the prior two seasons, all involving left arm pain, weakness and numbness following contact. He denied any previous neck, shoulder, or upper back injuries or symptoms, and all other past medical history was unremarkable. Post-injury cervical MRI & plain film radiographs revealed a loss of cervical lordosis. The intervertebral discs were of normal height and alignment. Subject (and parents’) goals were to return to football when safe to do so while avoiding further episodes of BPN.

**CLINICAL IMPRESSION #1**

The subject's mechanism of injury and subsequent symptoms indicated a fairly classic presentation of brachial plexus neuropaxia. Examination should focus on strength, stability, range of motion, and posture throughout the cervical spine, scapulothoracic region, anterior chest and shoulders, as well as discussion of the subject's tackling technique. Weakness, tightness, and postural adaptations in these areas would indicate the subject would benefit from strengthening, stretching, manual techniques, stabilization exercises, postural interventions, and tackling technique corrections. The repetitive and worsening nature of the subject's multiple recent BPN injuries, including neurologic involvement, made the assessment of underlying compensations and adaptations, rather than symptom relief alone, especially important.

**EXAMINATION**

The subject complained of dull, burning pain in the left lateral aspect of the cervical spine and left shoulder at rest, and noted an area of altered sensation in the left anterior humerus, all of which were exacerbated by active or passive right cervical sidebending. He also noted sharp pain in the posterior cervical and left periscapular regions with active cervical extension.

Table 1 lists physical examination findings, including range of motion, measured using standard goniometry, and strength, using manual muscle testing. It was noted that the subject's active cervical extension took place almost exclusively at the upper segments of the cervical spine, with virtually no motion palpated below the level of C3 during AROM. Bilateral passive scapular retraction performed by the therapist elicited a report of tightness in the pectoral region by the subject; while this test has not been formally studied or validated, this was thought to indicate decreased muscle length of the pectoralis muscles. Cervical segments from C3-4 to C7-T1 were hypomobile and...
tender with posterior-anterior (PA) mobilizations as well as manual segmental side-glide examination on the involved left side, while the C1 and C2 vertebrae were pain-free and unrestricted with PA mobilizations and side-glides. Thoracic spinous processes were grossly well aligned with no pain or hypomobility with PA spring testing. Strength of the deep anterior cervical stabilizers was noted to be weak, as the subject was able to maintain a chin tuck/head lift maneuver for less than ten seconds.50,51,52 The subject’s posture at rest was notable for bilaterally protracted and internally rotated scapulae.

**CLINICAL IMPRESSION #2**

Findings confirmed weakness in scapular and cervical stabilizers, as well as tightness throughout the cervical spine and presumed tightness of pectoralis minor. The authors expected to see improvement in manual muscle testing, ability to stabilize during perturbation exercises, and gross pain-free ROM of the cervical spine and shoulder within two to three weeks. Full, pain-free cervical and shoulder range of motion, strength, and stability during perturbation exercises were expected to take at least four to six weeks given the repeated nature of the injury and the long-term nature of his underlying impairments.

**INTERVENTION**

Initial treatment focused on subject education and reducing stress on the cervical nerve roots by re-establishing normal range of motion and posture. The nature of the subject's BPN syndrome, loss of cervical lordosis, and poor tackling habits was discussed at length, along with the resulting potential

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<th>Table 1. Clinical Examination Findings.</th>
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<td><strong>Active Range of Motion</strong></td>
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<td>C3-T1 Left Sideglides</td>
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<td>C3-T1 PA Mobilizations</td>
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<td><strong>Strength Testing</strong></td>
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<td>Middle trapezius</td>
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<td>Rhomboids</td>
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<td>Infraspinatus</td>
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<td>C6, C7 Myotome</td>
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<td>Anterior Cervical Stabilizers</td>
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<td><strong>Functional Testing</strong></td>
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<tr>
<td>Active Contralateral Sidebending</td>
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<td>Tackling Form (per patient/parents’ report)</td>
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for catastrophic spinal cord or nerve root injury. The subject was instructed in a home program of self-stretching for the cervical spine, shoulder, and anterior chest, along with active scapular and cervical repositioning to begin correcting his posture. The subject performed self-stretching at home with gentle overpressure into cervical flexion, and right and left rotation; these were also passively stretched by the therapist in the clinic. Contralateral side-bending was avoided due to re-creation of brachial plexus symptoms. Anterior chest muscle tightness was addressed with a doorway pectoral self stretch at home, keeping a neutral spine and retracting the scapulae as the subject moved forward through the doorway. The shoulders were stretched into flexion at home using a cane in supine, bilaterally. Proper scapular positioning was taught using seated scapular retraction and unilateral scapular circles, each done with an emphasis on moving the scapula while keeping a neutral spine posture to avoid compensation in the spine. Active cervical retractions were also prescribed, to be performed with the subject sitting with scapulae retracted. Each exercise was to be performed twice per day, 10-15 repetitions with five second holds.

Manual Grade II left side-glides and posterior-to-anterior (PA) joint mobilizations of the painful and hypomobile middle and lower cervical segments by the therapist were performed during the first two follow-up visits, but were abandoned due to persistent muscle guarding and discomfort during the mobilizations, as well as continued symptoms overall. Given the poor response to this aspect of treatment, a new method of regaining cervical ROM was needed. To regain normal extension in these segments, the subject was taught to actively extend the cervical spine with a towel wrapped around the middle and lower cervical segments, with instruction to feel his neck bending in the segments covered by the towel (Figure 1). While appearing similar to the commonly-used Mulligan SNAG technique, the towel in this case was used for tactile cueing rather than joint mobilization. The subject was able to perform the stretch without the guarding and pain elicited by the manual joint mobilizations, and he finally felt motion in the targeted segments, which traditional stretches and mobilizations did not seem to achieve. This combination of tactile feedback and active participation by the subject helped not only with range of motion but also with proprioception and motor learning, which was the used later to incorporate proper active extension with tackling techniques. Active cervical extension was also performed in the prone-on-elbows position (Figure 2), letting the ribcage drop toward the table, which helped combine lower cervical and upper thoracic extension with scapular retraction. Each of these active cervical extension stretches were done twice per day at home, 10-15 repetitions for five seconds each.

Scapular strengthening exercises were also initiated in the early visits. At first these consisted of
unilateral and bilateral prone retraction with horizontal abduction, prone rows with a 1.36 kg (3 lb.) hand weight, and seated row with surgical tubing (three sets of 15 repetitions each, every other day only). Isolated scapular retraction was emphasized with each exercise, and care was taken to avoid excessive hyperextension or hyperabduction at the glenohumeral joint. The rowing exercises were specifically performed using a two-part motion of scapular retraction first, followed by glenohumeral motion, to further emphasize the scapular musculature. Strengthening of the deep anterior cervical stabilizers was initiated using a supine chin tuck/head lift (cervical retraction/flexion) exercise against gravity, five second holds, three sets of five to ten repetitions, done every other day.

