ABSTRACT

**Background:** Returning to a satisfactory activity level is expected by patients after cartilage repair, and may define overall surgical success.

**Purpose:** To investigate: 1) the level and improvement in activity in patients at two years after matrix-induced autologous chondrocyte implantation (MACI), 2) what factors are associated with post-operative (and improvement in) activity level, and 3) whether patients are satisfied with their ability to participate in recreational and/or sporting activities.

**Study Design:** Prospective cohort.

**Methods:** One hundred and fifty patients that underwent MACI were included in this analysis (83 tibiofemoral and 67 patellofemoral). All patients completed the Tegner Activity Scale (TAS) and the Knee Injury and Osteoarthritis Outcome Score (KOOS) pre-surgery and at two years (range: 24-26 months) post-surgery, as well as a questionnaire evaluating satisfaction with their ability to return to recreational and sporting activities.

**Results:** The TAS significantly improved (p<0.001) from 2.97 (SD 0.92, range 0-7) to 4.09 (SD 1.49, range 0-9), while the KOOS Sport significantly improved (p<0.0001) from 27.5 (SD 23.1, range 0-95) to 61.1 (SD 27.3, range 0-100). Overall, 88 patients (59%) improved ≥1 point on the TAS, while 121 patients (81%) improved ≥10 points on the KOOS Sport, previously reported as the minimal detectable change for each. Patient age, duration of symptoms (DOS) and gender were associated with post-operative activity level, though body mass index (BMI), defect size and concomitant procedures were not. Overall, 128 patients (85%) were satisfied with their ability to return to recreational activities, with 99 (66%) satisfied with sport participation. The two-year TAS, and TAS improvement, were significantly associated with satisfaction in performing recreational activities (two-year TAS, rho = -0.42, p < 0.0001; TAS improvement, r = -0.33, p < 0.0001) and sport participation (two-year TAS, rho = -0.49, p < 0.0001; TAS improvement, r = -0.37, p < 0.0001).

**Conclusions:** The TAS and KOOS Sport significantly improved after MACI, though only 59% of patients improved ≥1 point on the TAS. Despite this, 85% and 66% of patients were satisfied with their ability to return to recreational activities and participate in sport, respectively. Age, DOS and gender were associated with activity, and overall these findings can be used to provide realistic activity expectations to patients undergoing MACI.

**Level of Evidence:** Level 3, prospective cohort study

**Keywords:** Chondral defect, clinical outcomes, matrix-induced autologous chondrocyte implantation, movement system, patient satisfaction, return to sport.

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**Conflict of Interest Statement:** No benefits in any form have been received or will be received from a commercial party related to the subject of this article.

**Ethics:** Ethics approval was obtained by the Hollywood Private Hospital (HPH145).

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INTRODUCTION
Matrix-induced autologous chondrocyte implantation (MACI) is a cartilage regenerative procedure that involves an initial cartilage biopsy, followed by isolation and cultivation of chondrocytes ex-vivo, seeding of cells onto a collagen membrane and subsequent re-implantation of the cell scaffold into the knee. MACI has demonstrated an ability to reduce pain and symptoms associated with full thickness cartilage defects. However, while Zak et al. reported that a reduction of symptoms is imperative, achieving a satisfactory post-operative activity level is often expected by the athletic patient, and may well define the overall success of the surgery. A systematic review reported that the rate of return to sport (RTS) varied from 75-89% after a range of knee cartilage repair procedures (osteochondral autograft and allografts, chondrocyte implantation and microfracture). A more recent meta-analysis by Krych et al. also reported that overall 76% of patients RTS at mid-term follow up (mean 47 months) after cartilage restoration surgery. While published evidence is relatively scarce on this topic, particularly with respect to MACI, Zak et al. reported that participation in regular sports similar to pre-injury recreational levels and intensity is possible for most patients following matrix-associated autologous chondrocyte transplantation (MACT). However, a range of factors may affect post-operative activity level (in addition to ongoing knee problems), including family and work commitments, as well as other musculoskeletal and health concerns, particularly in a community level patient cohort (as opposed to professional and elite athletes).

Given the limited research that exists on exactly what level of (and improvement in) activity MACI patients do attain after surgery, as well as what factors may affect post-operative activity and whether patients are indeed satisfied with their level of activity, this study sought to address these questions. The purpose of this study was to investigate: 1) the level of activity that a community level cohort of patients undergoing MACI attains at two years after surgery, 2) what factors are associated with post-operative activity level, as well as the improvement in activity level after surgery, and 3) whether patients are satisfied with their ability to participate in recreational and/or sporting activities. It was hypothesized that: 1) patient activity level would significantly improve following MACI, 2) certain factors (including defect location and size, gender, age) would be associated with the level of (and improvement in) post-operative activity level, and 3) a high percentage of patients would be satisfied with their ability to participate in recreational and/or sporting activities at two years following surgery.

METHODS
Patients
In this prospective study, 160 patients undergoing tibiofemoral (TF) or patellofemoral (PF) MACI were referred into a structured research program between July 2005 and April 2014, and followed for two years (range: 24-26 months) post-operatively. Patients were deemed suitable for MACI if they presented with symptomatic grade III/IV unipolar chondral lesions, assessed with the International Cartilage Repair Society (ICRS) classification system, were 15-65 years of age and deemed able to follow a structured rehabilitation program. MACI was contraindicated in the presence of ligamentous instability (unless it was to be addressed surgically at the time of MACI surgery), prior extensive meniscectomy (>1/3 meniscus), inflammatory arthritis and/or had varus/valgus lower limb mal-alignment (as indicated by > 3° TF anatomic angle). Joint mal-alignment was clinically assessed by the orthopaedic specialist, and long leg alignment radiographs (Maquet views) were ordered if the surgeon felt that further investigation was warranted. PF patients also underwent computed tomography (CT) imaging to assess the degree (if any) of patellofemoral knee joint mal-alignment. Patients underwent surgery by six orthopedic surgeons (with ≥8 years experience in orthopedic practice) operating out of five hospitals (four private and one public).

Of the 160 patients that underwent MACI surgery and were recruited, 10 patients could not be located for the two year clinical review, so were excluded from the analysis. Therefore, 150 patients (93.8%) were included, including 83 in the TF joint (63 medial femoral condyle; 20 lateral femoral condyle) and 67
in the PF joint (35 patella; 32 trochlea) (Table 1). Of the 150 patients, 92 patients (61.3%) had undergone prior surgery including arthroscopy (n=88), microfracture (n=4), partial meniscectomy (n=61), anterior cruciate ligament (ACL) reconstruction (n=8), extensor realignment (n=4) and/or lateral release (n=15). At the time of MACI, 40 patients (26.7%) underwent concomitant surgery including ACL reconstruction (n=5), posterior cruciate ligament reconstruction (PCLR) (n=3), partial meniscectomy (n=10), high tibial osteotomy (n=4) and combined lateral PF retinacular release and anteromedial tibial tubercle transfer (TTT) (n=26). All PF realignment surgeries were undertaken in the PF MACI group.

**Knee Surgery**

Initially, patients underwent arthroscopic knee surgery to harvest a sample of articular cartilage from a non weight bearing area of the knee. At this time, the chondral defect, together with meniscal and ligamentous integrity, were evaluated. The chondrocytes from the cartilage harvest were cultured for approximately six to eight weeks and seeded onto a type I/III collagen membrane (ACI-Maix Matricel GmbH, Germany). In a second stage surgery performed via open arthrotomy, the defect was prepared and the loaded membrane was fixed to the subchondral bone. On pre-operative CT imaging, 26 patients (all undergoing PF MACI) presented with lateralization of the tibial tuberosity >9mm, which was deemed an indication for concomitant lateral PF retinacular release and anteromedial tibial tubercle transfer (TTT) performed using the Heatley modification12 of the Fulkerson technique,13 in combination with MACI.

**Post-operative Management**

Early post-surgery, all patients (PF and TF MACI) underwent 0-30° continuous passive motion (within 12-24 hours) for a minimum of one hour daily; cryotherapy for edema control; ankle pump exercises; isometric quadriceps, hamstrings and gluteal contractions; practical education regarding proficient weight bearing (≤20% body weight), and education on how to fit their hinged knee brace (initially worn 24 hours

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**Table 1. Patient demographics at the time of surgery, for both the tibiofemoral (TF) and patellofemoral (PF) patient cohorts.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measure</th>
<th>TF</th>
<th>PF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>n</td>
<td>83</td>
<td>67</td>
</tr>
<tr>
<td>Defect Location</td>
<td>n (%)</td>
<td>63 (MFC), 20 (LFC)</td>
<td>35 (patella), 32 (trochlea)</td>
</tr>
<tr>
<td>Gender (males / females)</td>
<td>n (%)</td>
<td>52 (62.7) / 31 (37.3)</td>
<td>43 (64.2) / 24 (35.8)</td>
</tr>
<tr>
<td>BMI</td>
<td>Mean (range)</td>
<td>26.6 (18.4-36.2)</td>
<td>26.3 (19.4-36.7)</td>
</tr>
<tr>
<td>DOS (y)</td>
<td>Mean (range)</td>
<td>8.4 (1-26)</td>
<td>7.3 (1-21)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>Mean (range)</td>
<td>38.2 (15-62)</td>
<td>37.9 (20-65)</td>
</tr>
<tr>
<td>Defect Size (cm²)</td>
<td>Mean (range)</td>
<td>3.2 (0.7-10.0)</td>
<td>3.0 (0.7-12.2)</td>
</tr>
<tr>
<td>≤1.0</td>
<td>n (%)</td>
<td>7 (8.4)</td>
<td>9 (13.4)</td>
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<td>1.1-2.0</td>
<td>n (%)</td>
<td>18 (21.7)</td>
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<td>2.1-3.0</td>
<td>n (%)</td>
<td>14 (16.9)</td>
<td>11 (16.4)</td>
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<td>3.1-4.0</td>
<td>n (%)</td>
<td>13 (15.7)</td>
<td>6 (9.0)</td>
</tr>
<tr>
<td>4.1-5.0</td>
<td>n (%)</td>
<td>9 (10.8)</td>
<td>12 (17.9)</td>
</tr>
<tr>
<td>≥5.1</td>
<td>n (%)</td>
<td>22 (26.5)</td>
<td>15 (22.4)</td>
</tr>
</tbody>
</table>

MFC = medial femoral condyle; LFC = lateral femoral condyle; BMI = Body Mass Index; DOS = Duration of Symptoms.
per day, and progressed as per the recommendations in Table 2). All patients participated in an outpatient rehabilitation program over a 12-week period, with ongoing advice and education provided up until 12 months (and beyond) as required. Supervised by two primary therapists, rehabilitation over the period was undertaken by five therapists (Physiotherapists and Accredited Exercise Physiologists). An overview of the rehabilitation protocol followed is provided in Table 2. However, the progression of weight bearing, knee bracing and exercises differed depending on graft location (TF versus PF) and size, concomitant surgeries (i.e. ligament reconstruction, osteotomy etc.) and individual patient progression and load tolerance. Furthermore, while the exercise program consisted of a combination of supervised rehabilitation sessions (that became less frequent following the initial three months post-surgery) as well as home (and pool) based supplemental exercises, the frequency and dosage of each individual exercise differed based on the exercise (and recovery time that may be required) and individual patient progression and tolerance to the exercises.

Table 2. Overview of rehabilitation undertaken by tibiofemoral (TF) and patellofemoral (PF) patients participating in the research program.

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Rehabilitation Guidelines</th>
</tr>
</thead>
</table>
| Week 1-2 | - WB: ≤ 20% BW  
- Ambulatory Aids: 2 crutches used at all times  
- Knee ROM: passive and active ROM restricted to 0-30°  
- Knee Bracing: hinged brace, 0-30°  
- Rehabilitation: ankle pump exercises, isometric contractions (of the quadriceps, hamstrings, adductor and gluteal musculature) and straight leg exercises (hip flexion, extension, abduction and adduction), passive and active knee flexion exercises, soft tissue massage therapy, patella mobilization, CPM and cryotherapy |
| Week 3-6 | - WB: progress toward 60% BW (TF) and full WB (PF)  
- Ambulatory Aids : 1-2 crutches dictated by WB status  
- Knee ROM: progress toward 0-125° (TF and PF)  
- Knee Bracing: progress toward full permitted knee flexion (TF and PF)  
- Rehabilitation: continuation and progression (i.e. increasing load) of isometric/straight leg and passive/active knee flexion exercises, soft tissue massage therapy, patella mobilization, CPM as needed, cryotherapy. Inclusion of aquatic therapy exercises (including deep water forwards, backwards and sideways walking, heel raises, mini squats, straight leg hip flexion, extension, abduction & circumduction, knee flexion and extension, cycling, scissor kicks), heel raises, weighted isotonic hip flexion, extension, adduction and abduction, trunk strengthening (such as supine situps, weight supported isotonic trunk flexion), hamstring and calf stretches, recumbent cycling |
| Week 7-12 | - WB: progress toward full WB as tolerated  
- Ambulatory Aids: 1 crutch as required until full WB achieved  
- Knee ROM: full active ROM  
- Knee Bracing: full knee flexion (brace removed from 7-12 weeks)  
- Rehabilitation: introduction of proprioceptive/balance activities (such as double and single limb standing exercises on stable and unstable surfaces), upright stationary cycling, walking, progression of resistance (such as weighted isotonic knee flexion exercises) and CKC (such as flexed and straight leg bridging, single limb heel raises) exercises, quadriceps and gluteal stretches |
| 3-6 months | - Rehabilitation: introduction of rowing ergometry and elliptical trainers, OKC quadriceps-focused (such as terminal, progressing toward full range knee extension) and CKC (such as leg press, squats, lunges and step variations) exercises, initiation of plyometric and jump/land exercises relevant to the patient’s individual activity goals |
| 6-12 months | - Rehabilitation: gradual increase in difficulty/demands of proprioceptive/balance, and resistance during OKC and CKC exercises, plyometrics, introduction of agility drills relevant to patient’s sport, return to competitive activity after 12 months |

ROM = range of motion; BW = body weight; WB = weight bearing; CPM = continuous passive motion; CKC = closed kinetic chain; OKC = open kinetic chain.
Clinical Assessment
Firstly, the TAS was employed pre-surgery and at two years post-surgery to grade current work and sporting activities. This reports on the patient's activity level on a 0-10 point scale, ranging from sick leave or disability (0 points) through to elite competitive sports (10 points). Patients selected one of the levels of participation that best described their current activity level. While the minimum detectable change (MDC) for the TAS has been reported as 1 point in patients with ACL injuries and meniscal lesions, it has not been reported specifically for those with cartilage lesions or undergoing cartilage repair. Secondly, the Knee Injury and Osteoarthritis Outcome Score (KOOS) was employed in all patients. The KOOS is a knee specific questionnaire which includes five individual subscales: Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation (Sport) and Knee Related Quality of Life (QOL). Each of these five subscales is scored from 0 (worst) to 100 (best). The KOOS has proven valid, reliable and responsive to treatment following cartilage repair. Specifically for this study, the KOOS Sport subscale was employed to evaluate the improvement in sport-related activities (i.e. running, jumping, turning/twisting, kneeling and squatting). While evidence is lacking to suggest an MDC for the KOOS Sport subscale in patients undergoing cartilage repair, an MDC of 10 points is commonly employed.

Finally, at two years post-surgery a patient satisfaction questionnaire was employed, based on the Self-Administered Patient Satisfaction Scale (SAPSS) developed by Mahomed et al., though used previously for patients following MACI. This was employed to investigate each patient’s level of satisfaction with the MACI surgery overall, as well as their satisfaction with MACI in relieving knee pain, improving their ability to perform normal daily activities, improving their ability to return to recreational activities and improving their ability to participate in sport. A Likert response scale was employed with descriptors Very Satisfied, Somewhat Satisfied, Somewhat Dissatisfied and Very Dissatisfied.

Data and Statistical Analysis
Firstly, this study sought to investigate outcomes in community level patients undergoing MACI concomitantly with a range of other surgical procedures (26.7% of patients in this sample). However, it is acknowledged that these adjunctive procedures could influence post-operative activity and associated satisfaction so t-tests were employed to investigate differences in patient variables (age, BMI, defect size and duration of symptoms - DOS), the pre-operative and two-year post-operative TAS, as well as overall TAS improvement, between patients undergoing MACI with or without a concomitant procedure. No significant differences (p > 0.05) were observed between the groups in any variables, so these groups were collapsed and the entire cohort was included.

Repeated measures analysis of variance (ANOVA) was initially employed to investigate the mean change in the TAS and KOOS Sport subscale across the entire cohort from pre-surgery to two years post-surgery. Furthermore, the number of patients that improved by ≥1 point on the TAS and ≥10 points on the KOOS Sport subscale over the two year period, considered as the MDCs for these measures, was reported. T-tests were employed to investigate any differences in patient demographics (age and body mass index - BMI), injury and/or surgery history (defect size and DOS) and the TAS (pre-operative TAS, post-operative TAS and overall TAS improvement) within the following group comparisons: 1) TF and PF patients, 2) patella and trochlea cases (in the PF MACI cohort), 3) males and females, 4) defect size (≤2 and >2 cm²), 5) patient age (≤ and >40 years), and 6) those undergoing extensor realignment or not (in the PF MACI cohort). Pearson's correlations were employed to investigate the association between the TAS and KOOS Sport subscale, as well as that between the two-year post-operative TAS (and TAS improvement) and: 1) patient age, 2) defect size, 3) DOS and 4) BMI.

The level of patient satisfaction with their ability to 1) return to recreational activities and 2) participate in sport, was reported. Furthermore, the mean (SD) two-year TAS and mean (SD) TAS post-operative improvement was presented for each of the four satisfaction domains (Very Satisfied, Somewhat Satisfied, Somewhat Dissatisfied and Very Dissatisfied) across the entire cohort, and ANOVA was employed to compare the TAS among these four groups. Spearman's correlations were employed to investigate the association between the two-year post-operative
TAS (and TAS improvement) and patient satisfaction with MACI for improving the ability to undertake recreational activities and participate in sport. Statistical analysis was performed using SPSS software (SPSS, Version 19.0, SPSS Inc., USA), while statistical significance was determined at $p<0.05$.

**RESULTS**

Across the entire patient cohort (inclusive of all TF and PF patients), the TAS significantly improved ($p<0.001$) from 2.97 (SD 0.92, range 0-7) pre-surgery to 4.09 (SD 1.49, range 0-9) at two years post-surgery. A mean improvement of 1.12 (SD 1.55, range -3-6) TAS points was observed. A total of 88 patients (59%) improved ≥1 point on the TAS, including 50 TF patients (60%) and 38 PF patients (57%).

Across the entire patient cohort, the KOOS Sport significantly improved ($p<0.0001$) from 27.5 (SD 23.1, range 0-95) pre-surgery to 61.1 (SD 27.3, range 0-100) at two years post-surgery. A total of 121 patients (80.7%) improved ≥10 points on the KOOS Sport subscale, including 74 TF patients (89.2%) and 47 PF patients (70.2%). A moderate though significant association ($r=0.40$, $p<0.0001$) existed between the improvement in the TAS and KOOS Sport, over the two year period.

In comparing patients undergoing TF and PF MACI, there were no significant differences between the groups in age ($p=0.799$), BMI ($p=0.901$), defect size ($p=0.676$) and DOS ($p=0.200$), or the pre-operative ($p=0.455$), post-operative ($p=0.672$) and change ($0.887$) in TAS (Table 3). Specifically in the PF group, patients undergoing MACI for trochlea (versus patella) lesions had significantly larger defects ($p=0.001$); however, while both groups had similar TAS scores pre-operatively ($p=0.918$), the trochlea MACI group had significantly better TAS scores ($p<0.0001$) at two years post-surgery (Table 3). Furthermore, PF MACI patients that required (and hence underwent) extensor realignment surgery had significantly larger chondral defects ($TTT = 3.4cm^2$, no $TTT = 2.7cm^2$, $p=0.020$), compared with patients that did not require realignment (Table 3). Those that underwent concomitant extensor realignment had similar pre-operative TAS scores ($p=0.953$), though had significantly lower TAS scores ($p<0.0001$) at two years post-surgery (Table 3).

When comparing males and females, BMI was significantly greater ($p=0.002$) in males, though no difference was seen in all other demographic and/or surgical variables (Table 3). There was no significant difference ($p=0.221$) in the pre-operative TAS based on gender, though males reported significantly higher TAS scores ($p<0.0001$) at two years (Table 3). Patients $> 40$ years (versus ≤ 40) of age demonstrated a significantly greater DOS ($p=0.017$) and defect size ($p=0.008$) and, despite similar TAS scores pre-surgery ($p=0.451$), demonstrated a significantly worse TAS score ($p<0.0001$) at 2 years post-surgery (Table 3). While those undergoing MACI with a defect size $>2cm^2$ demonstrated a significantly lower ($p=0.013$) DOS than those with a defect size $\leq 2cm^2$, there were no other differences in patient demographics or pre- and post-operative TAS scores (Table 3). Correlations revealed that the TAS was significantly correlated with patient age (two-year TAS, $r=-0.46$, $p<0.0001$; TAS improvement, $r=-0.35$, $p<0.0001$) and DOS (two-year TAS, $r=-0.31$, $p<0.0001$; TAS improvement, $r=-0.24$, $p=0.003$), though there was no significant correlation with BMI or defect size.

Across the entire MACI cohort, 85% of patients were satisfied with the ability of MACI to improve their ability to return to recreational activities, 66% with the ability of MACI to participate in sport, and 85% were satisfied with the MACI surgery overall (Table 4). The mean TAS rating at two years post-surgery, together with the mean TAS improvement, is shown in Table 4, according to the patient's satisfaction level associated with improving the ability to return to recreational activities, improving the ability to participate in sport, and overall satisfaction level. When statistically comparing the mean two-year TAS (and TAS improvement), across the four satisfaction responses, in response to whether patients were satisfied with MACI for improving recreational activities there was no difference (two-year TAS, $p=0.242$; TAS improvement, $p=0.957$) between the Somewhat Satisfied (two-year TAS, mean 3.79; TAS improvement, mean 0.82) and Somewhat Dissatisfied (two-year TAS, mean 3.39; TAS improvement,
mean 0.85) domains. This was also observed in response to whether patients were satisfied with MACI for improving sport participation, with no difference (two-year TAS, \( p = 0.748 \); TAS improvement, \( p = 0.724 \)) between the Somewhat Satisfied (two-year TAS, mean 3.80; TAS improvement, mean 0.82) and Somewhat Dissatisfied (two-year TAS, mean 3.89; TAS improvement, mean 0.71) domains.

The two-year TAS and TAS improvement, were significantly associated with patient satisfaction in performing recreational activities (two-year TAS, \( \rho = -0.42 \), \( p < 0.0001 \); TAS improvement, \( r = -0.33 \), \( p < 0.0001 \)) and satisfaction in participating in sport (two-year TAS, \( \rho = -0.49 \), \( p < 0.0001 \); TAS improvement, \( r = -0.37 \), \( p < 0.0001 \)).

**DISCUSSION**

Limited research exists on exactly what level of activity patients do attain after MACI, as well as whether patients are indeed satisfied with their post-operative activity level. This study sought to primarily investigate the level of (and improvement in) activity that a community level cohort of patients can achieve after MACI.

<table>
<thead>
<tr>
<th>Group Comparison</th>
<th>Group</th>
<th>Age (y)</th>
<th>DOS (y)</th>
<th>BMI</th>
<th>Defect Size (cm²)</th>
<th>Pre-operative Tegner</th>
<th>Post-operative Tegner</th>
<th>Tegner Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graft Location</td>
<td>TF</td>
<td>38.2±11.3</td>
<td>8.4±7.8</td>
<td>26.6±4.0</td>
<td>3.1±2.4</td>
<td>2.9±1.1</td>
<td>4.0±1.4</td>
<td>1.1±1.6</td>
</tr>
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<td></td>
<td>(15-62)</td>
<td>(1-26)</td>
<td></td>
<td></td>
<td>(18.4-36.2)</td>
<td>(0.7-10.0)</td>
<td>(0-7)</td>
<td>(1-8)</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>37.9±11.3</td>
<td>7.3±5.5</td>
<td>26.3±4.3</td>
<td>3.0±2.0</td>
<td>3.0±0.6</td>
<td>4.1±1.6</td>
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<tr>
<td></td>
<td>(20-65)</td>
<td>(1-21)</td>
<td></td>
<td></td>
<td>(19-4.36.7)</td>
<td>(0.7-12.2)</td>
<td>(0-5)</td>
<td>(2-9)</td>
</tr>
<tr>
<td>p value</td>
<td>0.799</td>
<td>0.200</td>
<td>0.901</td>
<td>0.676</td>
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<td>0.672</td>
<td>0.887</td>
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<td>PF Graft Location</td>
<td>Patella</td>
<td>37.5±11.3</td>
<td>7.8±4.7</td>
<td>25.6±4.4</td>
<td>2.6±1.5</td>
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<td></td>
<td>(25-62)</td>
<td>(1-18)</td>
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<td></td>
<td>Trochlea</td>
<td>38.7±11.3</td>
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<td>(20-65)</td>
<td>(1-21)</td>
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<td></td>
<td>(19-4.36.0)</td>
<td>(1.0-12.2)</td>
<td>(0-5)</td>
<td>(2-9)</td>
</tr>
<tr>
<td>p value</td>
<td>0.620</td>
<td>0.104</td>
<td>0.399</td>
<td>0.001</td>
<td>0.918</td>
<td>&lt;0.0001</td>
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<td>&lt;0.0001</td>
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<tr>
<td>Gender</td>
<td>Males</td>
<td>37.9±12.1</td>
<td>7.9±5.5</td>
<td>27.2±3.7</td>
<td>3.3±2.4</td>
<td>3.0±1.0</td>
<td>4.4±1.5</td>
<td>1.4±1.6</td>
</tr>
<tr>
<td></td>
<td>(15-65)</td>
<td>(1-23)</td>
<td></td>
<td></td>
<td>(20-2.36.7)</td>
<td>(0.7-12.2)</td>
<td>(1-9)</td>
<td>(1-6)</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>38.9±9.7</td>
<td>8.9±8.2</td>
<td>25.1±4.4</td>
<td>2.9±1.8</td>
<td>2.9±1.0</td>
<td>3.6±1.2</td>
<td>0.7±1.4</td>
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<tr>
<td></td>
<td>(22-60)</td>
<td>(1-26)</td>
<td></td>
<td></td>
<td>(18-4-34.4)</td>
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<td>(1-7)</td>
<td>(2-8)</td>
</tr>
<tr>
<td>p value</td>
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<td>0.002</td>
<td>0.090</td>
<td>0.221</td>
<td>0.001</td>
<td>&lt;0.0001</td>
<td>0.001</td>
</tr>
<tr>
<td>Defect Size</td>
<td>≤2cm²</td>
<td>38.0±12.3</td>
<td>10.1±8.3</td>
<td>26.0±4.1</td>
<td>1.4±0.4</td>
<td>3.0±1.1</td>
<td>4.2±1.5</td>
<td>1.2±1.7</td>
</tr>
<tr>
<td></td>
<td>(15-65)</td>
<td>(1-23)</td>
<td></td>
<td></td>
<td>(18-4-36.7)</td>
<td>(0.7-2.0)</td>
<td>(1-7)</td>
<td>(3-9)</td>
</tr>
<tr>
<td></td>
<td>&gt;2cm²</td>
<td>39.7±10.3</td>
<td>7.0±5.0</td>
<td>26.8±4.0</td>
<td>4.7±2.1</td>
<td>2.9±0.8</td>
<td>4.0±1.3</td>
<td>1.1±1.4</td>
</tr>
<tr>
<td></td>
<td>(17-62)</td>
<td>(1-26)</td>
<td></td>
<td></td>
<td>(19.5-36.2)</td>
<td>(2.2-12.2)</td>
<td>(0-5)</td>
<td>(1-7)</td>
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<td>p value</td>
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<td>0.013</td>
<td>0.711</td>
<td>&lt;0.0001</td>
<td>0.722</td>
<td>0.190</td>
<td>0.400</td>
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</tr>
<tr>
<td>Age</td>
<td>≤40 y</td>
<td>30.0±6.3</td>
<td>7.0±5.8</td>
<td>26.3±3.9</td>
<td>2.9±2.2</td>
<td>3.1±0.9</td>
<td>4.6±1.6</td>
<td>1.5±1.7</td>
</tr>
<tr>
<td></td>
<td>(15-39)</td>
<td>(1-26)</td>
<td></td>
<td></td>
<td>(19-4-36.7)</td>
<td>(0.7-12.2)</td>
<td>(0-7)</td>
<td>(2-9)</td>
</tr>
<tr>
<td></td>
<td>&gt;40 y</td>
<td>48.3±7.1</td>
<td>9.9±7.8</td>
<td>26.4±4.3</td>
<td>3.4±2.3</td>
<td>2.9±0.9</td>
<td>3.5±1.1</td>
<td>0.7±1.3</td>
</tr>
<tr>
<td></td>
<td>(41-65)</td>
<td>(1-26)</td>
<td></td>
<td></td>
<td>(18-4-36.2)</td>
<td>(0.7-10.0)</td>
<td>(0-7)</td>
<td>(1-8)</td>
</tr>
<tr>
<td>p value</td>
<td>&lt;0.0001</td>
<td>0.017</td>
<td>0.829</td>
<td>0.008</td>
<td>0.451</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>PF MACI (with and without realignment)</td>
<td>PF MACI</td>
<td>40.3±12.9</td>
<td>9.0±5.4</td>
<td>25.9±3.8</td>
<td>2.7±2.3</td>
<td>3.0±0.6</td>
<td>4.4±1.7</td>
<td>1.4±1.6</td>
</tr>
<tr>
<td></td>
<td>(20-65)</td>
<td>(1-21)</td>
<td></td>
<td></td>
<td>(19-4-36.7)</td>
<td>(0.7-12.2)</td>
<td>(0-5)</td>
<td>(3-9)</td>
</tr>
<tr>
<td></td>
<td>PF MACI (with TTT)</td>
<td>37.2±7.9</td>
<td>5.8±5.1</td>
<td>26.5±5.0</td>
<td>3.4±1.5</td>
<td>3.0±0.5</td>
<td>3.7±1.4</td>
<td>0.7±1.4</td>
</tr>
<tr>
<td></td>
<td>(23-49)</td>
<td>(1-18)</td>
<td></td>
<td></td>
<td>(19-5-33.9)</td>
<td>(1.0-6.0)</td>
<td>(0-5)</td>
<td>(2-7)</td>
</tr>
<tr>
<td>p value</td>
<td>0.111</td>
<td>0.001</td>
<td>0.741</td>
<td>0.020</td>
<td>0.953</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>

PF= patellofemoral, MACI = Matrix-Induced Autologous Chondrocyte Implantation, TTT= tibial tubercle transfer, DOS= duration of symptoms, BMI= body mass index
patients attains at two years after MACI. Second, it sought to investigate what factors were associated with post-operative activity level, as well as whether patients were satisfied with their ability to participate in recreational and/or sporting activities. The most important finding from this study is that while a significant mean improvement was observed in the TAS and KOOS Sport as a result of MACI, only 59% of patients improved ≥1 point in the TAS and only 57% reported ≥4 points on the TAS at two years post-surgery. Despite this, 85% of patients were still satisfied with the ability of MACI to improve their ability to return to recreational activities, 66% with the ability of MACI to participate in sport, and 85% were satisfied overall with their MACI outcome.

This study employed the TAS as the activity-specific measure, with the KOOS Sport also reflecting change in sport-related tasks. A systematic review by Hambly reported that 88% of cartilage repair studies demonstrated post-operative TAS improvement, though this spanned all cartilage procedures, with limited evidence specifically in MACI. The current study demonstrated a significant mean group improvement of 1.12 TAS points; however, only 59% of patients demonstrated an absolute TAS improvement (similar between TF and PF MACI), despite 81% of patients improving ≥10 points in the KOOS Sport. Furthermore, only 57% of patients reported ≥4 points on the TAS at two years, albeit the majority (91%) reported a TAS of ≤3 points before surgery. Therefore, given prior studies report mean improvement in the TAS after cartilage repair, caution is required in interpreting mean improvement in the absence of data reporting individual improvement rates.

A number of factors may influence post-operative activity level. Firstly, this study did not demonstrate any difference between TF and PF MACI patients. However, while patients undergoing MACI for

<table>
<thead>
<tr>
<th>Satisfaction Question</th>
<th>Level of satisfaction with improving the ability to return to recreational activities?</th>
<th>Level of satisfaction with improving the ability to participate in sport?</th>
<th>Level of satisfaction with the MACI surgery overall?</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Very Satisfied</em> (n)</td>
<td>70</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>TAS (mean ± SD, range)</td>
<td>4.67 ± 1.75, 1-9</td>
<td>5.18 ± 1.79, 3-9</td>
<td>4.59 ± 1.71, 1-9</td>
</tr>
<tr>
<td>TAS Improvement (mean±SD, range)</td>
<td>1.53 ± 1.73, -3-6</td>
<td>1.98 ± 1.75, -3-6</td>
<td>1.49 ± 1.66, -3-6</td>
</tr>
<tr>
<td><em>Somewhat Satisfied</em> (n)</td>
<td>58</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td>TAS (mean ± SD, range)</td>
<td>3.79 ± 1.17, 1-9</td>
<td>3.80 ± 1.22, 1-7</td>
<td>3.83 ± 1.23, 2-7</td>
</tr>
<tr>
<td>TAS Improvement (mean±SD, range)</td>
<td>0.82 ± 1.33, -1-5</td>
<td>0.82 ± 1.39, -1-5</td>
<td>0.96 ± 1.41, -1-5</td>
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<tr>
<td><em>Somewhat Dissatisfied</em> (n)</td>
<td>13</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>TAS (mean ± SD, range)</td>
<td>3.39 ± 0.87, 2-6</td>
<td>3.89 ± 1.22, 3-7</td>
<td>3.23 ± 0.83, 3-6</td>
</tr>
<tr>
<td>TAS Improvement (mean±SD, range)</td>
<td>0.85 ± 1.14, 0-3</td>
<td>0.71 ± 1.12, -1-3</td>
<td>0.39 ± 1.16, 0-3</td>
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<tr>
<td><em>Very Dissatisfied</em> (n)</td>
<td>9</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>TAS (mean ± SD, range)</td>
<td>2.67 ± 0.50, 2-3</td>
<td>3.00 ± 0.51, 2-4</td>
<td>3.00 ± 0.82, 2-4</td>
</tr>
<tr>
<td>TAS Improvement (mean±SD, range)</td>
<td>-0.33 ± 0.50, -1-0</td>
<td>0.50 ± 1.18, -1-3</td>
<td>-0.30 ± 0.48, -1-0</td>
</tr>
<tr>
<td>Overall Satisfied (%)</td>
<td>85.3%</td>
<td>66.0%</td>
<td>84.7%</td>
</tr>
<tr>
<td>Overall Dissatisfied (%)</td>
<td>14.7%</td>
<td>34.0%</td>
<td>15.3%</td>
</tr>
</tbody>
</table>

MACI= Matrix-Induced Autologous Chondrocyte Implantation
trochlea (versus patella) lesions specifically in the PF MACI group demonstrated significantly larger chondral defects, the trochlea MACI group actually had significantly better post-operative TAS scores, as well as overall TAS improvement. This finding was surprising, and may be related to the variation in geometry and loading of the two PF surfaces during movement. Furthermore, PF MACI patients undergoing concomitant extensor realignment surgery demonstrated significantly larger chondral defects, compared with patients that were deemed to have normal alignment undergoing MACI in isolation for PF cartilage lesions, and also demonstrated an inferior improvement in the post-operative TAS. The evidence is mixed when evaluating the effect that prior and/or concomitant surgery (i.e. ligamentous and/or meniscal repair, TF or PF re-alignment) has on post-operative activity level and RTS, when performed in combination with a cartilage repair procedure. A recent study reported similar clinical and radiological outcomes in patients undergoing TF and PF MACI (only Level 3 evidence), though it did not report pre- and post-operative activity.

Generally, younger patients have a higher likelihood of returning to sports and, as expected, the TAS was significantly correlated with age in the current study, with patients ≤40 years of age demonstrating better post-operative TAS scores and TAS improvement, compared with those >40 years. While no association was observed between activity and BMI (or graft size), Pestka et al. reported that 73% of patients returned to sport after chondrocyte implantation, though neither defect location nor graft size were associated with the return to physical activity. While the pre-operative TAS did not differ based on gender, largely as a result of patients being evaluated in their symptomatic state, males reported significantly higher TAS scores at two years. However, DOS in this study was significantly correlated with activity. Mithoefer et al. reported that the pre-operative DOS did influence the rate of RTS in an athletic population. They further demonstrated that patients with a longer DOS had significantly lower TAS scores post-operatively. This is in contrary to Zak et al. However, these studies appeared to stratify DOS by either < or > 12 months. This may be fine if the maximum DOS is two to three years in which activity level may not change too much for even a healthy unaffected active individual, though recalling activity over a longer time frame may prove difficult for many, while expecting activity level not to naturally change over five years or more, which is often unrelated to health (rather work, family etc.), is likely unrealistic. Therefore, in MACI patients it may not be appropriate to compare pre-injury to post-operative active level in patients with a longer DOS as reported in this study (the mean DOS in this study was 8.3 years and 7.3 years for TF and PF MACI patients, respectively).

Research reporting return to activity and/or sport rates after MACI is limited. After a range of cartilage repair procedures (osteochondral autograft and allografts, chondrocyte implantation and microfracture), 75-89% of patients returned to sports participation though this systematic review was undertaken in athletes. A more recent meta-analysis by Krych et al. also reported that overall 76% of patients RTS at mid-term follow up after cartilage restoration surgery, ranging from 58% (microfracture) to 93% (osteochondral autograft). Particularly in a community-level patient cohort (as opposed to professional athletes), a range of factors will affect post-operative activity level above and beyond ongoing knee problems, including family and work commitments, as well as other musculoskeletal and health concerns. Erdle et al. recently reported that the pre-morbid level of sporting and recreational activities cannot be achieved at a minimum of 10 years after first-generation chondrocyte implantation, though they did not inquire as to when patients altered their post-operative activity, nor the reasons behind this. The current study did not evaluate other factors that can contribute to post-operative activity, though these reasons for not attaining a higher activity profile must be acknowledged. This study therefore aimed to not only evaluate the actual post-operative activity level, rather it also assessed each individual patient's level of satisfaction with what they could do, which may take into account these other factors not otherwise evaluated.