After six visits (16 days) the subject demonstrated normal myotomal strength, full shoulder ROM, and improved scapular strength (grossly 4/5), with full ROM and only mild discomfort at the end-range of active cervical extension. Several new exercises were begun to incorporate this new mobility and strength into the subject’s ability to eventually tackle while maintaining cervical extension. Bilateral upper extremity overhead presses were done with exercise tubing in a bent-over position with the subject’s torso as close to the horizontal plane as possible to closer replicate actual tackling posture (Figure 3). Scapular strengthening was progressed to standing horizontal abduction with tubing, which was performed unilaterally with emphasis on scapular retraction. Scapular retraction was also performed bilaterally in prone with the subject in full active cervical extension (Figure 4) in order to combine the action of the thoracic and scapular stabilizers with the cervical extensors, further reinforcing proper tackling posture and cervicothoracic stabilization. Several traditional shoulder strengthening exercises were performed similarly with the subject in cervical extension, including lat pull-downs, overhead dumbbell press, bent-over rows (Figure 5), overhead military press on a Smith machine, and dumbbell push-ups.

Before the subject could be safely discharged, his tackling form needed to be corrected. This was performed by simulating the tackling motion up to the point of contact with the subject maintaining cervical extension.
extension (the “heads-up” position). At first this was performed with the subject simulating contact with the therapist as the therapist held a large exercise ball, with the subject facing a mirror for visual feedback. Once the subject understood correct positioning and muscular stabilization, rhythmic perturbations were applied at the head, shoulder, arms and physioball (Figure 6) to further reinforce proper stability and tackling form while maintaining cervical extension. The subject was instructed in anticipatory firing of the shoulder, scapular, and cervical stabilizers before contact so that the muscular support system would be engaged and prepared to maintain stability at the point of contact and through the end of the tackling motion, rather than attempting to fire them after the fact.

After 10 visits (five weeks) the subject had regained full pain-free active and passive cervical extension, symptom-free contralateral side-bending, normal (4+ to 5/5) scapular strength, and proper head and neck positioning which was maintained during tackling replication.

**Return phase/Clearance**

The subject was cleared by his physician to return to full contact sports including football upon demonstration of full symptom-free strength and ROM of the cervical spine and upper extremity, as well as normal cervical plain-film radiographs. The physician specifically recommended that the subject discontinue football if any further episodes of BPN occurred.

**Follow-Up**

The subject's season had ended by the time he was cleared to return, but he was able to return to full participation the following season without further BPN episodes and with normal “heads-up” tackling form per his parent's report.

**DISCUSSION**

The authors believe that this subject's successful recovery depended heavily on restoring normal passive and active cervical extension, increasing periscapular and cervical strength, and, finally, performing neuromuscular re-education and tackling form modification.

**Restoring cervical extension**

While the authors do not advocate extension stretching for all subjects with cervical dysfunction, in this case, due to the subject's chronic BPN and habit of tackling with the crown of the helmet, it was essential to restore normal safe mechanics and function. Many players hit with their heads down in an effort to avoid looking at their target or (erroneously) to produce more force; however, this subject may have kept his head down simply because his loss of cervical extension prevented him from looking up to face his target.

In light of recent findings by Hakkaku, et al that athletes with BPN have decreased extension ROM, the approach detailed in this case report may be applicable to many athletes with BPN. Screening specifically for extension ROM loss may help identify athletes at risk for BPN, and may also help identify some of the high number of athletes who have suffered chronic or repetitive BPN episodes, or have not reported their BPN injuries to medical staff at all.

The ineffectiveness of traditional passive self-stretching and manual joint mobilizations led the authors to find that the subject's loss of extension was not consistent throughout the region; he had essentially normal active and passive ROM in the upper cervical segments but the middle cervical, lower cervical, and upper thoracic segments remained in neutral or in flexion with marked muscle guarding. Restoring normal ROM therefore required stretching specific...
segments of the cervical spine individually rather than moving the neck as a whole. Active self-stretching with the towel serving as a tactile cue to guide his movement at the restricted segments allowed for improved proprioception, joint position sense, and motor learning, and also produced less muscle guarding and pain than the other passive methods attempted at first. Without regaining mobility in the restricted segments of his cervical spine and then re-learning the ability to actively extend from those segments, the subject likely would have had difficulty incorporating optimal segmental cervical extension into a proper “heads-up” tackling form and may have returned to his previous habit of tackling with his head down and cervical spine in flexion.

Role of scapular & cervical strength
Scapular stability and positioning was emphasized from the first visit through the long-term maintenance program. Subjects with neck pain have been found to demonstrate altered scapular positioning and muscle activation. This area was
considered vital to normalize strength and stability of the shoulder complex, necessary for tackling, as well as to provide a stable and well-positioned thoracic spine from which to move and stabilize the cervical spine. Scapular strengthening exercises were performed unilaterally in prone on a treatment table, rather than bilaterally on an exercise ball as commonly described in rehabilitation literature. This position was chosen to avoid compensation from the glenohumeral joint, lumbar spine, or contralateral scapula, as well as to improve motor control and neuromuscular reeducation of the periscapular muscles.

Strength and endurance of the deep anterior flexors is critical for dynamic cervical stability, and has been shown to be decreased in subjects with chronic neck pain. Several authors have demonstrated improved strength and decreased pain using a variety of therapeutic exercises directed at these deep muscle groups. While not as specific as performing an isolated supine cranio cervical flexion maneuver, lifting the head against gravity while maintaining cranio cervical flexion has been shown to be effective. This specific exercise allowed the subject to progress his cervical strength and endurance at home without equipment. This was also thought to be more applicable to football, where the subject would be using all cervical stabilizers, including the deep and superficial layers, to withstand contact at the head. Finally, isolated deep flexor exercise alone has not been shown to carry over to functional tasks. For this reason, these muscles were specifically used during tackling replication exercise later in the process, using rhythmic stabilization and functional positioning, in order to reinforce proper stabilization of the cervical spine while in the act of tackling.

Combining cervical extension with arm motion

Ordinarily, subjects with cervical dysfunction are encouraged to maintain a neutral spine position with all corrective and functional exercise. In this circumstance, normalizing this subject’s tackling form (and thus reducing risk of catastrophic injury) required combining his newly-improved cervical extension and upper back/scapular strength with the arm and torso positioning used in football tackling to help him avoid cervical flexion when making contact. This may be even more important in light of recent findings of decreased extension ROM in athletes with BPN, indicating a possible relationship between loss of cervical extension and BPN.

Anticipation: engaging stabilizers before contact

The subject was instructed in anticipatory firing of the cervical, scapular, and glenohumeral stabilizers before contact so that these muscles would be engaged and prepared in order to maintain dynamic stability of all involved segments and joints leading up to the point of contact, rather than attempting to fire them after contact was initiated. Research by Hodges, Falla and others has indicated a loss of this anticipatory firing of the stabilizing musculature in individuals with chronic cervical and lumbar spine pain, and specific re-training exercise has shown to normalize the anticipatory firing pattern of transversus abdominis in subjects with chronic low back pain. Anticipatory stabilization firing may be even more important in cases of brachial plexus neuropraxia because of the apparent inability to stabilize at contact, allowing the head, neck and shoulder girdle to deviate from their neutral positions, thereby placing tension or compression on the nerve roots.

Monitoring/Improving tackling form

All of these changes would be for naught if the subject returned to his prior tackling habits on the football field. Observing him in live contact situations with his team was essential to monitor and give feedback on his tackling form. His coaches, trainers, and parents were included in this oversight to be sure he maintained good form throughout the season, and they were encouraged to give reminders and corrections if needed.

Limitations

As with all case reports, this case report is limited in its generalizability and its ability to prove cause and effect. It is also limited by its lack of objective data (hand-held dynamometry would have been preferable to manual muscle testing) and also lacked patient-reported outcome measures, pre- and
post-intervention radiographs, formal measurement of anterior chest wall (or pectoralis minor/major) tightness, and long-term follow-up.

CONCLUSIONS

The results of this case report indicate that the 17-year-old subject who had sustained several episodes of BPN was able to return to contact sport performance (football) after comprehensive rehabilitation that focused on range of motion, strength, dynamic stability, and activity modification. This case report details a more comprehensive and detailed approach to resolving recurring brachial plexus neuropraxia than is currently found in the literature. In addition to regaining strength and mobility of the cervical spine, the elements of scapular strengthening, anticipatory firing of stabilizing musculature, and tackling form modification are, in the opinion of the authors, equally crucial elements to resolving BPN in athletes and preventing recurrence. Future research might include case series with long-term follow-up, and might also further examine the relationship between BPN and loss of cervical extension, for both predictive and therapeutic applications.

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ABSTRACT

**Background and Purpose:** Shoulder injuries are common amongst overhead athletes. Dysfunctional motor patterns (scapular dyskinesis) may be the cause or result. Improperly treated, they can sideline athletes or reduce quality of life. Current treatment protocols are lengthy and may result in recurrence. Individualization of treatment is key. Functional tests, like the Selective Functional Movement Assessment (SFMA), help discern and properly identify dysfunction, paving the way for interventions like reflexive neuromuscular stabilization (RNS). RNS focuses on restoring proper motor control and may positively influence healing. The purpose of this case report is to describe an evaluation and treatment strategy for scapular dysfunction in an overhead athlete.

**Case Description:** The subject was a 16-year-old, multi-sport athlete in the high school setting. He presented with upper back pain during his sophomore baseball season. Clinical findings upon examination included but were not limited to irregular scapular positioning as compared bilaterally, dysfunctional scapular movement patterns, soft tissue muscular irritability and loss of gleno-humeral (GH) ROM in internal and external rotation, flexion and abduction. Intervention consisted of a combination of positional release therapy and reflexive neuromuscular stabilization aided by some traditional therapeutic modalities.

**Outcomes:** The combination of conservative treatments and RNS provided relief of the subject's symptoms in a shorter time frame, three treatments over the course of six days, than just utilizing traditional protocols. The utilization of the paired treatments resulted in diminished pain, restored ROM and improvement in perceived fluidity (speed and stability) of motion as observed by the clinician. A minimal clinically important difference (MCID) was reported on the disablement of the physically active scale (DPAs) on all follow-up treatments as well as on the numeric pain rating scale (NPRS) after the first and second treatments. The minimal detectable change (MDC) requirement was met on the patient specific functional scale (PSFS) prior to the second and third treatment. The activities measured with the PSFS were: GH flexion, GH abduction and throwing a baseball.

**Discussion:** In this case report, the use of the SFMA along with a traditional orthopedic examination allowed for proper identification and location of the dysfunctional motor patterns. The coupling of a traditional modality like the moist heat pack, with PRT and RNS proved to be a beneficial treatment combination for this subject as it provided a clinically meaningful resolution of his condition. Even though current literature suggests that treatment for scapular dysfunction is comprised of three phases over the course of ten weeks, clinicians should focus on the individualization of the treatment, possibly utilizing novel interventions like PRT and RNS.

**Level of Evidence:** 4 Case Report

**Keywords:** Movement patterns, motor control, shoulder complex

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There are no conflicts of interest regarding this case report.
INTRODUCTION
Pain and injuries to the shoulder complex are common amongst overhead athletes. The sequencing of the throwing motion engages multiple muscles and joints due to the various motions that occur through numerous planes. The shoulder complex is comprised of series of bones (clavicle, humerus, scapula, sternum and rib cage) and three joints; sternoclavicular, acromioclavicular, glenohumeral, and a single scapulothoracic articularation. A great deal of mobility at the glenohumeral joint is derived from the shape of the glenohumeral (GH) joint and the mobility of the scapula in relation to the thorax. This relation creates the three-dimensional (3D) pattern known as scapulohumeral rhythm (SHR). Observations of the scapula that help define position are the medial border and inferior angle prominences relative to the thoracic cage. Individuals with healthy, fully functional shoulder complexes will have bilateral positional symmetry. This can be determined through a visual assessment. Proper anatomical positioning is essential to efficiently optimize SHR. Alterations of scapular positioning and motion are known as scapular dyskinesis. The abnormal movement patterns exhibited in this condition are: early scapular elevation (shrugging) during GH abduction and/or a rapid downward rotation during GH adduction, abnormal static scapular positioning and/or dynamic scapular motion characterized by the medial border and inferior angle prominences.

These alterations may be the result of a number of causes: fatigue, neurologic dysfunction (eg, accessory, long thoracic or dorsal scapular nerve palsies) or muscular inhibition created by intra-articular GH or subacromial pathologies (eg, subacromial impingement, rotator cuff pathology, internal impingement, labral pathology, GH instability, GH arthritis, and adhesive capsulitis). Scapular dyskinesis has been shown to be present in as few as 67% and as many as 100% of athletes with shoulder injuries in various studies and may present in asymptomatic individuals as well. Traditional rehabilitation protocols focus on stretching and strengthening, however, in recent years muscle activation and motor control have become the staple. Commonly utilized protocols are three-phased (acute, recovery, maintenance) and may not be individualized based upon the results of clinical examination. These traditional protocols tend to last upwards of three months depending on severity and, based on clinical experience, if not conducted on an individual basis (and closely supervised) may culminate in reinforcing negative motor patterns. In 2014, Cools et al. created a clinical reasoning algorithm, which identified two causes of the dysfunction, flexibility and muscle performance. The algorithm ultimately leads the clinician to suggested therapeutic strategies. It may appear as though the guidelines, principles and protocols are straightforward however, the actual rehabilitation progression is commonly elaborate and prolonged (i.e., the diagnosis and classification may be more advanced than the treatment).

Incorporating a functional movement assessment into the evaluation process enables proper location and identification of sources of dysfunction. The selective functional movement assessment identifies three types of dysfunction: joint mobility dysfunction (JMD), tissue extensibility dysfunction (TED) and stability or motor control dysfunction (SMCD). Joint mobility dysfunction is defined as a reduction of mobility of a spinal articular segment or peripheral joint. Tissue extensibility dysfunction recognizes multiple soft tissues which could contribute to dysfunction (muscle, tendon, fascia, capsule, ligament, etc), and SMCD is an updated description of movement pattern or stability problems. The term SMCD is an updated term which correctly describes “movement pattern stability problems”. In order to accurately distinguish a stability issue, one must reflect on a number of things: the CNS, PNS, motor programing, movement organization, timing, coordination, proprioception, joint and postural alignment, structural instability and muscular inhibition as well as what the original term centered around, strength of stabilizers.