In this study, the TAS was associated with patient satisfaction in both performing recreational activities and participating in sport. However, while 59% of patients in this study reported an improvement in
the post-operative TAS as a result of surgery, 85% of patients were still satisfied with the ability of MACI to improve their ability to return to recreational activities, and 66% with their ability to participate in sport. This discrepancy may highlight the aforementioned issue in employing the TAS itself, whereby patients may be able to participate in a higher level of activity, rather they have reduced this due to other reasons. This may also provide rationale for the difference in the percentage of patients surpassing the MDC in the TAS (≥1 point, 59%) and KOOS Sport (≥10 points, 81%) in the current study, whereby the TAS requires patients to report their current activity level, though the KOOS Sport requires patients to report their level of difficulty in performing sport-related tasks. It was interesting to note that when comparing the groups who were either Somewhat Satisfied or Somewhat Dissatisfied with their ability to undertake recreational activities and/or sport, no group difference in the TAS existed. This would again suggest that there are other factors that will influence the patient’s perceived satisfaction toward their ability to be active.

Some limitations are acknowledged in this study. Firstly, this study employed the TAS as its activity-specific score. The TAS does not evaluate the reason for change in activity that may be unrelated to the knee, and other activity scales such as the Noyes Activity Score could be considered in future research. Secondly, it did not assess the actual time to return to particular activities or sports, nor the level of pre-injury activity level, rather only activity level (and associated restrictions) when symptomatic. Therefore, this study cannot report on whether patients returned to their pre-injury activity levels; only that patients improved from their symptomatic state as a result of surgery, and whether or not they were satisfied with this post-operative level. Again, evaluating pre-injury activity is difficult in MACI patients given the often lengthy DOS (as seen in this patient cohort), unlike those who may undergo ACL reconstruction almost immediately after an acute ACL injury.

Thirdly, almost 27% of patients in this sample underwent MACI concomitantly with another surgical procedure. While this can be seen as a limitation, a patient sample undergoing various concomitant surgeries is also a strength given this study sought to evaluate a community level cohort of patients who often undergo MACI in combination with a range of other procedures. A preliminary statistical analysis also demonstrated no differences in patient factors or TAS outcomes between those undergoing MACI alone or combined with another procedure. Furthermore, we acknowledge the range of defect sizes, and that smaller lesions may be amenable to alternative procedures such as microfracture. However, MACI was the preferred method of the treating surgeons referring patients for the research program. Finally, given this was a large cohort of patients undergoing MACI for symptomatic knee cartilage defects, the group was heterogeneous with respect to graft size and location, concomitant procedures, patient age and other demographical parameters, diligence in rehabilitation, pre-operative activity/sport level and activity level desired post-surgery. However, this also presents a study strength, given it aimed to report on post-operative activity level (and satisfaction with) in a community-level cohort of patients undergoing MACI, as opposed to an elite group of athletes.

CONCLUSION

The TAS and KOOS Sport significantly improved in patients two years after MACI, though only 59% of patients improved ≥1 TAS point. Despite this, 85% and 66% of patients were satisfied with their ability to return to recreational activities and participate in sport, respectively. Age, DOS and gender were associated with post-operative activity. These findings can be used to provide realistic activity expectations to patients undergoing MACI.

REFERENCES


ABSTRACT

Background: Unaccustomed eccentric exercise during sport or training may lead to delayed onset muscle soreness (DOMS), which has been demonstrated to influence postural control, potentially resulting in further injury. Afferent sensory input is critical to effective postural control, but little is known about somatosensory changes at the knee following induction of DOMS of the quadriceps muscle. The ‘soreness’ or hyperalgesia associated with DOMS has been postulated to occur because of damage to/inflammation of the exercised muscle, however, effects on central nociceptive mechanisms, which are known to induce altered postural responses, have been less studied.

Purpose/Hypothesis: It was hypothesized that DOMS of the quadriceps muscle would result in widespread hyperalgesia and hypoesthesia at the knee. Therefore, the purpose of this study was to investigate the effects of DOMS on knee somatosensory changes in asymptomatic healthy participants.

Study Design: Quasi-experimental cohort study

Methods: Thirty participants (15 males and 15 females) took part in the study. Eccentric exercise consisted of 10 sets of 10 maximum eccentric quadriceps contractions performed with the dominant knee. Outcome measures consisted of pain intensity (Visual Analog Scale), pressure pain threshold (PPT), vibration perception threshold (VPT) and proprioception, measured via threshold to detection of passive motion (TDPM) at the knee, at three different assessment time points: (1) pre-eccentric exercise; (2) immediately and (3) 48 hours post-eccentric exercise.

Results: Not surprisingly, pain intensity increased and PPT of the vastus medialis and rectus femoris muscles decreased (hyperalgesia) immediately post-exercise on the exercised limb. However, at 48 hours, hyperalgesia was demonstrated at other lower extremity muscles, including bilaterally at the tibialis anterior muscles, and also at the hand. Evidence of hypoesthesia was also demonstrated. VPT and TDPM increased (worsened) ipsilaterally both immediately and 48 hours after exercise, and TDPM increased bilaterally at 48 hours. Females demonstrated greater impairment in TDPM than males at 48 hours. Expanding distribution of hyperalgesia, ipsilaterally impaired VPT and bilaterally impaired proprioception were demonstrated in the presence of DOMS.

Discussion/Conclusion: Inflammation from unaccustomed eccentric exercise may induce neuroplastic changes in nociceptive pathways resulting in wider distribution of pain and hypoesthesia. Futures studies examining the effect of DOMS related somatosensory changes on postural control may be warranted.

Level of evidence: 3

Key words: Eccentric exercise, exercise-induced damage, gender, knee, quantitative sensory
INTRODUCTION
Delayed onset muscle soreness (DOMS) is common in sport, and is defined as a subacute pain state usually arising 24-48 hours after a bout of unaccustomed eccentric muscle contractions.1 DOMS has been attributed to an inflammatory reaction and nociceptive sensitization induced by minor myofibrillar and cytoskeletal damage occurring during eccentric exercise2 and is generally characterized by muscle pain, impaired force production and increased fatigability. Signs and symptoms found with DOMS have been attributed in part to central sensitization of nociceptive pathways.3 Central sensitization, or nociplasticity, has been identified in both chronic4 and acute5 musculoskeletal conditions and is associated with a number of somatosensory changes demonstrated via quantitative sensory testing. For example, widespread pain hyperalgesia,4 vibratory perception deficits and mechanical hypoesthesia6 have been demonstrated in patients with knee osteoarthritis, potentially contributing to functional deficits observed in this patient population.6,7 Somatosensory changes have also been demonstrated following acute knee injury. Individuals at greater than one-year post-anterior cruciate ligament (ACL) reconstruction demonstrated somatosensory deficits in both proprioception (TDPM) and vibratory perception in the surgical knee, when compared to both the opposite limb and to knees of age and sex matched controls.8 Studies of experimentally induced muscle pain may provide a controlled means to examine the sensory changes that occur with musculoskeletal injury.9

In studies with induced DOMS, muscle hyperalgesia has been demonstrated through pressure algometry over the exercised muscle3 and in an expanded distribution regional to the exercised muscle.10 This increased local and regional pain sensitivity potentially implicates alterations in both peripheral and central nociplastic mechanisms in DOMS-induced hyperalgesia. At the quadriceps muscle, Hedayatpour et al found pressure hyperalgesia, i.e., a decrease in pressure pain threshold (PPT), mostly in the distal aspect of the muscle after induction of DOMS.11 Understanding the underlying mechanisms of altered somatosensation and motor control post-injury may aid in developing both management and injury prevention strategies.

Impaired proprioceptive acuity following onset of DOMS has been reported, including alterations in joint position sense12 and force sense.13 Diminished sensory input is believed to adversely affect postural control.14 Correspondingly, altered postural responses to unexpected perturbations,15 and altered quadriceps muscle activation patterns,15 have also been observed after induction of DOMS. Considering that the muscle spindle is thought to provide the main input to proprioception,16 Brockett et al17 proposed that eccentric exercise may damage intrafusal as well as extrafusal muscle fibers leading to proprioceptive deficits; however, this would not explain other sensory phenomena that have been reported with induction of DOMS.18

High-resistance strength training, including components of eccentric exercise, is commonly used by athletes to enhance performance, with DOMS occurring as a common consequence of this type of training. Inadequate recovery from DOMS can lead to overtraining,19 altered motor control and further injury. DOMS of the quadriceps may lead to somatosensory changes at the knee, yet few studies have investigated this hypothesis. Therefore, the purpose of this study was to investigate the effects of DOMS on knee somatosensory changes in asymptomatic healthy participants. It was hypothesized that DOMS elicited in the quadriceps muscle would result in widespread hyperalgesia (demonstrated by lower PPTs in the upper as well as the lower limbs,) and sensory hypoesthesia at the knee measured via vibration perception threshold (VPT) and threshold to detection of passive motion (TDPM).

METHODS
Participants
Healthy volunteers (age 18-35) were recruited by local advertisement from the general population and invited to participate in the study. The participants had no previous knee injury, denied pain in any body part, and had not taken any pain-relieving, anti-inflammatory or psychiatric medications in the month prior to the study. Participants were blinded to the results during the testing period and no information on the postulated hypothesis was provided. All participants read and signed a written consent form prior to their participation in the study. The
Eccentric Exercise Protocol
The participants were seated on a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) with the body stabilized by straps over the thighs, waist, and chest and the lateral epicondyle of the femur aligned with the axis of rotation. In order to induce DOMS, one bout of 10 sets of 10 maximum eccentric quadriceps contractions of the dominant knee were performed at 60°/s with the range of motion set to 10° of knee flexion and 90° knee flexion and the isokinetic dynamometer set in continuous passive mode. Leg dominance was determined by asking the participant which leg they would use to kick a ball. The dynamometer passively extended the limb between each eccentric action of the knee extensors. One minute of rest was allotted between sets. Verbal encouragement was given during each set to promote maximal effort. Prior to the exercise session, participants performed a warm-up consisting of eight minutes of cycling on a cycle ergometer (Monark, Vansbro, Sweden) at 70 rpm and 50 watts as previously described. Participants were advised to maintain a normal level of activity between data collection time points.

Outcome Measures
Outcome measures were serially assessed at baseline, immediately after the eccentric exercise protocol, and 48 hours post-exercise. A Visual Analog Scale (VAS) was used to assess the perceived maximal intensity of muscle pain 48 hours before, via recall, and 48 hours post-exercise during their regular activities of daily living (e.g. walking, stair climbing and sit to stand), and also immediately after the eccentric exercise protocol during walking. Pressure pain threshold was bilaterally assessed over both lower extremities. The tip (area: 1cm²) of an algometer (Model FDX100, Wagner Instruments, CT, USA) was applied perpendicularly to the tissue, at a steady rate of increasing pressure until the individual reported a change from pressure to a pain. Prior to PPT assessments, the participants were familiarized with algometric testing on their arm to clarify the procedure. The assessments were performed twice, and the mean calculated to determine the PPT which was used for analysis. An interval of at least 20 seconds was maintained between each PPT assessment. Participants were blinded to results. All assessments were performed by the same tester (KA) who was not blinded. PPT has shown excellent inter-rater reliability in healthy humans. PPT was assessed bilaterally, in a random order, over the muscle belly of the rectus femoris, vastus medialis, and tibialis anterior muscles. In addition, PPT at the webspace between the contralateral first and second metacarpal of the hand was also assessed to evaluate for widespread changes (Figure 1). Test areas were marked with an indelible pen to maintain consistent test sites on subsequent assessments. All somatosensory testing was performed with the participant in sitting on the Biodex isokinetic dynamometer.

Figure 1. Sites for sensory assessment (Star indicates site of pressure pain threshold; Triangle indicates vibration perception threshold).
VPT was assessed bilaterally using a Biothesiometer (Bio-Medical, OH, USA) applied at the center of the patella. Excellent intra-rater and test-retest reliability has been reported. The vibratory tip (13 mm cylinder) oscillates at a frequency of 100 Hz at the site of application and the vibration amplitude of vibration (expressed in “biothesiometer units”) was increased until the participant perceived an initial vibration sensation. Three trials of this measurement were taken and the mean was used in the main analysis.

Proprioception was examined using TDPM. This method has been shown in a previous study by these authors to be reliable and has been used previously in athletes and patients. Participants were tested in the seated position (hip flexed at 70˚, knee flexed at 45˚, ankle in neutral) on the Biodex System 3 (Biodex Medical Systems Inc, Shirley, NY, USA). A custom-made device, utilizing a motor and pulley system, moved the extremity passively into either flexion or extension at a slow rate (0.5˚/s) after a random delay. The direction of movement and limb to be tested was randomly assigned. The participant was provided a handheld switch and was instructed to push the switch upon detecting change of joint position. An air splint inflated to 20 mm Hg was placed on the foot to minimize cutaneous input. The participant was blindfolded and listened to white noise to minimize visual and auditory inputs, respectively. Before every trial the participant was asked to co-contract the knee for 10 s to minimize the effects of thixotropy which can alter TDPM. A pre-test trial was followed by three actual trials, the mean of which was used for data analysis. The amount of linear movement of the pulley (x) was documented and used to obtain the angle of threshold to detection of motion (θ in degrees) using the formula $\theta = \tan^{-1} \left( \frac{x}{r} \right)$ where $r =$ shank length.

**Sample Size Calculation**

The sample size determination was conducted with an appropriate software (Tamaño de la Muestra, 1.1, Spain). The determinations were based on detecting significant differences of 20% on PPTs between sessions with an alpha level of 0.05, and a desired power of 80%. This generated a sample size of at least 16 participants.

**Statistical Analysis**

Statistical analysis was performed using SPSS software, version 24.0 (Chicago, IL, USA). Mean, standard deviations and/or 95% confidence intervals were calculated for each variable. The Kolmogorov-Smirnov test revealed a normal distribution of the variables ($p>0.05$). Measurements (before, immediately after and 48 hours after eccentric exercise) and side (ipsi-lateral or contra-lateral) were introduced as within-subject factors and sex was introduced a covariate in a full-factorial repeated measure analysis of covariance for the VAS, PPT, VPT and TDPM. Bonferroni adjustment for multiple comparisons was used as post hoc test. In all tests, $p<0.05$ was considered significant.

**RESULTS**

Thirty age and sex matched participants, 15 males (mean age: 24.4 ± 3.8 years; BMI: 23.4 ± 3.3 kg/m²) and 15 females (mean age: 24.5 ± 3.7; BMI: 19.8 ± 1.3 kg/m²), aged 19 to 34 years (mean age: 25 ± 4 years; height: 169 ± 9 cm; BMI: 21.6 ± 3.1 kg/m²) participated in this study. All were right dominant; therefore, DOMS was induced on the right lower extremity.

The analysis showed a significant measurement × side interaction ($F_{(2,60)} = 48.902; p < 0.001$) for induced muscle pain, without influence of sex ($F_{(2,30)} = 2.615; p = 0.112$). Pain was mostly induced on the ipsilateral quadriceps muscle immediately and 48 hours after eccentric exercise (Table 1).

The RM-ANCOVA also revealed significant measurement × side interactions for PPT over the rectus...
femoris ($F_{(2,60)}=14.832; p<0.001$) and vastus medialis ($F_{(2,60)}=13.792; p<0.001$), but not for tibialis anterior ($F_{(2,60)}=0.157; p=0.693$). The ipsilateral rectus femoris and vastus medialis muscles exhibited pressure pain hyperalgesia, i.e., expressed as decreased PPTs, immediately after and 48 hours after eccentric exercise (Table 1). No influence of sex was found for either rectus femoris ($F_{(2,30)}=1.681; p=0.191$), vastus medialis ($F_{(2,30)}=0.660; p=0.420$) or tibialis anterior ($F_{(2,30)}=1.072; p=0.305$). A significant effect of measurement was shown for PPT in the tibialis anterior muscle ($F_{(2,60)}=43.239; p<0.001$), suggesting a bilateral decrease in PPT over the tibialis anterior 48 hours after eccentric exercise (Table 1). Finally, a significant decrease in PPTs at the hand ($F_{(1,30)}=15.057; p<0.001$) after eccentric exercise, potentially indicating widespread hyperalgesia to pressure pain. In this point, a significant effect of sex ($F_{(2,30)}=17.061, p<0.001$) was found. Females exhibited a greater decrease in PPT, i.e., higher pressure pain hyperalgesia, as compared to men.

Finally, significant measurement × side interactions for VPT ($F_{(2,60)}=19.281; p<0.001$) and TDPM ($F_{(2,60)}=4.577; p=0.037$) were also shown (Table 2).
The International Journal of Sports Physical Therapy | Volume 15, Number 1 | February 2020 | Page 17

The exercised side exhibited an increase in VPT and TDPM, suggesting vibration hypoesthesia and decreased proprioceptive acuity 48 hours after eccentric exercise. A significant effect of sex was found for TDPM (F(2,30)=9.743 p=0.003) but not for VPT (F(2,30)=0.468, p=0.497). Females exhibited more loss of proprioceptive acuity than men (Figure 3).

**DISCUSSION**

In the present study, a comprehensive battery of tests was used to examine the effects of eccentric exercise (DOMS) on quantitative sensory testing measures. Diminished thresholds of pressure pain were found at a site distant from the quadriceps (the hand) at 48 hours, but not immediately after eccentric exercise. Vibration perception was impaired demonstrating ipsilateral hypoesthesia both immediately and 48 hours after eccentric exercise, while proprioception, measured via TDPM, was impaired ipsilaterally immediately after eccentric exercise and also bilaterally 48 hours later. Further, females demonstrated greater deficits in proprioception and had increased hyperalgesia at a site remote to the quadriceps (hand). These findings have both mechanistic and clinical implications.

Muscle hyperalgesia is a hallmark of DOMS. The pain experienced following a bout of high intensity eccentric exercise typically occurs during physical activity or with applied pressure stimuli, and not at rest, supporting the notion that mechanical hyperalgesia is a main consequence of DOMS. Peripheral sensitization is likely the main mechanism responsible for hyperalgesia to pressure of the exercised muscle in DOMS. This study found evidence of regional expansion of hyperalgesia, termed secondary hyperalgesia, which may occur due to peripheral and central changes in nociceptive processing. While consistent with results of previous DOMS research of the tibialis anterior muscle, the findings of secondary hyperalgesia in individuals with DOMS in the quadriceps may be critical in understanding persistent weakness in this muscle group following knee injury/disease. This is particularly

<table>
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<th>Variable</th>
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* Statistically significant differences (RM-ANCOVA, p<0.001), # Statistically significant differences (RM-ANCOVA, p<0.05)
relevant considering recent work which demonstrated force deficits in both the ipsilateral and contralateral quadriceps muscles following induction of DOMS.37

In addition, this study demonstrated evidence of possible widespread hyperalgesia, indicated by significantly diminished PPTs at the contralateral hand at 48 hours when compared to pre-exercise. DOMS is believed to occur due to minor myofibrillar and cytoskeletal damage causing an inflammatory reaction and nociceptive sensitization.2 Inflammatory mediators cause neuroplastic changes of nociceptors resulting in primary hyperalgesia of the eccentrically exercised muscle.34 Continued nociceptive input, particularly from a large muscle group such as the quadriceps, may result in facilitation of nociceptive processing at spinal and potentially supraspinal levels, which produces heightened intensity and expanded distribution of pain.4 This may be particularly salient considering recent research that suggests a ‘repeated bout effect’ (i.e., less physiological disturbance) with subsequent bouts of induced DOMS.38

Of importance, females demonstrated lower PPTs at the hand than men. This potentially indicates that females may be predisposed to widespread hyperalgesia following musculoskeletal insult as compared to males. Several factors may be responsible for these differences. A propensity to widespread hyperalgesia may occur due to impaired inhibitory mechanisms39 as well as factors such as impaired sleep, psychosocial factors and sedentary lifestyle. Future studies which more closely examine these factors in relation to DOMS may be indicated.

The present study demonstrated deficits in VPT acuity of the exercised limb. Other studies have reported vibratory perceptual deficits associated with musculoskeletal pain conditions, including patellofemoral pain40 and knee osteoarthritis,22,27 and suggested that these changes may be due to central nocicplasticity, although peripheral neuropathy could not be ruled out. This study, in contrast, demonstrated sensory deficits that were clearly not present prior to induction of DOMS. The phenomenon of pain inhibiting sensory input has been referred to as a ‘reverse pain gate,’ or ‘touch-gate,’ suggesting that pain may inhibit non-nociceptive sensation.41 Apkarian et al41 proposed that perceptual deficits associated with pain or inflammation may be due to central neural mechanisms rather than impairment at the receptor level in line with previous studies.42,41

The present study also demonstrated somatosensory deficits in proprioception measured via TDPM, indicating that the limb was passively moved a significantly greater distance through range before the individual was able to perceive it. This finding is supported by a previous study reporting an attenuation of position sense of the lower limbs in presence of DOMS.12 TDPM may be a more appropriate measure of proprioceptive hypoesthesia since it measures the quantity of joint motion that must occur before movement is perceived. Hypoesthesia of TDPM has also been observed following musculoskeletal injury like anterior cruciate ligament injury29,30 and knee osteoarthritis.44,45 Considering that muscle fatigue has been implicated as a factor in certain ACL injuries,46 understanding the relationship between muscle fatigue and/or muscle soreness may be critical. In most instances, deficits in proprioception following knee injury have been attributed to loss of afferent input due to joint damage.29,47 However, in this study joint damage was not sustained, under-scoring the major contribution of the muscle spindle to proprioception. Hypoesthesia was found bilaterally even with unilateral induction of DOMS, pointing to a spinal or supraspinal influence on sensory afferents. It is generally accepted that motor control and enhanced function is reliant on somatosensory input.48 Thus, hypoesthesia following a bout of eccentric exercise may predispose athletes to traumatic injury. Eccentric exercise is commonly used by athletes to enhance performance, with DOMS a common consequence of this training. With rates of lower extremity injury increasing in recent years and particularly ACL injury in adolescent females,49 understanding the effects of muscle soreness on somatosensation may be important for prevention of traumatic joint injury.

Some sex differences were demonstrated regarding DOMS related altered somatosensation. While hyperalgesia was increased in females at a site distant from the quadriceps (hand), pain intensity reported at 48 hours after eccentric exercise was similar for males.
and females, which is similar to previous research.50 Interestingly, sex differences were also noted in TDPM but not in VPT, suggesting these two modalities, mediated via different neural pathways, may be affected by muscle soreness in distinct ways. The higher deficit in proprioception observed in females compared to males was consistent with the results of previous research51 underlining the potential higher risk for musculoskeletal disorders or injuries. Interestingly, time course recovery after eccentric exercise has been reported to be similar between males and females for soreness intensity but different for muscle strength and thickness with longer recovery time for females.52 The present study provides new findings concerning sex similarities and differences when both males and females are exposed to the eccentric exercise protocol. It confirmed that the experimental approach used to induce DOMS, the targeted body region and the methodology used most likely explain the presence or not of sex differences in DOMS. Future studies should keep these aspects in mind and plan sex-specific training programs including, e.g. different recovery time to avoid risk of overloading and injuries.

The impact of DOMS related signs and symptoms on function, balance and postural control was not explored. Future work examining the effect of DOMS related somatosensory changes on function may be beneficial. DOMS is a common sequela of sports training. Considering its potential effect on somatosensation, it is possible that it may predispose athletes to injury. This study serves as important preliminary research for the development of a future larger scale investigation on the effects on eccentric exercise on somatosensation, motor control and function.

CONCLUSION
In conclusion, widespread hyperalgesia, ipsilaterally impaired vibration perception and bilaterally impaired proprioception were demonstrated at 48 hours after eccentric exercise. Moreover, this study revealed sex differences in the extent of hyperalgesia and proprioception deficit that may explain the higher prevalence of musculoskeletal disorders and injuries in females compared to males. These results may provide some explanation for previous findings of altered postural control and muscle activation patterns following induction of DOMS. Athletes performing strenuous lower limb eccentric exercise in training leading to DOMS may experience increased pain and hypoesthesia and be predisposed to lower quarter joint trauma.

REFERENCES


ABSTRACT

Background: Strains of the adductor muscle group of the hip are common amongst ice hockey players. The ratio of isometric strengths between the hip adductors and abductors has been offered as a risk factor for hip adductor strain; however, there is no description for how the ratio between hip adductor and abductor strength varies as a function of hip abduction angle.

Hypothesis/Purpose: The aim of this study was to determine the influence of hip joint abduction angle on measured ratios of hip adduction to abduction torque in experienced, recreational, male hockey players. The primary null hypothesis for this study was that hip joint abduction angle would not influence hip adduction-to-abduction torque ratios in male hockey players.

Study Design: Counterbalanced observational cohort.

Methods: Twelve uninjured, male, recreational hockey players, with a minimum experience level of midget AAA/minor competitive or equivalent. Participants performed maximal isometric side-lying hip adduction and abduction exertions against a rigidly constrained load cell at 0, 10, and 20 degrees of hip abduction. Measured peak torques from each exertion were used to derive the hip adductor-to-abductor torque ratio. Kinematics of the trunk, pelvis, and lower limbs were monitored using an optoelectronic motion capture system.

Results: Adductor-to-abductor torque ratio increased from 1.49 (SD = 0.20), to 1.92 (SD = 0.20) and to 2.30 (SD = 0.54) with successively increasing hip abduction angle (p < 0.001). Peak torque was significantly different between all angles (p ≤ 0.016) except between adduction exertions performed at 10 and 20 degrees of abduction (p = 0.895). Small changes in hip angle during the exertion were coincident with exertion direction, which confirmed the isometric nature of the task.

Conclusion: Hip abduction angle has a significant impact on the measured adductor-to-abductor torque ratio. The ratio increased due to a combination of increased adductor torque and decreased abductor torque as the hip abduction angle increased.

Level of Evidence: 2b

Keywords: Athletes, isometric dynamometry, groin pain, hip injuries, hip strength
INTRODUCTION

Hip adductor strains are significant injuries at both the minor and professional levels of ice hockey, representing up to 10% of all injuries and 43% of all muscle strains.\(^1-3\) Strength imbalances between agonist and antagonist muscle groups have been associated with a variety of sport-related injuries including muscle strains.\(^4,6\) Of particular interest is the link drawn between agonist and antagonist strength imbalances and adductor strains in elite hockey players.\(^7\) Specifically, the average adduction-to-abduction strength ratio (measured using a handheld dynamometer) of players that sustained an adductor strain was 0.78, and the average ratio for players who did not become injured was 0.95. Since the original study, several other researchers have reported hip strength\(^8-11\) and torque ratios\(^12-14\) for injured and uninjured elite athletes participating in a variety of sports and non-athletes with femoro-acetabular impingement; however, protocol inconsistencies hinder the potential for comparing hip adductor-to-abductor strength/torque ratios across studies. Particular inconsistencies include participant positioning (e.g. supine-lying, side-lying), hip posture (e.g. abduction/adduction angle), participant compensations/restraints (e.g. using assessment table for support), and task (e.g. isometric, isokinetic).

Hip abduction posture is particularly important for isometric dynamometry in the frontal plane. Hip abductor muscle lengths decrease while the adductor muscle lengths increase as the hip is abducted.\(^15\) Changes in hip abductor and adductor muscle length with increasing hip abduction angle are likely to impact the position on the force-length relationship at which the muscles operate. Previous work has demonstrated that peak hip abduction force/torque decreases and peak hip adduction force/torque increases with increasing hip abduction angle.\(^9,16\) Hypothetically this means that the adduction-to-abduction torque ratio would also increase with increasing hip abduction angle; however, the impact of changing the hip abduction angle on the adduction-to-abduction torque ratio has not been directly investigated.

The primary goal of this investigation was to determine the influence of hip joint abduction angle on measured ratios of hip adduction to abduction torque in experienced, recreational, male hockey players. It was hypothesized that the ratio would increase with greater hip abduction angles. A secondary objective was to evaluate the accuracy of participant positioning and to monitor the effectiveness of restraints to preserve the isometric nature of the task.

METHODS

Participants

Male participants were recruited from local recreational ice hockey teams. Inclusion criteria stipulated that participants had to currently play recreational ice hockey (minimum once per week)\(^17\) and have a minimum level of experience equivalent to or greater than midget AAA/minor competitive. Goaltenders were excluded from participating due to the difference in their functional demands compared to skaters. Additional exclusions were those with a current lower body injury or low back pain, an adductor strain within the prior year, neurological impairments, previous surgery in the lower limb or spine, current involvement in a concussion return-to-play protocol, diagnosed hip pathology, and uncontrolled diabetes. All participants provided written informed consent and the study protocol was approved by the Research Ethics Board at the Canadian Memorial Chiropractic College (REB #1504B01).

Instrumentation

Kinetic

Forces exerted during each task were measured by a uniaxial load cell (MLP-1K, Transducer Techniques, Temecula, CA, USA) that was fixed to a chain. Stated measurement error for the load cell was 0.05% of the full-scale (1000 pounds).\(^18\) The chain was secured to the ceiling for adduction trials (Figure 1A) or an immovable weight on the floor for abduction trials (Figure 1B). Analog data were digitally sampled at a rate of 1000 Hz using a ±10V range on a 16-bit analog-to-digital conversion board (ODAU III, Northern Digital Inc., Waterloo, ON, Canada).

Kinematic

Three-dimensional kinematic data were recorded from the shank bilaterally, pelvis, and thorax with
two optoelectronic cameras (Optotrak Certus, Northern Digital Inc., Waterloo, ON, Canada). The Optotrak Certus cameras are capable of measuring the position of an infrared-light emitting diode (IRED) with an accuracy of 0.1 mm and resolution of 0.01 mm. Separate rigid bodies holding three IREDs were strapped to each of the participant's shanks at the widest point of the gastrocnemius, to the pelvis at the level of the anterior superior iliac spines (ASISs), and around the thorax at the approximate level of the sixth thoracic vertebra (T6). A fifth rigid body was attached to the uniaxial load cell to continuously monitor its position and orientation. An investigator digitized additional anatomical landmarks while the participant stood in an upright and anatomically neutral posture. Specific bilateral landmarks were the ASISs, iliac crests, greater trochanters, medial and lateral aspects of the knee joints, tibial tuberosities, medial and lateral malleoli, and acromion processes. Unilateral landmarks were the suprasternal notch, xiphoid process, and the spinous processes of the twelfth thoracic (T12) and fifth lumbar (L5) vertebrae. Two marked points were also digitized on either side of the load cell and referenced to the load cell's rigid body. Three-dimensional coordinates for all digitized locations were continuously monitored throughout data collection by assuming a fixed geometrical relationship between the position and orientation of the segment's rigid body and the digitized location. All kinematic data from the rigid bodies and digitized landmarks were synchronized with the kinetic data and recorded at a rate of 100 Hz.

Protocol

Upon arriving at the lab, participants were asked to complete an 11-item inventory to determine their leg dominance, and their Q-angle was measured. Participants followed a three-minute standardized warm-up consisting of squats, lunges and side-to-side resistance band walks to challenge the muscles targeted during the procedure. Following the warm-up, participants were outfitted with the kinematic instrumentation. As a baseline measure, kinematic data were obtained during an upright standing trial prior to beginning the maximal exertion protocol. The participant was instructed to look directly ahead of them while standing with their arms at their side, and feet pointed forward and approximately shoulder width apart.

Participants were then positioned into side-lying on a massage table with their dominant limb on the upper side for all hip abduction and adduction strength trials (Figure 1). This position has been shown to be more reliable compared to supine and standing. All exertions were performed with the dominant limb. A strap was placed around the participants' thorax.
to control its motion and minimize artifacts due to differences in trunk/pelvis orientation between the ascribed hip abduction angles. The participant’s non-dominant lower leg was also strapped to the table in addition to manual stabilization of the pelvis provided by an examiner. Foam cushions were used to mitigate lateral bending of the lumbar spine. Investigators positioned the participant and cued them to maintain their body in the frontal plane during all exertions. Participants were also instructed to have their arms crossed to avoid utilizing the upper body and core musculature to generate additional force through muscle irradiation. A strap was placed around the ankle of the participant’s dominant lower limb and connected to the chain with the load cell.

Participants acclimated themselves to the instrumentation and isometric task by performing several practice trials at submaximal effort. The task required participants to isometrically exert either an upward (hip abduction) or downward (hip adduction) force with a straight leg in 0 degrees of hip flexion/extension and internal/external rotation. After the participant had indicated familiarity with the task, they performed maximal isometric adduction and abduction exertions in the side-lying position at 0, 10, and 20 degrees of ascribed hip abduction. These angles have previously been studied and represent angles utilized by ice hockey players. Ascribed hip abduction angles were determined using a goniometer with the stationary arm of the goniometer aligned between both ASISs and the moving arm extended along the long axis of the femur. The 0 degree position was defined as a 90 degree angle between the stationary and moving arms. Each exertion was three seconds in duration with a one-second ramp up to their maximum and a two-second hold at the maximum. Investigators provided verbal encouragement to participants to achieve maximal performance during each exertion. A minimum of two minutes rest was given between each exertion to minimize the potential for fatigue development.

Participants were instructed to notify the examiners of any pain during the procedure, as determined by a verbal numeric pain scale.

Each participant performed three abduction trials at each abduction angle and three adduction trials at each abduction angle for a total of 18 maximum voluntary isometric contractions (MVICs). The orders of the ascribed hip abduction angles, and direction of exertion (i.e. abduction or adduction) were administered in a block-randomized manner.

Data Processing and Biomechanical Analysis

Load cell voltages and kinematic data were initially imported to Visual3D (C-Motion Inc., Germantown, MD, USA). Three-dimensional coordinates for the digitized locations from the upright standing trial were used to construct anatomical frames of reference for the shanks, femurs, pelvis, and trunk. Femoral kinematics were determined using the digitized locations for the knee joint and the greater trochanter. Hip joint centers were defined as a quarter of the intertrochanteric distance from the digitized positions for each greater trochanter. The elevation angle of the participant's dominant femur with respect to the lab's horizontal plane was also calculated.

All kinematic data from the isometric exertions were digitally filtered using a dual pass of a second order Butterworth filter with a cutoff frequency of 6 Hz. Load cell voltages were digitally filtered with a dual pass of a second order Butterworth filter at a cutoff frequency of 20Hz before calibration to units of force (Newtons). The direction for the exerted force was determined by mathematically connecting the two digitized points on the load cell. The anatomical point of force application was derived by intersecting the force vector with the shank of the participant's dominant lower limb. Hip adduction and abduction torques were determined using the following equation (1):

\[ T = [r \times (F \hat{v})] \cdot \hat{X} \]  

In this equation, \( T \) = hip torque in the frontal plane; \( r \) = moment arm connecting the hip center to the point of force application near the ankle on the participant's dominant lower limb; \( F \) = force magnitude; \( \hat{v} \) = unit vector representing the force's direction; \( \hat{X} \) = unit vector representing the direction of the hip's anterior axis. Peak hip torque was expressed relative to baseline for each exertion.

Hip abduction and femoral elevation angles were obtained at two instances, baseline and peak torque,
for each exertion (Figure 2). Movements of the hip joint and femur during exertion were determined as the relative changes in hip joint abduction and femoral elevation angles from baseline to peak torque. Hip abduction angles and femoral elevation angles at baseline and peak torque, as well as movements of the hip joint and femur for each ascribed hip abduction angle were averaged across the three abduction and adduction trials for subsequent statistical analysis. Averages of the baseline adjusted peak hip torques across the three trials in abduction and adduction at each of the ascribed hip abduction angles were used to derive the adduction to abduction torque ratio. These values were also used as dependent measures in subsequent statistical analyses.

**Statistical Analysis**

All statistical analyses were performed with SPSS software (SPSS Corporation, Chicago, IL, USA). Descriptive measures (averages and standard deviations) were determined for the hip positions at baseline and peak torque, as well as the change in hip position between baseline and peak torque. A one-way repeated measures analysis of variance (ANOVA) was conducted to identify the effect of ascribed hip abduction angle on the hip adductor-to-abductor torque ratio. A two-way repeated measures ANOVA was performed to determine the effect of exertion direction and ascribed hip angle on the absolute value of the hip torque in the frontal plane. Three additional two-way repeated measures ANOVAs (one for each of the ascribed hip abduction angles) were performed to determine the effects of exertion direction and instance (initiation or peak torque) on the measured hip joint abduction and femoral elevation angles. Pairwise post-hoc comparisons with Holm’s adjustments were used to determine differences for dependent measures with a statistically significant main and/or interaction effects. A total of nine paired comparisons were performed as post-hoc analyses for a statistically significant interaction between exertion direction and the ascribed hip angle. Three paired comparisons were performed for a statistically significant main effect of ascribed hip angle on the hip adductor-to-abductor torque ratio. Four paired comparisons were performed for statistically significant interactions between the exertion direction and instance (initiation or peak torque) for kinematic data at each of the three ascribed hip angles. The level of statistical significance was set to 0.05 for all analyses.

**RESULTS**

**Participants**

Data were obtained from a total of 12 participants with one participant’s data being excluded due to absence of a suitable baseline prior to each exertion. Demographics for all participants are summarized in Table 1.

**Kinetic Analysis**

All kinetic data are summarized in Table 2. The hip adductor-to-abductor torque ratio increased with increasing hip abduction angle ($p \leq 0.019$). A statistically significant interaction was observed between the ascribed hip angle and the direction of exertion ($p$...
Adduction torque was greater than abduction torque for all three hip abduction angles, which was reflected by all ratios being greater than 1 \( (p < 0.001) \). Abduction torque decreased with increasing hip abduction angle \( (p \leq 0.013) \), and adduction torque was lowest for the 0 degree of hip abduction trials \( (p \leq 0.016) \). There was no difference between adduction torques for the exertions at 10 degrees and 20 degrees of hip abduction \( (p = 0.895) \).