Once the dysfunction is properly located and identified, it is important to select the proper treatment. Reflexive Neuromuscular Stabilization (RNS) is an updated concept derived from Reactive Neuromuscular Training (RNT) and is an umbrella term describing a variety of rehabilitation techniques designed to restore dynamic stability and motor control to an injured joint. This is achieved through utilizing
movement pattern exercises which facilitate the central nervous system's (CNS) ability to interpret and integrate peripheral signals. Joint movement and position sense promote the peripheral signals in and around the articular structures of the joint. When pertaining to the shoulder, mechanoreceptor feedback and central programming from the articular structures relay this information to the motor cortex helping the body perceive joint movement and position. All this is accomplished by placing a light external stimulus which augments the dysfunctional movement, thus forcing the patient to actively correct the faulty pattern. RNS is typically used in conjunction with traditional rehabilitation protocols to promote the return of functional movement and is accompanied by quicker return to play (RTP) timelines than traditional protocols. Currently, there is no definitive guideline as to when RNS should be implemented within a rehabilitation protocol, however, clinical reasoning and experience dictate addressing RNS towards the end of a rehabilitation session when the muscles are most fatigued allowing for resetting healthy motor patterns. In an RNS treatment session, the clinician identifies the faulty movement (e.g., shrugging during shoulder flexion) and provides a stimulus that is designed to trigger the dysfunctional movement. The purpose of this triggering is to create proprioceptive awareness with the intent of allowing the patient to react and as a by-product initiating the "desired" movement in the pattern (i.e., movement in the opposite direction). The activity is best performed with the eyes closed and prior to the initiation of movement. Between each repetition the patient is encouraged to completely relax while the clinician stimulates the reflexive reaction and then the patient performs the movement. The advantage to RNS is that it mimics what naturally occurs in the body during movement. The body makes few conscious movement decisions when it is functioning optimally. The closer the process gets to reflex reaction, the better for normal performance. The purpose of this case report is to describe an evaluation and treatment strategy for scapular dysfunction in an overhead athlete.

CASE DESCRIPTION
The subject, an otherwise healthy 16-year-old multi-sport (football and baseball) high school athlete, presented with upper back pain (UBP) during his sophomore baseball season. The symptoms were chronic and the patient had been symptomatic for approximately three and a half weeks with no prior history of back pain or injury. The patient did not recall any single traumatic incident resulting in the onset of symptoms. The discomfort began to slowly extend up through his neck and into his right shoulder complex. The patient had appeared in games as both a pitcher and centerfielder but was transitioning solely to centerfield. During practices the patient noted a significant decrease in throwing velocity (88 mph down to 67 mph), as measured with a radar gun, and distance; most noticeably when attempting to throw from mid-centerfield to home plate. Prior to injury the patient was capable of such a throw with ease, but as symptoms progressively worsened he had difficulty with his throws reaching past second base.

Decreases in upper body strength were identified by the strength and conditioning coach while focusing on various back exercises (lat pull down, seated high and low rows, hang clean and power clean). These exercises elicited both significant weakness and pain throughout his upper back. After two weeks pushing through workouts in the gym and on the field, pain levels around the upper back increased, ultimately sidelining him from sport specific activity and leading him to the clinic for evaluation and treatment.

CLINICAL IMPRESSION #1
The lack of an acute traumatic incident led the clinician to believe the nature of the injury was chronic and did not appear emergent. When the nature of the injury is chronic, dysfunctional movement patterns may play a key role in the cause. A functional movement assessment becomes a key part of the evaluation process to single out any dysfunctional movement patterns. One popular movement assessment available is the Selective Functional Movement Assessment (SFMA), which is a regional/global orthopedic functional examination. The use of the SFMA allows for location and identification of the type of dysfunction and should be implemented as part of a traditional orthopedic examination. This form of a treatment-based classification (TBC) may allow for individualization when implementing the intervention.
EXAMINATION
Upon initial examination the patient presented with pain and point tenderness around the right (dominant) glenohumeral (GH) joint and scapula with decreases in ROM. Range of motion was measured using a goniometer with the patient in a seated position. Placing the patient in a seated position removed any hip involvement and allowed the clinician to take measurements as well as observe bilateral scapular movement and positioning occurring solely within the shoulder complex. Internal and external rotation measurements were taken in 90°/90°. The patient had full PROM however, flexion and abduction produced 3/10 on the NPRS. All measurements are presented in Table 1. All motions produced increases in pain while the fluidity (speed + stability) throughout flexion and abduction were deficient when compared bilaterally as noted through clinician observation. A tender point evaluation was conducted marking any painful points during palpation around the scapula and GH joint. Upper limb neural tension tests were all negative and no common symptoms of neurologic pathology were present, (ie. burning, numbness, tingling).

Special tests for the rotator cuff (RC) and labrum produced the following results: Gum-Turn test and Belly Press test were negative, while the Lift-Off test produced minimal pain thus ruling out RC pathology. The Dynamic Labral Shear test, Kim Test, and Grind test elicited negative results ruling out labral lesions. As there was no identifiable mechanism and each test produced negative results, the clinician proceeded with the Selective Functional Movement Assessment (SFMA) to evaluate movement patterns.

The SFMA top tier tests (used to quickly evaluate regions) demonstrated dysfunctional non-painful (DN) movements for cervical flexion (CF), cervical extension (CE), right cervical rotation (CR), and left upper extremity (UE) patterns one and two. Dysfunctional painful (DP) UE patterns one and two were present on the right. The only functional painful (FP) movement was cervical rotation to the left, all other movements, multi-segmental flexion, extension and rotation, single leg stance and overhead deep squat all produced functional non-painful (FN) movements. During the UE patterns irregular scapular positioning and movements were detected. Using the results of the SFMA top tier, the clinician followed up with the SFMA algorithmic breakouts to further discern the type of dysfunction. Working through all the breakouts, starting with the DN and working through the DP, it was determined the main dysfunction causing the subject’s symptoms was an SMCD in the UE patterns of the right side.

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<td><strong>ROM:</strong></td>
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<td>ER</td>
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<td>Abduction</td>
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<td>Flexion</td>
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<td><strong>MMT w/o pain:</strong></td>
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<td>Upp. Trap.</td>
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<tr>
<td>Rhom/Lev Scap</td>
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<td>IR (side)</td>
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<td><strong>MMT w/pain:</strong></td>
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<td>Serr. Ant.</td>
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<tr>
<td>IR (90°/90°)</td>
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<td>ER (90°/90°)</td>
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Lastly, a tender point evaluation was conducted with the subject lying prone and the clinician marking (with a pen) any points of tenderness from the neck down to the mid-back. Tender points were located around the distal neck along the levator scapulae and into the upper trapezius, along the medial border of the scapula as well as throughout serratus anterior.