### Kinematics Analysis

Hip angles and femoral elevation angles at initiation and peak torque during each of the six combinations of ascribed hip angle and exertion direction are presented in Tables 3 and 4. Statistically significant interactions between exertion direction and instance were observed for hip angles and femoral elevation angles at each of the three ascribed hip angles \( (p \leq 0.037) \).

### Table 2

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The average discrepancy between the ascribed hip angle and exertion direction was 2.3 degrees. At initiation, the hip angle was, on average, 4.2 degrees greater for abduction exertions than adduction exertions at 0 degrees and 10 degrees of ascribed hip angles.
abduction \((p \leq 0.007)\). Hip angle at peak torque was also significantly different between abduction and adduction exertions for all three ascribed hip abduction angles (average difference = 7.2 degrees, \(p \leq 0.002)\). Significant changes in hip angle from initiation to peak torque were also observed for adduction exertions at 10 degrees (average change = 2.5 degrees) and 20 degrees (average change = 3.9 degrees) of ascribed hip abduction \((p \leq 0.010)\). There was no significant change in hip angle during abduction exertions at any of the ascribed hip angles \((p \geq 0.111)\).

**Femur**
Femoral elevation at peak torque was greater for abduction exertions than adduction exertions at all three ascribed hip angles \((p \leq 0.002)\). Conversely, there were no differences in femoral elevation between abduction and adduction exertions at initiation for any of the ascribed hip angles \((p \geq 0.208)\).

#### Table 3.

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<th>Hip Angle</th>
<th>Exertion</th>
<th>Initial MEAN (SD)</th>
<th>Peak MEAN (SD)</th>
<th>Initial p-value</th>
<th>Peak p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Adductor</td>
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<td>Adductor</td>
<td>Initial: -12.5 (2.2)</td>
<td>Peak: -13.2 (2.9)</td>
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<td></td>
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<tr>
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<td>Adductor</td>
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<td>Peak: -20.0 (3.4)</td>
<td>0.111</td>
<td></td>
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</tbody>
</table>

The following is an example for reading the table. For an ascribed hip abduction angle of 10 degrees, there was a difference in the hip abduction angle at the start of the exertion \((p = 0.002)\) and at peak exertion \((p < 0.001)\). A statistically significant reduction in the abduction angle occurred between the start and peak of abduction exertions \((p = 0.010)\) and no such change during abduction exertions \((p = 0.326)\).
Femoral elevation angle changed significantly from initiation to peak torque for all six combinations of ascribed hip angle and exertion direction (p ≤ 0.001).

**DISCUSSION**

Previous studies have investigated the change in hip abduction and adduction force with different hip abduction angles. The current study was the first to directly demonstrate that hip abduction angle can significantly influence the hip adduction-to-abduction torque ratio. Furthermore, this investigation was the first to the authors’ knowledge to evaluate patient positioning and monitor the kinematics of the lower limb, pelvis, and thorax during maximal isometric hip abduction and adduction exertions. This information is particularly useful considering that the hip adductor-to-abductor torque ratio has been used to determine potential injury risk.

Manual muscle testing is widely used by many health practitioners during pre-season testing to guide training or rehabilitation. Agonist-antagonist strength
The ratios from these tests are often used to inform injury risk, as demonstrated in hockey players,7,12 soccer players,4 and Gaelic football players.33 The ratios reported in the current investigation were higher than those reported in previous studies that used hockey and soccer players;7,36,37 however direct comparisons should not be made due to differences in the testing parameters. Tyler and colleagues7 performed adduction trials with the athlete in a side-lying position and the hip adducted, which may reduce the force-producing capacity of the adductor muscles. Furthermore, these authors performed abduction trials with the hip abducted “above horizontal”. This discrepancy in hip posture for the adduction and abduction trials possibly provided a mechanical advantage to the hip abductors compared to the testing position of the adductors. Hip adduction-to-abduction ratios in the current investigation were determined for the same ascribed hip abduction angle. This decision was made due to the fact that co-contraction at a given angle is an important aspect of normal joint motion.38 An acute muscle injury, such as a hip adductor strain, occurs at a given joint angle, most often in the eccentric phase of the hockey stride as the hip moves into an abducted position.38 Therefore, testing two opposing muscle groups at the same joint angle is likely more representative of the interaction between these muscle groups when an injury occurs. Although the hockey stride involves a combination of hip abduction, extension, and external rotation, the intention for this study was to evaluate the abduction-adduction component as a risk factor for injury. Therefore, hip extension or external rotation strength were not tested in the current investigation.

An optoelectronic motion-capture system provided data to allow the authors to monitor three-dimensional orientations for the lower limbs, pelvis, thorax, and the direction of the exerted force during all trials in this investigation. The kinematic information allowed the authors to derive the hip torque exerted in the frontal plane during each trial. This analysis accounts for differences that might occur in the direction of the exerted force and the point of application on the lower limb.

Measuring kinematics of the lower limbs, pelvis, and thorax also provided an opportunity to determine the accuracy of the ascribed hip abduction angles at both initiation and peak torque during exertions, as traditional goniometric assessments of the hip tend to overestimate hip ROM.40 Measured hip angles at the initiation of exertions accurately matched the ascribed hip angles, but were different between abduction and adduction exertions. Conversely, femoral elevation angles at the initiation of exertions were greater than their expected elevation (e.g. a femoral elevation angle of 10 degrees would be expected for exertions with an ascribed hip abduction angle of 10 degrees). Furthermore, there were no statistically significant differences in the femoral elevation angle at the initiation of the abduction and adduction exertions. These conflicting findings indicate that the observed differences in hip posture at the initiation of abduction and adduction exertions was likely the result of pelvic positioning at the initiation of the exertions. Monitoring the kinematics throughout the test also allowed for an investigation into the extent to which the isometric nature of the task was maintained. Small (average changes of 2.5 degrees and 3.9 degrees), yet statistically significant, changes in hip posture were observed for adduction exertions performed with 10 and 20 degrees of ascribed hip abduction. The small changes in hip posture indicate that the isometric nature of the task was adequately maintained by the experimental setup. Overall, any movement of the hip joint was consistent with the direction of exertion (i.e. hip abduction decreased during adduction exertions and increased during abduction exertions).
There are several limitations to this study. First, only male hockey players were utilized and therefore this work cannot be extrapolated to female hockey players. Studies have shown reduced abductor torque in female youth athletes compared to male youth athletes. It is possible that due to anatomical differences of the pelvis and Q-angle in females that the adductor-to-abductor ratio may differ in this population. The small sample size and cross-sectional design also prevents the use of this data for normative or injury risk factor purposes. Other limitations pertain to the experimental setup and protocol. The decision to evaluate abduction and adduction torque in a lateral recumbent position was consistent with the position used by Tyler and colleagues. Previous work has demonstrated that the lateral recumbent position is the most reliable method for evaluating isometric hip abduction strength. Furthermore, a rigid mechanical restraint was used to ensure that the exertions were isometric. This may reduce the clinical validity of findings presented in the current investigation; however, previous work has recommended the use of an externally fixed dynamometer (i.e. rigid mechanical restraint) on the basis that intertester bias exists when using a handheld dynamometer. Finally, this study did not test the hip in an adducted position, which is commonly used clinically, because a decision was made to test strength in ranges-of-motion representative of ice hockey.

CONCLUSION
The results of this study demonstrated that the hip abduction angle has a significant impact on the adductor-to-abductor strength ratio, therefore the ability of this ratio to determine injury risk could be dependent upon the angle at which the hip muscles are tested. The adductor-to-abductor strength ratio is a reported risk factor for adductor strain; however, previous work has provided insufficient details regarding hip positioning and joint angles as well as a rationale for the chosen testing parameters. The value of using this ratio to infer injury risk may be limited by the data collection methods and clinicians should use caution when interpreting the ratio when the testing parameters are not standardized. Using one angle to test both adduction and abduction is likely to be more representative of the agonist/antagonist relationship between opposing muscles. While the chosen angle can vary, it should fall within the functional range of the task or the position in which an injury most often occurs. In addition, this study demonstrated that femoral and hip posture can change during the exertion, which changes the intended hip position of this test. Because of this finding, we recommend that specific measures are taken to stabilize the pelvis and femur during isometric testing of the hip, as many studies do not adequately address this compensatory motion.

REFERENCES


ABSTRACT

Background: The Modified Star Excursion Balance Test (MSEBT) and the Y-Balance Test- Lower Quarter (YBT-LQ) are utilized to assess dynamic postural stability. These assessments cannot be used interchangeably secondary to kinematic variations and performance differences. A Modified Y-Balance Test-Lower Quarter (MYBT-LQ) was developed to determine if a modification allows performance scores to be directly compared to the MSEBT.

Purpose: The purpose of this research was to determine if reach distances were similar for young, healthy individuals between three different balance tests: the YBT-LQ, the MYBT-LQ, and the MSEBT.

Study Design: Repeated measures, descriptive cohort study

Methods: Twenty-eight participants (17 males, 11 females) were recruited from a convenience sample of young, healthy adults. Participants completed all testing within a single session and performed three trials in each direction, on each leg, for all balance tests. Scoring performance was calculated for each balance test using the average normalized reach distance in the anterior, posterolateral, and posteromedial directions. A one-way ANOVA was used to compare between-subject posteromedial and posterolateral scores, while anterior scores were analyzed using a Kruskal Wallis test. The intraclass correlation coefficient (ICC) was used to determine within-subject participant performance reliability.

Results: Analyses indicated significant differences in the posterolateral and posteromedial reach directions between the YBT-LQ and MSEBT and between the MYBT-LQ and MSEBT, while no significant difference was found between the YBT-LQ and MYBT-LQ in any direction. No anterior reach differences were noted between any of the tests. Within-subject ICCs showed a very strong level of agreement between right and left anterior and right posteromedial reaches between all three tests, while only the YBT-LQ and MYBT-LQ demonstrated very strong agreement in all directions.

Conclusion: Reach performance on the MSEBT differed from the performance on the YBT-LQ and MYBT-LQ in the anterior, posteromedial and posterolateral directions in this population. These findings further support the difference in motor control strategies used during these tests.

Levels of Evidence: 2c

Key Words: balance, postural stability, movement system

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INTRODUCTION
The neuromuscular system plays an integral role in postural control during dynamic balance activities to limit the occurrence of loss of balance. When there is a lack of coordination between the sensory and motor aspects of the neuromusculoskeletal system, balance is hindered, and postural instability may occur. Postural instability could lead to falls or uncoordinated and uncontrolled body movements that could ultimately produce injuries. Previous research has shown that impairments within the neuromuscular system result in an increased risk for injury in young, active individuals, therefore warranting dynamic balance screening. The Modified Star Excursion Balance Test (MSEBT) and the Y-Balance Test of the Lower Quarter (YBT-LQ) are reliable measures in the assessment of postural control within this population. Gorman et al. concluded that the YBT-LQ is a reliable derivation of the MSEBT, yet this could potentially lead clinicians to infer that these tests can be used interchangeably and that data collected during each test could be compared equally. Fullam et al. identified kinematic variations and differences in performance scores on these tests, which has confirmed that they cannot be used interchangeably in the assessment of dynamic balance. Specifically, authors of previous research have described significant differences have been identified in anterior reach distances comparing the SEBT and YBT-LQ. The present study introduced and evaluated an alteration to the YBT-LQ that included a modification intended to counteract the physical alignment differences between the YBT-LQ and MSEBT.

The Star Excursion Balance Test (SEBT) utilizes an eight point star-shaped pattern, upon which an individual stands in the middle, balanced on one foot, while reaching as far as possible in each of the eight directions with the opposite leg. The SEBT has been shown to be an effective assessment of dynamic postural control and is reliable at identifying risk for injury in individuals with chronic ankle instability, but limitations have also been discussed through extensive research. Plisky and colleagues determined that a difference in anterior reach distance of greater than four centimeters between each limb was associated with a higher risk of injury in high school basketball players. Robinson and Gribble hypothesized that the eight reach directions within the SEBT were redundant in both healthy populations and in those with chronic ankle instability. Reducing the number of reach directions tested, referred to as the Modified SEBT (MSEBT), has been a common suggestion for improving the administration and time efficiency of the SEBT, though the directions most appropriate to test for measurements continues to be debatable. The directions that have been utilized for the MSEBT in other studies consist of anterior, posteromedial, and posterolateral directions.

The YBT-LQ was developed based on the MSEBT protocol, but instead of reaching and touching a taped line, the individual stands on a stance plate and slides a reach indicator along a static frame while maintaining balance on the opposite lower extremity (Figure 1). The YBT-LQ was developed to address some of the limitations of the SEBT to provide a more consistent dynamic balance assessment tool. The YBT-LQ assesses dynamic limits of
stability during single limb stance while the opposite leg reaches in the same three directions as the MSEBT: anterior, posteromedial, and posterolateral.\(^3\) It can also be utilized to assess risk of injury from functional asymmetries associated with young, athletic populations.\(^{13,14}\) As with the SEBT, the YBT-LQ reach distances are normalized to leg length.\(^5\) The YBT-LQ has also been proposed to provide a better assessment of movement quality as compared to the SEBT, by allowing more focused attention to observing the subject and their technique during performance of the test, rather than primarily on marking the reach distance.\(^{13}\)

Because the YBT-LQ was developed from the MSEBT, it was hypothesized that the results would be equivalent or very similar between the two dynamic balance assessments.\(^7\) However, Fullam et al.\(^6\) and Coughlan et al.\(^7\) have shown differences between the MSEBT and YBT-LQ in the composite anterior reach score as well as the sagittal plane hip and knee angular displacements, while no significant differences were noted in the posteromedial and posterolateral directions.\(^6,7\) Differences in the anterior reach direction impacts the overall composite score of the evaluation, which affects the interpretation of test results.\(^6\) It was suggested that these discrepancies resulted from variations in dynamic neuromuscular demands and/or the use of different postural control strategies during the task of reaching in each direction.\(^6,7\) Differences among the reach directions between the YBT-LQ and the MSEBT are clinically relevant because patients with neuromuscular control deficits, such as those with chronic ankle instability, will likely perform differently on one test versus the other.\(^6\)

During performance of the YBT-LQ, participants push a reach indicator slightly lateral to midline and inferior to the floor level of the stance foot, which varies from the midline and floor-level reach performed during the MSEBT. A modification to the reach indicator of the YBT-LQ was introduced by the current researchers in order to better match an individual’s physical position and alignment during performance of the MSEBT and the YBT-LQ (Figure 2). This modification allowed the reach indicator to be pushed from a central location, at stance foot level, similar to the physical parameters of the MSEBT. This modification of the YBT-LQ, the Modified YBT-LQ (MYBT-LQ), was intended to counteract the physical differences between testing parameters so that any additional discrepancies in performance could be attributed to other factors. As the MSEBT and YBT-LQ cannot be used interchangeably at this time, secondary to performance differences and kinematic variations, further research assessing the kinematics and postural strategies required to perform these tests have been deemed necessary.\(^6\) The purpose of this research was to determine if reach distances were similar for young, healthy individuals between three different balance tests: the YBT-LQ, the MYBT-LQ, and the MSEBT.

**METHODS**

Prior to recruitment of participants, approval was obtained from the university’s Institutional Review Board (IRB). A convenience sample of twenty-eight participants (11 females, 17 males, mean
age = 25.0 ± 2.2 years) was recruited from a pool of healthy, young individuals located in Roanoke, VA. Inclusion criteria for the study required participants to be healthy adults aged 18-35 years who self-reported that they were free of any lower extremity injuries in the prior six months and did not have any diagnosed neurological or balance disorders. Participants were excluded from the study if any of the following were present: lower extremity amputation, history of lower extremity fracture, vestibular disorders, undergoing current treatment for inner ear/sinus/upper respiratory infection, concussion within the prior three months, past medical history of surgery for a lower extremity injury within the prior six months, currently pregnant, or medically prohibited from participating in physical activities. Prior to engaging in any formal data collection, participants read a description of the study and signed a consent form.

Participants completed a total of three different balance tests during a single testing session, including the YBT-LQ (Functional Movement Systems™, Danville, VA), the MSEBT, and the MYBT-LQ. Performances were normalized using leg length, and maximal reach distances for anterior, posterolateral, and posteromedial directions. Prior to testing, each participant received an orientation to the balance assessments, and bilateral lower extremity leg lengths were measured. Leg length data were collected by the same researcher for all participants for consistency of measurements. The order of the three balance tests was randomized to account for the impact of fatigue and learning effect. Each test was demonstrated and scored by the same researcher who was certified to administer the Y-Balance Test through Functional Movement Systems™ (Danville, VA). Prior researchers have demonstrated good to excellent intra-rater reliability (0.85-0.91), and good to excellent interrater reliability (0.80-0.85 and 0.99-1.0, respectively) when the YBT-LQ was performed by trained examiners. Participants were allotted three practice trials per lower extremity and direction prior to testing. A two-minute rest period was required after completion of all practice trials prior to initiation of testing.

Participants performed all versions of the tests barefoot in order to decrease external stability of the ankle provided by shoes. During YBT-LQ testing, the foot was placed on the center of the stance plate while the other remained free for reaching. Per the Y-Balance Test protocol, participants were instructed to stand on the center of the stance plate with toes behind the pre-set line and to push the reach indicator in the red target area toward the direction being tested. The reach distance was measured at the trailing edge of the reach indicator to the nearest 0.5 cm. Additionally, per Y-Balance Test protocol, trials were discarded and repeated if the participant failed to maintain unilateral stance on the stance plate (i.e. reach foot touched the floor), failed to maintain reach foot contact with the reach indicator on the target area while in motion (i.e. kicked the reach indicator), used the reach indicator for stance support, failed to keep the entire plantar aspect of the stance foot in contact with the stance plate (i.e. lifting the heel), or failed to return the reach foot to the starting position in a controlled manner (i.e. loss of balance).

In contrast to the YBT-LQ, during the MYBT-LQ participants pushed the reach indicator by using an additional fabricated tab that was centered on the superior surface of the reach indicator and flush with the trailing edge (Figure 2). The fabricated tab was attached to the top of the Y Balance reach indicator such that the reach foot was centered over the reach indicator and was not effectively reaching below the stance surface or lateral to midline, which is physically more similar to the MSEBT.

To perform the MSEBT, the participants stood on the YBT stance plate and followed the same protocol as the YBT-LQ, with the exception of sliding the reach indicator. Instead of pushing the reach indicator, participants reached out and lightly touched the YBT frame with the reach foot in each of the three testing directions (Figure 3). Performance of the MSEBT on the YBT frame was deemed necessary to minimize the effect of perceptual differences associated with standing on a raised surface versus the floor. The distances were recorded in the same manner as for the YBT-LQ (within 0.5 cm). The trial was invalid if the participant did not maintain unilateral stance limb support throughout the trial (loss of balance), transferred body weight onto the reach foot, failed to keep the entire plantar surface of the stance foot
in contact with the stance plate, and/or if the reach foot did not contact the YBT frame.

**Statistical Methods**

Prior to conducting this study, an a priori power analysis was conducted to determine the necessary sample size using G*Power 3.1 (© 2010-2019 Heinrich Heine Universität Düsseldorf). Calculations based on a similar study conducted by Fullam and colleagues indicated that a sample size of 27 was necessary to achieve 80% power. A between- and within-subjects analysis was performed comparing the differences between the normalized reach distances on the YBT-LQ, MSEBT, and MYBT-LQ. Posterolateral and posteromedial reach distances for the YBT-LQ, MYBT-LQ, and MSEBT were analyzed utilizing a one-way ANOVA and Tukey’s HSD post hoc tests, while anterior reach distances were analyzed using a Kruskal Wallis test due to non-normality. Intraclass correlation coefficients (ICCs), using a consistency definition and a two-way mixed model, were analyzed to determine the reliability of individual participant performance among the three tests. All participants served as their own controls. Statistical analysis was completed using IBM SPSS Statistics for Windows, Version 24.0. (Armonk, NY: IBM Corp) with an alpha value of 0.05 utilized to determine any statistically significant different results were found among the variables.

**RESULTS**

The normalized reach distances of the YBT-LQ, MYBT-LQ, and MSEBT were analyzed for the 28 participants. A significant main effect was found between subjects for the average reach distances for the posterolateral [right: $F(2)=4.816$, $p=0.011$, left: $F(2)=5.455$, $p=0.006$] and posteromedial [right: $F(2)=3.425$, $p=0.037$, left: $F(2)=3.121$, $p=0.049$] reach directions between the three tests. The average anterior reach distances were not found to be significantly different [right: $X^2(2)=0.779$, $p=0.677$, left: $X^2(2)=1.869$, $p=0.393$] between any of the three tests (Figure 4). Tukey’s HSD post-hoc analyses indicated significant differences in the right posteromedial reach direction between the MYBT-LQ and MSEBT (Figure 5 and Table 1), and significant differences in bilateral posterolateral reach directions between the YBT-LQ and MSEBT and between the MYBT-LQ and MSEBT (Figure 6 and Table 1). There was no significant difference between the YBT-LQ and MYBT-LQ in any reach direction ($p=0.23$), no significant difference between any of the three tests in the left posteromedial reach direction ($p=0.51$),
and no significant difference between the YBT-LQ and MSEBT in the right posteromedial reach direction (p = 0.14) (Table 1).

Intraclass correlation coefficients comparing YBT-LQ and MYBT-LQ demonstrated very strong agreement for all reach directions, and all three tests demonstrated very strong agreement in the anterior reach direction (Table 2). Reaches in the right posteromedial direction showed very strong agreement for MYBT-LQ and MSEBT and for YBT-LQ and MSEBT, while there was less strong agreement among the remaining tests and reach directions (Table 2).

DISCUSSION
The primary aim of the present study was to determine if there were differences between reach distances during performance of the YBT-LQ, the newly developed MYBT-LQ, and the MSEBT. Analyses revealed that participants performed more similarly on the YBT-LQ and MYBT-LQ, and less similarly on the MSEBT, indicating that the modification to the YBT-LQ did not significantly alter performance outcomes of the YBT-LQ. It has previously been proposed that differences occurred between performance in the YBT-LQ and SEBT due to variations in the position of the reach foot; the SEBT is performed by reaching directly in line and at floor level, while the YBT-LQ is performed by reaching slightly lateral to the position of the stance foot and at a level slightly below that of the stance foot.\(^7\) The MYBT-LQ was specifically developed for the present study to evaluate these differences inferred by Coughlan and colleagues\(^7\). The YBT-LQ and MYBT-LQ showed very strong agreement in overall reach distance performance, which suggests that differences shown in previous research between the YBT-LQ and MSEBT should not be attributed to the foot position relative to the reach indicator or stance foot.

Variations in performance between the MSEBT and YBT-LQ have also been attributed to varying feedback and feedforward mechanisms of postural control.\(^7\) In the YBT-LQ, it is proposed that a continuous feedback loop is present due to the proprioceptive input to the reach foot as it pushes the reach indicator during testing. This feedback loop is thought to assist participants in determining how far they have reached and when they are nearing the limits
of their stability. In contrast, the MSEBT utilizes a feedforward mechanism of postural control as participants reach to their limits of stability prior to making contact with the support surface; this means that participants must rely heavily on anticipatory actions before they receive sensory input from the ground. The present study appears to further support a difference in postural control mechanisms between these tests. The MYBT-LQ altered the physical alignment to more closely approximate the MSEBT, yet the reach distance outcomes remained similar to those of the YBT-LQ. Reaching out while utilizing proprioceptive feedback from the reach indicator may have provided an advantage during the YBT-LQ and MYBT-LQ that allowed for greater reach distances in the posteromedial and posterolateral directions. In the present study, participants displayed more difficulty locating the YBT frame while performing the MSEBT atop it, compared to the YBT-LQ and MYBT-LQ. This could be due to the role of the proprioceptive systems and a continuous feedback loop that is present during the YBT-LQ and MYBT-LQ.

Contrary to the findings of Coughlin and colleagues, no statistically significant differences were noted between the three tests in the anterior direction. In order to perform these balance assessments, participants utilize three different sensory systems (visual, vestibular, and proprioceptive) to maintain postural control. It is likely that participants performed similarly on the three tests in the anterior direction due to the increased visual input and awareness of their body position during completion of the anterior reach. In the posteromedial and posterolateral directions, the participants could not see the labeled frame, were unaware of their reach distances during the performance of each trial, and had to seek the rail positions during the MSEBT. Participants likely relied more heavily on vestibular and proprioceptive input to perform the posteromedial and posterolateral reaches which may have led to more variation between the overall group's performances in these directions. In contrast, participants' performance of the anterior direction likely utilized all three sensory systems, yielding a more uniform reach distance in this direction. Additionally, unlike participants in the Coughlan study, the participants in the present study were not members of organized collegiate sports teams at the time of testing. This may have resulted in a group of participants who did not have the proprioceptive abilities typically demonstrated by collegiate athletes. These participants, however, may be more representative of average healthy active young adults, making the findings applicable to a larger subset of the population.

**Clinical Relevance**

The outcomes of this study support prior findings indicating that performance scores on the YBT-LQ and MSEBT are not equivalent and thus, the assessments should not be used interchangeably. A modification designed to align the physical parameters of the two tests (MYBT-LQ) did not result in significant differences in reach distances when compared to the MSEBT, and therefore is not suggested for future use of the YBT-LQ. Choosing between the MSEBT and the YBT-LQ should continue to be at the discretion of the sports or rehabilitation professional and should

<table>
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YBT-LQ= Y-Balance Test Lower Quarter; MYBT-LQ= Modified Y-Balance Test Lower Quarter; MSEBT= Modified Star Excursion Balance Test
best match the needs of the professional and their athlete/patient, since both tests are reliable and have demonstrated injury prediction capabilities. Given that the primary difference between the two tests is the pattern associated with the reach, sports and rehabilitation professionals should select the test that best aligns with the individual’s sports, recreation, or job duties. Those who are able to utilize environmental inputs during their movements may benefit from testing using the YBT, while those who are required to target in open space should choose the MSEBT.

A potential limitation in the present study is the method of testing during the MSEBT. Standing atop the YBT frame allowed for consistent positioning and measurement of reach distances, but it did not address the altered visual perception that may result from standing on a raised surface.

**CONCLUSION**
Results of the present study show strong correlations between performance on the YBT-LQ and the MYBT-LQ, suggesting that feedback from the reach indicator may be responsible for variations noted when comparing performance to the MSEBT. These findings also indicate that there is no need to modify the YBT-LQ reach indicator to more closely replicate the physical parameters of the MSEBT, as the reach distance outcomes do not differ significantly. Results of this study also indicate that healthy active young adults demonstrate performance variations in the posterolateral and posteromedial reach directions when performing the YBT-LQ, MYBT-LQ, and MSEBT, while anterior reach directions do not differ. Future research that investigates the effect of standing on a raised versus level surface during completion of the MSEBT (i.e., on the YBT frame) would be beneficial in helping determine the cause of variable findings on these balance tests.

**REFERENCES**
ABSTRACT

**Background:** Due to the lack of verifiable iliotibial band elongation in response to stretching, the anatomical, biomechanical, and physiological responses to treatment of iliotibial band syndrome remain unclear. The lateral intermuscular septum, consisting of multiple myofibroblasts, firmly anchors the iliotibial band to the femur.

**Purpose and Hypothesis:** The purpose of this in-situ study was to examine the constraining effect of the lateral intermuscular septum on available passive hip adduction range of motion in un-embalmed cadavers. It was hypothesized that an iliotibial band-septum-complex release would significantly increase passive hip adduction.

**Design:** Within-specimen repeated measures in-situ design.

**Setting:** Anatomy laboratory.

**Methods:** Metal markers were inserted into selected anatomical landmarks in eleven (11) un-embalmed human cadavers. With the specimen supine, the test-side lower limb was passively adducted until maximum passive hip adduction was reached. This movement was repeated three times each within two conditions: (1) band-septum-complex intact and (2) band-septum-complex dissected. Digital video of marker displacement was captured throughout each trial. Still images from a start and an end position were extracted from each video sequence. A custom Matlab program was used to calculate frontal plane hip adduction angle changes from obtained images.

**Results:** Mean change in passive hip adduction after band-septum-complex release was -0.3° (SD 1.6°; 95% CI: -1.33, 0.76). A paired samples t-test revealed a non-significant difference (t=-.611; p=.555) in passive hip adduction for the band-septum-dissected condition (18.8±3.9°) versus the band-septum-intact condition (18.5°±4.7°).

**Conclusion:** The lateral intermuscular septum does not appear to have a constraining effect on passive hip adduction in un-embalmed cadavers. Future research should evaluate the constraining effect of other selected tissues and conditions on hip adduction. Furthermore, inflammatory, metabolic, viscoelastic, and sensorimotor control properties within the iliotibial band in response to stretching should be investigated.

**Level of Evidence:** 3

**Key words:** Hip adduction, iliotibial band, lateral intermuscular septum, selected cutting.
INTRODUCTION

Iliotibial band syndrome (ITBS) is one of the most common causes of lateral knee pain in physically active individuals including runners, cyclists, tennis and football players or dancers. The reported incidence is between 5% - 14% in runners and 6% - 22% in army recruits. Lavine et al report that ITBS counts for 22% of all lower extremity overuse injuries. Iliotibial band syndrome frequently involves tissue inflammation and subsequent pain-induced functional limitations at the knee during sports and everyday activities. However, etiology and treatment related to ITBS are currently being debated.

The iliotibial band (ITB) is a robust tissue, representing the laterally thickened distal continuation of the tensor fascia lata. The longitudinal oriented ITB fibers are continuous with the fascia lata of the thigh, completely enclosing the lateral thigh. The ITB adheres firmly to the femoral linea aspera via the entire length of the lateral intermuscular septum (IMS), which divides the anterior and posterior thigh compartments, and extends distally between the vastus lateralis and biceps femoris muscles. The IMS is anteriorly attached to the vastus lateralis. Posteriorly, the proximal quarter connects to the gluteus maximus and its distal three quarters to the short head of the biceps femoris. Some of the distal ITB fibers contribute to the iliopatellar ligament, while the remaining fibers attach to the anterior-lateral tibial tubercle, also known as Gerdy’s tubercle. Histologically, the ITB appears to be a tendon-like structure with only a sparse number of elastic fibers.

Iliotibial band syndrome is commonly thought to be caused by repetitive anterior-posterior motion of the deep ITB tissue over the lateral femoral epicondyle. This most frequently occurs at approximately 30° of knee flexion during cyclical flexion-extension movement, as found in walking and running activities. However, other authors contradict this friction model and instead propose that medial-lateral movement of the ITB at approximately 30° of knee flexion results in compressive forces between a highly innervated fat pad deep to the ITB and the lateral femoral epicondyle. Despite discrepancies, both suggested mechanisms lead to subsequent inflammatory processes of local tissues.

Various non-surgical management strategies have been proposed for ITBS treatment, including stretching, foam rolling, neuromuscular training, and manipulative treatment that include a strain-counter-strain technique and manual myofascial release techniques. Stretching appears to be the most frequently suggested management strategy for reducing ITB dysfunction and symptoms. It should be noted that treatment efficacy and tissue response to stretching has limited evidence supporting its value. Investigators have reported symptom improvement and increased hip adduction range of motion (as per the findings of the Ober-test) in response to clinical stretching exercises. Yet, the anatomical, biomechanical, and physiological explanations for treatment response remain under debate. Utilizing strain gauges in un-embalmed cadavers, Falvey et al demonstrated that the ITB does not significantly elongate in response to a stretching maneuver, due to its firm longitudinal attachment to the femur. More recently, Wilhelm et al demonstrated in fresh cadaveric ITB tissue in-vitro that the junction between tensor fascia lata and the ITB is the only ITB region that may exhibit significant deformation in response to a clinically relevant stretching load. Moreover, the authors were able to demonstrate that their clinical ITB stretching strategy did not result in appreciable mid-substance ITB tissue deformation.

Consequently, symptom improvements in response to non-surgical treatment of ITBS must be related to another, yet unknown factor. Such findings could possibly be explained through deformation of the IMS versus the ITB, which has not been examined to date. The IMS' thin layer of dense irregular connective tissue originates from the deep lower limb fascia, coursing dorsal-medially and terminating on the linea aspera. Selected authors suggest that a considerable share of myofibroblasts can be found in the deep lower limb fascia, potentially rendering this tissue responsive to stretching. Moreover, Langevin et al reported the mechano-transduction of fascial tissue, suggesting connective tissue's capacity to adapt to a tension force. Furthermore, van der Wal concluded that a stretching regime designed to target a specific tissue in isolation could transmit to other connected, surrounding tissues. Hence, an ITB clinical stretch could influence IMS fibers, allowing...
those fibers to change the impact that stretching could subsequently have on ITB dynamics.

Cadaveric selective cutting has been previously used to examine the constraining effects of different tissues on selected mechanical properties or movements. The selective cutting model in the present study was crafted in response to previous observations when piloting on cadaveric specimens for a different study in the thigh region. It was then that the investigators qualitatively observed increased hip adduction in response to an ITB-IMS complex release. This observation was however not quantified and had not been previously reported.

Therefore, the purpose of this in-situ study was to examine the constraining effect of the lateral IMS on available passive hip adduction range of motion in un-embalmed cadavers. Examining this effect will help determine the role of the IMS in ITBS and serves as a basis for further investigation into IMS mechanical response to treatment. The authors hypothesized that surgical release of the ITB conjunction with the lateral IMS would significantly increase available passive hip adduction in un-embalmed cadavers, testing the lateral IMS' role in constraining hip adduction and offer a testable mechanism possibly responsible for changed hip adduction after stretching.

### METHODS

#### Research Design and Variables

The investigators implemented a prospective study using a within-specimen repeated measures design. The dependent variable was the available passive range of motion hip adduction. The independent variable used in this study was the ITB-IMS complex condition, which had the following two levels:

1. ITB-IMS complex intact
2. ITB-IMS complex separated

#### Subjects

The specimen sample comprised 11 fresh un-embalmed human cadavers (7 male and 4 female). Mean age at time of death was 70.5 (SD ± 12.8) years, ranging from 48 to 94 years. All cadaveric specimens used for this study were from the Texas Tech University Health Sciences Center gross anatomy laboratory. Cadaveric specimens were handled according to university policy and the State of Texas regulations defined by the Texas Tech University Health Sciences Center Anatomical Board. Specimen characteristics including comorbidities and individual cause of death are presented in Table 1. Data collection was completed using six right and five left lower limbs.

### Table 1. Study specimen characteristics.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Comorbidities and Cause of Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>75</td>
<td>Congestive Heart Failure; Coronary Atherosclerosis</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>75</td>
<td>Non-Small Cell Lung Carcinoma; COPD</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>94</td>
<td>Acute Stroke; Peripheral Vascular Disease; Atherosclerotic Heart Disease</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>76</td>
<td>Stage IV Melanoma with Brain Metastases</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>76</td>
<td>Embolic Infarcts of both Cerebral Hemispheres; Hypertension</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>70</td>
<td>Dementia; COPD; Diabetes Mellitus; Hypertension</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>48</td>
<td>Metastatic Pancreatic Cancer</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>69</td>
<td>COPD</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>72</td>
<td>Hemorrhagic Shock; Multi Organ Failure; Acute Respiratory Failure; CVA</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>72</td>
<td>Septic Shock; Urinary Tract Infection; Encephalopathy; Acute Renal Failure</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>49</td>
<td>Multi Organ Failure; Malignant Colon Tumor; Hypoglycemia</td>
</tr>
</tbody>
</table>

M = Male, F = Female, COPD = Chronic Obstructive Pulmonary Disease, CVA = Cerebrovascular Accident
All specimens fulfilled the following criteria:

1. Bilateral intact full-length lower limbs
2. No detectable abnormalities or damages to the pelvis, thigh, ITB, or IMS
3. No known previous hip surgery
4. No known current hip fractures
5. No severe lower quarter tissue contractures.

**Pre-Measurement Preparation**

After placing the specimen supine on the examination table, the lower limb that was found most neutrally aligned during gross inspection was identified as the test-side lower limb. The rationale behind that was to visually identify obvious lower limb malalignment that may possibly have been caused from capsular or other soft tissue restrictions around the hip, and thus could have had a limiting impact on passive available hip adduction range of motion. Subsequently, threaded markers were inserted into each anterior superior iliac spine (ASIS) bilaterally and the test-side femur in order to compare the extent of passive available hip adduction with the ITB-IMS complex intact versus the ITB-IMS complex separated. Markers were placed in a standardized manner in the supine lying specimen. After the respective bony landmark was located through manual palpation, a countersink was used to create a starter hole for drill bit guidance. After pre-drilling, the commercially available drill bit (Black & Decker™, New Britian, CT, USA) was removed, and a 3.5-inch Philips-head screw was implanted into the pre-drilled hole. Following the insertion of one marker into each ASIS, the first line was created between the markers at the anterior superior iliac spine (“ASIS line”). The second line was created between the two femoral markers (“Thigh line”). The test-side lower limb was moved to an

**Instrumentation**

To objectively record maximum available passive hip adduction range of motion during all test conditions, digital motion recordings of the screw markers were captured using a commercial-quality high-resolution video camera (CANON XF305 HD, Canon Inc, Tokio, Japan). The camera was connected to a 21.5" LED CCTV monitor (ToTeVision, Seattle, WA, USA). The video camera was mounted on a boom above the test table and aligned perpendicular to the testing plane in 1m-distance to the specimen. This distance was chosen in order to avoid contortion artifacts and ensure measurement validity. Video was recorded in high-definition with 1920-1080 pixels resolution and a frame rate of 50 frames per second in natural room illumination. Prior to each recording series, the 18x-zoom, 4.1-73.8mm lens was zoomed all the way out prior to zero back in on the specimen. The camera was set in autofocus mode during data capture.

**Pre-Preparatory Procedures**

Prior to marker insertion, both lower limbs were repeatedly moved in (1) hip abduction/adduction, flexion/extension, and internal/external rotation, and (2) knee flexion/extension for five minutes to reduce tissue stiffness and minimize any remnant muscle rigor. Subsequently, the supine-lying specimen was placed appropriately on the testing table and the screw markers were inserted to the ASISs and anterior femur as previously described. With the screw markers in place and final camera set-up complete, the test-side lower extremity was moved passively through the frontal plane range to ensure that all important items were sufficiently captured on the video as witnessed in real-time on the LED monitor.

**Data Collection Procedures**

Throughout testing, the specimen’s torso was stabilized by one investigator who stood cranial to the specimen to ensure its position consistency. The opposite lower limb was placed in slight hip abduction in order to be able to move the test side lower limb through the whole passive available hip adduction range of motion. Two lines were constructed using the previously mentioned markers on determined anatomical landmarks. The first line was created between the markers at the anterior superior iliac spines (“ASIS line”). The second line was created between the two femoral markers (“Thigh line”). The test-side lower limb was moved to an
investigator-selected hip abduction angle greater than 90-degrees between the ASIS line and the thigh line to initiate data capture. Subsequently, the test-side lower limb was passively adducted towards the opposite limb until maximum available passive hip adduction was reached, determined by end of available passive movement indicated by pelvic motion. While moving the lower limb, care was taken that the intercondylar line was aligned parallel to the table surface to maintain lower limb neutral rotation. During movement, the heel was always maintained in slight contact with the table surface to avoid hip flexion. (Figure 1) This procedure was repeated three times with the ITB-IMS complex intact. Following the third trial, the ITB-IMS conjunction was carefully separated while preserving ITB integrity. The skin was incised, starting 5 cm distally from the ipsilateral ASIS, and stopped just proximal to the distal femoral marker. The entire lateral IMS was separated from the ITB starting at the distal end of tensor fascia lata (TFL) muscle and extending distally to the level of the distal femoral marker. After complete ITB-IMS separation was confirmed visually and via palpation, the skin was sewed back together. Following ITB-IMS junction transection, three passive hip adduction range of motions trials were performed in the same fashion as previously described. Digital motion recording was captured throughout each trial.

Image Digitization Process
Range of passively available hip adduction was defined by the change in the frontal plane angle created by the line between the ASIS line and the thigh line (Figure 1). To calculate this, still images of a hip adduction start and an end position were extracted from each captured video sequence. Predefined start position was a right (90 degrees) angle between the ASIS line and the thigh line. The end position was visually confirmed to be the maximum available recorded hip adduction position, where no further angular motion was detected on the video between the two lines with subsequent passive movement of the lower limb. Image digitization for data reduction purposes was conducted using a custom MATLAB program (Version R2016b; The Mathworks, Inc, Natwick, MA USA). This standardized reliable and valid uniplanar measurement procedure has been previously incorporated by several authors across different joint structures and tissues. The MATLAB program prompted the user to select and import a baseline right angle image that represented the start position. In this image, four fixed points defined as the cross heads of the screw markers were chosen: starting with one point at the left ASIS followed by one point at the right ASIS, followed by one point on the proximal femur and one point on the distal femur. Each image was digitized three times in the exact same manner. The customized MATLAB program calculated the respective hip adduction angles for each digitization event, resulting in three values per image. A second image representing the end position of the same trial was subsequently selected and the procedure was precisely repeated and automatically transferred to an Excel spreadsheet. Hip adduction angle values of all three digitization events were used to calculate the mean hip adduction angle per image. The total change in hip adduction was calculated by subtracting the mean end position.

Figure 1. Sample of passive available hip adduction measure with ITB-IMS-complex intact, a = ASIS line; b = thigh line; \( \alpha = 90^\circ \) angle between ASIS line and thigh line, starting position; \( \beta = \) angle between ASIS line and thigh line in maximum available passive hip adduction, end position.
angle from the mean starting position angle and can be described with the following formula:

\[
\text{Passively available hip adduction} = \frac{\text{mean start hip angle } \alpha - \text{ mean end hip angle } \beta}{\text{H9251} - \text{H9252}}
\]

*see Figure 1 for depiction of angles

**Data Analysis**

Descriptive data analysis was calculated to summarize sample demographic characteristics. Moreover, values of central tendency (mean) and dispersion (standard deviation and 95% confidence intervals) for passive hip adduction range of motion for each condition (ITB-IMS separated versus ITB-IMS intact) were established. Data normality was defined as meeting at least two of the three following criteria: (1) Shapiro Wilk test p-value > 0.05, (2) skewness between -2 and +2, and (3) kurtosis between -2 and +2. A paired samples t-test was utilized to determine whether a difference in passive available hip adduction existed between the ITB-IMS-intact versus ITB-IMS-separated conditions. Significance was set at \( \alpha = .05 \). All data analyses were performed using IBM SPSS Statistics (V23.0; IBM Corp. Armonk, NY, USA).

**RESULTS**

**Specimen**

A total of 11 cadavers were examined (Table 1). All provided cadavers fulfilled the inclusion criteria, so no specimen was excluded from the study.

**Digital images**

A total of 12 digital images per specimen were extracted from the digital recordings [3 trials x 2 ITB-IMS conditions (intact vs. separated) x 2 positions (start position vs. end position)]. All in all, 132 images were analyzed via MATLAB as described above.

**Amount of passive available hip adduction**

Passive available hip adduction in the ITB-IMS-intact condition was compared to the same movement in the ITB-IMS-separated condition. Mean change in passive available hip adduction range of motion after releasing the ITB conjunction with the lateral IMS was - 0.3° (SD 1.6°; 95% CI: -1.33, 0.76). Passive available hip adduction in the ITB-IMS-separated condition (18.8 ± 3.9°) was not significantly greater (\( t = -.611; p = .555 \)) versus the ITB-IMS-intact condition (18.5° ± 4.7°; Figure 2).

**DISCUSSION**

In the present study, separating the IMS from the ITB did not change the available range of passive hip adduction in un-embalmed cadavers. This was contrary to the investigator’s experimental hypothesis, where an increase in hip adduction was expected. In ITBS patients, ITB flexibility often appears decreased, resulting in reduced hip adduction range of motion. Increased ITB tightness adds to excess friction of the ITB over the lateral femoral epicondyle during cyclic knee motion in the sagittal plane, maintaining local tissue inflammation. Applied therapeutic inputs through stretching exercises or foam roll use have been used for reducing ITB dysfunction and symptoms. However, no plausible explanation has been offered as to why these interventions succeed.

Therapeutic interventions are reported to influence ITB flexibility as evidenced by Ober-test results. Yet, limited evidence exists for the efficacy of any ITB stretching regimen. A systematic review by Cheatham et al suggest that self-myofascial release using a foam roll is beneficial for enhancing joint range of motion in various joints including the hip joint. Still, one must question the mechanical influence that such interventions have on ITB mechanical response. In a recent cadaveric study, Wilhelm et al
demonstrated that the primary ITB region that exhibits significant elongation in response to a clinically relevant stretching load was the proximal portion, which includes the TFL muscle.\(^8\) Similarly, Falvey et al\(^2\) explained the absence of elongation in response to a stretching maneuver due to the ITB’s firm longitudinal attachment to the femur via the IMS.

Even though the junction between the TFL and ITB is the only region of ITB complex that is appreciably extensible, patients report subjective symptom improvements, where increased hip adduction range of motion can be witnessed following clinical stretching exercises, foam-rolling or other (self-)myofascial release maneuvers to the entire complex.\(^{4,18,21,43}\) Fredricson et al\(^20\) considered that changes in different hip and thigh muscles (i.e. gluteal muscles, TFL, and vastus lateralis) might have added to increased hip adduction range of motion during stretching maneuvers meant to stretch the ITB versus actual changes in ITB length. However, they did not examine for other factors while keeping the hip movement in the frontal plane. In response, the current investigators examined the IMS' constraining effect on hip adduction mobility in the frontal plane.

As displayed in Figure 2 of the present study, the very small changes in mean hip adduction angle in response to IMS dissection were not statistically significant, which would most likely also not be clinically relevant at a difference of less than a degree. There are three possible explanations as to why an ITB-IMS conjunction release did not influence passive available hip adduction. First, the IMS attaches firmly to a large portion of the lateral femur.\(^7,9-11\) While the IMS indirectly crosses the hip joint through the ITB attachment and then through the TFL, it does not directly cross the hip joint. Thus, it may not directly affect adduction range of motion. However, when the ITB-tensor fascia lata complex that has multiple tissue types (i.e. muscle and tendinous structures) is stretched, the force is likely dissipated through the pathway of least resistance.\(^8\) In such a case, the TFL is likely not offering an appreciable amount of resistance, especially in un-embalmed cadavers with no muscle tone. So, when the hip was passively moved into adduction with the IMS intact, much of the lengthening likely occurred at the TFL level, concurring with previous findings.\(^8\)

Secondly, authors have suggested that the ITB may not be the primary resistance to hip adduction.\(^2,44\) These authors proposed that the superior portion of the hip capsule, as well as gluteus medius and minimus muscles, limit adduction range of motion to a greater extent than the ITB itself.\(^44\) In a selected cutting study utilizing lightly embalmed cadavers with similar mobility to that seen in living persons, Willet and colleagues\(^44\) witnessed results similar to the current study when cutting the ITB at midthigh level. Mean increase in hip adduction following ITB transection measured with a goniometer were 0.72° during the modified Ober test and 0.70° during the Ober test, respectively.\(^44\) However, after transection of either the gluteus medius and minimus tendons or the hip joint capsule the authors found significant increase in hip adduction range of motion in both the modified Ober test and the Ober test.\(^44\) Future research could examine the Willet et al effects further by selectively cutting the ITB first followed by the IMS. This could further test the influence of the IMS intended in the current study.

Third, it is unknown whether the cadaveric specimens utilized in the current study, as well as in the study of Willet et al\(^44\) had been suffering from ITB tightness or pathology before death. This may have allowed other structures including the hip capsule to restrict adduction movement first, whereas in individuals with ITB pathology the ITB-IMS may have played a larger role in hip adduction restriction as suggested by other authors.\(^40,41\)

Upon raw data examination, it was noted that some specimens lost a small amount of adduction movement once the IMS was dissected (Table 2). This phenomenon could have been the result of an ITB displacement in relation to the axis of rotation for hip adduction. Although, the values were all within a very small range of just one degree, thus having no effect on this study's overall outcome – that is that passive available hip adduction does not appreciably change in response to an ITB-IMS dissection in un-embalmed cadavers – these findings should be investigated further. Future research could examine the IMS’ constraining effect on sagittal plane ITB alignment and ITB length. Moreover, future studies could assess whether the IMS may have a constraining effect on hip adduction subject to different hip joint positions in the sagittal and transverse planes.
In the absence of any appreciable passive hip adduction changes in response to IMS dissection, one must further inquire into why clinically stretching an inextensible structure such as the ITB can effectively reduce ITBS symptoms and increase hip range of motion. Many different explanations are conceivable, however no sound evidence yet exists. First, one could suppose that stretching and foam-rolling do not have a mechanical influence on ITB fibers but rather influence the inflammatory state of the tissue. Acute inflammation is accompanied by an active resolution program, which starts within the first few hours after inflammation onset and involves the production of specialized pro-resolving mediators. Researchers have suggested that stretching has a positive influence on the resolution of inflammatory processes within connective tissue. Utilizing a carrageenan inflammation model in rats, Berrueta et al. observed that inflammatory processes decreased in vivo as well as ex vivo with both active and passive stretching compared to a no stretching condition. Besides a significantly decreased inflammatory thickness and cross-sectional area of the thoracolumbar fascia in their model, total and neutrophil cell counts within the inflammatory lesion were significantly smaller in stretched rats as compared to non-stretched rats. Moreover, the stretching induced increases in specialized pro-resolving mediators in vivo and ex vivo, suggesting a direct effect of stretching on the tissue. This recently discovered interaction between musculoskeletal connective tissue and the immune system could potentially explain ITBS response to stretching and play a role in non-surgical ITBS treatment decisions.

The impact of stretching on ITB tissue metabolic changes may provide another plausible explanation for mechanical ITB interventions’ effects. Hotfield et al examined changes on arterial blood flow and tissue perfusion after a series of self-myofascial release exercises using foam rolls. These authors demonstrated a hyper-perfusion in the ITB area, both immediately and 30 minutes after performing a foam rolling procedure. Blood circulation plays an essential role in tissue healing as it supports nutrients and oxygen supply. Such a response could lend to tissue healing and pain reduction.

The third possible explanation for ITB stretching efficacy in ITBS patients centers on altered viscoelastic properties of the fascial tissue. It is postulated that foam-rolling causes fascial tissue warming that results in increased pliability by transforming the tissue into a more fluid-like form and breaking up fibrous adhesions between the different fascial layers and thus restore soft-tissue extensibility. Therefore, further study is merited regarding this concept.

A final possible explanation may center on fluid volume and pain response found in tissue underlying the ITB. It is possible that stretching and foam rolling could reduce vastus lateralis fluid volume, thus influencing the mechanical lever with respect to the hip axis of rotation. This may allow for a greater passive hip adduction before ITB resistance is met. Moreover, reducing fluid volume may influence pain by decreasing pressure associated with inflammation and mechanosensitivity. Thus, future investigations should further examine the influence of ITB stretching and foam-rolling on pro-inflammatory, metabolic, viscoelastic and fluid volume properties.
and responses to better explain treatment selection and response.

LIMITATIONS
One study limitation is found in its in-vitro design, where results from cadaveric investigations cannot be transferred to an in-vivo situation without critical considerations for missing information, such as muscle tone, contractile tension, and joint forces that are found in a living person. Moreover, in-vitro tissue properties may slightly differ from in-vivo tissue characteristics by virtue of their changes in mechanical properties. However, conducting this study would not be possible in-vivo due to its selective cutting design. Furthermore, the cadavers used for this investigation were un-embalmed in order to rule out major tissue alterations in response to embalming processes.

Furthermore, the study is limited by the age range of the specimens. Patients suffering from ITBS are usually from a younger population. In contrast, the cadavers used in this study were from an older population, making it challenging to transfer the results to younger individuals. However, younger cadaveric samples are difficult to obtain, hence investigators are often forced to use cadavers from older age groups.

Finally, the cadaveric specimens utilized in the current study were most likely not suffering from ITB tightness or pathology prior to death. This may have allowed other structures including the hip capsule to restrict adduction movement first, whereas in individuals with ITB pathology the ITB-IMS may have played a larger role in hip adduction restriction.

CONCLUSION
The results of the current study suggest that the lateral IMS does not have a constraining effect on passive hip adduction range of motion in un-embalmed cadavers. Future investigations should concentrate on evaluation of inflammatory, metabolic, viscoelastic, and fluid volume properties within the ITB and other selected tissues such as the vastus lateralis, gluteus medius and minimus musculotendinous tissue, and the hip joint capsule in response to an ITB stretching regime to better explain ITBS treatment selection and response.

REFERENCES


ABSTRACT

Background: The side-bridge (SB) is a commonly used closed-chain task to assess trunk muscle endurance and side-to-side endurance asymmetry. An open-chain variation of the SB, that positions the participant in an inclined side-lying posture, may be useful for those who report shoulder pain or fatigue as the reason for terminating the closed-chain SB. Low back loading demands of the open- and closed-chain variations should be matched to facilitate comparison of SB endurance measures.

Purpose: To quantify the low back reaction moments during the open- and closed-chain SB and determine the appropriate open-chain angle of inclination that matches the lateral bend moment magnitude of the closed-chain SB.

Study Design: Observational cohort

Methods: Upper body and trunk postural data were obtained during the closed-chain SB and during the open-chain SB at each of four inclination angles from a group of eight healthy male adults. Ground reaction force (GRF) data were also collected during the closed-chain SB. Low back reaction moments were calculated using a static ‘top-down’ linked segment model in both SB variations. Latent growth modeling was used to determine the angle of inclination in the open-chain SB that produced a low back lateral bend moment that matched the closed-chain SB. Sensitivity of the matching open-chain inclination angle was evaluated by rotating the measured GRF vector from the closed-chain SB by five degrees clockwise and counter-clockwise in the frontal plane.

Results: The open-chain inclination angle that best matched the loading demands of the closed-chain SB was 38±12 degrees. Clockwise rotation of the measured GRF in the closed-chain SB increased the matching inclination angle to 56±17 degrees. Counter-clockwise rotation reduced the matching inclination angle to 17±11 degrees. Secondary descriptive analysis of spine posture and off-axis low back moments revealed biomechanically relevant differences between SB positions.

Conclusion: The average open-chain SB angle of inclination that matched the closed-chain SB approximated the 45-degree recommendation offered in the literature. Differences in spine posture and off-axis low back reaction moments, and the potential impact on holding times, should be considered if using the open-chain SB.

Level of Evidence: 2b

Keywords: lateral bend, linked-segment, low back pain, trunk endurance
INTRODUCTION

The side-bridge (SB) is a closed-chain task that is simple to employ in a clinical setting to reliably assess isometric trunk muscle endurance and side-to-side asymmetries in trunk muscle endurance.1-6 Anecdotally, the closed-chain nature of the SB places significant loading demands on the shoulder of the supporting upper limb,7 which is partially confirmed by reports that shoulder pain and fatigue are common reasons for test termination in healthy and non-injured participants.4,8 The fact that shoulder pain and fatigue are commonly reported reasons for termination of the SB may threaten its validity as an assessment of absolute or relative trunk muscle endurance. This could be problematic for assessing absolute or relative trunk muscle endurance in athletes, given the prevalence and incidence of shoulder injuries across a variety of sports.9-14 Conceivably, unilateral shoulder injuries could impose an imbalance that might influence assessment of side-to-side asymmetries in trunk muscle endurance. For this reason, an open-chain variation of the SB has been proposed to benefit those for whom shoulder pain and fatigue might limit their performance on the closed-chain SB;7 however, a logical precursor for using the open-chain SB as a substitute for the closed-chain SB is to ensure that the low back loading demands, a proxy for trunk muscle demands, are matched between the open-chain and closed-chain variations. To date, neither the mechanics of the open-chain SB, nor their relationship to the mechanics of the closed-chain SB, have been described.

Mechanics of the closed-chain SB can be readily inferred from the posture required to perform the exercise, which has been described and/or illustrated in several previous studies.15-18 Briefly, for a right SB, the performer begins by lying on the ground on their right side and raises their legs, torso and pelvis off of the ground. Placement of the left hand is either on the right shoulder, on the left hip or along the left side of the performer's pelvis/thigh. The performer's bodyweight is supported by their feet and right forearm in the raised position for a right SB. The interactive force between the performer's forearm and the ground imposes an external low back moment that occurs predominately in the frontal plane and directed contralateral to the supporting side (i.e. to the left for a right SB).17 An equal and oppositely directed net internal trunk “muscle” moment is required to isometrically maintain the SB posture. Surface electromyographic studies of the trunk musculature have demonstrated that activity is greatest in the external oblique muscle that is ipsilateral to the supporting upper limb.15,18,19 These electromyographic data provide insight to the trunk muscular demands during the closed-chain SB; however, there is no empirical data that supports (or refutes) anecdotal reports that substantial biomechanical demands are placed on the ipsilateral shoulder musculature during the closed-chain SB.

The open-chain SB positions the person in a side-lying posture on an incline with their lower body supported by an apparatus. Theoretically, a predominant frontal plane external moment is imposed on the low back for the open-chain SB by gravity acting on the weight of the person's upper body. The magnitude of the external moment can be modulated as a direct function of the body's inclination angle. McGill recommended an inclination angle of 45 degrees without providing biomechanical justification or a rationale for this choice.7 Thus, it is uncertain if the recommended 45-degree inclination angle would induce comparable external demands on the low back between the open- and closed-chain SB. If the open-chain SB is to be used in lieu of the closed-chain SB for those whom report shoulder pain or fatigue as the reason for test termination, then it is important to ensure that the inclination angle for the open-chain SB would impose a loading demand on the low back that matches those of the closed-chain SB. Trunk muscle demand and performance comparisons between the closed- and open-chain variations of the SB have yet to be reported.

The objectives of this study were to quantify the low back reaction moments during the open- and closed-chain SB and determine the appropriate open-chain angle of inclination that matches the lateral bend moment magnitude of the closed-chain SB.

METHODS

Participants
A sample of young and healthy male participants was recruited for this biomechanical comparison of the
closed-chain and open-chain SB. Participants were included if they were between 18-40 years of age and were free of any activity-limiting musculoskeletal conditions at the time of testing as determined by the Physical Activity Readiness Questionnaire (PAR-Q). The experimental procedure and consent process were approved by the Research Ethics Board at the Canadian Memorial Chiropractic College (REB# 1608X01).

Instrumentation

**Kinematics**

Three-dimensional postural data were recorded by two banks of optoelectronic cameras (Optotrak Certus, Northern Digital Inc., Waterloo, ON, Canada). A righthand global lab coordinate system was constructed such that the XZ plane was represented by the lab floor with the +X-axis directed anteriorly and the +Z-axis directed cephalad during the closed-chain SB trials (Figure 1A). Data from the forearms, upper arms, head, thorax, and pelvis were monitored by sets of three infrared light-emitting diodes affixed to rigid plastic plates. The rigid plastic plates were secured to each body segment using Velcro straps and positioned at the external occipital protuberance of the head, T9, sacrum, and midway along the length of the forearms and upper arms.

Anatomical landmarks were digitized on each participant prior to beginning the experimental trials, corresponding to the ulnar and radial styloids, medial and lateral humeral epicondyles, anterior, posterior, and middle aspects of the glenohumeral joints, suprasternal notch, acromion processes, xiphoid process, T12 spinous process, left and right tragus, left and right vertex of the head, iliac crests, anterior superior iliac spines, and greater trochanters. Landmarks were virtually tracked throughout data collection using positional information from the appropriate segmental rigid body (e.g. the styloid and epicondyle landmarks were tracked with the forearm rigid body). All postural data were digitally sampled at a rate of 100 Hz.

**Kinetics**

The magnitude, direction, and point-of-application for the interactive force between the ground and participants’ forearm was obtained during closed-chain SB trials with an in-ground force plate (BP400600, Advanced Mechanical Technology Inc., Watertown, MA, USA). Analog data from the force plate were digitally sampled at a rate of 1000 Hz using a 16-bit analog-to-digital conversion board (ODAUIII, Northern Digital Inc., Waterloo, ON, Canada). Force plate data were temporally and spatially synchronized with the kinematic data.

**Protocol**

Participants were positioned in the closed-chain SB so that their anatomical frontal plane was approximately parallel to the YZ plane of the lab's global coordinate system. This positioning facilitated a sensitivity analysis, performed *a posteriori* using the
The participant's ulnar aspect of the right forearm was positioned on an in-ground force plate, elbow flexed 90° and positioned under the shoulder, spine in ‘neutral’ position, hips and knees extended, and ankles at approximately 90° with the left foot in front of the right foot (Figure 1A).5 The spine was considered ‘neutral’ when the relative orientation between the participant's pelvis and thorax approximated the relative orientation between these segments in a relaxed upright standing posture based on visual inspection.21 The closed-chain SB posture was held for five seconds and repeated for five trials. Rest periods between trials were at least 20 seconds rest between trials and were individually paced based on participant reported recovery. There was no limit on the maximum rest duration between trials.

Participants were positioned in the open-chain SB with the ankles, knees, and hips supported by an incline apparatus in a left side-lying position, spine in ‘neutral’ position as previously defined, and arms folded across the chest (i.e. elbows flexed, shoulders abducted and internally rotated, hands crossed comfortably over chest) (Figure 1B). Pilot testing revealed that a left side-lying position was necessary for the open-chain SB to ensure equivalence of polarities for the low back lateral bend reaction moments derived for the open- and closed-chain SB variations. The open-chain SB posture was also held for five seconds and repeated for five trials at each angle as determined by the incline apparatus (32 degrees, 42 degrees, 52 degrees, and 62 degrees). These inclinations spanned the range of available discrete adjustments for the incline apparatus. Furthermore, the chosen inclinations spanned a range around the recommended 45-degree inclination. An inclination angle of 90 degrees was equivalent to upright standing. The order of testing for each inclination was randomized and the same conditions on rest periods that were used for the closed-chain SB were applied to the open-chain SB trials.

Data Processing and Biomechanical Analysis
Kinetic and kinematic data were imported to Visual3D (C-Motion Inc., Germantown, MD, USA). The kinematic data were digitally filtered with a dual-pass Butterworth filter with a low pass cutoff frequency of 6Hz. Voltage data from the force plate were converted to units of force (Newtons) and moment (Newton-meters) and the center-of-pressure was calculated. The marker data and digitized points were used to define the following anatomical segments: head; thorax; pelvis; upper arms; and forearms. A single frame of data from each trial, where the participant's posture was deemed stable, was taken. At this frame, the inclination of the thorax segment with respect to the lab coordinate system was calculated and the locations of the elbow joints, shoulder joints, wrist joints, acromion, iliac crest, greater trochanter were exported. For the closed-chain SB trials, the center-of-pressure coordinates and the three-dimensional components of the ground reaction force at the chosen frame were also exported. These anatomical landmarks (for all SB trials) and force plate data (only for closed-chain SB trials) were inputs to a custom Matlab code (The Mathworks Inc., Natick, MA, USA) that calculated angles of the pelvis segment and lumbar spine (i.e., orientation of thorax with respect to pelvis),22 and derived reaction moments at the low back for all SB trials via static top-down biomechanical linked-segment analysis.21,23 The linked-segment analysis also used participant sex, total body mass, and segment lengths to derive each segment's mass and its three-dimensional location (i.e., center-of-mass).24

An analysis to determine the sensitivity of low back lateral bend reaction moments to the orientation of the reaction force between the ground and the participant's forearm was also performed. This was done to address the secondary objective related to determining if the matching inclination angle for the open-chain SB is relatively independent of differences in participant performance strategies for the closed-chain SB. This was achieved by retaining the center-of-pressure coordinates and mathematically rotating the three-dimensional components of the ground reaction force vector about the lab's +X-axis by 5 degrees in each of the clockwise and counterclockwise directions. Effectively, this altered the Y and Z components of the ground reaction force vector, which are key contributors to the lateral bend component for the low back reaction moment. Low back reaction moments were recalculated for the closed-chain SB trials using the same coordinates for
the anatomical landmarks and the rotated ground reaction force data. Clockwise rotation of the ground reaction force would theoretically decrease the low back lateral bend reaction moment. Conversely, rotating the ground reaction force in a counter-clockwise direction would theoretically increase the low back lateral bend reaction moment.

All low back reaction moments, spine angles, and thorax inclination angles derived for the chosen frames of data were averaged across all five trials of each condition and participant. These average values represented the dependent measures for individual participants that were used in subsequent statistical analyses.

**Statistical Analysis**

Three latent growth curve analyses were used to fit quadratic relationships of the form (SAS, Cary, NC, USA):

\[ A = \alpha M^2 + 90 \]  

Equation 1

This is where \( M \) is the low back lateral bend reaction moment, \( \alpha \) is a regression coefficient, and \( A \) is an inclination angle. Each of the three latent growth curve analyses corresponded to one orientation for the ground reaction force (i.e., as measured, clockwise rotated, counter-clockwise rotated). The specific form of the equation was chosen to represent: (1) the nonlinear nature of the moment-angle relationship for a rigid beam supported at one end with only gravity acting at its center-of-mass (analogous to the open-chain SB); and (2) the fact that the angle corresponding to zero lateral bend reaction moment should coincide with the upright neutral standing posture. Pairs of moments and inclination angles from the open-chain SB trials, along with one set of the moments from the closed-chain SB, were entered to each of the analyses. In each of the three latent growth curve analyses, moments from the closed-chain SB were entered as mock observations without an angle so they did not influence the derived model parameters. Predicted values for the open-chain SB inclination angle to achieve the low back lateral bend reaction moment in the closed-chain SB were derived from the mock observations. Confidence intervals (90%) were constructed around each of the predicted values, which were unique to each participant.

### RESULTS

**Participants**

Demographics for the eight male adult participants are presented in Table 1.

**Kinetic Analysis**

The magnitude of the average lateral bend reaction moment increased with successively lower inclination angles in the open-chain SB (Figure 2). Closed-chain SB lateral bend reaction moments were on average -83±15 Nm (directed to the left). The average corresponding inclination angle to the lateral bend reaction moments from the closed-chain SB using the measured ground reaction forces was 38±12 degrees (Table 2). Clockwise rotation of the ground reaction force by 5 degrees reduced the magnitude of the derived closed-chain SB low back lateral bend reaction moments to an average of 64±13 Nm. This increased the inclination angle for the open-chain SB with a matched low back lateral bend reaction moment to 56±15 degrees (i.e. closer to upright standing). Conversely, counter-clockwise rotation of the ground reaction force increased the magnitude of the derived closed-chain SB low back lateral bend reaction moments to an average of 100±18 Nm and a corresponding decrease in the matching inclination angle to 17±11 degrees (i.e. closer to parallel with the ground).

### Table 1. Participant demographics.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>185</td>
<td>87.4</td>
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<tr>
<td>2</td>
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<td>26</td>
<td>188</td>
<td>88.5</td>
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<tr>
<td>Average (SD)</td>
<td>26.0 (0.9)</td>
<td>181 (6)</td>
<td>83.0 (13.4)</td>
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</table>
Analysis of off-axis moments showed differences in the polarities of the low back axial twist reaction moments between the closed-chain and open-chain SB (Figure 3). The closed-chain SB showed an average low back axial twist reaction moment of \(-22\pm14\) Nm (directed to the right), while the open-chain SB showed and average low back axial twist reaction moment of \(27\pm8\) Nm (directed to the left) across all four inclination angles.

### Postural Analysis

The average angle of the thorax, with respect to the lab's global coordinate system, during the closed-chain SB was \(21\pm4\) degrees (Figure 4). During the open-chain SB, the inclination angle of the thorax closely approximated the respective angle of the incline apparatus with an average difference of one degree across the four angles. For both SB conditions, the lumbar spine was flexed \(17\pm7\) degrees (Figure 5A) and effectively neutral in lateral bend (\(\pm4\) degrees to the right) (Figure 5B). For all angles of the open-chain SB, the lumbar spine closely approximated neutral in axial rotation (\(1\pm3\) degrees) (Figure 5C). In contrast, for the closed-chain SB, the lumbar spine was rotated \(9\pm3\) degrees to the right (Figure 5C).

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**Table 2.** Results from the three latent growth analyses for individual participants. Data from the sensitivity analysis is also presented. Group averages and standard deviations are presented at the bottom of the table. A predicted angle of 90 degrees was equivalent to upright standing. Negative values represent a declined position where the head would be pointed downward.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Closed-Chain Moment (Nm)</th>
<th>Predicted Angle (degrees)</th>
<th>90% Confidence Interval Limits (degrees)</th>
<th>Closed-Chain Moment (Nm)</th>
<th>Predicted Angle (degrees)</th>
<th>90% Confidence Interval Limits (degrees)</th>
<th>Closed-Chain Moment (Nm)</th>
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<td>24 36</td>
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<tr>
<td><strong>Average</strong></td>
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<td><strong>38</strong></td>
<td><strong>32 43</strong></td>
<td><strong>64</strong></td>
<td><strong>56</strong></td>
<td><strong>49 62</strong></td>
<td><strong>100</strong></td>
<td><strong>17</strong></td>
<td><strong>9 24</strong></td>
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</tbody>
</table>
Figure 3. Comparison of low back axial twist moments between the closed- and open-chain side bridge. Negative values represent right axial twist. Mean values are presented; error bars represent the standard deviations.

Figure 4. Thorax inclination angles for the closed- and open-chain side bridge with corresponding bench inclination angle. Mean values are presented; error bars represent the standard deviations.

Figure 5. Comparison of lumbar spine postures between the closed- and open-chain side bridge in flexion (A), lateral bend (B), and axial rotation (C). Mean values are presented; error bars represent the standard deviations.
DISCUSSION
The closed-chain SB task has been widely used as an assessment of trunk muscle isometric endurance capacity and some studies have linked side-to-side asymmetry in holding times to the development of LBP. Motivation for the current study was based on the suggestion that an open-chain SB may be a suitable alternative for those who report shoulder pain or fatigue as the reason for terminating the closed-chain SB endurance test. Theoretically, to use the open-chain SB as an alternative for the closed-chain SB would require matching of the biomechanical demand imposed on the trunk muscles between these two variations as a logical precursor. This work provides the first empirical description of the biomechanical demand collectively imposed on trunk muscles (i.e., low back reaction moment) during the open-chain SB and its relationship to that of the closed-chain SB. We also demonstrated that the low back loading demands of the open- and closed-chain SB can be manipulated, respectively, by changing the upper body’s inclination angle in a side-lying posture and by altering the direction of the interactive force between the forearm and ground. Dependence of the low back loading demands in the closed-chain SB on performance strategies (e.g. steering of the ground reaction force) elevates the difficulty of identifying a consistent inclination angle for the open-chain SB with matching low back loading demands. Therefore, the utility of the open-chain SB as a direct alternative for the closed-chain SB may be limited.

Results of the latent growth analysis using the measured kinetic data indicated that the closed-chain SB low back lateral bend reaction moment was matched in the open-chain SB at an inclination of 38 degrees; however, there was a large amount of individual variability observed (SD = 12 degrees). McGill’s original suggestion of a 45-degree inclination angle for the open-chain SB falls within one standard deviation of the average inclination identified by the data in the current investigation. However, the amount of variability in the “matched” inclinations among participants raises a pragmatic concern about the utility of the open-chain SB and the broad application of a single inclination in clinical practice. Data from the sensitivity analysis demonstrated a large influence of the direction for the ground reaction force vector on the low back lateral bend reaction moment in the closed-chain SB. The extent to which a performer is physically able to manipulate the direction for the ground reaction force vector in the closed-chain SB is unknown, nor can it be visually observed by an assessor. Nonetheless, the current sensitivity analysis demonstrated that a 5-degree change in the angle of the ground reaction force for the closed-chain SB, approximately in the anatomical frontal plane, resulted in an 18-degree to 21-degree change in the matching inclination for the open-chain SB. This provides a valuable proof-of-principle for the effect of variability in performance strategies, that may exist within and between participants, which can hinder the determination of an inclination that adequately matches the low back loading demands between the closed- and open-chain variations of the SB. Furthermore, the current investigation focused on the ground reaction force vector in the closed-chain SB as a key determinant of the low back lateral bend reaction moment, which is only one of several factors (e.g. participant positioning, anthropometry, etc.) that can influence the biomechanical demands of both the open- and closed-chain SB variations.

The close approximation of the thorax and apparatus inclination angles indicated acceptable positioning of participants in the open-chain SB. Results of the postural analysis indicate the lumbar spine was flexed relative to standing neutral position in both SB conditions. To the authors knowledge, this is the first empirical description of the spine posture for both SB conditions. For the open-chain SB, the flexed lumbar spine posture may be the result of the slightly flexed position of the hip and knee within the incline apparatus. For the closed-chain SB, a possible explanation may be that the right or downward axial rotation of the trunk, induced by positioning the left arm across the chest, may have also caused the lumbar spine to flex forward. In contrast, the open-chain SB showed a relatively neutral position in the axial plane as the arms were crossed symmetrically over chest. Spine posture differences between the open- and closed-chain SB variations suggests that demands imposed on specific trunk muscles may also differ between the tasks.

Magnitudes and polarities of the lateral bend and axial twist low back reaction moments of the
closed-chain SB were consistent with those reported by Kavcic and colleagues. Interestingly, for the current investigation, the closed-chain SB produced an axial twist reaction moment to the right while the open-chain SB produced an axial twist reaction moment to the left. Differences in polarity for the axial twist reaction moments reported in the current investigation are a direct consequence of the differences in the side-lying postures used for the open- and closed-chain SB variations. Participants performed the closed-chain SB in a right side-lying posture, and the open-chain SB was performed with participants in a left side-lying posture. These differences in side-lying posture were necessary in the current study to ensure equivalence of polarities for the lateral bend low back reaction moment between the open- and closed-chain SB variations. The dominant contribution to the axial twist low back reaction moment was induced by gravity acting on the upper body's center-of-mass for both the open- and closed-chain SB variations. Gravity acting on the upper body's center-of-mass imposed a rightward external moment in axial twist for the right side-lying posture used for the closed-chain SB. Conversely, gravity acting on the upper body's center-of-mass imposed a leftward external moment in axial twist for the left side-lying posture used for the open-chain SB. The discrepancy in polarity for the low back axial twist reaction moment between the open- and closed-chain SB variations may have non-trivial implications on performance as different patterns of trunk muscle co-activation would likely be required to resist the different external axial twist moments. Thus, differences in the polarities of axial twist low back reaction moments suggest that the open- and closed-chain SB are not directly equivalent, which should be considered when substituting the open-chain SB in clinical practice.

This study is not without limitations. First, results are based on a relatively small and homogenous sample. The small sample size may explain the large degree of variability in the matched open-chain SB inclination angle. Furthermore, the current sample consisted only of males with a small age range and thus limits the generalizability of the results. Given the allometric differences between males and females, adults and elderly, and among different ethnicities, results from this study cannot be directly extrapolated to other populations. Second, due to limitations in the adjustability of the apparatus used in the current study, the lower extremity was slightly flexed during the open-chain SB trials. This may have placed the lumbar spine in slight flexion that may otherwise not have been observed if the lower extremity was straight as described by McGill.