**CLINICAL IMPRESSION #2**

At this juncture it was concluded the SMCD was likely the primary culprit behind the symptoms. Upper trapezius, levator scapulae, and serratus anterior appeared upregulated (facilitated) creating tension, irregular scapular positioning, and aberrant movement patterns ultimately leading to pain. This led the clinician in a direction to better individualize the treatment. The combination of traditional techniques and RNS seemed ideal for pain management and resetting motor patterns. The use of a moist hot pack would help relax and down-regulate the superficial soft tissue structures therefore decreasing pain and allowing for the RNS to properly restore functional motor patterns and restore fluidity of movement and ROM bilaterally. The fostering of new motor patterns would likely decrease the chances of recurrence.

**INTERVENTIONS**

**Treatment Procedure**

The initial goal of treatment was to decrease pain and relax the surrounding soft tissues structures. For this, the combination of a moist heat pack was used to relax the superficial tissue while Positional Release Therapy (PRT) was utilized to address any tender points discovered during the tender point examination. Positional release therapy is a technique stemming from strain-counterstrain and is used by placing the body (tissues and appendages) in a position of relaxation and comfort to remedy somatic dysfunction.36 Between the moist hot pack and PRT tension decreased and tender points were eliminated. The next step was to restore functional scapular movement patterns. Reflexive Neuromuscular Stabilization provided stimulus to the muscles to restore (groove) the desired motor patterns. Starting with retraction, the clinician used his fingers to place a stimulus along the lateral border of the scapula as the subject elevated (“shrugged”) his shoulder. This movement was conducted a few times with finger placement moving back and forth along the lateral border. Next, stimulus was applied across the spine of the scapula as the patient abduced his arm. This was to correct upward rotation. The last phase of the RNS treatment utilized the “Reach, Roll and Lift” and “Pillow Press” techniques.37

The “Reach, Roll and Lift” was accomplished with the patient in a folded over kneeling “prayer” position. (Figure 1) The starting position involves the subject kneeling down and sitting back on his heels. The “Reach” has the patient slide his hand as far out as possible remaining in complete contact with the surface at all times. This engages serratus anterior.37 Once the patient was symmetrical bilaterally he advanced to the “Roll”. The “Roll” engages the external rotators and stabilizes the humerus in external rotation. Last is the “Lift”. While maintaining full reach and ER the patient was instructed to lift his arm off the table facilitating the lower trapezius.

The Pillow Press places the patient in the supine position with the involved side raised above the head, palm facing upwards and propped up on a max of three pillows. (Figure 2) The uninvolved side is placed palm down alongside the body. With the goal of producing an isometric contraction, the patient was asked, with both hands, to press down on the pillows and the table simultaneously. This may be repeated removing one pillow at a time. The contraction facilitates lower trapezius firing on the involved side and the upper trapezius firing on the uninvolved side with retraction while depressing the scapula just as with the “Lift”.37

To reinforce proper motor control and facilitate proper function, the FMS “Functional Taping & Assessment Clinical Manual, recommends taping.37 Leukotape® was utilized for facilitation taping of the upper and lower trapezius. To accomplish this, three strips of cover-roll® were first placed from the acromion process down the lateral border to the inferior angle, the acromion process across the spine of the scapula to the C6-C7 junction, and lastly, the third strip was applied across the thoracic spine over the paraspinal musculature connecting the other two strips to make a triangle. The second phase of the taping was applying the Leukotape® over the
Cover-roll® keeping the muscles in a shortened, relaxed position as not to impose force. (Figure 3)

Once the tape was applied the patient was reassessed. Range of motion remained normal and pain-free. The patient was instructed to keep the tape on until his next visit when new tape was applied. Facilitation taping was used throughout the remainder of the season before every game and bullpen session.

Patient-Reported Outcomes

Four outcomes measures were selected for data collection. They were selected for the purposes of gathering patient perceived measurements of disablement and quality of life from a global (whole-body) as well as local (shoulder complex) standpoint. Outcome measures utilized during the treatment process were the Disablement for the Physically Active scale (DPAs), Numeric Pain Rating Scale (NPRS), the Shoulder Pain and Disability Index (SPADI), and the Patient Specific Functional Scale (PSFS). (Table 2)

The DPAs is a generic and multidimensional patient reported outcome instrument which is used to measure the perceived limitations a patient with a musculoskeletal injury may experience. The DPAs was taken prior to each treatment and at discharge. Initial DPAs score was 52 out of a possible 80. The minimal clinically important different (MCID) of 9 was met for each follow-up score. At the time of discharge, the score had decreased to 16 which is the minimum, or best score possible.

The NPRS is a unidimensional numeric counterpart to the visual analog scale (VAS) and is used to measure pain intensity. The first NPRS score was taken at the time of initial evaluation and was rated as an 8/10 for current pain (refer to figure 1.1). Pre- and

Figure 1. The Reach-roll-lift exercise for scapular stability, focuses on lower trapezius. A. “Reach” component; B. “Roll” component; C. “Lift” component
post-initial treatment his current NPRS scores were 7 and 2 respectively for a decrease of 5 meeting the MCID requirement.40-42 The following treatment also met the requirements of the MCID with pre-and post-treatment scores of 3 and 1. By the end of the third treatment all pain had been eliminated.

The SPADI is used to measure pain and disability accompanying shoulder pathology. It is a self-administered guide consisting of two subcategories, pain and disability, broken into 13 items, and lower scores indicate better outcomes.9 All three SPADI scores were taken prior to each treatment with an initial total score of 21.25%. The initial score dropped to 10.77% prior to the second treatment and 2.30% prior to the third treatment. These SPADI scores just missed the criteria for the minimal detectable change (MDC) of 13 points.46,47

Lastly, the PSFS, which is an instrument intended to evaluate functional change, mainly in patients presenting with musculoskeletal disorders, was utilized.48 Activities tested were: GH flexion, GH abduction and throwing. As for total scores, each score was taken pre-treatment. The initial score was 3.67 and increased to 5.67 meeting the MDC of 2.49 The following treatment also met the MDC for a total score of 8 and the final score was 9.33. For a complete listing of all scores please refer to Table 1. Of note, ranges of motion tested during initial evaluation increased as follows: ER increased from 67° to 93°, IR increased from 60° to 87°, abduction and flexion both produced full arcs of motion with bilateral fluidity. At final examination, all motions and all MMT's were pain-free and MMT's were graded at 5/5 for all musculature. A follow-up SFMA top tier was conducted and demonstrated no dysfunctional painful movements. All movements were now functional non-painful with the exception of upper extremity patterns one and two on the left side. Both resulted in dysfunctional non-painful movements. As the left shoulder was not the focus of the treatment, this was not identified as return criteria. The subject would eventually follow-up to clear out those dysfunctional patterns at a later time. Lastly, some sport-specific throwing tests were conducted. The two tests were throwing a fastball from the wind-up position and throwing from mid-centerfield to home plate. Prior to injury the subject’s fastball was clocked at approximately 88 mph by radar gun. During this post-treatment test he clocked in at 87 mph. As for throwing distance, he was once again able to complete the throw from mid-centerfield to home plate.