Given that the current data indicates that the low back loading demands are different between the open- and closed-chain SB, it is worth commenting on the relative utility of isometric holding times from each condition as measures of trunk muscle endurance. As previously mentioned, shoulder pain or fatigue is commonly reported as a reason for terminating the closed-chain SB, which detracts from the construct validity of its isometric holding times. This may pose a problem for assessing absolute or relative trunk muscle endurance in athletes, given the prevalence of shoulder injuries across a variety of sports. Unilateral shoulder injuries could theoretically impose an imbalance that might influence assessment of side-to-side asymmetries in trunk muscle endurance. It is important to acknowledge that data from a study of female NCAA Division 1 swimmers reported no group-level differences in closed-chain SB isometric holding times between those with and without shoulder pain or disability. Nevertheless, the open-chain SB is analogous to the prone cantilevered Biering-Sorensen position that is commonly used to assess trunk extensor muscle endurance. Eliminating the need to use the upper extremity for support by cantilevering the upper body in a side-lying position on an incline in the open-chain SB reduces the anatomical degrees of freedom that could impact the isometric holding time. Thus, the conditions for test termination are more likely to be related to the loading demands placed on the low back in the open-chain SB. Isometric holding times from the open-chain SB may thus have greater construct validity for trunk muscle endurance, but further work in this area is required before implementation in a clinical setting.

CONCLUSION

Although the open-chain SB has been suggested as an approximate alternative to the closed-chain
SB when shoulder pain or dysfunction may limit performance, results of this study suggest the low back loading demands are not equivalent. McGill’s recommended 45-degree inclination angle for the open-chain SB provides a suitable approximation of the low back lateral bend reaction moment in the closed-chain SB; however, there is inter-individual variability that requires further investigation. By eliminating the need for the participant to use their upper limb to support their body, it is likely that open-chain SB holding times are a more specific representation of trunk muscle endurance. Future studies where trunk muscle activation and/or holding times are directly compared between the open- and closed-chain SB are warranted to assess the practical significance of between-variation differences in lumbar spine postures and moments reported herein.

REFERENCES


ABSTRACT

Background: The identification of asymmetrical inter-limb ankle dorsiflexion range of motion (DF ROM) has the potential to influence the course of treatment during the rehabilitation process, with limitations in ankle DF ROM potentially increasing injury risk. However, reliability for methods to identify ankle DF ROM asymmetries remain under described in the literature.

Purpose: To determine the reliability of the trigonometric calculation method for measuring ankle DF ROM during the weight-bearing lunge test (WBLT) for both a single limb and the symmetry values. The secondary purpose was to establish values of ankle DF ROM asymmetry and identify the influence of leg dominance on ankle DF ROM.

Study Design: Cross-sectional study.

Methods: Ankle DF ROM was measured bilaterally in 50 healthy and recreationally active participants (28 men, 22 women, age = 22 ± 4 years, height = 172.8 ± 10.8 cm, body mass 71.5 ± 15.1 kg), using the trigonometric measurement method during the WBLT. Each ankle was measured twice in a single testing session to establish within-session reliability.

Results: Values are presented for asymmetries in DF ROM. No differences were identified between the dominant and non-dominant limb (p = 0.862). Within-session reliability for measuring a single limb was classified as ‘good’ (ICC = 0.98) with a minimal detectable change value of 1.7°. For measuring ankle DF ROM asymmetry, reliability was established as ‘good’ (ICC = 0.85) and a minimal detectable change value of 2.1° was determined.

Conclusions: Although symmetry in ankle DF ROM may not be assumed, the magnitude of asymmetry may be less than previously reported in a population of recreationally active individuals. Discrepancies between previous research and the findings of the present study may have been impacted by differences in measurement methods. Furthermore, clinicians should be aware that the error associated with measures of asymmetry for ankle DF ROM during the WBLT is greater than that of a single limb.

Level of Evidence: 2b

Key words: ankle dorsiflexion, inter-limb asymmetry, reliability, trigonometric calculation method
INTRODUCTION
During many athletic activities, ankle dorsiflexion range of motion (DF ROM) is required for the efficient dissipation of ground reaction forces. Limited ankle DF ROM has been reported to affect lower-limb force profiles within athletic activities, as ankle DF ROM restriction has been shown to correlate with greater peak vertical ground reaction forces during landings. As a result, athletes with limited ankle DF ROM may exhibit movement strategies with gross technical errors during bilateral and unilateral squatting and landing tasks, as well as during gait. Reduced weight-bearing ankle DF ROM has been identified as being a modifiable risk factor for many lower limb injuries, with weight-bearing ankle DF ROM of 34° being associated with 2.5 times greater injury risk in military recruits. Proximally, a limitation in weight-bearing ankle DF ROM has been shown to present as a risk factor for hamstring strains in Australian football athletes (relative risk = 2.32). Furthermore, elite junior basketball players with weight-bearing ankle DF ROM values <36.5° possess a 18.5% to 29.4% risk of developing patella tendinopathy within a year. This risk is significantly greater than the 1.8% to 2.1% for players with >36.5° ankle DF ROM. Therefore, restrictions in weight-bearing ankle DF ROM may increase injury risk through the development of mechanical compensations during athletic activities.

Restrictions in ankle DF ROM may result from injury to the rearfoot complex and have been identified. Furthermore, changes in ankle DF ROM have been suggested to occur in response to the functional demands placed on the ankle complex. As such, athletes with a history of lower-leg injury or those exposed to asymmetrical loading might have an inter-limb asymmetry in ankle DF ROM. Although current literature does not provide a clear understanding of the influence inter-limb asymmetries may have on an athlete's performance, asymmetries in ankle DF ROM have been positively correlated with performance deficits during change of direction tests.

However, research investigating normative values for weight-bearing ankle DF ROM has provided conflicting evidence regarding the extent of asymmetries. Cosby and Hertel showed only a 0.8° difference in weight-bearing ankle DF ROM using a lunge test. Similarly, Konor et al found no difference between left and right sides during the weight-bearing lunge test (WBLT) in healthy adults. However, normative data from Hoch and McKeon demonstrated inter-limb asymmetries for ankle DF ROM in healthy participants frequently reached 1.5 cm when measuring toe-to-wall distance. Furthermore, Rabin et al identified ankle DF ROM for the non-dominant leg exceeding the dominant leg DF ROM by 10° in 23% of male military recruits. Better delineation of relative ankle DF ROM symmetry as measured in a weight-bearing position has several potential clinical and research purposes. Clinically, this information could be used to inform the course of treatment during the rehabilitation process or while prescribing interventions to increase ankle DF ROM. Furthermore, it is common practice to perform bilateral comparisons when assessing deficits in DF ROM, which might lead to diagnostic errors if symmetry is assumed. Without prior assessment and knowledge of normative DF ROM asymmetries, the rehabilitation program for an athlete with a similar asymmetry could be misjudged through a lack of consideration for the functional demands placed on the ankle joint.

In order to identify asymmetries in ankle DF ROM that are relevant to functional activities, it has been suggested that using an active weight-bearing assessment provides the most valid representation of ankle DF ROM capacity during dynamic tasks such as squatting and landing. As such, the WBLT has been the subject of many recent investigations. However, a number of different measurement methods can be used to quantify ankle DF ROM during the WBLT, including measuring tibial angle with either a standard goniometer or inclinometer, Achilles tendon angle with an inclinometer, or the distance of the great toe from the wall using a tape measure. In an attempt to establish the most reliable method to measure ankle DF ROM during the WBLT, Langarika-Rocafort et al compared five commonly used techniques; heel-wall distance, toe-wall distance, tibia angle, Achilles tendon angle and a trigonometric angle derived from heel-wall distance and ground-knee distance. The trigonometric measurement method was found to have the highest...
between-session intra-rater reliability (ICC = 0.95, SEM = 1.18°) compared to measurements of tibial angle (ICC = 0.87, SEM = 2.17°) and Achilles angle (ICC = 0.87, SEM = 2.28°). As a result, the trigonometric calculation method may be a more reliable method for the clinician to use to establish ankle DF ROM during the WBLT.

While the between-session intra-rater reliability of the trigonometric method has been established, the within-session intra-rater reliability has yet to be determined. Furthermore, the extent of inter-limb asymmetries in a young, healthy, and active cohort has yet to be established. The aims of this study, therefore, were: i) to determine the within-session, intra-rater reliability of measuring ankle DF ROM using the trigonometric calculation method during the WBLT in healthy and recreationally active participants for both a single limb and the symmetry values measured, ii) to establish values of ankle DF ROM asymmetry and iii) identify the influence of leg dominance on ankle DF ROM.

**METHODS**

**Study design**
Participants reported to the laboratory for a single testing session. Testing was conducted by the lead investigator who had 10 years’ experience measuring ankle DF ROM during the WBLT and is an accredited member of the British Association of Sport Rehabilitators and Trainers. Prior to data collection, all participants completed a pre-exercise questionnaire and provided written informed consent. Following the recording of height and body mass, participants reported their dominant leg, defined as their preferred leg for kicking a ball. Ankle DF ROM for both legs was then measured using the WBLT with no prior warm-up using a randomized counterbalanced design. Following a 10-minute rest, participants were re-tested in order to determine within-session reliability of the WBLT using the trigonometric calculation method.

**Participants**
Using the findings of Rabin et al for inter-limb asymmetries for ankle DF ROM between the dominant and non-dominant limb (effect size = 0.83), a representative analysis was performed to determine the appropriate sample size to utilized. Calculations indicated that to achieve 80% statistical power, a minimum of 39 participants were required to detect inter-limb asymmetries. A total of 50 participants volunteered for the study (28 men, 22 women, age = 22 ± 4 years, height = 172.8 ± 10.8 cm, body mass 71.5 ± 15.1 kg). All participants self-reported to be physically active, defined as regularly performing at least 30 min of moderate intensity physical activity three times per week for at least six months prior to testing. Participants were excluded if they had a history of a lower-extremity surgical procedure or injury to the lower-extremity in the six-months prior to testing. Ethical approval was provided by the lead authors institution’s Research Ethics Panel.

**Procedures**
In order to measure the heel-wall distance, a 70 cm tape measure was fixed to the floor, perpendicular to the wall used for testing. Measurements of ground-knee distance were obtained with a 70 cm tape measure fixed vertically to the wall and perpendicular to the tape measure on the ground. A longitudinal line was marked down on each of the scales for testing purposes. Prior to performing the test, participants were provided with a demonstration and standardized instructions. Participants then completed three familiarization trials for each leg before performing three trials on each limb, with the mean value from the three attempts from each foot being used for data analysis.

To ensure neither the participant nor investigator could target a specific outcome on subsequent attempts, no markings were made on the tape measure that would indicate the previous attempt. Following a 10-minute break participants were retested using the same procedures on both legs in order to establish within-session reliability. The results were recorded on a separate sheet in order to blind the investigator from previous distances and participants were not informed of their previous scores. For all participants, leg order was randomized for both trial 1 and 2. Ankle DF ROM symmetry was calculated in degrees as the absolute difference between the means of the right and left legs. Figure 1 provides an illustration of testing procedures and measurements used for the trigonometric calculation.
Participants began the test by facing a bare wall, with the great toe of the test leg positioned against the wall. The great toe and the center of the heel were aligned using the marked line on the ground. Participants were instructed to place the non-test foot behind them, with the heel raised and at a distance that they felt helped maximize their performance on the test. This position was established during familiarization. In order to maintain balance, participants were asked to keep both hands firmly against the wall throughout. The participants were then instructed to slowly lunge forward by simultaneously flexing at the ankle, knee and hip on the test leg in an attempt to make contact between the centre of the patella and the vertical marked line on the wall. No attempt was made to control trunk alignment. Subtalar joint position was controlled by keeping the test foot in the standardized position and ensuring the patella contact with the vertical line was accurate.\textsuperscript{16}

The aim of the test was for the participant to get their heel as far away as possible from the wall, while making contact between the patella and the wall and maintaining firm pressure between the heel and the ground. Throughout the test, the investigator was positioned behind the participant in a low crouched position in order to visually monitor heel-lift. Heel lift was defined as the visual lifting of the calcaneus, resulting in a greater ground surface area observed under the rearfoot. Any elevation of the heel during the test was regarded as a failed attempt and feedback was provided to the participants regarding their inability to prevent the heel from rising.

Upon successful completion of an attempt, where contact between the patella and the wall was made with no change in heel position relative to the ground, participants were instructed to move the test foot further away from the wall by approximately 0.5 cm. No restrictions were placed on the number of attempts made by a participant. At the last successful attempt, the distances between the heel and the wall, and the distance between the anterosuperior edge of the patella and the ground were recorded to the nearest 0.1 cm. Ankle dorsiflexion angle for each attempt was calculated with the heel-wall and ground-knee distances, using the trigonometric function outlined by Langarika-Rocafort et al\textsuperscript{18} (DF ROM = 90 - arctan[ground-knee/heel-wall]).

**Statistical Analysis**

The assumption of normality for data sets was checked using the Shapiro-Wilk test, with normative data for the inter-limb mean difference for ankle DF ROM graphically presented using a frequency-distribution histogram. An independent \( t \)-test were performed to establish the difference between the dominant and non-dominant for ankle DF ROM during the WBLT. Effect sizes were calculated for each comparison, with 0.2 being considered small, 0.5 moderate and 0.8 or greater large.\textsuperscript{21}

The within-session intra-rater reliability for single limb measurements of ankle DF ROM and ankle DF ROM symmetry was initially assessed using a paired samples \( t \)-test to calculate systematic bias between trial 1 and 2.\textsuperscript{22} Relative reliability was determined using intra-class correlation coefficient (ICC) calculated as suggested by Hopkins\textsuperscript{23} and reported with

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**Figure 1.** Participant performing the weight-bearing lunge test with example calculation. GK = ground-knee distance; HW = heel-wall distance; TA = trigonometric angle.
95% confidence intervals, with ICCs interpreted as follows: 0.00-0.25 *poor*, 0.26-0.50 *fair*, 0.51-0.75 *moderate*, and 0.76-1.00 *good* reliability. Absolute reliability was calculated using the coefficient of variation (CV; SD / mean *100), the 95% limits of agreement, standard error of measurement (SEM; SD√1-ICC) \(^2\) and minimal detectable change (MDC; SEM*1.96*√2). All statistical tests were performed using SPSS® statistical software package (v.24; SPSS Inc., Chicago, IL, USA), with the *a-priori* level of significance set at \(p < 0.05\). ICC and CV% were calculated using a customized spreadsheet.

**RESULTS**

The mean difference for ankle DF ROM was 2.3˚ ± 2.0˚. Forty-one participants (82%) reported their dominant leg to be their right, with the remaining nine participants (18%) reporting their left leg as dominant. WBLT values are summarized in Table 1. Mean WBLT values for the dominant and non-dominant limb were 36.5 ± 4.5˚ and 36.5 ± 4.3˚, respectively. No statistically significant difference was identified between the dominant and non-dominant limb.

The within-session reliability of the WBLT is summarized in Table 2. There were no systematic biases for the WBLT using the trigonometric calculation method between trials for either ankle DF ROM or ankle DF ROM symmetry (\(p > 0.05\)). The relative reliability was established as ‘good’ for within-session reliability for a single measure (ICC = 0.98) and inter-limb asymmetries in ankle DF ROM (ICC = 0.85). All values representing relative and absolute reliability are reported in Table 2.

**DISCUSSION**

The aim of this study was to determine the reliability of the trigonometric calculation method for measuring ankle DF ROM during the WBLT for both a single limb and the symmetry values measured. Furthermore, this study attempted to establish values for the inter-limb asymmetries of ankle DF ROM among healthy recreationally active individuals. Of all participants, 44% presented asymmetries in ankle DF ROM exceeding the MDC of 2.1˚ found in this investigation (Table 2), with 8% of participants demonstrating an inter-limb asymmetry greater than 5˚, with the largest asymmetry being 8.8˚. Therefore, with 44% of the sample having asymmetry values greater than the MDC, the current findings suggest that the clinician should not assume symmetry without conducting thorough assessments.

These data support the findings of Hoch and McKeon\(^{15}\) and Rabin et al\(^{11}\) by identifying the existence of inter-limb asymmetries in ankle DF ROM during the WBLT in healthy populations. Using the toe-wall distance during the WBLT, Hoch and McKeon et al\(^{15}\) reported that 68% of participants

<table>
<thead>
<tr>
<th>Table 1. Asymmetry within the weight bearing lunge test for dominant-to-non-dominant limb comparison (n=50).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle dorsiflexion</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Dominant side</td>
</tr>
<tr>
<td>Nondominant side</td>
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</tbody>
</table>

\* Significant difference (\(p < .05\)).

<table>
<thead>
<tr>
<th>Table 2. Within-session intra-rater reliability for the weight-bearing lunge test using the trigonometric measurement method for testing ankle dorsiflexion range of motion for a single limb and ankle dorsiflexion range of motion symmetry (n=50).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability measure</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>Ankle DF ROM</td>
</tr>
<tr>
<td>Ankle DF ROM symmetry</td>
</tr>
</tbody>
</table>

DF ROM = dorsiflexion range of motion; ICC = intra-class correlation coefficient; CV % = coefficient of variation.
exhibited an asymmetry of 1.5 cm or less, with some participants approaching asymmetries of approximately 3 cm. Using the conversion calculation suggested by Konor et al\textsuperscript{16} where 1 cm in toe-wall distance corresponds with approximately 3.6° of ankle DF ROM, 32% of the sample in Hoch and McKeon\textsuperscript{15} would have demonstrated ankle DF ROM asymmetries of > 5.4°, with some participants approaching asymmetries of 10.8°. This is similar to that of Rabin et al\textsuperscript{11} where 64 healthy male military recruits possessed a bilateral mean difference of 5.8° in favour of the non-dominant leg during the WBLT and 23% of participants presented with asymmetries >10°.

Although the findings from the present study support the notion that bilateral differences are present in healthy populations, these data indicate that the magnitude of inter-limb asymmetry for ankle DF ROM is likely less than previously reported. These findings identify a much smaller mean asymmetry in comparison to previous investigations,\textsuperscript{11,15} with 56% of the population possessing inter-limb asymmetries on the WBLT of less than the MDC of 2.1°. This resulted in rightward skew of the data (Figure 2), indicating that a large portion of the sample presented with a negligible asymmetry in ankle DF ROM, relative to the MDC. Furthermore, none of the participants who volunteered for the present study exceeded an asymmetry of 10°, with the greatest asymmetry recorded being 8.8° between limbs.

One possible reason for not observing a similar magnitude in asymmetry may be the measurement method of ankle dorsiflexion angle. Both measurement methods adopted by Hoch and McKeon\textsuperscript{15} and Rabin et al\textsuperscript{11} used to record ankle DF ROM during the WBLT have been identified to possess a greater MDC for a single limb than the 1.7° found in the present investigation (Table 2).\textsuperscript{18} As the MDC represents the boundaries of measurement error,\textsuperscript{25} it is possible that the testing procedures used by both investigations may have contributed to the level of inter-limb asymmetry observed. For example, the MDC for the measurement method used by Rabin et al\textsuperscript{11} has been reported to be 6.0° for testing a single limb.\textsuperscript{18} Although it is unclear why the trigonometric calculation method provides greater reliability than other measurements of ankle DF ROM during the WBLT,\textsuperscript{18} it may be that measuring distances produces superior repeatability than measurements of angles. This suggestion is supported by Langarika-Rocafort et al,\textsuperscript{18} where ICC values for all distances associated with the trigonometric calculation method were much higher (ranging 0.95 – 0.96) than measuring tibia (0.87) and Achilles angle (0.87) during the WBLT.

To the authors’ knowledge, no previous investigation has established the within-session intra-rater reliability for measuring asymmetries in ankle DF ROM during the WBLT. These findings indicate that the error in measurement for inter-limb differences in ankle DF ROM (MDC = 2.1°) is greater than the error associated with testing a single limb (MDC = 1.7°). Measurements of tibia angle for single limb ankle DF ROM during the WBLT have previously been shown to possess MDC values >6.0°.\textsuperscript{18} As the present investigation showed greater error associated with measures of inter-limb asymmetries in ankle DF ROM, the mean inter-limb difference of 5.8° in ankle DF ROM (measured as tibia angle) reported by Rabin et al\textsuperscript{11} may represent error in the measurement technique that is compounded by testing both limbs. Although other investigations have reported intra-rater MDC values as low as 3.2° when measuring tibia angle for a single limb,\textsuperscript{19} none have established the reliability for measuring asymmetry. Therefore, it remains possible that the difference between the findings of Rabin et al\textsuperscript{11} and that of the present study is due to measurement error associated with the techniques employed to establish inter-limb differences in ankle DF ROM.

![Figure 2](image-url). Frequency-distribution histogram for inter-limb mean difference with the weight-bearing lunge test (n = 50).
No systematic bias was found in data between trials using the within-session design. This demonstrates that the procedures were well-controlled during testing. As a result, learning effects, acute changes caused by the previous trials (e.g., fatigue or warming up of relevant tissues) and participant bias were not confounding factors during testing. This is an important consideration for clinicians when administering the WBLT in practice in order to establish real measurements in ankle DF ROM, with poor control of conditions negatively impacting the clinician’s ability to interpret data.

Within the present study, the MDC for a single limb measurement for ankle DF ROM during the WBLT was identified as 1.7°, with a SEM of 0.6° (Table 2). These values for reliability are lower than reported for alternative measurement methods of ankle DF ROM during the WBLT, with MDC and SEM values ranging between 3.1˚ to 6.4˚ and 1˚ to 2.4˚, respectively. Although all reported methods for measuring ankle DF ROM during the WBLT have been identified as having ‘good’ reliability (ICC >0.7), Langarika-Rocafort et al demonstrated that the trigonometric calculation method used in the present study possessed the highest intra-rater reliability and smaller MDC value in comparison to four other measurement methods. Based on the results presented here and those reported by Langarika-Rocafort et al, it is suggested that the trigonometric calculation method should be used when measuring ankle DF ROM asymmetries, as it appears to be a more sensitive measure. Practically, the trigonometric calculation method does not require specialized equipment, is time efficient, and utilizes a simple method for calculating ankle DF ROM. Regardless, clinicians and practitioners should be aware of the different results based on the method used, so as to avoid erroneous conclusions when comparing their patients’ or clients’ results to the literature.

Despite the present study using the same measurement technique as Langarika-Rocafort et al, better reliability is reported. It is speculated that one potential reason may be due to the administration of the WBLT. In order to identify peak ankle dorsiflexion angle during the WBLT, Langarika-Rocafort et al relied upon participants informing the investigator of when they had reached maximum distance from the wall prior to measurement. In contrast, in the present investigation, measurement was taken at the last successful attempt, which was defined as the farthest distance away from the wall where they could make contact between the patella and the wall and prior to the point of heel lift. These two approaches are markedly different and are likely to produce different results. Heel lift was carefully monitored by the investigator and defined as the visual lifting of the heel, where a greater surface area of the ground could be seen under the rearfoot. It is proposed that this is an important distinction, as it is questionable that participants can identify at what point ankle DF ROM has terminated and compensatory strategies will be adopted, thus influencing the outcome measurement through a lack of standardization. This is especially problematic during the WBLT, as participants are unable to observe ankle motion on the test leg and the accuracy of identifying movement strategy, primarily through the sensorimotor system varies by task.

Leg dominance has previously been shown to possess a relationship with inter-limb asymmetry in ankle DF ROM, with greater ankle DF ROM observed in the non-dominant limb. However, the results of present investigation did not identify a difference in ankle DF ROM during the WBLT between the dominant and non-dominant leg. Although it remains unclear why the present study did not see a similar finding, a few possibilities exist. Firstly, Rabin et al proposed that asymmetries in ankle DF ROM between the dominant and non-dominant leg may exist due to the mechanical loading placed on the ankle complex during habitual activities. This is based on a rationale that the ankle joint complex adapts to the demands imposed upon it, with the non-dominant leg being subjected to larger requirements for balance and stability, resulting in greater joint ROM. As all participants in Rabin et al were military recruits, it may be that specific physical activities undertaken by the participants in preparation for basic military training resulted in the ankle DF ROM asymmetries identified between the dominant and non-dominant leg, as opposed to the present study sample who were physically active but not military trained.

Another possible explanation for the lack of agreement may be due to difference in procedures when
conducted the WBLT. Unlike the present study that used the trigonometric calculation method for recording ankle dorsiflexion ROM, Rabin et al\(^1\) used an inclinometer placed on the tibia, 15 cm below the tibial tuberosity. As previously discussed, intra-rater reliability for this method has been reported to be inferior to the trigonometric calculation method.\(^1\) As an analysis of intra-rater reliability was not conducted as part of Rabin et al\(^1\) design, it is possible that the procedures used may have contributed to the contrast in findings.

Whether the asymmetry in ankle DF ROM observed in this investigation is clinically meaningful is at present unknown. Limitations in ankle DF ROM have been linked to greater peak forces\(^2\) and increased knee abduction moments\(^2\) during landing activities and these suboptimal movement strategies are associated with ACL injuries.\(^2\)\(^8\) Large asymmetries in ankle DF ROM may, therefore, present as a modifiable variable for reducing risk factors associated with lower extremity injury during dynamic activities.

Asymmetry in ankle DF ROM has been shown to impact change of direction performance. Gonzalo-Skok et al\(^1\) found a negative relationship between ankle DF ROM asymmetry during the WBLT and 180° change of direction test in elite youth male basketball players. As weight-bearing peak dorsiflexion angle can approach approximately 50° during change of direction tasks,\(^3\) it is likely that limitations in ankle DF ROM have the potential to alter movement patterns during such athletic activities. This may result in asymmetries in ankle DF ROM contributing to suboptimal movement strategies to be utilized on the limited side, leading to reduced performance in athletic tasks. Unfortunately, Gonzalo-Skok et al\(^1\) did not report values for inter-limb asymmetries and, therefore, it is unclear if the asymmetries found in the present study have the potential to negatively impact performance. More research is required to establish a threshold for when an asymmetry may present as a risk factor for the development of injury or a cause towards suboptimal performance.

The results from this investigation indicate that ankle DF ROM symmetry should not be assumed by the clinician. The assumption of symmetry in ankle DF ROM during the rehabilitation of an athlete would be inappropriate for restoring function. Instead, it may be more reasonable to identify whether the athlete possesses sufficient ankle DF ROM to cope with the movement demands placed on them by the sport and relevant training. As athletic activities, such as squatting,\(^3\) landing,\(^3\) running,\(^3\) and change of direction tasks\(^3\) may all require large amounts of ankle DF ROM, ensuring an athlete possesses sufficient mobility to cope with these demands appears to be a more logical guide.

This investigation was not without limitations. Firstly, a relatively young population of recreationally trained individuals was used. As such, the findings presented in this study provide preliminary data and are not yet representative of a wider population. Further work is required to establish normative values across the wider population. The degree to which asymmetry in ankle DF ROM becomes clinically relevant is currently unclear. Whether a threshold exists that may increase an athlete’s injury risk or result in a decline in performance outputs requires further investigation in order to inform a clinician’s practice.

During testing, as the investigator was not blinded to the measurements, it is possible that the investigator had knowledge of the initial values. Although an attempt was made to control for this, recollection of values may have occurred. This investigation also used only one, experienced tester to establish values during the WBLT. Therefore, these results are not generalizable to the novice clinician. Furthermore, the intra-rater reliability for the trigonometric calculation method has not yet been established. Without data on the inter-rater reliability the wide-spread adoption of this measurement technique should be used with caution.

**CONCLUSIONS**

Recreationally active individuals may present with asymmetrical weight-bearing ankle DF ROM during the WBLT that is normal and not necessarily associated with leg dominance. These findings suggest the extent of asymmetry found using the WBLT is less than what has been previously reported in the literature. Furthermore, measuring weight-bearing ankle...
DF ROM for a single limb using the trigonometric calculation method is simple and reliable; however, the error associated with identifying asymmetries in weight-bearing ankle DF ROM may exceed the absolute inter-limb difference. Therefore, asymmetries in weight-bearing ankle DF ROM may be error associated with the testing procedures and not a true inter-limb difference. Future investigations should examine the intra-rater reliability of the trigonometric calculation method, as well as investigating the mechanical implications of ankle DF ROM asymmetry during functionally relevant activities.

REFERENCES


ABSTRACT

Background: Shoulder girdle pain is a common disabling complaint with a high lifetime prevalence. Interventions aimed at decreasing shoulder pain without stressing shoulder girdle structures have the potential to improve participation in multimodal shoulder rehabilitation programs.

Hypothesis/Purpose: The aim of this study was to determine the acute effects of moderate intensity lower extremity exercise on mechanically induced shoulder pain in individuals without shoulder injury. It was hypothesized that participants would exhibit less shoulder pain, as indicated by increased pain thresholds, following lower extremity exercise.

Study Design: Repeated measures study.

Methods: Thirty (30) healthy participants were recruited to participate in this study. Pain pressure algometry was used to mechanically induce shoulder pain over the infraspinatus muscle belly. This was performed on the dominant shoulder before and immediately after performing 10 minutes of moderate intensity lower extremity exercise using a recumbent exercise machine. Heart rate and rate of perceived exertion were measured following exercise. Repeated measures ANOVA was used to compare pain pressure threshold scores between the baseline and post-exercise time points. Significance was set at p ≤ 0.05 a priori. Effect size (ES) was calculated using Glass’s Δ.

Results: Moderate intensity lower extremity aerobic exercise led to significantly (F=8.471, p=0.003) decreased evoked shoulder pain in healthy adults with moderate effect sizes (0.30-0.43).

Conclusions: Lower extremity aerobic exercise significantly decreased pain of the infraspinatus in this sample of young healthy participants. Utilization of lower extremity exercise may be of benefit for younger patients to decreased acute shoulder pain.

Level of Evidence: 2b: individual cohort study

Key Words: aerobic exercise, exercise induced hypoalgesia, pressure algometry, shoulder pain
INTRODUCTION
Shoulder girdle pain is among the most common pain complaints with point prevalence rates ranging from 6.9 to 26% and lifetime prevalence rates ranging from 6.7 to 66.7% in the general population. Specific athletic populations, throwers and swimmers, experience pain at higher rates than the general population. Physical therapists commonly use shoulder specific exercises, manual therapy, and electrical and/or thermal modalities to assist in pain management and promote return to functional and sporting activities. Despite these established interventions, numerous studies have demonstrated the urgency for further research regarding shoulder pain reduction. It has been reported that up to 41% of patients who sought treatment for primary shoulder complaints were still experiencing pain greater than six months following initial treatment. It is evident there is a need for alternative treatments for pain specifically addressing the shoulder girdle.

Numerous prior studies have indicated that aerobic exercise is associated with alterations in pain perception. This phenomenon has been termed exercise-induced hypoalgesia or exercise-induced analgesia, henceforth referred to as hypoalgesia. In general, investigators have typically found diminished pain perception, or hypoalgesia, to occur during and following many different types of exercise. Emerging evidence from a recent meta-analysis of exercise-induced hypoalgesia suggests that exercise of non-painful muscles for individuals with regional chronic pain conditions produces a hypoalgesic effect and may be considered an effective method to temporarily decrease or relieve pain in painful muscles. However, the concept of aerobic exercise-induced hypoalgesia has never been explored at the shoulder girdle.

Therefore, the aim of this study was to determine the acute effects of moderate intensity lower extremity exercise on mechanically induced shoulder pain in individuals without shoulder injury. It was hypothesized that participants would exhibit significant changes in pain perception of the infraspinatus following a lower extremity aerobic exercise protocol.

METHODS
Subjects
A sample of convenience consisting of 30 healthy volunteers was recruited to participate in this study. Participants between the ages of 18 and 30 years were recruited specifically to decrease the prospect of age-related degeneration of shoulder girdle structures. Participants were considered healthy using the following criteria: denied any history of seeking medical care for shoulder or neck injuries and reported no current (within the prior six months) shoulder or neck pain. Exclusion criteria consisted of prior shoulder surgery or fracture, inability to perform lower extremity aerobic exercise at a moderate intensity or current treatment for any musculoskeletal disorder.

Testing Procedure
All participants completed two test sessions. The first testing session consisted of baseline outcome measures of participants' pain pressure threshold (Baseline 1), a fifteen-minute rest interval, and a reassessment of participants' pain pressure threshold (Baseline 2). Participants returned for the second day of testing 24–48 hours following the first session. Participants were instructed to refrain from performing any upper body exercises between testing sessions and to avoid aerobic exercise immediately before the testing sessions. The second testing session consisted of baseline outcome measures of participants' pain pressure threshold (Baseline 3), a fifteen-minute aerobic exercise protocol, and a reassessment of participants' pain pressure threshold. Participants' final heart rate and rating of perceived exertion were also evaluated immediately following the exercise protocol.

Pain Pressure Testing
Pain pressure threshold (PPT) is the minimal amount of force required for the sense of pressure to change to pain. A hand-held digital algometer (Wagner, Pain Test FP Algometer, Greenwich, CT) with a 1 cm² blunt tip was used for testing. Pain pressure threshold was analyzed over the infraspinatus muscle belly with the participant in prone in the anatomical position. The infraspinatus has been commonly used for pain pressure testing at the shoulder. Testing occurred on the dominant arm as defined by the preferred hand for writing. The infraspinatus muscle belly was located by palpation inferior to the approximate midpoint of the scapular spine (Figure 1). Standardized procedures for use of the pressure algometer were
performed by the same investigator for all measures, with the average of three measurements used for analysis. The time between pain pressure threshold measures was 30 seconds. Training on pain pressure threshold measurement procedures was performed prior to the commencement of the study. These procedures have been demonstrated reliable and valid (ICC = 0.985, SEM = 0.453kg/cm²) by the authors of this study.

Aerobic Exercise Protocol
The aerobic exercise protocol was completed on a recumbent stationary stepping machine (NuStep TRS 400 Recumbent Cross Trainer, Ann Arbor, MI) (Figure 2). Participants self-selected a “somewhat hard” (13/20) intensity using the Borg Scale and were instructed to keep this intensity for the duration of the exercise protocol. The level of intensity was self-controlled by participants adjusting the amount of weighted resistance and cadence applied to the foot pedals. Participants were instructed to use their legs only for the exercise. Final heart rate was measured immediately following the aerobic exercise protocol using a finger pulse oximeter (OxyWatch C20, Choicemmed, Deerfield, IL)

All testing was completed in a university research laboratory and approved by the Institutional Review Board at East Tennessee State University. All participants provided written informed consent as per institutional guidelines.

Statistical Analysis
Demographic data was summarized as means (SD). A repeated measures ANOVA was used to determine the effect of lower extremity aerobic exercise on pressure threshold measures for the whole sample. SPSS version 22.0 (SPSS, Inc. Chicago, IL) was used for all analyses. The Greenhouse-Geisser correction was applied if Mauchly's test of Sphericity was violated. Significance was set at p < 0.05 a priori. Post hoc pairwise comparisons were performed if a significant effect was found. Effect size with 95% confidence interval was calculated for all statistically significant findings. Effect size (ES) was calculated using the effect size index [baseline PPT – post-exercise PPT] / standard deviation baseline PPT]. Further, individual changes in pain pressure threshold were compared to previously described minimum clinically important change scores (3.3lb/cm²).

RESULTS
Thirty (30) participants met the inclusion criteria and completed the testing. See Table 1 for demographic and exercise variables.
Participants rated their final perceived exertion (RPE) with an average of 13.3/20. The target for this exercise was 13/20. The final heart rate at the end of the exercise session was 120.6 beat per minutes (bpm). This represents approximately 62% of each individual participant’s age-predicted maximum heart rate as determined using the maximum heart rate estimation formula (208 – 0.7 * age). Mauchly’s test of Sphericity was significant, thus the Greenhouse-Geisser correction was utilized. The results of the ANOVA for effects of exercise on shoulder pressure pain thresholds were significant (F=8.471, p=0.003). Post-hoc pairwise comparison analyses indicate that pressure pain measures at Baseline 1 was significantly less than Baseline 2 (p = 0.005), indicating an increased pain response after a 15-minute rest period. Further results demonstrate that the post-exercise condition was significantly higher than all baseline conditions, suggesting a decrease in mechanically induced pain (p < 0.001, Table 2).

The effect sizes for all significant findings are indicated in Table 3. Furthermore, 6/30 participants reported changes that exceeded the minimal clinically important difference for pain pressure threshold, indicating less pain following the exercise.

### DISCUSSION

The purpose of this study was to determine the effect of distant (lower extremity) exercise on evoked pressure pain in the shoulder. Pressure threshold testing is commonly used as an objective measure of evoked pain. Mechanically induced or evoked pain is pain brought about with movement for which most physical therapy patients seek treatment.  

The results indicate that aerobic exercise of body regions distant to the location of evoked pain, significantly decreased pain responses (increased pain pressure threshold) with moderate effects. Further, 20% (6/30) of the participants also reported changes greater than the described minimal clinically important difference for pressure threshold testing indicating a clinically relevant decrease in pain. This is the first study to determine a potential hypoalgesic effect at the shoulder during aerobic exercise. These findings are similar to prior studies which have shown increased pain thresholds in response to acute and ongoing exercise albeit at other anatomic sites such as...

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### Table 1. Participant Demographics.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Number</th>
<th>Age in Years</th>
<th>Right Hand Dominant</th>
<th>Final RPE</th>
<th>Final Heart Rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>20</td>
<td>20.9 (1.8)</td>
<td>16</td>
<td>13.4 (2.4)</td>
<td>120.4 (23.2)</td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
<td>19.9 (1.9)</td>
<td>10</td>
<td>13.0 (2.3)</td>
<td>121.0 (26.5)</td>
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<tr>
<td>Total</td>
<td>30</td>
<td>20.6 (1.6)</td>
<td>26</td>
<td>13.3 (2.4)</td>
<td>120.6 (24.3)</td>
</tr>
</tbody>
</table>

RPE= rate of perceived exertion, bpm= beats per minute

### Table 2. Pain Pressure Threshold Measures (pounds/cm²).

<table>
<thead>
<tr>
<th>Participants</th>
<th>Day 1 Baseline 1</th>
<th>Day 1 Baseline 2</th>
<th>Day 2 Baseline 3</th>
<th>Day 2 Post Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>11.4 (3.2)</td>
<td>11.0 (3.4)</td>
<td>11.9 (5.2)</td>
<td>13.6 (5.7)</td>
</tr>
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<td>Males</td>
<td>17.3 (4.6)</td>
<td>16.5 (4.6)</td>
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<tr>
<td>Total</td>
<td>13.4 (4.6)</td>
<td>13.0 (4.4)*</td>
<td>13.2 (5.2)</td>
<td>14.9 (5.8)*</td>
</tr>
</tbody>
</table>

* Significant difference between baseline 1 and 2, p = 0.005  
† Significant difference between post exercise and baselines 1, 2, and 3, p < 0.001

### Table 3. Effect Size for Significant Findings.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Effect (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1, Baseline 1 &amp; Day 1, Baseline 2</td>
<td>0.11 (-0.25 – 0.47)</td>
</tr>
<tr>
<td>Post Exercise and Day 1, Baseline 1</td>
<td>0.30 (-0.06 – 0.67)</td>
</tr>
<tr>
<td>Post Exercise and Day 1, Baseline 2</td>
<td>0.43 (0.05 – 0.80)</td>
</tr>
<tr>
<td>Post Exercise and Day 2, Baseline 3</td>
<td>0.33 (-0.04 – 0.69)</td>
</tr>
</tbody>
</table>
as the shank, forearm or hand.\textsuperscript{23-26} This study adds to mounting evidence that aerobic exercise can be used to specifically improve mechanically evoked pain in healthy participants. These findings also indicate a significantly increased pain response (decreased pressure threshold) between Baseline 1 and Baseline 2 with a very small effect size (0.11). This difference was also below the reported minimum detectable change (2.54lb/cm\(^2\)) for pressure threshold testing and below the standard error of measurement in this study.\textsuperscript{22} The reason for this statistical increase in evoked pain after resting for 15 minutes is unknown. This may represent the variable nature of pressure threshold testing and is not likely of clinical value with an effect size close to zero.\textsuperscript{27,28}

The optimal dosage of exercise to induce systemic related hypoalgesia is not known. In prior studies, a typical dose-response relationship has been described.\textsuperscript{10,29} That being, the higher the intensity of exercise, the greater the pain relieving effect when assessing healthy participants. The self-determined dosage of exercise as "somewhat hard" was based on the standardized Borg scale. While this was consistently maintained by participants, the final heart rate the participant's demonstrated wide variability. There was likely a dose-response relationship based upon a visual post-hoc evaluation of the distribution of the data (Figure 3). Specifically, the data shows a trend line indicating that higher final heart rate was associated with a positive change in pain pressure threshold (thus an increase in the threshold), despite moderate variability in individual responses.

Practically, this implies that the greater the exercise intensity, the greater the noted hypoalgesic effects. A similar dose-response relationship has been described previously\textsuperscript{26} which noted the largest effect sizes when assessing pain perception in healthy individuals were found when aerobic exercise was performed at a high intensity (i.e. greater than 70\% VO\(_2\) max or max heart rate) yet with similar exercise duration (>10 minutes). The effects of aerobic exercise on pressure threshold in individuals with chronic pain conditions are more varied. Patients with longstanding and widespread pain conditions such as fibromyalgia or chronic fatigue syndrome have demonstrated impaired systemic pain regulatory function.\textsuperscript{30,31} Patients with localized pain conditions, such as knee osteoarthritis, demonstrate similar decreased pain responses with distant exercise.\textsuperscript{32} This study calculated pain responses at only one time point immediately (less than 5 minutes) following exercise. Pain relieving effects may last up to 30 minutes following the completion of the aerobic exercise.\textsuperscript{10}

While this was not a mechanistic study, some discussion regarding of how pain responses were improved is warranted. Perhaps the most widely considered mechanism for exercise-induced hypoalgesia is that exercise creates a stimulus causing activation of descending inhibitory pain systems involving the endogenous opioids.\textsuperscript{29,33,34} Additional basic science research has implicated a role for beta-endorphins, endocannabinoids, serotonin and/or the interactions among some or all of these chemicals which have been associated with changes in pain sensitivity.\textsuperscript{3,35} Regardless of the complexity of the pain reducing effect, the hypoalgesic response appears to be systemic and thus the effects of exercise on evoked pain can occur at both local and distant sites.

There are many passive local pain-relieving interventions such as electrical or thermal agents and manual therapies which have the potential to decrease pain prior to, during, or following joint specific exercise. The findings in this study indicate that young healthy participants without shoulder injury exhibit decreased pain following self-determined moderate intensity aerobic exercise. Patients with shoulder injury may also exhibit a hypoalgesic benefit from distant exercise based on the systemic effect

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure3.png}
\caption{Relationship between Heart Rate and Pain Pressure Threshold.}
\end{figure}
of aerobic exercise. In addition to the many benefits of aerobic exercise, distant exercise may be considered as an active hypoalgesic agent for shoulder pain. More generally, aerobic exercise could play a role as an active pain reducing modality, when otherwise not contra-indicated, as means to improve exercise tolerance and promote active self-efficacious options for pain relief. Such exercise may be more applicable to younger patients (based on the age of our sample) or athletes with acute or postoperative pain as opposed to those with longstanding widespread pain as responses to exercise for chronic pain patients are reported to be impaired. Older individuals may have different responses based on reported variability in pain responses over the lifespan.

**Limitations**

This study evaluated the acute effects of lower extremity exercise on evoked shoulder pain. The sample was selected based on convenience and was further limited to young and healthy volunteers. The response of participants of different ages, those with shoulder injury or chronic pain may differ from the outcomes of this study. Evoked pain due to acute injury may differ from mechanically induced pain in healthy participants as the roles of local inflammation and tissue injury are not accounted for. Only the acute effects of the aerobic exercise protocol were evaluated. Observing the duration of these hypoalgesic effects was beyond the scope of this study. Finally, the results indicate an immediate decrease in pressure evoked pain following aerobic exercise. There are many other modalities of evoked pain which were not evaluated in this study. Future studies should consider improved methods to screen for cardiovascular health and utilize ongoing heart rate monitoring, in addition to perceived effort, to better quantify the cardiovascular loading.

**CONCLUSIONS**

The results of the current study indicate that pain pressure threshold measures in the shoulder improved immediately following lower extremity aerobic exercise with a moderate effect size, indicating lower extremity aerobic exercise has an immediate systemic hypoalgesic effect on evoked shoulder pain in healthy individuals. Clinicians seeking active treatment options to decrease shoulder pain might consider remote aerobic exercise.

**REFERENCES:**


ABSTRACT

**Background:** Post-operative range of motion (ROM) loss and pain can limit quality of life, prolong functional return to activity, and may be sport/career threatening. Dry needling (DN) is intended assist in the treatment of these complaints.

**Purpose:** To determine if the addition of upper quarter DN to a rehabilitation protocol is more effective in improving ROM, pain, and functional outcome scores when compared to a rehabilitation protocol alone after shoulder stabilization surgery.

**Study Design:** Single-Blind Randomized Clinical Trial

**Methods:** Thirty-nine post-operative shoulder patients were randomly allocated into two groups: (1) standard of care rehabilitation (control group) (2) standard of care rehabilitation plus dry needling (experimental group). Patient's pain, ROM, and functional outcome scores were assessed at baseline (4 weeks post-operative), and at 8 weeks, 12 weeks, and 6 months post-operative.

**Results:** Of 39 enrolled patients, 20 were allocated to the control group and 19 to the experimental group. At six-month follow up, there was a statistically significant improvement in shoulder flexion ROM in the control group. Aside from this, there were no significant differences in outcomes between the two treatment groups. Both groups showed improvement over time. No adverse events were reported.

**Conclusion:** Dry needling of the shoulder girdle in addition to standard of care rehabilitation after shoulder stabilization surgery did not significantly improve shoulder ROM, pain, or functional outcome scores when compared with standard of care rehabilitation alone. Both group's improvement was largely equal over time. The significant difference in flexion at the six-month follow up may be explained by additional time spent receiving passive range of motion (PROM) in the control group. These results provide preliminary evidence that dry needling in a post-surgical population is safe and without significant risk of iatrogenic infection or other adverse events.

**Level of Evidence:** Therapy, Level 2.

**Key Words:** Dry needling, glenohumeral instability, surgical shoulder stabilization, Movement System
INTRODUCTION
Patients often have limited range of motion following a post-operative immobilization period. Di-Silvestro noted that increased stiffness and loss of range of motion may lead to slower recovery times, decreased performance, and even early degeneration of the glenohumeral joint.\(^1\) In a sports or military population, a loss of glenohumeral range of motion can threaten the individual's ability to return to sport or his/her military occupational specialty.\(^2\)\(^-\)\(^4\) Loss of glenohumeral range of motion after shoulder stabilization surgery may be the result of a decreased length of glenohumeral ligaments or increased tightness of the joint capsule.\(^1\)\(^,\)\(^5\) It has been proposed that loss of glenohumeral range of motion may also be due to scapulothoracic neuromotor abnormalities associated with trigger points, which may contribute to pain and subsequent range of motion loss in the shoulder girdle.\(^9\) Trigger points (TP) are described in the literature as localized hyperirritable areas associated with hypersensitive palpable taut bands located in muscle tissue that may be painful on compression and/or stretch and that can give rise to a typical referred pain pattern.\(^7\)\(^-\)\(^11\) TPs have been described as being either active or latent.\(^12\) An active TP produces spontaneous referred pain and frequently produces clinical symptoms. A latent TP is usually asymptomatic and may cause referred pain in response to compression, stretch or overload of the affected tissues.\(^9\)\(^,\)\(^13\) Latent TPs are also believed to alter muscle activation patterns which can result in limited range of motion or weakness of the muscles involved.\(^12\)\(^,\)\(^14\)\(^,\)\(^15\)

Dry needling (DN) is an emerging treatment amongst physical therapists and involves the insertion of a solid monofilament needle into tissue for the management of pain and neuromusculoskeletal dysfunction.\(^16\) The needle is usually placed in muscle TPs, in the proximity of nerves, or placed in connective tissue.\(^17\)\(^,\)\(^18\) Some position statements by State Boards of Physical Therapy have specifically defined DN as an ‘intramuscular procedure involving the isolated treatment of myofascial (muscle) TPs’.\(^18\) A more expansive view of DN includes the target areas of muscles, ligaments, tendons, subcutaneous fascia, scar tissue, peripheral nerves, bones, and neurovascular bundles.\(^17\) DN can also be performed in tissues that vary in terms of the depth of needle penetration, with some DN performed at either a superficial or deep tissue level that may or may not include TPs. There are many theories associated with the proposed effects of DN but its effectiveness can likely be credited to a variety of factors.\(^17\) While the science behind the procedure continues to evolve, its use has gained substantial popularity over the past several years based on the number of articles in print. A review of the term ‘dry needling’ in the national PubMed database, by year, yielded one reference in 2000,\(^19\) seven new references in 2009, and 51 new references in 2014. This technique has advanced from being taught in one physical therapy curriculum at Georgia State University in 2006,\(^20\) to a technique that is introduced to entry level physical therapy students in many of the Physical Therapy programs in the United States. There are many studies available showing the benefits of this intervention treating myofascial pain.\(^7\)\(^,\)\(^21\)\(^-\)\(^23\) In contrast, there is a relatively small amount of literature examining the claim of improved range of motion, and to date, only one study has been performed to evaluate the benefit of DN in a post-operative setting.\(^24\) In case reports by Mason et al, and Dembowski et al, patients receiving DN demonstrated good improvement in range of motion as well as improved functional movement patterns.\(^8\)\(^,\)\(^22\)

The primary purpose of this study was to determine if the addition of upper quarter DN to a rehabilitation protocol is more effective in improving range of motion, functional movement, and pain when compared to a rehabilitation protocol alone after shoulder stabilization surgery. The secondary purpose was to determine if the addition of upper quarter DN to a rehabilitation protocol is more effective in improving functional outcomes when compared to a rehabilitation protocol alone after shoulder stabilization surgery. It was hypothesized that the inclusion of DN would result in an increase in range of motion, increase in functional movement, and decrease in pain at an accelerated rate when compared to rehabilitation alone.

METHODS
A parallel single-blinded, randomized clinical trial was conducted. Subjects presenting status post shoulder stabilization surgery were recruited from a
direct access physical therapy clinic. Using G Power 3.1.2⁵ a sample size of 34 was determined prior to commencement of the trial. This sample size provides 80% power to detect an effect size of 1.0 at the eight-week follow-up with an alpha level of .05. To account for a potential 10-15% of subjects lost to follow-up, 38 subjects was the goal for recruitment.²⁶ The effect size was determined based on prior studies on DN of upper quarter musculoskeletal disorders having reported very large changes (effect sizes > 1.5) in ROM after DN.²²-²⁴,²⁷ This study was therefore adequately powered to detect differences in ROM. The study protocol was approved by the Keller Army Community Hospital institutional review board and registered with ClinicalTrials.gov (ClinicalTrials.gov Identifier: NCT02704975). Participants were drawn from a primarily homogeneous sample consisting of military cadets and Active Duty Army personnel. All participants signed an informed consent prior to inclusion in the study. Participants rights were protected throughout the duration of the study. To be included in the study subjects had to present status post shoulder stabilization repair surgery within the preceding four-week time period. Additional study inclusion and exclusion criteria can be found in Table 1.

A screening and intake form was completed for each subject prior to enrollment to ensure they met inclusion and exclusion criteria. Subject flow diagram is presented in Figure 1.

**INTERVENTIONS**
The randomization sequence was created using Excel 2010 (Microsoft, Redmond, WA, USA) by an investigator not involved with subject recruitment or data collection. Randomized blocks of six were used to establish group assignment. The group assignment was recorded on an index card. This card was folded in half such that the label with the patient’s group assignment was on the inside of the fold. The folded index card was then placed inside an envelope, and the envelope was sealed. The treating physical therapist opened the envelope and proceeded with treatment according to the group assignment. Investigators taking all measurements were blinded to the intervention group of the subject.

Subjects were assigned to one of two groups: a DN group or a control group. Immediately upon completion of all baseline measurements, group allocation was performed. Between post-operative weeks 4 and 8 subjects in the DN group received standard rehabilitation and weekly DN treatment for a total of four DN treatments. Treatment during this time period was chosen due to the frequent presence of trigger points in the shoulder girdle and upper trapezius during this time frame as a result of lengthy immobilization and sling wear.²⁸ Subjects in the control group received standard rehabilitation alone. Standard rehabilitation protocols used throughout the study can be found in Appendices A and B. For subjects in the DN group, manual palpation of the shoulder girdle musculature was performed to determine the presence of TPs. A provider with greater than three years of DN experience performed DN to all detected TPs. Upon identification of a TP, a solid monofilament needle was inserted into the skin and directed towards the TP (Figure 2). Needling technique was chosen by the physical therapist according to patient tolerance and physical therapist preference. Needling techniques utilized included pistoning (inserting and withdrawing needle rapidly from each TP), needle left in situ for 10 to 15 minutes, needling with electrical stimulation, and a combination of these techniques.¹⁷

<table>
<thead>
<tr>
<th>Table 1. Inclusion and exclusion criteria.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inclusion</strong></td>
</tr>
<tr>
<td>• Age 18-40 DOD* beneficiaries</td>
</tr>
<tr>
<td>• Status post shoulder stabilization repair surgery</td>
</tr>
<tr>
<td><strong>Exclusion</strong></td>
</tr>
<tr>
<td>• Self-reported pregnancy</td>
</tr>
<tr>
<td>• History of blood borne pathogens/infectious disease/active infection/metal allergy</td>
</tr>
<tr>
<td>• Bleeding disorders or currently taking anti-coagulant medications</td>
</tr>
<tr>
<td>• Participants who are not fluent in English</td>
</tr>
</tbody>
</table>

* DOD = Department of Defense
Treatment was performed until the physical therapist felt all areas of dysfunction had been addressed (i.e. reduced muscle twitch response, improvement in pain, improvement in patient tolerance, etc). To avoid performance bias, during rehabilitation, subjects in the control group received equal amounts of time with their treating therapist as the subjects in the DN group. To accomplish this, the therapist performed manual PROM into flexion, abduction, external rotation, and internal rotation for subjects in the control group for the same length of time that subjects in the DN group received their needling intervention. Therapists were instructed to perform this additional PROM at a “sub-therapeutic” level; that is, within current available range of the subject, without entering resistance.

Figure 1. Subject Recruitment/Retention Flow Diagram. DN = dry needling; NPR = numeric pain rating scale; ROM = range of motion.
OUTCOMES

The primary outcome measures were passive range of motion of the glenohumeral joint, functional range of motion of the glenohumeral joint, and pain. Passive range of motion measures performed included shoulder flexion, glenohumeral external rotation, and internal rotation. (Figure 3) Composite shoulder flexion was performed with subject in supine. The elbow was extended, forearm relaxed, and wrist in neutral position. The subject's arm was raised into forward flexion by the practitioner. The stationary arm of the goniometer was placed parallel to the spine but at the lateral aspect of the body. The moving arm of the goniometer was placed along the midline of the humerus (Figure 3A).\textsuperscript{30-32} Glenohumeral external rotation was performed with subject in supine on the plinth. The tested arm was abducted to 90 degrees, the elbow flexed to 90 degrees, and the forearm in the mid-position between supination and pronation and perpendicular to the plinth. The subject's arm was externally rotated by the practitioner. The stationary arm of the goniometer was horizontal to the plinth with the axis on the olecranon process. The moving arm of the goniometer was in line with the styloid process of the ulna (Figure 3B).\textsuperscript{30-32} Glenohumeral internal rotation was performed with subject in supine on the plinth. The tested arm abducted to 90 degrees, the elbow flexed to 90 degrees, and the forearm in the mid-position between supination and pronation and perpendicular to the plinth. The subject's arm was internally rotated by the practitioner. The stationary arm of the goniometer was horizontal to the plinth with the axis on the olecranon process. The
moving arm of the goniometer was in line with the styloid process of the ulna (Figure 3C). Goniometric measurement has been observed to be a valid and reliable measure of glenohumeral joint angle.\textsuperscript{30-32} Range of motion testing was performed twice and the average of the two trials was recorded.

Functional movement measures performed included hand to neck (Figure 4A), hand to scapula (Figure 4B), and hand to opposite scapula (Figure 4C). Description of and scoring criteria for the three functional movement measures are provided in Table 2.\textsuperscript{33} Pain was not recorded or taken into consideration during the grading of these functional movements. The numeric pain rating scale (NPRS) was used to assess level of resting pain at each visit. This scale is scored from a 0-10, and the subject was asked to report their level of pain with the instruction that “0 is no pain, and 10 is the worst pain imaginable”. The NPRS is a valid and reliable tool in patients with shoulder pain.\textsuperscript{34,35} Secondary outcome measures included the global rating of change score (GROC), the patient specific functional scale (PSFS), and the shoulder pain and disability index (SPADI).

The GROC is used to assess overall change from initial presentation and was recorded at each follow-up visit. This score is rated on a 15-point scale from -7 (a very great deal worse) to +7 (a very great deal better) where subjects will select an answer that best describes their current perceived status since injury onset.\textsuperscript{36,37} The PSFS is a self-report questionnaire assessing pain, instability and activities of daily living (ADLs).\textsuperscript{34} The SPADI is a self-report questionnaire assessing pain and disability. The SPADI is a reliable and valid tool for assessing outcome in shoulder injuries.\textsuperscript{38,39} Repeat measurements of all variables were obtained at two additional time points post operatively, 8 weeks and 12 weeks. All measurements in both groups were repeated by the same investigator who remained blinded to group assignment.

**STATISTICAL ANALYSIS**

Data were analyzed with SPSS version 24 (SPSS Inc, Chicago, IL) and R version 3.3.1 (Comprehensive ‘R’ Archive Network – Kansas, USA). Means, standard deviations, and 95% confidence intervals (CIs) were calculated for each variable. Homogeneity of the data was assessed using Levene’s test and all data were assessed for normal distribution using a Shapiro-Wilk test. Skewness, kurtosis, skewness ratio, and kurtosis ratio were also calculated to assess for normal distribution. Several dependent variables lacked normal distribution and homogeneity of variance.

Despite this, analysis of variance (ANOVA) was performed due to its robust nature and the lack of a non-parametric equivalent to the mixed model ANOVA. A 2x4 mixed model ANOVA was used for each outcome measure with time (baseline, follow-up 1, follow-up 2, and follow-up 3) as the within-subject factor and

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**Figure 4.** A: Hand to neck functional movement test B: Hand to scapula functional movement test C: Hand to opposite scapula functional movement test.
group (DN or control) as the between-subject factor. For the repeated measure, Mauchly's test for sphericity was performed and in the case of a significant result, a Greenhouse-Geisser correction was used. If a significant main effect for time was observed, post hoc testing (paired t-tests with Bonferroni correction) was employed. If a significant main effect for group or interaction effect between group and time were found, post hoc testing (unpaired t-tests with Bonferroni Holm correction) was employed. Despite a significant finding on the Shapiro-Wilk test and the lack of normal distribution for the data of flexion, external rotation, GROC, pain (NPRS), PSFS, and SPADI, parametric post hoc analysis was performed as described above. In an effort to be as thorough as possible, secondary analysis was performed using non-parametric tests, which yielded similar results. Data were also analyzed using both per protocol and intention to treat analysis methods. Again, both analysis methods yielded similar results. Results reported below are those of intention to treat analysis using parametric testing as described above.

**RESULTS**

Forty-three patients were screened for inclusion between March 2016 and April 2017 at which point the trial was ended due to completion of recruitment goal. Forty patients (34 male, 6 female) met the inclusion criteria and agreed to participate in the study. Additional demographic data can be found in Table 3. One patient who agreed to participate in the study was excluded prior to the initiation of treatment when it was discovered that he did not meet inclusion criteria. From baseline to follow-up two, no other patients were lost to follow-up and no adverse events were reported. Between follow-up two and three, three subjects were lost to follow-up, two of whom moved away from the area and one of whom began

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### Table 2. Description and scoring criteria of three function-related tests.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description of Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>The fingers reach the posterior median line of the neck with the shoulder in full abduction and external rotation, 0/5 cm beneath it in full internal rotation. The wrist is not laterally deviated.</td>
</tr>
<tr>
<td>1</td>
<td>The hand reaches the opposite scapula, 6-15 cm beneath it.</td>
</tr>
<tr>
<td>2</td>
<td>The hand reaches the opposite iliac crest.</td>
</tr>
<tr>
<td>3</td>
<td>The hand reaches the buttock.</td>
</tr>
<tr>
<td>4</td>
<td>Subject cannot move the hand behind the trunk.</td>
</tr>
</tbody>
</table>

* This test measures an action essential for daily activities, such as using the arm to reach, pull, or hang an object overhead or using the arm to pick up and drink a cup of water. 
† This test measures an action essential for daily activities, such as using the arm to pull an object out of a back pocket or tasks related to personal care. 
‡ This test measures an action important for daily activities, such as using the arm to reach across the body to get a car’s seat belt or using the arm to turn a steering wheel.
receiving treatment elsewhere. Subjects were randomly assigned to either the control group (n = 20) or the DN group (n = 19) and were all analyzed in the groups to which they were assigned using an intention to treat analysis. A per protocol analysis returned similar results to the intention to treat analysis. Baseline subject characteristics can be found in Table 4.

The 2x4 mixed model ANOVA revealed a significant main effect for time for all dependent variables, but that there was no significant main effect for group (p > 0.05). A significant interaction between time and group was observed in shoulder flexion only (p = 0.019). No other interaction effect between time and group was observed. Post hoc analysis using unpaired t-tests with Bonferroni correction revealed an improvement in the shoulder flexion control group at the six-month time point only. During post hoc analysis using paired t-tests with Bonferroni correction for pairwise comparisons, the significant main effect for time was observed across all time points for the dependent variables of shoulder flexion ROM, shoulder ER ROM, PSFS, and SPADI (p ≤ 0.003), however, for the dependent variables of shoulder IR ROM, hand to neck functional ROM, hand to scapula functional ROM, hand to opposite scapula functional ROM, GROC, and NPRS, the significant main effect for time was not observed across all time points.

Visual representation of the significant main effect over time but lack of interaction effect between the groups for dependent variables for flexion ROM, external rotation ROM, PSFS, and SPADI are presented in Figure 5.

DISCUSSION
The purpose of this study was to determine if the addition of upper quarter DN to a rehabilitation protocol is more effective in improving range of motion, functional movement, and pain when compared to a rehabilitation protocol alone after shoulder stabilization surgery. This is the first research study that has investigated the addition of DN to a rehabilitation protocol following shoulder stabilization surgery. The results of the current randomized clinical trial suggest that the addition of DN of the shoulder girdle to a standard rehabilitation program does not improve range-of-motion, pain, or self-reported outcome measures more than a standard rehabilitation program alone in young, athletic individuals who have recently undergone shoulder stabilization surgery.

The only statistically significant interaction effect found between time and group occurred at the six-month follow up for the measure of flexion ROM. Although both groups improved significantly over time, contrary to the original hypothesis, the improvement in ROM observed in the control group was greater than that seen in the experimental group. The between group mean change observed in this study was 13.83 degrees of shoulder flexion range of motion with lower and upper bounds of the 95% confidence interval of 3.81 degrees and 23.86 degrees respectively.

<table>
<thead>
<tr>
<th>Table 3. Demographics and Location/Type of Surgical Intervention Performed (N = 39).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td><strong>Age</strong> (years)</td>
</tr>
<tr>
<td>20.78 ± 3.33</td>
</tr>
<tr>
<td><strong>Surgical Side</strong></td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Right</td>
</tr>
<tr>
<td><strong>Surgical Procedure</strong></td>
</tr>
<tr>
<td>Arthroscopic Bankart Repair (Anterior Labrum)</td>
</tr>
<tr>
<td>Arthroscopic Posterior Labral Repair</td>
</tr>
<tr>
<td>Arthroscopic Anterior and Posterior Labral Repair</td>
</tr>
<tr>
<td>Open Bankart Repair</td>
</tr>
<tr>
<td>Latarjet</td>
</tr>
</tbody>
</table>

*Values are mean ± standard deviation unless otherwise indicated.*
If the true mean does fall within the upper and lower bounds of the observed confidence interval, it is possible that it lies at the lower bound of 3.81 degrees and does not represent a meaningful difference.\textsuperscript{40} It is also possible that the difference between the two groups could be explained by the additional time spent on PROM between weeks four and eight. Despite the efforts made by therapists to perform “sub-therapeutic” PROM to prevent bias,\textsuperscript{28} the additional time spent on PROM in the control group may have provided long term benefit in shoulder flexion ROM.

These results differ slightly from the only other study examining the effects of DN in post-operative shoulders.\textsuperscript{24} Arias-Buria et al observed that subjects receiving DN and physical therapy experienced statistically significant and clinically meaningful changes in self-reported functional outcome scores, activities of daily living, and strength when compared to subjects receiving physical therapy alone. However, they observed no statistically significant difference between the groups in the measures of pain or ROM.\textsuperscript{24} Similarly, no statistically significant difference was observed in the measure of pain and no clinically meaningful difference between the groups in the measure of ROM.

Arias-Buria\textsuperscript{41} et al conducted a randomized clinical trial comparing DN and physical therapy and physical therapy alone in patients with subacromial...
impingement syndrome. The investigators observed changes in functional outcome measures (Disabilities of the Arm, Shoulder, and Hand questionnaire) but no significant results between groups for changes in pain.41 Another randomized clinical trial performed on subjects with a diagnosis of non-specific shoulder pain also failed to show a difference in pain, ROM, and functional outcome measures between a DN and physical therapy group when compared to a group who received physical therapy alone.42 Clewley et al6 demonstrated significant changes in both pain and ROM in a patient with adhesive capsulitis of the shoulder after the inclusion of DN to the individual’s physical therapy program in a case report. While these results are promising, their case report does not allow inference of a causal relationship between DN and improvement in pain and ROM.5,29

These prior reports are largely consistent with the results of the current study, but it must be mentioned that both the pathology and demographics of the previously mentioned studies are far different than this one. This study was performed on a young, active, and otherwise healthy population of individuals who had recently undergone shoulder stabilization surgery while the others were performed on older individuals with differing pathology than this population. Secondarily, the three randomized trials mentioned above24,41,42 used the Hong technique for DN43 (“fast in, fast out”), and the techniques used in the current study were variable and left to provider choice. Because there is no strong consensus on the superiority of one DN technique over another,17 it is possible that a more standardized DN protocol in the current study would have yielded different results in the measured outcomes. The differences in study population and needling technique may provide a possible explanation for the lack of significant differences noted in this study while others have observed significant differences in functional

Figure 5. (A) Flexion passive range of motion change from 4 weeks (baseline) to 6 Months; (B) External rotation passive range of motion change from 4 weeks (baseline) to 6 Months; (C) Patient Specific Functional Scale change from 4 weeks (baseline) to 6 Months; (D) Shoulder pain and disability index change from 4 weeks (baseline) to 6 Months.

*Significant main effect for time across all time points; Significant interaction effect found only at 6-month Flexion ROM follow-up.
Further examination of the change scores and confidence intervals provided in Table 5 may be useful in determining if further research is warranted or if a larger sample size would yield significant results. For the dependent variable of flexion, between weeks 4 and 8 and weeks 4 and 12, not only do the confidence intervals include the value of zero, but the values do not include the possibility of a clinically meaningful change in favor of the DN group. Between four weeks and six months, the confidence intervals do include the value of zero, but likely do not represent a clinically meaningful change as discussed above. For the dependent variable of pain, across all time points, the confidence intervals include the value of zero and also fail to meet the clinically important difference value of 2.0 for the NPRS. Therefore, although the possibility that a true difference does exist between the two groups in the current study cannot be ruled out, it is very likely that the magnitude of the true difference is, in the case of pain, less than 2.0 on the NPRS. The need to conduct subsequent studies examining the difference between DN plus rehabilitation and rehabilitation alone in young, otherwise healthy individuals who have recently undergone shoulder stabilization surgery is likely to be un-necessary. If such a study were to be performed with a larger sample size,

<table>
<thead>
<tr>
<th>Table 5. Outcome Data By Group*.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Means</td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>8 Week Follow-Up</td>
</tr>
<tr>
<td>Flexion PROM</td>
</tr>
<tr>
<td>ER PROM</td>
</tr>
<tr>
<td>IR PROM</td>
</tr>
<tr>
<td>Hand to Neck</td>
</tr>
<tr>
<td>Hand to Scapula</td>
</tr>
<tr>
<td>Hand to Opposite Scapula</td>
</tr>
<tr>
<td>GROC</td>
</tr>
<tr>
<td>NPRS</td>
</tr>
<tr>
<td>PSFS</td>
</tr>
<tr>
<td>SPADI</td>
</tr>
<tr>
<td>12 Week Follow-Up</td>
</tr>
<tr>
<td>Flexion PROM</td>
</tr>
<tr>
<td>ER PROM</td>
</tr>
<tr>
<td>IR PROM</td>
</tr>
<tr>
<td>Hand to Neck</td>
</tr>
<tr>
<td>Hand to Scapula</td>
</tr>
<tr>
<td>Hand to Opposite Scapula</td>
</tr>
<tr>
<td>GROC</td>
</tr>
<tr>
<td>NPRS</td>
</tr>
<tr>
<td>PSFS</td>
</tr>
<tr>
<td>SPADI</td>
</tr>
<tr>
<td>6 Month Follow-Up</td>
</tr>
<tr>
<td>Flexion PROM</td>
</tr>
<tr>
<td>ER PROM</td>
</tr>
<tr>
<td>IR PROM</td>
</tr>
<tr>
<td>Hand to Neck</td>
</tr>
<tr>
<td>Hand to Scapula</td>
</tr>
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<td>Hand to Opposite Scapula</td>
</tr>
<tr>
<td>GROC</td>
</tr>
<tr>
<td>NPRS</td>
</tr>
<tr>
<td>PSFS</td>
</tr>
<tr>
<td>SPADI</td>
</tr>
</tbody>
</table>

DN = Dry Needling; SD = standard deviation; Within Group Mean Change = Change from baseline to follow-up; PROM = Passive range of motion; Hand to Neck = Hand to neck functional range of motion; Hand to Scapula = Hand to scapula functional range of motion; GROC = Global rating of change functional outcome score; NPRS = Numeric pain rating scale; PSFS = Patient specific functional scale; SPADI = Shoulder pain and disability index functional outcome measure.

*Outcome values at each time point are mean ± SD (95% confidence interval) and values for change scores are mean (95% confidence interval) and values for change scores are mean (95% confidence interval). Values reported represent intention to treat analysis.
while additional statistically significant differences may be found, it is likely that these results would not be clinically meaningful.46

The main strength of this study is that it was the first study attempting to determine if the addition of upper quarter DN to a rehabilitation protocol is more effective in improving range of motion, pain, and functional movement when compared to a rehabilitation protocol alone after shoulder stabilization surgery. Also, while the power analysis indicated we needed only to recruit 34 individuals to have enough power to detect a change, an additional 15% were recruited with the recruitment of 39 subjects, of whom only three were lost to long term follow-up and none of whom were lost to short and intermediate term follow-up.

There are several limitations to this study. The most meaningful weakness may simply be the differences in manual therapy (PROM) intervention received between the groups. It could be argued that the additional PROM received by the control group may have improved long term outcomes in shoulder flexion PROM. This group may therefore have acted as a “manual therapy” group rather than a true control. Another limitation is the nature of single blinded randomized clinical trials. While the assessor remained blinded throughout the study period, the individuals receiving treatment were not blinded to the group they were in. This may have resulted in a compensatory increase in the performance of the members of the control group, thus biasing the results of the study.29,47 Also, the follow-up period may be considered relatively short; longer follow-up periods may be necessary to determine the possibility that long term differences could exist between these two groups. Perhaps most importantly, the inclusion criteria in this study were very specific and our resultant sample population represented a very specific subset of the population. For this reason, these results cannot be generalized outside of the population included in this study. Finally, it has been proposed that a specific subset of individuals who would respond best to DN does exist, but that the population in the current study may not fit those parameters.48 For this reason, future research is needed to elucidate the subset of individuals who would respond most favorably to this intervention.

While not mentioned directly in the purpose of the study, it should be noted that throughout the course of treatment of our DN group (76 DN treatments in total), no adverse events were reported. The possibility that DN may increase the likelihood of iatrogenic infection after surgery has been raised in the literature and the validity of this argument has not been fully refuted.49,50 The current study provides preliminary evidence that the inclusion of DN into a post-operative rehabilitation program as early as four weeks after surgery carries with it little to no risk of iatrogenic infection in the post-surgical population.

CONCLUSION

The results of this investigation indicate that DN of the shoulder girdle in addition to standard of care rehabilitation after shoulder stabilization surgery did not significantly improve range of motion, functional range of motion, pain, or functional outcome scores when compared with standard of care rehabilitation alone. These results do not support the addition of DN into the standard post-operative treatment regime in individuals who have recently undergone shoulder stabilization surgery.