Figure 2. Pillow press with 2 pillows. The subject simultaneously presses down on the pillows with the palm facing up while the other hand presses down on the table with the palm facing down.

Figure 3. Supportive taping used for the subject
A. Pull first strip of Cover-Roll® from acromion to inferior angle. Second strip from acromion to C6-7 junction and third strip intersecting the first two strips.
B. Follow the same path with Leukotape®.
DISCUSSION
Clinical results associated with treatment of this subject were positive indicating the selection and versatility of the evaluation and treatment was ideal for this individual. Results of the patient reported outcomes demonstrated improvements in pain and disability in this case. The manner in which the subject presented was reason enough for the clinician to not only conduct a typical orthopedic evaluation but also a functional movement screening. As there was no specific lesion or injury, the utilization of the SFMA was key in identifying type and detecting the location of a dysfunctional motor pattern. The identification of dysfunction enabled the clinician to construct an individualized treatment plan, focused on stability and motor control.

The versatility and variety of treatments each served a purpose. The use of the moist hot pack not only relaxed the superficial tissue but also relaxed the subject during the rest of the treatment which played an important role as sometimes patients are not always willful believers in their treatment (due to pain presentation or inability to relax), and then may face barriers to healing or altering movement strategies. The PRT was a quick and effective technique for identifying and treating tender points along the scapula and upper back. Once all tender points were eliminated, the clinician was successful in using RNS to relearn the proper motor patterns. This combination of PRT and RNS appears to be a proactive effective combination for treating soft tissue structures presenting with dysfunctional motor patterns.

There are many ways to evaluate and treat the shoulder complex but a treatment-based classification system should be considered especially when a specific mechanism is unknown. Using a system to classify the dysfunction will allow the clinician to go beyond traditional rehabilitation protocols and incorporate treatment techniques focusing on dysfunction and not only specific local injuries.

Any case report is accompanied by limitations. In the instance of a single case report with a focus on one subject there is going to be less clinical generalizability as compared to a case series or a study with a larger sample size. Through one subject there is no proven validity or reliability of the treatment. The nature of the subject’s complaint also plays a major role. Since there was no discernable injury and the issue at hand was a dysfunction, it is harder to compare cases in in future research. The subject was also given instructions to rest in between treatments but there was no monitoring of the individual during these times. Lastly, since multiple treatment interventions were used, it is hard to distinguish the amount of contribution of each to the eventual outcome.

**Table 2. Patient-reported outcomes.**

<table>
<thead>
<tr>
<th></th>
<th>IE Pre Tx 1</th>
<th>Post Tx 1</th>
<th>Pre Tx 2</th>
<th>Post Tx 2</th>
<th>Pre Tx 3</th>
<th>Post Tx 3/Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPAs</td>
<td>52</td>
<td>40*</td>
<td>26*</td>
<td>16*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPRS (Current)</td>
<td>8/10</td>
<td>2/10*</td>
<td>3/10</td>
<td>1/10</td>
<td>1/10</td>
<td>0/10</td>
</tr>
<tr>
<td>SPADI (Total Score)</td>
<td>21.25%</td>
<td>10.77%</td>
<td>2.30%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSFS</td>
<td>GH flexion = 3 GH ABD = 5 Throwing = 3 Avg = 3.67</td>
<td>GH flexion = 6* GH ABD = 7 Throwing = 4 Avg = 5.67*</td>
<td>GH flexion = 8 GH ABD = 9 Throwing = 7* Avg = 8*</td>
<td>GH flexion = 10 GH ABD = 10 Throwing = 8 Avg = 9.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DPAs=Disability in the Physically Active Scale; NPRS=Numeric Pain Rating Scale; SPADI=Shoulder Pain and Disability Index; PSFS=Patient Specific Functional Scale
ER; IR; ABD; Flex = measured using AROM

*MCID met: DPAs = 9
NPRS = 2
SPADI = 8 or 13.1 (Shoulder Pain)

**MDC met: SPADI = 18.1 (Musculoskel. UE Problems)
SPADI = 21.5 (Shoulder Problems)
PSFS = 2 (avg score), 3 (single activity)
CONCLUSIONS
The subject of this case report improved quickly as he returned to sport within a week. Given the clinically meaningful reduction in pain and improvements in reported function, this case report demonstrates how RNS combined with traditional therapeutic modalities positively affected the rehabilitation and return to sport of an adolescent overhead athlete. Future higher-level research is needed to fully explore the effectiveness of RNS when treating dysfunctional motor patterns.

REFERENCES


ABSTRACT

Background and Purpose: Tendinopathy of the supraspinatus muscle is a frequent cause of shoulder pain. Although it is a common condition, the pathophysiology is not fully understood. The purpose of this clinical commentary is to provide an overview of the pathophysiology of supraspinatus tendinopathy and discuss the conservative treatment solutions.

Description: Supraspinatus tendinopathy is thought to be caused by both intrinsic, and extrinsic factors. Structural and biological changes happen when tendinopathy develops. Cellular and extracellular modifications characterize tendon healing stages that continue over time. Assessment is paramount in order to differentiate the structure involved, and to offer a proper treatment solution.

Relation to Clinical Practice: Knowledge of the general concepts regarding the development of supraspinatus tendinopathy, and of the healing process should guide physiotherapists when proposing treatment options. Physical modalities commonly utilized for supraspinatus tendinopathy such as: laser, ultrasound, and shock-wave therapy have little and contradictory evidence. Exercise in form of eccentric training may be considered as it seems to have beneficial effects, however, more research is needed.

Key words: Rehabilitation, rotator cuff, shoulder
BACKGROUND AND PURPOSE
Tendinopathy is a generic term that indicates a condition characterized by pain in and around a tendon associated with repetitive activities, and impaired function that happens when the healing process fails to properly regenerate the tendon.\(^1\)\(^2\) Tendinopathies account for over 30% of musculoskeletal consultations, and shoulder pain is the third most common musculoskeletal complaint.\(^4\)

Tendon injuries of the rotator cuff (RC) are among the most common problems of the shoulder,\(^5\)\(^6\) affecting people performing sports as well as repetitive activities related to work or daily living.\(^7\)\(^8\) Moreover, tendinopathies of the RC increase with aging\(^10\) affecting more than 80% of the people over eighty years of age,\(^11\) with the supraspinatus tendon being the most commonly affected.\(^12\)\(^14\) Although supraspinatus tendinopathy is a frequent shoulder condition, to date a definitive understanding of the associated pathology remains elusive, and there is not agreement on treatment.\(^15\) Therefore, the purpose of this clinical commentary is to provide an overview of the pathophysiology of supraspinatus tendinopathy and discuss the conservative treatment solutions.