REFERENCES


### APPENDIX A

#### SHOULDER RECONSTRUCTION REHABILITATION GUIDELINES

( Bankart Repair, Anterior Capsulorrhaphy )

<table>
<thead>
<tr>
<th>PHASE I:</th>
<th>Generally 0 - 6 weeks post-op</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE I GOALS:</td>
<td>Protect the surgical repair &amp; avoid a “stiff” shoulder</td>
</tr>
<tr>
<td>PRECAUTIONS:</td>
<td><em>NO</em> active use of arm - must <strong>ALWAYS</strong> wear sling/immobilizer, even while sleeping*</td>
</tr>
<tr>
<td>ROM GUIDELINES:</td>
<td>Avoid gaining ROM too quickly by adhering to the following:</td>
</tr>
<tr>
<td></td>
<td>o Wks 1-2: limit flexion to 90° and external rotation to 0° (neutral)</td>
</tr>
<tr>
<td></td>
<td>o Wks 3-4: limit flexion to 110° and external rotation to 10°</td>
</tr>
<tr>
<td></td>
<td>o Wks 5-6: limit flexion to 130° and external rotation to 20°</td>
</tr>
<tr>
<td>SLING:</td>
<td>Sling/immobilizer with abduction pillow is worn for 6 weeks per ortho/PT</td>
</tr>
<tr>
<td>WOUND:</td>
<td>Post-op dressing remains intact until post-op day #2 (~48 hours after surgery)</td>
</tr>
<tr>
<td></td>
<td>May begin showering after post-op day #2 (no need to cover incision site)</td>
</tr>
<tr>
<td></td>
<td><em>Do NOT</em> submerge shoulder in tub or pool for 4 weeks*</td>
</tr>
<tr>
<td></td>
<td>Suture/staple removal @ 10-14 days per Ortho/PT</td>
</tr>
<tr>
<td></td>
<td>Begin scar massage after incision site sloughs/scar is formed</td>
</tr>
<tr>
<td>REHABILITATION:</td>
<td>*Note: Exercise prescription is dependent upon the tissue healing process and individual functional readiness in all stages. If any concerns or complications arise regarding the progress for any patient, physical therapy will contact the orthopedic surgeon.</td>
</tr>
<tr>
<td></td>
<td>Start with the following exercises: (10-20 repetitions, 3-4 x daily)</td>
</tr>
<tr>
<td>~weeks 1-2</td>
<td><strong>Modified Pendulum:</strong> (May be done in the sling.) While supporting the affected arm with the unaffected hand, move the shoulder forward, backward, side to side and in clockwise and counterclockwise directions. Progress to full pendulum after 3-5 days.</td>
</tr>
<tr>
<td></td>
<td><strong>Supine Assisted Shoulder Flexion:</strong> Lie on back with arm down at side and thumb pointed towards the ceiling. Use unaffected hand to grasp the wrist of the affected arm and slowly raise it until a point of mild discomfort (within ranges of motion described above).</td>
</tr>
<tr>
<td></td>
<td><strong>Elbow, Wrist, &amp; Hand:</strong> Perform elbow and wrist flexion, extension, pronation, and supination while holding the shoulder in a neutral position at side. For the hand, use a foam ball, newspaper, or therapy putty to squeeze repetitively.</td>
</tr>
<tr>
<td></td>
<td><strong>Gentle (“Two Finger”) Isometrics:</strong> Use the unaffected hand to provide very light, pain free resistance during shoulder flexion, adduction, extension, and abduction (No rotation).</td>
</tr>
<tr>
<td>~weeks 3-4</td>
<td><strong>Gentle (“Two Finger”) Isometrics:</strong> add gentle, pain free resistance for IR &amp; ER</td>
</tr>
<tr>
<td></td>
<td><strong>Aerobic Conditioning on Recumbent Bike:</strong> <em>Sling must be worn</em></td>
</tr>
<tr>
<td></td>
<td><strong>Scapular Retraction &amp; Protraction:</strong> Gently “pinch” shoulder blades together. Hold for 5 seconds and relax. Then spread shoulder blades apart. Hold for 5 seconds and relax.</td>
</tr>
<tr>
<td>~weeks 5-6</td>
<td><strong>Lower Extremity Weight Lifting:</strong> May begin leg &amp; calf press, hamstring curls, hip add/abd</td>
</tr>
<tr>
<td></td>
<td><strong>Shoulder AAROM exercises:</strong> Wand, pulley, gentle towel stretch, etc.</td>
</tr>
<tr>
<td>FOLLOW-UP:</td>
<td>Physical Therapy: weekly; Ortho: ~6 wks post-op; Supervised rehab: 1-2 x per wk</td>
</tr>
<tr>
<td>DOCUMENTATION:</td>
<td>Precautions, pain level, medications and modalities</td>
</tr>
<tr>
<td></td>
<td>Observation: (incision sites) - Signs/symptoms of infection? Site healing well?</td>
</tr>
<tr>
<td></td>
<td>Neurovascular status: Distal pulses, motor and sensation intact?</td>
</tr>
<tr>
<td></td>
<td>Shoulder passive ROM (forward flexion, ER with shoulder at side)</td>
</tr>
</tbody>
</table>
APPENDIX A (continued)

SHOULDER RECONSTRUCTION REHABILITATION GUIDELINES
(Bankart Repair, Anterior Capsulorraphy)

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>Generally 7-12 weeks post-op</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE II GOALS</td>
<td>ROM: Full shoulder flexion and internal rotation, ~90% full external rotation</td>
</tr>
<tr>
<td></td>
<td>Pain free ADLs</td>
</tr>
<tr>
<td>PRECAUTIONS</td>
<td><em>NO pushups, heavy lifting, or other sports participation</em></td>
</tr>
<tr>
<td></td>
<td><em>NO repetitive overhead use of shoulder</em></td>
</tr>
<tr>
<td>SLING</td>
<td>Wean from wearing sling/immobilizer per ortho/PT guidance</td>
</tr>
<tr>
<td>REHABILITATION</td>
<td>Continue phase I exercises as needed</td>
</tr>
<tr>
<td></td>
<td>Progress to the following exercises and increase intensity gradually when patient is ready (i.e., no increase in shoulder pain or stiffness since the previous exercise session)</td>
</tr>
<tr>
<td></td>
<td><em>Note: all strengthening should be done, starting with low weights, high repetitions, and in a painless ROM</em></td>
</tr>
<tr>
<td>~weeks 7-8</td>
<td>Upper body cycle: begin with three 1-min sets (forwards and backwards) progress gradually</td>
</tr>
<tr>
<td></td>
<td>Shoulder AROM and AAROM exercises: Wand, pulley, towel stretch, sleeper’s stretch, etc.</td>
</tr>
<tr>
<td></td>
<td>Progressive strengthening: ER &amp; IR with arm at side, FF &amp; scaption to 60-90°, prone rows (first set: 20 repetitions, then 1 additional set at the same weight to muscle failure)</td>
</tr>
<tr>
<td></td>
<td>Beginning level pool program – no overhead strokes</td>
</tr>
<tr>
<td></td>
<td>Aerobic Conditioning: Bike, elliptical, stairmaster as desired.</td>
</tr>
<tr>
<td></td>
<td>Beginning level neuromuscular/functional training exercises (see appendix)</td>
</tr>
<tr>
<td></td>
<td>Beginning level shoulder stabilization exercises (see appendix)</td>
</tr>
<tr>
<td>~weeks 9-12</td>
<td>May begin jogging (start with 5 minutes and progress gradually as tolerated)</td>
</tr>
<tr>
<td></td>
<td>Progressive strengthening: ER/IR with shoulder in 30° elevation, FF/scaption to 60-90°, rows (first set: 15 reps, then 2 additional sets at the same weight to muscle failure)</td>
</tr>
<tr>
<td></td>
<td>Beginning to intermediate level neuromuscular/functional training exercises (see appendix)</td>
</tr>
<tr>
<td></td>
<td>Beginning to intermediate level shoulder stabilization exercises (see appendix)</td>
</tr>
<tr>
<td>FOLLOW-UP</td>
<td>Physical Therapy: bimonthly; Ortho: ~3 months post-op;</td>
</tr>
<tr>
<td></td>
<td>Supervised rehabilitation: 2-3 x per week as needed</td>
</tr>
<tr>
<td>DOCUMENTATION</td>
<td>Pain level, medications, modalities</td>
</tr>
<tr>
<td></td>
<td>Shoulder ROM &amp; strength</td>
</tr>
</tbody>
</table>
# APPENDIX A (continued)

## SHOULDER RECONSTRUCTION REHABILITATION GUIDELINES
*(Bankart Repair, Anterior Capsulorraphy)*

<table>
<thead>
<tr>
<th>PHASE III:</th>
<th>Generally 4-6 months post-op</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE III GOALS:</strong></td>
<td>Pushups at own pace without pain</td>
</tr>
<tr>
<td></td>
<td>&gt; 90% internal/external rotation strength return</td>
</tr>
<tr>
<td><strong>PRECAUTIONS:</strong></td>
<td><em>NO</em> participation in contact/collision sports or military schools until ~9 months post-op*</td>
</tr>
<tr>
<td><strong>REHABILITATION:</strong></td>
<td>Continue phase II exercises as needed</td>
</tr>
<tr>
<td></td>
<td>Progress to the following exercises and increase intensity gradually when patient is ready</td>
</tr>
<tr>
<td></td>
<td>(i.e., no increase in shoulder pain or stiffness since the previous exercise session)</td>
</tr>
<tr>
<td></td>
<td><em>Note: all strengthening should be done, starting with low weights, high repetitions, and in a painless ROM</em></td>
</tr>
<tr>
<td>~weeks 13-16</td>
<td>Warm-up: 5-10 minutes on upper body cycle</td>
</tr>
<tr>
<td></td>
<td>General upper quarter stretching: 5-10 minutes (shoulder, thoracolumbar spine)</td>
</tr>
<tr>
<td></td>
<td>Progressive strengthening: ER/IR with shoulder in 45-90° elevation, FF/scaption to 90-120°, (first set: 10-15 reps, then 2 additional sets at the same weight to muscle failure)</td>
</tr>
<tr>
<td></td>
<td>May also begin general light intensity strengthening with shoulder in “safe” position (avoid heavy overhead lifting, avoid shoulders in the 90° elevation, 90° ER position)</td>
</tr>
<tr>
<td></td>
<td>Intermediate level neuromuscular/functional training exercises (see appendix)</td>
</tr>
<tr>
<td></td>
<td>Intermediate level shoulder stabilization exercises (see appendix)</td>
</tr>
<tr>
<td>~weeks 17-26</td>
<td>Intermediate/advanced level neuromuscular/functional training exercises (see appendix)</td>
</tr>
<tr>
<td></td>
<td>Intermediate/advanced level shoulder stabilization exercises (see appendix)</td>
</tr>
<tr>
<td></td>
<td>Progressive sports training: Begin at 25-50% intensity, progress gradually (see appendix)</td>
</tr>
<tr>
<td><strong>FOLLOW-UP:</strong></td>
<td>PT: Monthly; Ortho: ~6 months post-op;</td>
</tr>
<tr>
<td></td>
<td>Supervised rehabilitation: 1-2 x per week as needed</td>
</tr>
<tr>
<td><strong>DOCUMENTATION:</strong></td>
<td>Pain level &amp; medications</td>
</tr>
<tr>
<td></td>
<td>Shoulder ROM &amp; strength</td>
</tr>
<tr>
<td></td>
<td>Biodex testing at 6 months post-op</td>
</tr>
<tr>
<td><strong>MISCELLANEOUS:</strong></td>
<td>After 6 months post-op: Exercises in phase III are continued, gradually increasing intensity &amp; duration as tolerated.</td>
</tr>
<tr>
<td></td>
<td>The recommendation is to wait until 9-12 months post-op to return to contact/collision or overhead sports or aggressive military training (i.e., airborne school). This time period may be adjusted slightly by the surgeon and therapist according to patient progress.</td>
</tr>
</tbody>
</table>
**APPENDIX: GENERAL SHOULDER PROGRESSIONS**

*The following is a supplement to the rehabilitation guidelines on various types of shoulder exercises. It is not an all-inclusive list, but provides ideas for gradually progressing a patient through rehabilitation.*

In general, beginning level shoulder exercises are performed with light resistance in a ROM below 90° of shoulder elevation. Intermediate level exercises are done with moderate resistance in a ROM below 120°. Advanced level exercises are done with moderate resistance in a full ROM, but avoiding the 90° abducted, 90° externally rotated position until ~5-6 months post-op. All training should be pain free.

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>Beginning Level (7-10 weeks post-op)</th>
<th>Intermediate Level (9-18 weeks post-op)</th>
<th>Advanced Level (16-26 weeks post-op)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Blade</td>
<td>Flexion/Extension IR/ER Superior/Inferior (arm at side)</td>
<td>FF range to 90° Scaption to 90° IR/ER through ROM Horiz add/add at 90°</td>
<td>FF range to 150° Scaption to 150° IR/ER through ROM Diagonal motions</td>
</tr>
<tr>
<td>Ball toss</td>
<td>Chest pass – 2 handed IR toss – (arm at side)</td>
<td>Overhead toss – (2 handed) Behind back toss</td>
<td>Overhead diagonal toss – (2 handed) Regular throwing toss</td>
</tr>
<tr>
<td>Prone stabilization</td>
<td>Weight shifting in sitting, standing, prone on all fours</td>
<td>All fours stabilization on stable surface</td>
<td>All fours stabilization on foam or theraball</td>
</tr>
<tr>
<td>Supine stabilization</td>
<td>Supine Shoulder Stabilization @ 90°</td>
<td>Supine Shoulder Stabilization from 60-120°</td>
<td>Supine Shoulder Stabilization (Available ROM)</td>
</tr>
<tr>
<td>Cuff strengthening</td>
<td>ER/IR – (arm at side) FF/Scaption to 60-90° (Thumb up)</td>
<td>ER/IR - (30-45° shld scaption) FF/Scaption to 90-120° (Thumb up)</td>
<td>ER/IR- (45-90°shld scaption) – gradually moving into abd PNF patterns</td>
</tr>
<tr>
<td>Scapular strengthening</td>
<td>Ceiling “punches” Rows</td>
<td>“Pushouts” (in standing) Rows (inferior/superior)</td>
<td>Pushup plus</td>
</tr>
<tr>
<td>Pushups</td>
<td>none</td>
<td>Wall pushups – progressing to inclined pushups</td>
<td>Knee pushups – progressing to modified regular pushups</td>
</tr>
<tr>
<td>Misc activities</td>
<td>Basketball: dribbling, chest and bounce pass Golf: putting Volleyball: bumping Pool: jogging, treading Wall ball drawing</td>
<td>Basketball: shooting within the key only Golf: chipping, short irons Volleyball: setting Pool: No overhead strokes Tossing Frisbee Catching drills: below 90°</td>
<td>Basketball: noncontact drills only Golf: gradual return Vball: gradual return ~6 mo Pool: gradual return Forehand, backhand racquet sports (no overhead)</td>
</tr>
</tbody>
</table>
# APPENDIX B

## SHOULDER POSTERIOR REPAIR REHABILITATION GUIDELINES
(Reverse Bankart Repair, Posterior Capsulorraphy)

<table>
<thead>
<tr>
<th>PHASE I:</th>
<th>Generally 0 - 6 weeks post-op</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE I GOALS:</strong></td>
<td>Protect the surgical repair &amp; avoid a “stiff” shoulder</td>
</tr>
<tr>
<td><strong>PRECAUTIONS:</strong></td>
<td><em>NO</em> active use of arm - must <em>ALWAYS</em> wear sling, even while sleeping*</td>
</tr>
<tr>
<td><strong>ROM GUIDELINES:</strong></td>
<td>Avoid gaining ROM too quickly by adhering to the following:</td>
</tr>
<tr>
<td></td>
<td>o Wks 1-2: limit flexion to 90° and internal rotation to 0° (neutral)</td>
</tr>
<tr>
<td></td>
<td>o Wks 3-4: limit flexion to 110° and internal rotation to 0°</td>
</tr>
<tr>
<td></td>
<td>o Wks 5-6: limit flexion to 130° and internal rotation to 0°</td>
</tr>
<tr>
<td><strong>SLING:</strong></td>
<td>Sling with external rotation brace x 6 weeks per ortho/PT</td>
</tr>
<tr>
<td><strong>WOUND:</strong></td>
<td>Post-op dressing remains intact until post-op day #2 (~48 hours after surgery)</td>
</tr>
<tr>
<td></td>
<td>May begin showering after post-op day #2 (no need to cover incision site)</td>
</tr>
<tr>
<td></td>
<td><em>Do NOT</em> submerge shoulder in tub or pool for 4 weeks*</td>
</tr>
<tr>
<td></td>
<td>Suture/staple removal @ 10-14 days per Ortho/PT</td>
</tr>
<tr>
<td></td>
<td>Begin scar massage after incision site sloughs/scar is formed</td>
</tr>
<tr>
<td><strong>REHABILITATION:</strong></td>
<td>*Note: Exercise prescription is dependent upon the tissue healing process and individual functional readiness in all stages. If any concerns or complications arise regarding the progress for any patient, physical therapy will contact the orthopedic surgeon.</td>
</tr>
<tr>
<td></td>
<td>Start with the following exercises: (10-20 repetitions, 3-4 x daily)</td>
</tr>
<tr>
<td>~<strong>weeks 1-2</strong></td>
<td><strong>Modified Pendulum:</strong> (May be done in the sling.) While supporting the affected arm with the unaffected hand, move the shoulder forward, backward, side to side and in clockwise and counterclockwise directions. Progress to full pendulum after 3-5 days.</td>
</tr>
<tr>
<td></td>
<td><strong>Supine Assisted Shoulder Flexion:</strong> Lie on back with arm down at side and thumb pointed towards the ceiling. Use unaffected hand to grasp the wrist of the affected arm and slowly raise it until a point of mild discomfort (within ranges of motion described above).</td>
</tr>
<tr>
<td></td>
<td><strong>Elbow, Wrist, &amp; Hand:</strong> Perform elbow and wrist flexion, extension, pronation, and supination while holding the shoulder in a neutral position at side. For the hand, use a foam ball, newspaper, or theraputty to squeeze repetitively.</td>
</tr>
<tr>
<td></td>
<td><strong>Gentle (&quot;Two Finger&quot;) Isometrics:</strong> Use the unaffected hand to provide very light, pain free resistance during shoulder flexion, adduction, extension, and abduction (No rotation).</td>
</tr>
<tr>
<td>~<strong>weeks 3-4</strong></td>
<td><strong>Gentle (&quot;Two Finger&quot;) Isometrics:</strong> add gentle, pain free resistance for IR &amp; ER</td>
</tr>
<tr>
<td></td>
<td><strong>Aerobic Conditioning on Recumbent Bike:</strong> <em>Sling must be worn</em></td>
</tr>
<tr>
<td></td>
<td><strong>Scapular Retraction &amp; Protraction:</strong> Gently “pinch” shoulder blades together. Hold for 5 seconds and relax. Then spread shoulder blades apart. Hold for 5 seconds and relaxx</td>
</tr>
<tr>
<td>~<strong>weeks 5-6</strong></td>
<td><strong>Lower Extremity Weight Lifting:</strong> May begin leg &amp; calf press, hamstring curls, hip add/abd</td>
</tr>
<tr>
<td></td>
<td><strong>Shoulder AAROM exercises:</strong> Wand &amp; pulley exercises</td>
</tr>
<tr>
<td><strong>FOLLOW-UP:</strong></td>
<td>Physical Therapy: weekly; Ortho: ~6 wks post-op; Supervised rehab: 1-2 x per wk</td>
</tr>
<tr>
<td><strong>DOCUMENTATION:</strong></td>
<td>Precautions, pain level, medications and modalities</td>
</tr>
<tr>
<td></td>
<td>Observation: (incision sites) - Signs/symptoms of infection? Site healing well?</td>
</tr>
<tr>
<td></td>
<td>Neurovascular status: Distal pulses, motor and sensation intact?</td>
</tr>
<tr>
<td></td>
<td>Shoulder passive ROM (forward flexion, ER with shoulder at side)</td>
</tr>
</tbody>
</table>
**APPENDIX B (continued)**

**SHOULDER POSTERIOR REPAIR REHABILITATION GUIDELINES**  
(Reverse Bankart Repair, Posterior Capsulorrhaphy)

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>Generally 7-12 weeks post-op</th>
</tr>
</thead>
</table>
| **PHASE II GOALS:** | ROM: Full shoulder flexion and external rotation, ~90% full internal rotation  
Pain free ADLs |
| **PRECAUTIONS:** | *NO* pushups, heavy lifting, or other sports participation*  
*NO* repetitive overhead use of shoulder* |
| **SLING:** | Wean from wearing sling/immobilizer per ortho/PT guidance |
| **REHABILITATION:** | Continue phase I exercises as needed  
Progress to the following exercises and increase intensity gradually when patient is ready  
(i.e., no increase in shoulder pain or stiffness since the previous exercise session)  
*Note: all strengthening should be done, starting with low weights, high repetitions, and in a painless ROM* |
| ~ weeks 7-8 | Upper body cycle: begin with three 1-min sets (forwards and backwards) progress gradually  
Shoulder AROM and AAROM exercises: Wand, pulley, towel stretch, sleeper’s stretch, etc.  
Progressive strengthening: ER & IR with arm at side, FF & scaption to 60-90°, prone rows  
(first set: 20 repetitions, then 1 additional set at the same weight to muscle failure)  
Beginning level pool program – no overhead strokes  
Aerobic Conditioning: Bike, elliptical, stairmaster as desired  
Beginning level neuromuscular/functional training exercises (see appendix)  
Beginning level shoulder stabilization exercises (see appendix) |
| ~ weeks 9-12 | May begin jogging (start with 5 minutes and progress gradually as tolerated)  
Progressive strengthening: ER/IR with shoulder in 30° elevation, FF/scaption to 60-90°, rows  
(first set: 15 reps, then 2 additional sets at the same weight to muscle failure)  
Beginning to intermediate level neuromuscular/functional training exercises (see appendix)  
Beginning to intermediate level shoulder stabilization exercises (see appendix) |
| **FOLLOW-UP:** | Physical Therapy: bimonthly; Ortho: ~3 months post-op;  
Supervised rehabilitation: 2-3 x per week as needed |
| **DOCUMENTATION:** | Pain level, medications, modalities  
Shoulder ROM & strength |
### PHASE III: Generally 4-6 months post-op

| PHASE III GOALS:           | Pushups at own pace without pain  
|                          | > 90% internal/external rotation strength return |
| PRECAUTIONS:              | *NO* participation in contact/collision sports or military schools until ~9 months post-op* |
| REHABILITATION:           | Continue phase II exercises as needed  
|                          | Progress to the following exercises and increase intensity gradually when patient is ready (i.e., no increase in shoulder pain or stiffness since the previous exercise session)  
|                          | *Note: all strengthening should be done, starting with low weights, high repetitions, and in a painless ROM* |
| *weeks 13-16*             | Warm-up: 5-10 minutes on upper body cycle  
|                          | General upper quarter stretching: 5-10 minutes (shoulder, thoracolumbar spine)  
|                          | Progressive strengthening: ER/IR with shoulder in 45-90° elevation, FF/scaption to 90-120°, (first set: 10-15 reps, then 2 additional sets at the same weight to muscle failure)  
|                          | May also begin general light intensity strengthening with shoulder in “safe” position (avoid heavy overhead lifting, avoid shoulders in the 90° elevation, 90° ER position)  
|                          | Intermediate level neuromuscular/functional training exercises (see appendix)  
|                          | Intermediate level shoulder stabilization exercises (see appendix) |
| *weeks 17-26*             | Intermediate/advanced level neuromuscular/functional training exercises (see appendix)  
|                          | Intermediate/advanced level shoulder stabilization exercises (see appendix)  
|                          | Progressive sports training: Begin at 25-50% intensity, progress gradually (see appendix)  
| FOLLOW-UP:                | PT: Monthly; Ortho: ~6 months post-op;  
|                          | Supervised rehabilitation: 1-2 x per week as needed |
| DOCUMENTATION:            | Pain level & medications  
|                          | Shoulder ROM & strength  
|                          | Biodex testing at 6 months post-op |
| MISCELLANEOUS:            | After 6 months post-op: Exercises in phase III are continued, gradually increasing intensity & duration as tolerated.  
|                          | The recommendation is to wait until 9-12 months post-op to return to contact/collision sports or aggressive military training (i.e., airborne school). This time period may be adjusted slightly by the surgeon and therapist according to patient progress. |
APPENDIX: GENERAL SHOULDER PROGRESSIONS

*The following is a supplement to the rehabilitation guidelines on various types of shoulder exercises. It is not an all-inclusive list, but provides ideas for gradually progressing a patient through rehabilitation.*

In general, beginning level shoulder exercises are performed with light resistance in a ROM below 90° of shoulder elevation. Intermediate level exercises are done with moderate resistance in a ROM below 120°. Advanced level exercises are done with moderate resistance in a full ROM, but avoiding the 90° abducted, 90° externally rotated position until ~5-6 months post-op. All training should be pain free.

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>Beginning Level ~7-10 weeks post-op</th>
<th>Intermediate Level ~9-18 weeks post-op</th>
<th>Advanced Level ~16-26 weeks post-op</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Blade</td>
<td>Flexion/Extension</td>
<td>FF range to 90° Scaption to 90°</td>
<td>FF range to 150° Scaption to 150°</td>
</tr>
<tr>
<td></td>
<td>IR/ER</td>
<td>IR/ER through ROM</td>
<td>IR/ER through ROM</td>
</tr>
<tr>
<td></td>
<td>Superior/Inferior</td>
<td>Horiz adb/add at 90°</td>
<td>Diagonal motions</td>
</tr>
<tr>
<td></td>
<td>(arm at side)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball toss</td>
<td>Chest pass – 2 handed</td>
<td>Overhead toss – (2 handed)</td>
<td>Overhead diagonal toss – (2 handed)</td>
</tr>
<tr>
<td></td>
<td>IR toss – (arm at side)</td>
<td>Behind back toss</td>
<td>Regular throwing toss</td>
</tr>
<tr>
<td>Prone stabilization</td>
<td>Weight shifting in sitting,</td>
<td>All fours stabilization on stable</td>
<td>All fours stabilization on foam or</td>
</tr>
<tr>
<td></td>
<td>standing, prone on all fours</td>
<td>surface</td>
<td>theraball</td>
</tr>
<tr>
<td>Supine stabilization</td>
<td>Supine Shoulder Stabilization @ 90°</td>
<td>Supine Shoulder Stabilization from 60-120°</td>
<td>Supine Shoulder Stabilization (Available ROM)</td>
</tr>
<tr>
<td>Cuff strengthening</td>
<td>ER/IR – (arm at side)</td>
<td>ER/IR - (30-45° shld scaption)</td>
<td>ER/IR- (45-90°shld scaption) – gradually moving into abd PNF patterns</td>
</tr>
<tr>
<td></td>
<td>FF/Scaption to 60-90° (Thumb up)</td>
<td>FF/Scaption to 90-120° (Thumb up)</td>
<td></td>
</tr>
<tr>
<td>Scapular</td>
<td>Ceiling “punches”</td>
<td>“Pushouts” (in standing)</td>
<td>Pushup plus</td>
</tr>
<tr>
<td>strengthening</td>
<td>Rows</td>
<td>Rows (inferior/superior)</td>
<td></td>
</tr>
<tr>
<td>Pushups</td>
<td>none</td>
<td>Wall pushups – progressing to inclined pushups</td>
<td>Knee pushups – progressing to modified regular pushups</td>
</tr>
<tr>
<td>Misc activities</td>
<td>Basketball: dribbling, chest and</td>
<td>Basketball: shooting within the key</td>
<td>Basketball: noncontact drills only</td>
</tr>
<tr>
<td></td>
<td>bounce pass</td>
<td>only</td>
<td>Golf: gradual return</td>
</tr>
<tr>
<td></td>
<td>Golf: putting</td>
<td>Golf: chiping, short irons</td>
<td>Vball: gradual return ~6 mo</td>
</tr>
<tr>
<td></td>
<td>Volleyball: bumping</td>
<td>Volleyball: setting</td>
<td>Pool: gradual return</td>
</tr>
<tr>
<td></td>
<td>Pool: jogging, treading</td>
<td>Pool: No overhead strokes</td>
<td>Forehand, backhand racquet sports</td>
</tr>
<tr>
<td></td>
<td>Wall ball drawing</td>
<td>Tossing Frisbee</td>
<td>(no overhead)</td>
</tr>
</tbody>
</table>
ABSTRACT

Background: There is a paucity of literature about the adverse events associated with Therapeutic Dry Needling (TDN). Much of the literature surrounding adverse events associated with TDN has been extrapolated from the acupuncture literature. Given that acupuncture and TDN are distinctly different in their application and proposed mechanisms, adverse events associated with TDN should be examined specifically.

Purpose: To determine and report the type of adverse events associated with the utilization of TDN.

Study Design: Prospective Questionnaire

Methods: Four hundred and twenty physical therapists participated in this study. Information related to minor and major adverse events that occurred during 20,464 TDN treatment sessions was collected. Each physical therapist respondent was asked to fill out two weekly self-reported electronic surveys over a six-week period. One survey was related to “minor adverse events” (i.e. pain, bleeding, bruising), while the other was related to “major adverse events” (i.e. pneumothorax, excessive bleeding, prolonged aggravation). Following the six-week period, descriptive statistics were used to describe the adverse events (AE) associated with TDN and calculate the frequencies of those events.

Results: A total of 7,531 minor AE's were reported, indicating that 36.7% of the reported TDN treatments resulted in a minor AE. The top three minor AE's were bleeding (16%), bruising (7.7%), and pain during dry needling (5.9%). The average ratio of minor AE's for all respondents across all weeks was 0.53 or approximately one event for every two patients. Twenty major AE's were reported out of the 20,494 treatments for a rate of <0.1% (1 per 1,024 TDN treatments). No associations were noted between the frequency of adverse events and the number of patients treated, practitioner age, level of education, years in practice, level of training or months experience with dry needling.

Conclusion: Expected minor AE's such as mild bleeding, bruising, and pain during TDN were common and major AE's were rare. Physical therapists and other medical practitioners need to be aware of the risks of TDN. Based on the findings of this study the overall risk of a major adverse event during TDN is small.

Key Words: Adverse reactions, dry needling, movement System, safety

Level of Evidence: 3, survey research

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INTRODUCTION AND HISTORY
Dry needling is a skilled intervention using a thin filiform needle to penetrate the skin and stimulate underlying myofascial trigger points, muscular tissues, and connective tissues for the management of neuromusculoskeletal pain and movement impairments.\(^1\) The utilization of dry needling by physical therapists in the United States has increased dramatically over the past five years. According to one of the leading dry needling educators in North America, over 4,000 physical therapists within the United States have been certified in dry needling.\(^2\)

Dr. Janet Travell pioneered the concept of needling myofascial trigger points in the early 1940’s. In 1942, Travell published a paper describing a method of injecting myofascial trigger points to reduce pain.\(^3\) This method employed by Travell is referred to as “Wet Needling”. Wet needling utilizes a hollow hypodermic needle to inject pain relievers, corticosteroids, or Botox into neuromuscular tissue. Wet needling is not currently performed by physical therapists in the United States. Another method of needling is referred to as “Dry Needling”. Dry needling is different than wet needling primarily due to the type of needle used and the intention of the insertion of the needle.\(^1\) Dry needling utilizes a thin solid filament needle to stimulate neuromuscular tissue to elicit a pain reducing response versus a direct anti-inflammatory or muscular response mediated by the introduction of a drug into the trigger point.

PROPOSED MECHANISMS
Several theories exist regarding the proposed mechanisms of how dry needling reduces pain. The “gate control” theory, alteration of the endogenous opioids, central sensitization disruption, and even placebo effects have been proposed.\(^4\) When inserting a needle into a trigger point, the insertion of a needle can elicit a local twitch response.\(^5\) This involuntary contraction of the trigger point can also aid in physiologic changes, such as alleviating spontaneous electrical activity and reducing the concentration of inflammatory and nociceptive chemicals, further relaxing the trigger point.\(^5\)

A common misconception associated with dry needling is that it is the same as acupuncture. While acupuncture and dry needling make use of similar needles, there are distinct differences between the two interventions.\(^6\) According to the U.S. Department of Health and Human Services,\(^7\) acupuncture is a traditional type of eastern medicine that uses thin needles to puncture the skin that are directed at “meridians”,\(^7,8\) whereas dry needling stimulates myofascial trigger points. Theoretically, stimulating these meridians will re-balance the flow of energy in the body and subsequently relieve pain.\(^8,9,10,11\)

REVIEW OF THE LITERATURE
There is a growing body of knowledge surrounding dry needling and its effectiveness at reducing musculoskeletal pain.\(^12\) Dry needling has been reported to be effective in treating low back pain,\(^13,14,15\) neck pain,\(^16\) tension headache,\(^18\) plantar fasciitis,\(^19\) and temporomandibular disorders.\(^20,21,22\)

In 2013, a meta-analysis and systematic review found dry needling more effective than sham or placebo for decreasing upper quarter myofascial pain immediately after treatment and at four weeks post treatment.\(^23\) A meta-analysis and systematic review in 2017 stated that very low to moderate evidence suggests that dry needling performed by physical therapists is more effective than no treatment, sham dry needling, and other treatments for reducing pain.\(^24\) Additionally, pressure pain thresholds improved in patients over a 12-week period.\(^24\)

Given the increasing popularity and emerging evidence supporting the use of dry needling as a reasonable adjunct to a therapeutic regimen, additional well-controlled double-blind studies with sufficient sample size are required to further determine its efficacy.

SAFETY
Patient and medical practitioner safety is of paramount importance when it comes to handling needles in the workplace. Since dry needling involves a needle penetrating the skin, iatrogenic injury to vessels, nerves, spinal cord, internal organs, implanted devices, or infection are possible hazards for patients. Additionally, medical practitioners are at risk of an accidental needle stick during use, disposal, or inadvertent contact while working in the vicinity of needles. According to the Center for Disease Control...
and Prevention, 385,000 sharp related injuries occur annually among healthcare workers with approximately 65% of those injuries occurring secondary to a needle stick.25

Dry needling is a relatively new intervention utilized by physical therapists in the United States. The practice of utilizing a needle to puncture the skin to reduce pain and improve function has raised questions regarding whether such an intervention falls within the scope of physical therapist practice. The American Physical Therapy Association (APTA) recognizes dry needling as a therapeutic intervention provided by or under the supervision of a physical therapist.26 While the APTA states, “dry needling falls within the practice of physical therapy” (p.2), there are several states that hold the position that dry needling falls outside of the scope of physical therapy practice.26

Dry needling and acupuncture both employ the use of thin filiform needles to puncture the skin in regions of the body that carry the same risk of causing an adverse event. There is a paucity of literature describing the incidence of adverse events associated with dry needling. Reports in the literature surrounding the adverse events associated with acupuncture are more plentiful.27,28,29 One of the largest acupuncture studies, with nearly 300,000 subjects, evaluated the adverse events associated with acupuncture.29 The authors found the most common minor adverse events to be bleeding, pain, sympathetic symptoms (i.e. nausea, vertigo, sweating) and two of the subjects sustained a pneumothorax, a major adverse event.29

When specifically looking at the literature related to dry needling adverse events, there is only one study that has investigated both the minor and major adverse events associated with dry needling. Brady et al30 surveyed 39 physical therapists over a nine-month period and recorded all of the adverse events that occurred during dry needling treatment sessions. They classified the events as “mild” or “significant.” Examples of mild adverse events included bleeding, bruising, and pain at the needle insertion site; whereas significant adverse events included pneumothorax, or any other severe reaction to dry needling. After recording 7,629 dry needling treatments, Brady et al30 found that “mild” adverse events occurred just under 20% of the time, while no “significant” adverse events occurred.

While Brady et al30 were the first to examine adverse events associated with dry needling, the number of respondents was only 39. This low respondent number and the lack of anonymity of the physical therapists reporting the adverse events may have limited the authors’ ability to fully report the incidence of significant adverse events. Furthermore, since the Brady et al30 study was performed in Ireland, one cannot assume the practices of physical therapists performing dry needling in Ireland mimic the practices of physical therapists within the United States. Thus, the purpose of this study was to determine and report the type of adverse events associated with the utilization of TDN. Additionally, this study will expand upon the work of Brady et al30 by increasing the number of subjects surveyed and to determine the incidence of adverse events associated with dry needling among physical therapists within the United States.

METHODS

Definitions
An adverse event is defined as “any ill-effect, no matter how small, that is unintended and non-therapeutic.”31,p.67 No standardized definitions exist for adverse events that occur during dry needling, thus making it difficult to operationally define an adverse event. For this study, definitions were adapted and developed from the work of White et al,31 Brady et al30 and Carnes et al.32 who provide general descriptions of severity and duration of adverse events. For this study, adverse events were divided into two categories; “minor adverse events" and “major adverse events." A “minor adverse event” is operationally defined as short-term, mild, non-serious, and the patient’s function remains intact with short-term consequences lasting hours or a few days.28,29, 30, 32,33 Examples of minor adverse reactions that can occur during dry needling are bleeding, bruising, and pain during or after treatment. Major adverse events are operationally defined as “medium to long-term, moderate to severe events that may require further treatment and can be serious and distressing lasting days or weeks.”30,32 Examples of major adverse reactions
are pneumothorax, nerve injury, infection, or excessive symptom exacerbation.28,29,32,33

**Ethical Approval**
Ethical approval was granted from an Institutional Review Board on 15 September 2017.

**Study Design**
A prospective questionnaire design.

**Subjects**
Subjects were recruited from a nationally recognized provider of continuing professional education in TDN technique, safety, and application. Each physical therapist trained and certified by the organization was sent a recruitment email soliciting their participation in the study. A database consisting of seven-thousand email addresses of physical therapists certified by the TDN continuing education provider was used to send a request to participate in the study. Of the seven-thousand solicited to participate, 420 completed at least one survey and over 50% of the 420 subjects completed the entire six weeks of survey data collection. Based on the manner in which the subject participation was requested, the sample was one of convenience.

Once respondents agreed to participate in the study, each was sent an informed consent and a demographics form. The demographic form included the participant’s age, level of education, number of years practicing physical therapy, post-graduate dry needling training and certification, level of dry needling certification, duration practicing dry needling, and work place setting.

**Survey Forms**
Surveys used by Brady et al30 were modified with permission and generated electronically via an online survey website. Once the recruitment phase concluded, one survey with two forms was sent to all participants and returned each week for the following six weeks. Form A recorded the total number of dry needling treatments and any minor event associated with the use of dry needling. The recorded minor events included bruising/hematoma, feeling faint, nausea, headache, drowsiness, bleeding at the needling site, needling pain during treatment, and aggravation of symptoms after treatment. Form B was completed only if the participant reported major AE’s. Major AE’s included: needling problems (e.g. pneumothorax, punctured organ, broken/forgotten needle), systemic effects (e.g. fainting, convulsion, vomiting, major skin reactions), infections, and altered symptoms (e.g. unexpected and/or prolonged aggravation). While most adverse events were self-explanatory, a ‘forgotten needle’ is defined as a needle that was accidently left in the patient by the physical therapist following a treatment session and was either discovered by the therapist or patient and then removed. Form B also requested information regarding body region/muscle(s) being treated, length/width of needle, technique used, patient position, and other information for determining potential sources of error.

**Distribution**
Surveys were distributed by email every Monday of each of the six weeks, as well as a reminder email sent on Friday and Sunday of each week. Along with the link to the survey, a printable PDF adverse event form was attached in the Monday email as a way to track adverse events as they occurred during the week. These documents were not required or collected, only distributed as a means of assistance and an attempt to improve reporting accuracy for the participant.

**Analysis**
Results were analyzed using Microsoft Excel and Statistical Package for Social Sciences (SPSS) Version 25. Descriptive statistics were used to calculate the frequency of AE’s among practitioners participating in the study, and parameter estimation (the use of sample data to estimate the parameter of a distribution) was used to estimate the frequency of AE’s among the participating therapists.

Major and minor AE’s were reported as a percentage of total treatments performed by all clinicians, as well as reported as a percentage of the total minor AE’s. Spearman’s Rank Order Correlation coefficients were calculated to test for associations between age, level of education, years practicing as a physical therapist, total number of dry needling treatments per week, level of dry needling training,
and the number of months performing dry needling. No statistical analysis was performed to compare body regions or muscles treated during minor or major adverse events. Descriptive data regarding the total number of upper quarter and lower quarter major AE's and the most common muscle being needled at the time of AE are reported.

RESULTS

Seven-thousand physical therapists were sent recruitment emails inviting them to participate in this study. Of these, 420 completed at least one weekly survey and the demographic information resulting in a 6% response rate. Two-hundred, twenty-three participants (53.1%) completed all six weeks of the study resulting in an overall response rate of approximately 3%. Table 1 provides an overview of participants' demographic information: average age (38.0 years), years practicing as a physical therapist (12.1 years), and years practicing dry needling (2.7 years). Eight-two percent of participants worked in an orthopedic practice, clinic or outpatient center. All participants in this study had completed training from a nationally recognized dry needling continuing education company. Level 1 training consists of dry needling theory, safety, indications, contraindications, and introductory needling techniques of the extremities, cervical, and lumbar spine. Level 2 training covers dry needling techniques in more technical areas of the extremities, temporomandibular joint, cervical, thoracic, and lumbar spine. Level 3 training focuses on advanced techniques to treat the complex patient. Sixty percent of the participants in this study had completed Level 1 training, 26% had completed Level 2 training, and 14% had Level 3 training.