STRUCTURE OF THE SUPRASPINATUS TENDON
Along with the subscapularis, teres minor, and infraspinatus muscles, the supraspinatus joins to form the RC which functions to compresses the head of the humerus into the glenoid fossa of the scapula.\(^16\) The supraspinatus muscle originates from the posterior aspect of the scapula, superior to the scapular spine and inserts on the greater tuberosity of the humerus, blending partially with the tendon of the infraspinatus muscle.\(^17\)\(^18\) The supraspinatus muscle is a specialized nonhomogeneous structure subjected to both compressive, and tensile forces.\(^19\) Moreover, in order to better resist compression, and to lubricate collagen bundles during shoulder movements, there is an increased number of glycosaminoglycans within the supraspinatus tendon when compared with the distal region of the biceps tendon.\(^20\)

Structurally, the supraspinatus muscle consists of two different sub-regions: anterior and posterior. Anterior muscle fiber bundles are bipennate, with a thick and tubular tendon while the posterior counterpart has a more parallel fiber bundle orientation, with a thin, and strap-like tendon.\(^21\) These two sub-regions have different mechanical properties,\(^22\) with the loading stress being higher in the anterior sub-region.\(^21\) Studies have shown that the different regions of the supraspinatus muscle move independently to each other.\(^23\) Additionally, these two sub-regions can be divided into three parts: superficial, middle, and deep. This division is generally associated with the development of supraspinatus tears.\(^24\)

Anatomically, the insertional supraspinatus tendon is divided into four transitional layered zones according to the extracellular matrix (ECM) content.\(^25\) The first zone is essentially made up of Type I collagen and a small amount of decorin. This zone may be considered the tendon proper. The second zone consists of mainly Types II and III collagen, with small amounts of Types I, IX, and X collagen forming fibrocartilage. The third zone is defined by a mineralized fibrocartilage which is composed by Types II and X collagen, and aggrecan. The fourth zone is formed by Type I collagen, with the collagen fiber orientation defining the effective bone-tendon attachment.\(^19\)

As in other tendons of the human body, histological changes such as: vascular, cellular, and extracellular matrix modifications have been recurrently found also in supraspinatus tendinopathies.\(^19\)\(^26\)\(^27\)

ETIOLOGY OF SUPRASPINATUS TENDINOPATHY
The model explaining tendinopathy development has been changing over the years. Currently, it is generally accepted that supraspinatus tendinopathy develops when excessive stresses exceed the healing capacity of the tendon cells (tenocytes),\(^28\) with the tendon failing to repair properly.\(^2\)

Supraspinatus tendon disorders have been classically described as degenerative processes starting from an acute tendinitis, progressing to tendinosis, and eventually resulting in partial or full thickness tendon rupture.\(^28\)\(^31\) However, currently the terms tendinitis and tendinosis should be avoided and the word tendinopathy should be preferred as recent research shows that there are minimal or no inflammatory
cells in painful tendons. To date, it appears that tendon disorders arise from a variety of different etiologic factors. Lesions of the supraspinatus tendon seem to start where the loads are thought to be the greatest, in other words, at the articular surface of the anterior insertion on the humerus. Excessive mechanical loads at the supraspinatus tendon insertion have been thought to cause an increased rate of collagen synthesis and turnover that are often related to tendon tears and ruptures. Although supraspinatus tendinopathy etiology is still poorly understood, several intrinsic and extrinsic factors have been theorized as contributors to the development of supraspinatus tendinopathies.

**INTRINSIC FACTORS**

Age has been shown to correlate with tendinopathy, having a negative impact on tendon properties, especially after forty years of age. With age, tendons tend to degrade, decrease the ability to withstand tensile loads, and elasticity. Furthermore, in a study with subjects of fifty-two years of age and older, Kumanagai et al have shown that calcifications and fibrovascular proliferation changes, as well as a drop in total glycosaminoglycan and proteoglycan content are present in the aging supraspinatus tendon.

Vascularization supply related to healing of supraspinatus tendinopathy has been investigated with contradictory results. Although Codman identified an area with poor blood supply within the supraspinatus tendon in chronic RC tendinopathies, and in small RC tendon tears, there is evidence of abundant neovascularization that may crowd out necessary collagen, weakening the tendon properties. Interestingly, the neovascularization, and the increased blood flow in tendinopathies seem to normalize during the course of conservative exercise-based treatments. Structural tendon adaptation, tendon length changes, neuro-chemical alterations, fluid movement, neuro-muscular adaptations, and neuro-vascular ingrowth have been proposed as mechanisms of the beneficial effects of exercise training in tendinopathies. There seems to be a genetic component as a factor for tendinopathies related to the occurrence of different forms of collagen genes. In addition, there is a higher risk of developing supraspinatus tendinopathy in patients whose siblings sustained RC tears, and in males.

**EXTRINSIC FACTORS**

Extrinsic factors responsible for supraspinatus tendinopathy are all those anatomical and biomechanical alterations that eventually result in narrowing of the subacromial space. Impingement syndrome as the mechanical compression of the RC tendons is thought to be one of the most important reasons for supraspinatus tendinopathy and seems to be affected by acromial shape, acromial angle, and the presence of acromio-clavicular spurs. However, in a recent randomized surgical trial, the efficacy of surgery to reduce shoulder impingement by improving subacromial space (shoulder decompression) has been questioned as it does not appear to provide clinically significant benefits compared to arthroscopy only or no surgery.

Posterior capsule tightness may cause an anterior-superior migration of the humeral head which may alter the gleno humeral arthokinematics, leading to reduction of sub-acromial space, and shoulder impingement. Although still under debate, changes in scapular kinematics have been linked to supraspinatus and RC tendinopathy as well as strength deficits, and postural alterations. To date, it is widely agreed upon that tendinopathies are pathological processes originating from several factors rather than a single specific cause.

**TENDON CHANGES IN TENDINOPATHY**

Several different cells types make up the tendon cell population. Tenocytes are the most represented cell type in tendons and are responsible for maintenance of tendons’ health as they produce collagen and ECM secretion. They have a round shape at the fibrocatilaginous regions that becomes more elongated within the tensile-load-bearing regions in its tendon mid-substance. Additionally, there are synovial-like cells, smooth muscle cells, and endothelial cells associated with blood vessels. The ECM is a complex structural entity that surrounds the tendon cells, providing the ability to the tendon to resist mechanical loads, influencing the viscoelastic properties, and assisting in healing from injury. It is formed by structural proteins
Collagen and elastin, specialized proteins (fibrillin and fibronectin), and proteoglycans.96

With the development of tendinopathy there are changes that seem to appear consistently. (Table 1) Generally, there is hypoxia,37 an increased number of small nerves,36,97-99 increased nociceptive substances and neurotransmitters such as substance P, and glutamate.100-104 Tenocytes tend to lose their native shape,57,105,106 become narcotic/apoptotic, assuming a fibrochondrogenic phenotype, and growing in number.28,36,59,106-109 Specifically, Scott et al.28 found that in an animal model supraspinatus tenocytes become more chondroid and demonstrated increased proliferation as a result of an injury.

With regard to the ECM, there is a decrease in the collagen content, an increased ratio of type III/type I collagen, thinning of the collagen fibers, hyaline degeneration, chondroid metaplasia, and fatty infiltration.36,106 Frequently, there is also an increased presence of hyaluronan, and chondroitin dermanatan sulfate.26 Additionally, Riley et al.110 have shown that in RC tendinopathy there is increased collagenase (MMP1) activity correlated to reduced gelatinase (MMP2), and stromelysin (MMP3) activity. This suggests a high level of collagen turnover that may be an adaptive response to the mechanical demands.110

Some debate still exists on the presence or absence of inflammatory cells in tendinopathy.111 Some authors indicate that there are no inflammatory cells in degenerative tendons32-38,46,92,112 while others have reported presence of inflammatory cytokines with the development of tendinopathy.113,114 Macroscopically, tendinopathic tendons tend to present with an irregular gray/brown color, thin, soft and fragile crux in contrast to the brilliant white colored, and firm fibroelastic normal tendon.115

### TENDON HEALING

Tendon injuries heal because of scar tissue processes that may last from twelve88 up to twenty-four months.116 However, the final repaired tissue differs from the native tissue, with a higher concentration of type III collagen, and a lower concentration of type I collagen, resulting in a lower tensile strength.2,117,118

Classically, scar formation goes through a three-phase healing process that starts off with an inflammation phase followed by a reparative phase, ending with a remodeling phase.119 Inflammation deploys during the first seven days from injury, with a high activity of phagocytes, and initiation of type III collagen synthesis.120,122 After a few days, and for up to six weeks, growth factors enhance cellular proliferation and type III collagen is gradually replaced by type I collagen which is thought to have stronger tensile properties.120,121 As a result of fibers getting larger and with an improved interdigitation, the scar tissue becomes stronger as the healing process proceeds.2 At approximately the sixth week, the remodeling phase commences, with the fibrils becoming aligned along the direction of the mechanical loads, improving the cross linking.122 Thus, in about a year, the repaired tissue will have a scar-like appearance, and a stiff consistency.89 Supraspinatus tendinopathy healing seems to follow this general tissue repair process even when there is no overt tendon fiber rupture. This means that other factors such as: blood perfusion, microscopic fiber damage, or other

<table>
<thead>
<tr>
<th>Cell/Tissue/Structure Involved</th>
<th>Description of change(s)</th>
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<tr>
<td>Tendon cells</td>
<td>Tenocytes become rounder 57,105,106</td>
</tr>
<tr>
<td></td>
<td>Increase in cell number 59,106</td>
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<tr>
<td></td>
<td>Chondroid metaplasia 29</td>
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<tr>
<td></td>
<td>Cellular apoptosis 107-109</td>
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<tr>
<td>Extracellular matrix</td>
<td>Fatty infiltration/regeneration 16</td>
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<tr>
<td></td>
<td>Loss of matrix organization 26,36,106</td>
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<tr>
<td>Vascularity</td>
<td>Increased vascularity 8,34,53,55-64</td>
</tr>
<tr>
<td>General/Other</td>
<td>Increased number of small nerves 36,97-99</td>
</tr>
<tr>
<td></td>
<td>Increased nociceptive neurotransmitters 100-104</td>
</tr>
<tr>
<td></td>
<td>Presence of inflammatory cells/mediators 113-114</td>
</tr>
<tr>
<td></td>
<td>Hypoxia 37</td>
</tr>
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</table>
unknown aspects may be key to influencing tendon healing.26

EXAMINATION AND ASSESSMENT FOR SUPRASPINATUS TENDINOPATHY

Patient history is paramount when considering the presence or absence of supraspinatus tendinopathy. Questions regarding aggravating/easing factors, duration of symptoms, physical activities, and general medical conditions should always be included. A self-reported questionnaire such as the Shoulder Pain and Disability Index (SPADI) may be utilized to monitor progression of pain, and functioning.123 At the physical examination, pain commonly presents in the arc of motion between 60° and 120° of shoulder abduction/scapular plane abduction,124 but does not tend to radiate.31 Since the clinician should differentiate from other structures, provocation tests that load tendon fibers should be utilized.31 These tests are generally performed in the form of resisted abductions with the shoulder in internal or external rotation (empty/full can tests).125 A positive lag test should alert the practitioner regarding the possibility of a total supraspinatus tear.126 Imaging may be helpful for a correct diagnosis as supraspinatus tendinopathy generally occurs concomitant to other shoulder disorders.127,128 Magnetic resonance imaging and ultrasound may be used to visualize the supraspinatus tendon, helping make more accurate diagnosis129,130 as they may provide information regarding fatty of the tendon infiltration that are recognized signs of chronic tendon tears.131

CONSERVATIVE TREATMENT OPTIONS

Knowledge of pathophysiology, tissue properties, and tissue healing process are key factors when developing a targeted and safe rehabilitation program. Although a singular accepted treatment for supraspinatus tendinopathy has not been agreed upon, treatment solutions traditionally consist of anti-inflammatory drugs, rest, stretching, and strengthening exercises.115

The role of inflammation continues to be a point of controversy for intervention related to tendinopathy.111 Some authors who have investigated a variety of human tendons indicate that there are no inflammatory cells in degenerative tendons12,33,46,92 while others have reported an increased presence of inflammatory cells in pathological tendons.114,114,132 Therefore, corticosteroid injections, and non-corticosteroid anti-inflammatory drugs should be carefully utilized for pain relief, and for a limited time1,133,134 as chronic tendinopathies are mostly degenerative in nature, and as such, corticosteroids may have adverse effects on tendon healing.135-136 Complete immobilization of the tendon should be avoided as it may cause a protein synthesis reduction, an increase in collagenase activity,138 and a catabolic biological response.139-141

Since alterations of upper trapezius/lower trapezius, and upper trapezius/middle trapezius ratios,142 shoulder kinematics,143,144 and posterior capsule tightness4,76,80,145 have been associated with many shoulder disorders, correction of posterior shoulder tightness and restoration of glenohumeral joint and scapular kinematics are encouraged.146 Such interventions illustrate the important role of the physical therapist in conservative management of movement system dysfunction that may be associated with supraspinatus tendinopathy.

Therapeutic modalities commonly utilized for tendinopathies may help limit or reverse the degenerative process of tendinopathy by improving repair processes,115 and by reducing the expression of neo-vascularity often associated to tendon symptoms.147 Laser therapy seems to be beneficial148 and superior to therapeutic ultrasound.149 However, the evidence regarding the effects of the various modalities adopted to date including therapeutic ultrasound, laser, and extracorporeal shock-wave therapy on supraspinatus tendinopathy is limited, and often contradictory.150-153

Mechanical loading is essential for tendon homeostasis, repair,85,154-157 and for prevention of the negative effects of immobilization.158,159 Graduated tendon loading in the form of isometric, concentric, and eccentric exercises should be considered in the rehabilitation program. Appropriate loading forces induce a tensile stretch to tenocytes, and activate protein kineases.160 Moreover, stretching techniques if applied correctly (generally 30 second holds for three repetitions with 30 seconds between repetitions)161 may help the collagen turnover of the
REFERENCES


CONCLUSIONS

Supraspinatus tendinopathy is a common shoulder disorder that requires further research in order to have a better understanding of pathophysiology. There is still a lack of evidence regarding the effectiveness of treatment options currently being utilized. Eccentric training may represent an appropriate, inexpensive, and easy-to-perform solution for treatment of supraspinatus tendinopathy; however, more research is warranted.


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