Data were collected over the course of six weeks starting in October 2017. Participants submitted data for an average of 4.2 weeks, while over half of the participants provided 5 - 6 weeks of data. In total, 1,768 weekly surveys were collected reporting 20,494 total treatments. Table 2 lists the minor AE's reported in this study. In this study, a total of 7,531 minor AE's were reported via Form "A", meaning 36.7% of total treatments resulted in a minor AE. Participants performed on average 10.9 dry needling treatments per week, while the ratio of weekly AE's ranged from 0 – 6.4. The average ratio of minor AE's for all participants across all weeks was 0.53 (approximately 1 event for every 2 patients). The total number of minor AE's is reported as well as the percentage of each minor AE. The percentage represents the occurrence of each minor AE per the total number of treatments reported.

<table>
<thead>
<tr>
<th>Event</th>
<th>Number Reported</th>
<th>Percentage per Total Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleeding</td>
<td>3288</td>
<td>16.04%</td>
</tr>
<tr>
<td>Bruising</td>
<td>1581</td>
<td>7.71%</td>
</tr>
<tr>
<td>Pain During</td>
<td>1216</td>
<td>5.93%</td>
</tr>
<tr>
<td>Pain After</td>
<td>558</td>
<td>2.72%</td>
</tr>
<tr>
<td>Aggravated Symptoms</td>
<td>312</td>
<td>1.52%</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>190</td>
<td>0.93%</td>
</tr>
<tr>
<td>Feeling Faint</td>
<td>159</td>
<td>0.78%</td>
</tr>
<tr>
<td>Headache</td>
<td>133</td>
<td>0.65%</td>
</tr>
<tr>
<td>Nausea</td>
<td>94</td>
<td>0.46%</td>
</tr>
</tbody>
</table>

Table 1. Participant Demographic Information (n = 420).

Table 2. Minor Adverse Events Reported with Dry Needling (20,494 treatments).
The top three minor AE’s were bleeding, bruising, and pain during dry needling. In this study, bleeding was the most commonly reported minor AE with 3,288 reported, at a rate of 16.04%. Bruising and pain during needling were 2nd and 3rd most reported, 1,581 (7.71%) reported bruising and 1,216 (5.93%) reported pain during treatment. All other minor AE’s reported had a frequency of <3% of total treatments.

Major AE’s required the respondents to fill out a separate Form “B” detailing the event. Twenty major AE’s were reported out of the 20,494 treatments for a rate of <0.1%, which equates to roughly 1 per 1024 treatments. Table 3 lists the major AE’s and their frequency. Prolonged symptom aggravation was reported six times. Four respondents reported fainting; one was likely due to patient sitting up quickly and the others lasted <5 seconds. Three participants reported forgotten needles. Two participants reported flu-like symptoms and two participants reported infection. One participant reported right lower extremity weakness lasting up to 18 hours. One case of excessive bleeding was reported and one case of numbness in the upper extremity was reported. As stated prior, no statistical analysis was performed to examine associations between major AE’s and a particular muscle or body region being dry needled. However, of the 20 reported major AE’s 12 occurred during dry needling of the lower quarter and eight occurred during dry needling of the upper quarter. No major AE’s were associated with dry needling of the thoracic spine, anterior chest, abdomen, or groin regions. The gluteal muscles, lumbar paraspinals, suboccipitals, and the upper trapezius were the muscles groups most often reported by the subjects to be associated with a major AE.

Finally, associations among adverse effects and demographic characteristics of the participants were estimated with correlation coefficients. A correlation matrix comprised of adverse effects and demographic measures was constructed utilizing Spearman's Rank order coefficient Rho. Spearman's rho was selected in order to replicate the work of Brady30 and to accommodate the violation of normality evident in some of the measures.

**DISCUSSION**

In this study, 7,531 or 36.7% of the 20,464 dry needling treatments resulted in a minor AE, while twenty major adverse events or < .1% were reported. The most commonly reported minor AE’s included bleeding (16.0%), bruising (7.7%), and pain (5.9%) during treatment. All of these minor AE’s are typical and are expected responses to a needle stick. The most common major adverse events were prolonged symptom aggravation (.03%), fainting (.02%), and forgotten needles (.01%). Prolonged symptom aggravation was defined as symptoms that are aggravated for days or even weeks following a dry needling session.30,32 The second most common major AE was the report of feeling faint, fainting, and experiencing nausea which are common complaints associated with vasovagal responses seen in patients undergoing procedures that involve a needle stick. Nearly 10% of all patients report a fear of needles.34 Additionally, it has been reported that 10% of patients

<table>
<thead>
<tr>
<th>Event</th>
<th>Number Reported</th>
<th>Percentage per Total Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolonged Symptom Aggravation</td>
<td>6</td>
<td>.03%</td>
</tr>
<tr>
<td>Fainting</td>
<td>4</td>
<td>.02%</td>
</tr>
<tr>
<td>Forgotten Needles</td>
<td>3</td>
<td>.01%</td>
</tr>
<tr>
<td>Flu Like Symptoms</td>
<td>2</td>
<td>.009%</td>
</tr>
<tr>
<td>Infection</td>
<td>2</td>
<td>.009%</td>
</tr>
<tr>
<td>Excessive Bleeding</td>
<td>1</td>
<td>.004%</td>
</tr>
<tr>
<td>Lower Limb Weakness</td>
<td>1</td>
<td>.004%</td>
</tr>
<tr>
<td>Numbness</td>
<td>1</td>
<td>.004%</td>
</tr>
<tr>
<td>Total Major Adverse Events</td>
<td>20</td>
<td>.1%</td>
</tr>
</tbody>
</table>
receiving an injection report feeling faint and nearly half of those individuals reported losing consciousness during an injection.\textsuperscript{34,35} Even though the results of this study indicate that only 1\% of the patients experienced a vasovagal response, physical therapists should be prepared to manage and respond to vasovagal responses to safeguard their patients from potential injury. The third most common major AE was a forgotten needle. Physical therapists often use multiple needles during dry needling. Based on the reports of this group of subjects, there were a few instances where needles used during a dry needling were accidently left in a patient following a treatment session and the patient/therapist discovered it and removed it. Approximately 1500 cases annually are reported in the United States of foreign objects accidently left in patients following surgery.\textsuperscript{36} Needles unintentionally left in a patient could occur for several reasons such as distractions, rushing, and lack of accountability. Physical therapists should develop tracking mechanisms, similar to those used during surgical procedures, to track and account for all needles used during a patient intervention.

When dry needling muscles that are in close proximity to vital organs and blood vessels, major adverse events like pneumothorax, excessive bleeding, or loss of consciousness are a real possibility. One might also think that dry needling the upper quarter of the body may introduce more risk of a major adverse event due to the exposure of the lungs, brachial plexus, and vessels of the upper limbs in the shoulder and neck region. Of the 20 reported major AE’s, 12 occurred while dry needling the lower quarter and eight when dry needling the upper quarter. The authors caution the reader not to assume that major AE’s occur more frequently in the lower quarter based on the findings of this study and recommend further investigation in this area. The results of the current study indicate that the muscle groups most often reported by the respondents to be associated with a major AE were the gluteal muscles, lumbar paraspinals, suboccipitals, and the upper trapezius. Based on this information, it is fair to say that minor AE’s during dry needling are relatively common and that major AE’s are rare in this group of self-selected subjects.

Table 4 demonstrates the differences between the results of the current study and the study performed by Brady et al.\textsuperscript{30} Brady et al\textsuperscript{30} mention in their discussion that future studies should recruit greater numbers of participants to improve the accuracy of reporting AE’s (especially major AE’s) associated with dry needling. Therefore, the current study was undertaken to build upon the work of Brady et al\textsuperscript{30} and recruited 420 participants that performed 20,494 treatments over a six-week period. The findings of this study closely mirror those of Brady et al.\textsuperscript{30} Both Brady et al\textsuperscript{30} and the results of the current study found that minor AE’s are a common occurrence and major AE’s are rare. Additionally, bleeding, bruising, and pain during treatment were the top three minor AE’s in both studies. Brady et al\textsuperscript{30} reported that 19\% of the 7,629 dry needling treatments resulted in a minor AE and they reported no major AE’s. The results of the current study indicate nearly double the minor AE’s at 36\% and 20 major AE’s (< .1\%), compared to “none” referenced by Brady et al.\textsuperscript{30} Brady et al\textsuperscript{30} state that it is difficult to delineate what constitutes an expected or

<table>
<thead>
<tr>
<th>Measure</th>
<th>Current Study</th>
<th>Brady et al.\textsuperscript{30}</th>
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</thead>
<tbody>
<tr>
<td>Participants</td>
<td>420*</td>
<td>39</td>
</tr>
<tr>
<td>Participation Rate</td>
<td>6%*</td>
<td>76%</td>
</tr>
<tr>
<td>Treatments</td>
<td>20,494</td>
<td>7,629</td>
</tr>
<tr>
<td>Minor AE’s</td>
<td>36%</td>
<td>19%</td>
</tr>
<tr>
<td>Major AE’s</td>
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<tr>
<td>Length of Study</td>
<td>6 weeks</td>
<td>9 months</td>
</tr>
<tr>
<td>Anonymity</td>
<td>yes</td>
<td>no</td>
</tr>
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</table>

\*7000 solicitation emails sent, 420 responded, 223 of respondents (53.1\%) completed all six weeks of the study.
acceptable consequence of a treatment and what is a true adverse event. Given that the current study nearly had double the minor AE's of the Brady et al study, it may be prudent for any future studies to consider an alternate reporting category such as "not adverse" to properly categorize AE's. More specific descriptive categorization may help limit over reporting of AE's and provide a more accurate view of true AE's. This study did not provide the participants the "not adverse" reporting category as an option, which could have falsely increased the rate of reported minor AE's. Another explanation for the increased rate of minor and major AE's when comparing this study to Brady et al may be due to the increased number of participants and treatments. It should also be noted that respondent anonymity was maintained throughout this study, which could have made participants feel more comfortable reporting both minor and major AE's.

According to the literature related to AE's during acupuncture, reports vary from a low of .14% to as high as 42%. When comparing the incidence of AE's in this study to AE's associated with the use of acupuncture, the authors believe they are difficult to compare due to the differences between the techniques and the methodology of the studies examining AE's. When comparing AE's associated with dry needling to other pain-relieving interventions such as opioids (78%), NSAID's (35%), aspirin (18.7%), and ibuprofen (13.7%), the risk of a major adverse event associated with dry needling is drastically lower. Furthermore, one might think that years of experience and/or training level related to the practice of dry needling may be associated to the number of AE's that a clinician experiences during dry needling. For example, more experienced clinicians may experience fewer adverse events when compared to their less experienced counterparts. However, as stated in the results, no associations were noted between the frequency of adverse events and the level of education, years in practice, practitioner age, level of training, months experience with dry needling or number of patients treated.

Similar to the studies performed by Brady et al and White et al, the current study demonstrated a large variation in reported AE's among participants. Due to the subjective nature of reporting a minor AE, the investigators believe some of the variation may have been due to a lack of well-defined guidelines surrounding what constitutes a minor AE. For example, how much bleeding and/or pain must occur during the dry needling treatment to consider it an adverse reaction. Future studies may be able to limit variations in reporting by improving AE definitions. Another finding was that over the six-week treatment period, the absolute number of dry needling treatments reported remained fairly consistent at 3,415/week among all participants; however, the number of reported AE's reduced weekly. At the end of the six-week study, the number of reported AE's declined from 2053 at week one to 787 at week six. One explanation for the decline in reported AE's could be related to survey/reporting fatigue experienced by the participants. A second possible explanation is that participants may have been more consciously aware of AE's and took steps to reduce them by altering their treatment approach. Lastly, they may have become desensitized to minor AE's, seeing them as normally occurring circumstances of dry needling and thus did not report them as frequently.

This study had several limitations. First based on self-reporting design of this study and the manner in which the subject participation was requested, it could be subject to nonresponse and self-selection bias. Additionally, the overall response rate of the study was 3%, and while there were a substantial number of treatment sessions performed, a low response rate was a limitation of recruiting participants out of convenience. Therefore, the results cannot be generalized to all physical therapists practicing dry needling. However, the rates of AE's reported by the subjects exceed most of the values reported by Brady, and if there is a bias on the estimates in the current study it could be an overestimate of the AE's which are still very low especially with regard to major AE's. Lastly, the definitive description of what constitutes a minor AE and the lack of use of the "not adverse' event" category could have falsely increased the rate of reported minor AE's. Improved descriptors and AE categorization may have allowed for more accurate reporting of AE's. Future studies should consider comparing therapist reported adverse events to patient reported adverse events, which may result in more accurate reporting of AE's and risk reporting.
CONCLUSION
The evidence surrounding dry needling is in its infancy as it relates to evaluating its efficacy and effectiveness. A recent meta-analysis demonstrates that moderate evidence exists to support dry needling as an effective intervention to reduce pain associated with musculoskeletal conditions. With the recent opioid epidemic, safe and effective treatment alternatives must be explored to help patients control their pain and improve their function. The Center for Disease Control and Prevention has suggested using physical therapy rather than long term or high dose additive pain killers to control pain. Physical therapists are well positioned to meet the needs of those patients in pain with traditional and alternative interventions like dry needling. Safety of the patient and the clinician is of paramount importance when evaluating the risk and potential reward of an intervention. According to the findings of this study, expected minor AE’s such mild bleeding, bruising, and pain during dry needling are common and major AE’s are rare. Physical therapists and other medical practitioners need to be aware of these risks and understand that dry needling poses little harm to a patient in the hands of a trained physical therapist.

REFERENCES


ABSTRACT

Introduction: Dysfunctional breathing (DB) is common (60-80%) in adults. Individuals with DB may have decreased pain thresholds, impaired motor control and balance, and movement dysfunction. These impairments likely adversely affect performance. Research has demonstrated that DB is multi-dimensional and includes biochemical, biomechanical, and psychophysiological categories.

Purpose: The purpose of this study was to test the impact of breathing exercises in an otherwise healthy population of individuals diagnosed with at least one category of DB. It was hypothesized that the exercise program would normalize at least one category of DB.

Methods: An experimental group with DB was recruited, then the control group was matched for gender, age, BMI and activity. Baseline breathing metrics were obtained for each category of breathing dysfunction: capnography for biochemical (ETCO2 of < 35mmHg at rest = DB), HI-LO for biomechanical (upper chest or paradoxical patterns = DB), and Self-Evaluation of Breathing Questionnaire (SEBQ ≥ 25 = DB) and Nijmegen Questionnaire (≥ 22 = DB) for psychophysiological. The experimental group performed a four-week progression of home breathing exercises, once daily and the control group continued normal activities (no interventions). Re-testing of all outcome measures was performed after four weeks.

Results: Thirty-five individuals comprised the participant sample (16 experimental, 19 control, mean age 26.0 years, mean BMI of 24.3). There were no statistically significant differences between groups at baseline. Eighty-one percent of subjects in the experimental group improved in at least one category compared to 21% of subjects in the control group. Seventy-eight percent of subjects with biomechanical category of DB in the experimental group normalized this dysfunction, while none normalized in the control group, which was statistically significantly different. Twenty-seven percent of subjects with biochemical DB in the experimental group normalized, while only 25% in the control group which was not statistically different. There were only two subjects in each group with the psychophysiological category, therefore no analysis was performed.

Conclusion: Home exercises were effective in reversing the biomechanical category of DB in 78% of young, otherwise healthy adults versus no exercise. However, the exercises did not affect the biochemical category of DB. Performing a set of home exercises may be an effective option for fitness and rehabilitation providers to suggest for clients to normalize biomechanical breathing dysfunction.

Level of Evidence: 2b

Key Words: Apical breathing, disordered breathing, hypocapnia, Movement System

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3 Gibson General Hospital, Star One Rehab, Fort Branch, IN, USA
4 Orthopedic and Sports Physical Therapy, Richmond, KY, USA
5 ProRehab PC, Evansville, IN, USA
6 OhioHealth, Mansfield, OH, USA
7 Skyline Medical Center, Nashville, TN, USA
8 ProRehab PC, Louisville, KY, USA

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Conflict of interest: Dr. Kiesel has equity in Functional Movement Systems which owns the Functional Movement Screen™.

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Dysfunctional breathing (DB) is an overarching term used to describe a detrimental adaptation in breathing that has not been otherwise medically diagnosed. DB is common in adults with the prevalence reported between 60-80%. Individuals with DB have decreased pain thresholds, impaired motor control and balance, and movement dysfunction, all of which may adversely affect an individual’s success in fitness activities as well as with rehabilitation programs.

Breathing involves coordinated activity of the diaphragm and pelvic floor with eccentric control of the many muscles that are associated with the thorax and abdominal wall. The diaphragm also plays a crucial role related to spinal stability during movement, resulting in an intimate connection between breathing, spinal stability and movement. When DB is present, this may relate to core dysfunction, muscle imbalance, and dysfunction in fundamental movements. Motor control deficits of fundamental movement patterns can be considered risk factors for musculoskeletal injury, and when multiple risk factors are present, fitness and athletic performance declines have been reported. Additionally, normal breathing is essential to maximize movement performance, especially for complex athletic tasks including throwing, jumping, hitting and other athletic movements. Because of the detrimental effects that DB can have on various aspects of physical performance, implementation of a screening and intervention program designed to identify and correct DB may be a helpful addition for professionals in the fitness and rehabilitation settings.

Recently, researchers have proposed the idea that within the umbrella term of “dysfunctional breathing”, perhaps different subtypes or different categories of DB exist. These different categories of DB have been described as including the biomechanical, biochemical, and psychophysiological categories. Tools are available to assess and test for each of these different categories of DB individually, and a screen for DB has also been proposed to identify individuals who likely have some category of DB and therefore would benefit from additional breathing assessments or tests.

**INTRODUCTION**

**THE THREE CATEGORIES OF DYSFUNCTIONAL BREATHING**

**Biomechanical**

The biomechanical category of DB refers to individuals who demonstrate an abnormal mechanical breathing pattern. A subject demonstrating a biomechanical breathing pattern disorder would be lacking what is considered a normal diaphragmatic breathing pattern while at rest. A clinical measure to determine presence of DB in the biomechanical category is the Hi-Lo Breathing Assessment. The most common disordered breathing pattern at rest is described as upper chest breathing or apical breathing. In this pattern, upper chest expansion is dominant during the inspiratory phase of breathing. Another example of biomechanical breathing dysfunction has been described as a paradoxical pattern where the lower abdomen is drawn in, rather than moving outward, during the inspiratory phase.

**Biochemical**

The biochemical category consists of individuals who exhibit reduced levels of CO2 in the blood, otherwise known as being in a state of hypocapnia. Capnography has been identified as a reliable clinical measure of respiratory function, measuring the end tidal CO2 (ETCO2) which is the partial pressure of CO2 exhaled by an individual. Hypocapnia is said to be present if the ETCO2 volume is ≤ 35 mmHg, and ETCO2 has demonstrated good concurrent validity when compared to direct blood measures.

**Psychophysiological**

The psychophysiological category is the least commonly described or identified category of DB. This category captures individuals who may have no issues with breathing during normal daily activities but can have abnormal or dysfunctional breathing under particular situations that are commonly stress-related. For these individuals, routine clinical testing for DB may return normal results, thus, self-reported questionnaires are utilized to capture this category of DB; the Nijmegen Questionnaire and the Self Evaluation of Breathing Symptoms Questionnaire (SEBQ) are the most common. Few studies are available that have tested various interventions to reverse DB. Most studies have used
the Nijmegen questionnaire as the primary outcome measure when breathing interventions have been tested. As a better understanding of the different categories of DB and definitive diagnostics for each category have emerged, more intervention studies can be conducted to determine the best manner to treat individuals with DB in order to address the different categories of DB. The purpose of this study was to test the impact of breathing exercises in an otherwise healthy population of individuals diagnosed with at least one category of DB. It was hypothesized that those who participate in the exercise program will normalize at least one category of DB. The secondary aim was to determine if the standardized breathing exercises had an effect on movement patterns as measured by the Functional Movement Screen™ (FMS™).

**METHODS**

Subjects ages 18-45 who were free of known respiratory disease and had no current musculoskeletal pain complaints were recruited by fliers and word of mouth. Those who were positive on a breathing screen were invited to enroll. The breathing screen, includes a breath hold time measure and a four-question general survey (Table 1). Any individual below the 25 second breath hold time threshold or scoring a ≥ 2 on the survey is considered to be positive on the breathing screen and likely have some type of dysfunctional breathing. Sample size determination for the primary outcome was calculated based on the estimate that 50% of the intervention group would improve at least one category compared to 10% in the control group. Utilizing an alpha level of .05 and 80% power to detect a type II error, a sample of 19 per group was calculated.

Institutional review board approval was obtained from the University of Evansville where the study was conducted in a clinical lab setting. At baseline, gold standard breathing metrics were obtained for each of the three categories. This included capnography for the biochemical category, (ETCO2 of < 35mmHg at rest was considered DB) the HI-LO test for the biomechanical category (upper chest or paradoxical patterns was considered DB), and the SEBQ (≥ 25 = DB) and Nijmegen Questionnaire (≥ 22 = DB) for breathing symptoms related to the psychophysiological category. The experimental group was recruited first, then the control group was recruited and matched for gender, age, BMI and activity level.

The experimental group performed a four-week progression of home exercises designed to improve breathing metrics while the control group was told to continue normal activities (had no intervention). Re-testing of breathing metrics for each category was performed four weeks after baseline for both groups.

**Breathing Measures**

**Biomechanical Category**

In order to determine if a subject had a biomechanical breathing problem, the Hi-Lo Breathing Assessment was utilized. The Hi-Lo is a manual assessment to determine if a subject is in a normal diaphragmatic breathing pattern or if they are in an abnormal pattern. It was performed in the sitting position with the tester standing or kneeling.

<table>
<thead>
<tr>
<th>Table 1. Screen for dysfunctional breathing.</th>
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</thead>
<tbody>
<tr>
<td>Breathing is considered dysfunctional if breath hold time is &lt; 25 seconds, or if any one of the following questions is scored as 2 or 3, the screen is considered positive (+) for the presence of dysfunctional breathing:</td>
</tr>
<tr>
<td>0) never/not true at all; (1) occasionally/a bit true; (2) frequently-mostly true; and, (3) very frequently/very true</td>
</tr>
<tr>
<td>Do you feel tense?</td>
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<tr>
<td>Do you feel a cold sensation in your hands or feet?</td>
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<tr>
<td>Do you notice yourself yawning?</td>
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<td>Do you notice breathing through your mouth at night?</td>
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at the front and slightly to the side of the subject. The tester placed one hand on the subject's sternum and one hand on the upper abdomen to determine whether thoracic or abdominal motion was dominant during breathing. Assessment for paradoxical breathing was also performed by determining if the abdomen moves in a direction opposite to the thorax during breathing; this is evident during inhalation if the abdomen moves toward the spine, and during exhalation if the abdomen moves in an outward direction. The scoring process was as follows: Is the upper chest dominant? If yes scores as dysfunctional and stop, if no continue. Is the pattern paradoxal? If yes score as dysfunctional and stop, if no continue. Is diaphragm dominant? (greater volume and diaphragmatic movement is first), if yes score as functional, if no score as dysfunctional. The Hi-Lo test reliability has been reported by others as acceptable (moderate agreement)13 and the researchers in this study achieved 88% agreement with a Kappa = .75 on 43 subjects.3

Biochemical Category
In order to determine if a subject had a biochemical breathing problem, capnography was utilized as the reference measure. Capnography is a measurement taken via nasal cannula to determine ETCO2. The average resting value over a three minute data collection period was utilized to obtain the measure, and the standard value of < 35 mmHg was utilized as the cut-off for dysfunction.21-24 The capnography unit (DRE Echo C02 Avante Health Solutions, USA) was calibrated according to the manufacturer recommended procedure prior to each data collection session. Respiration rate in breaths per minute was calculated from the capnography data.

Psychophysiological Category
In order to address the psychophysiological category, two separate breathing questionnaires were administered. The Nijmegen Questionnaire is a 16-item questionnaire originally developed in the 1980's to identify patients who have breathing dysfunction that is related to common diseases. A cut score of ≥ 22 on the Nijmegen was utilized to define DB.19,26 The Self-Evaluation of Breathing Questionnaire (SEBQ), Version 3,27,28 is a questionnaire that includes 25 questions to determine self-perception of breathing dysfunction. Test-retest reliability has been shown to be high, and a cut score of ≥ 25 on the SEBQ was utilized to operationally define DB for this study. The SEBQ is a new tool, and there is no established cut-score confirmed in the literature to define those with this category of breathing dysfunction. Expert opinion suggests a score of 25 as an appropriate cut-score and this was the score utilized in the study that created the screen for DB.3

A secondary aim of this study was to determine if the exercise program, designed to improve breathing metrics, had an effect on movement. Therefore, FMS™ scores were obtained at baseline and at post testing and analyzed for within group and between group change. The FMS™ consists of seven different fundamental movement patterns and is scored on a four-point ordinal scale. The reliability of the FMS™ is well established.29-31 Standardized testing instructions were utilized, and the two testers were trained in the FMS™ testing protocol in their didactic program.

EXERCISE INTERVENTION
Instruction on how to perform each exercise was provided by a student researcher who was trained by the primary researcher. The first set of exercises was performed for the first two weeks, then subjects met with the student researcher again to learn the progression of exercises for the second two weeks. The exercises emphasized the use of nasal inhalation and slow and full exhalation through the lips. A postural progression based on a neurodevelopmental approach was utilized with the earliest exercises (first two weeks) performed in the sidelying and hooklying postures, with progression to quadruped, half-kneeling and lastly standing (weeks 3-4). Appendix 1 provides the details of each exercise used in this study.

STATISTICAL METHODS
To determine if there were baseline differences between the control and treatment groups, T-tests were conducted on the continuous variables and the Chi-square test performed on categorical variables with the p < 0.05 considered significant for each. Frequency counts of subjects who demonstrated a change in at least one category of DB from pre to
post testing were obtained for each group. Chi-square testing and the number needed to treat (NNT) statistic with the 95% CI were performed. Further investigation into which categories of DB changed were also calculated. Within group pre to posttest composite scores, treated as a continuous variable, on the FMS™ composite scores were analyzed for change using the paired t-test. The independent t-test was utilized to assess for between group change. Additionally, to determine if there were any changes on the FMS™ from a Pass/Fail perspective (fail defined as presence of any score of 1 or 0), the Chi-square test was performed.

RESULTS
Of the 35 total subjects analyzed, there were significantly more females 29, compared to six males (p < .05). There were no differences of age, male 22.2 (1.4), female 20.7(1.8) years, BMI, male 24.5 (4.4), female 23.0 (2.5), or activity level, (male 5.1(1.9), female 4.7 (1.5) between sexes. There were no significant at baseline between the control vs. experimental group (Table 2). There were initially 25 subjects enrolled into the intervention group. Of those, five were not diagnosed with DB in any category and were excluded from participation in the study. An additional four subjects did not return for the post testing and were dropped from final analysis. There were 26 initially enrolled in the control group; six did not present with any DB and were therefore excluded, and one was ill and did not return for post testing and was therefore dropped from final analysis. Ultimately, 16 subjects were analyzed in the experimental group and 19 in the control group (see Figure). There were no baseline characteristic differences between groups (Table 2). In the experimental group, 81% of subjects improved by at least one breathing category compared to 21% of controls (p < .001, NNT = 2 [2-5]). (Table 3) Additionally, which of the categories of DB that changed after the intervention period was investigated. It was discovered that 78% of subjects with biomechanical dysfunction from the experimental group normalized while none from the control group changed (p < .001, NNT = 2 [2-3]). (Table 4) For subjects with biochemical dysfunction, 27% from the experimental

<table>
<thead>
<tr>
<th>Table 2. Baseline characteristics, presented as mean (SD). ANOVA or Chi-Square (for Sex and Hi-Lo Test) for examination of baseline variables between groups.</th>
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<tr>
<td></td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>BMI</td>
</tr>
<tr>
<td>Activity Level Questionnaire¹</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Breath Hold Time²</td>
</tr>
<tr>
<td>ETCO₂³</td>
</tr>
<tr>
<td>SEBQ⁴</td>
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<tr>
<td>Nijmegen⁵</td>
</tr>
<tr>
<td>Hi-Lo Positive⁶</td>
</tr>
</tbody>
</table>

BMI= Body mass index, ETCO₂= End-tidal CO₂ in mmHg (standard deviation); SEBQ= Self-Evaluation of Breathing Questionnaire
¹Activity Level Questionnaire is on a 10-point scale with higher values indicating higher activity level.
²Breath Hold Time= Breath holding time at Functional Residual Volume measured in seconds.
³End-Tidal CO₂ measured in mmHg, above 35 is considered normal.
⁴Self-Evaluation of Breathing Questionnaire, higher scores indicate greater breathing dysfunction.
⁵Nijmegen Questionnaire for Dysfunctional Breathing, higher scores indicate greater breathing dysfunction.
⁶Hi-Lo Test, when positive, indicates the presence of dysfunctional upper chest breathing.
The results of the current study demonstrate that the standardized exercise program utilized can be successful in improving one category of DB in otherwise healthy subjects. Most breathing intervention studies conducted in the past have grouped subjects with all categories of DB rather than grouping subjects by type or category of breathing dysfunction. Hagman et al.\textsuperscript{32} studied a breathing retraining program comparing subjects with DB to those with asthma and in their study a variety of tests and measures were utilized to diagnosis subjects with DB, including an

The International Journal of Sports Physical Therapy | Volume 15, Number 1 | February 2020 | Page 119
assessment for upper chest breathing. The intervention was performed by trained physios and focused on volitional control of diaphragmatic breathing, education and breathing awareness. At the five year follow up, subjects improved on most measures including a reduction in Nijmegen score. The study methods did not provide for assessment of the presence of upper chest breathing at follow-up, making comparison to the current study challenging.

A study by Jones et al 33 tested a breathing retraining program in subjects with DB (based on a Nijmegen score of >23 and no asthma) and reported a significant change in Nijmegen score and a variety of other outcome measures. The Jones et al study did include breath hold time, reporting a mean at baseline of 25.2 seconds. However, it was not clear how the BHT was conducted, but the value is much higher than the baseline value of 19.2 seconds in the current study. Upper chest breathing was not assessed in the Jones et al study, and the mean age of the retraining group was 41 years, compared to 23 years in the current study, again, making direct comparison difficult. Since most studies have primarily utilized the Nijmegen to define DB, subjects in these studies have an average score at baseline above the cut off of 23. In the current study, the average score on the Nijmegen was nine with only two subjects exceeding the cut off of 23. It appears that subjects in the current study had overall less symptoms related to DB when compared to the majority of other studies and this is likely because they were disease free. Additionally, the intervention in each study mentioned was directed at hands on breathing retraining and the current study utilized a basic home exercise approach and did not include hands on re-training or awareness and education related to DB.

The biochemical measure (ETCO2) was not utilized in previous studies. Some suggest using BHT as a proxy for this measure. The current study demonstrated that subjects with hypocapnia did not improve with this home exercise approach with only three of eight subjects that were below the ETCO2 threshold of 35 mmHg at pretest improving to above the threshold at the four-week follow up in the exercise group and only three out of 11 changed in the control group. There were no significant differences between the groups related to mean resting ETCO2 values or number of subjects that changed at pretesting. Only one subject that crossed the 35 mmHg threshold changed greater than the standard deviation for the entire sample which was 3.1 mmHg. Perhaps the small number of subjects that did cross from below to above the threshold of 35 mmHg was due to the nature of the measure. Many individuals measured were very close to the 35 mmHg cut-off, thus, it is plausible that this is just a small physiological fluctuation that happened to fall at the established cut-off. Because the exercises used in the current study didn’t show a change in the frequency of subjects with low ETCO2, or an improvement in mean values, further research is required to determine what type of intervention, if any, can demonstrate improvement of this metric. It is the experience of the lead author and in discussion with others that utilize a similar approach, subjects with low ETCO2 are challenging and take a hands-on approach and a much longer intervention period to see a change. Perhaps those with slightly low ETCO2 values, and no other signs or measures of DB, actually have acceptable functional breathing and being slightly below the commonly utilized cut-off of 35mmHg may not cause breathing symptoms for some individuals. Therefore, additional research is needed to determine the best intervention for subjects with hypocapnia or the cut-off may not be ideal for individuals with no other signs or symptoms of DB.

The authors hypothesized that improvements in breathing may result in changes in fundamental movement patterns. The results of the current study failed to demonstrate a significant improvement in FMS™ scores following the breathing retraining, suggesting other exercise intervention should be performed to improve movement such as demonstrated in previous studies.34,35

In the intervention group there were four subjects who did not return for follow-up testing. These subjects were not included in the main analysis because the primary outcome was a frequency count of subjects who were successful, rather than a continuous variable. When applying an intention to treat approach, assuming that the four dropouts did not change, the primary outcome is a control event rate drops to 65% with a NNT of 3 (2-11). The authors didn't include subjects in
this study that were positive on the breathing screen, but then ultimately did not end up having a breathing problem, based on the diagnostic process utilized in this study. These subjects would have been considered as false positives on the breathing screen. Of the 11 subjects who were false positives on the screen, eight of them failed the screen be able to achieve BHT of < 25 seconds. With no other findings on the breathing tests utilized, these subjects could be considered not to have a breathing problem, or we could consider simply low BHT, in and of itself, as a breathing problem. Future research should investigate this and if BHT can change with targeted intervention.

CONCLUSION
A standardized set of home exercises was effective in reversing the biomechanical category of DB in 78% of young, otherwise healthy adults. These exercises did not affect the biochemical category of DB, and further research is needed to determine effective interventions for those with this category of DB. The sample in this study was too small to draw conclusions regarding the psychophysiological category of DB. Performing a simple set of home exercises may be an effective option for fitness and rehabilitation providers to suggest for otherwise healthy clients to normalize biomechanical breathing dysfunction.

REFERENCES
15. Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. Reliability, Validity, and Injury Predictive Value of


**Weeks 1-2**

Breathing – Side Lying

Start by lying on your side with a small, soft rolled up towel placed between your hip and the floor. The towel will give you a target to breathe into during the exercise. Keep your neck and body relaxed and in a comfortable position. You may use a pillow under your neck for support and comfort.

Place a hand on your stomach. Breath in through your nose and into the hand placed on your stomach. You will feel your hand move out and your side pushing into the towel.

1) Breath in and out through your nose
2) Breathing in should last 3 seconds and be slow and controlled
3) Take a short pause, 1-2 seconds.
4) Breathing out should last 4-6 seconds and be slow and controlled
5) Take a longer pause, 2-3 seconds
6) Repeat steps 1-5
7) Once completed on one side switch to other side and repeat steps 1-6

Breathing – Hook Lying

Start by lying on your back with your knees bent up and feet flat on the floor. Neck and spine should be relaxed and in a straight line. You can use pillow to support your neck if needed. Place one hand over your heart and other hand over your belly button.

1) Breath in and out through your nose
2) Breathing in should last 3 seconds and be slow and controlled
3) Take a short pause, 1-2 seconds.
4) Breathing out should last 4-6 seconds and be slow and controlled
5) Take a longer pause, 2-3 seconds
6) Repeat steps 1-5
7) Once completed on one side switch to other side and repeat steps 1-6

Breathing - T-Spine Rotation with Rib Grabs

Start by lying on your side. Bend your top knee until it is perpendicular with your body. Place a pillow under your knee and head to provide support. Reach across your body with the arm on top and grab your ribs.

1) Breath in through your nose
2) While breathing out roll your top shoulder behind you towards the floor. Do not move your knee off the pillow.
3) Hold this position and continue breathing in and out your nose continuing to roll back as close to the floor as possible with each breathe out
4) When you can no longer lean back any further stay in the position and take 3 breaths in and out
5) Return to the starting position
6) Switch to opposite side and repeat.

Four point with Flexion/Extension

Begin on all fours with the hands placed under your shoulders and knees placed under your hips. Bring your left foot up next to your left hand.
1) Take a normal breath in and out through your nose
2) While breathing in over 3 seconds, tilt your hips towards the floor, allow your belly to drop down and spine to move into extension from neck to low back.
3) Take a short pause, 1-2 seconds
4) While breathing out 4-6 seconds, tilt your hips towards the ceiling, arch your back like a cat to move your spine into flexion from neck to low back.
5) Take a short pause, 1-2 seconds
6) Patient preference
   a. Go directly into repeating steps 2-5
   b. Repeat steps 1-5
7) Once completed on left side switch to right side and repeat steps 1-6

**Weeks 3-4**

**Four point with Flexion/Extension**

*Same as above in Weeks 1-2

**Half Kneeling Turns**

Begin by positioning yourself in the tall-kneeling position as shown. Make sure to stay tall during exercise.

1) Take a normal breath in and out through your nose using the high/low breathing learned in weeks 1-2
2) While keeping the correct position turn your head slowly to the right while breathing in for 3 seconds
3) Take a short pause, 1-2 seconds
4) Turn your head back to the start position while breathing out for 4-6 seconds
5) Take a short pause, 1-2 seconds
6) Repeat steps 2-5
7) Switch to opposite side by breathing in while turning head to the left.

**Toe Touch Progression**

Start by standing tall with feet together and toes up on a 1-2 inch board. Bend your knees and place a rolled towel between them then stand tall again. Your feet should not move, if they do use a smaller rolled towel. This will feel very awkward, but do not change it. Normal high/low breathing should be used throughout exercise. You will breathe in when reaching up and breathing out when reaching down. If breathing changes during a movement, continue practicing movement until it can be completed without large change in breathing.

**Phase 1:**

1) With your hands facing forward reach up for the ceiling as high as possible.
2) Reach down until your fingertips touch your toes
   a. If your fingertips do not touch your toes:
i. Squeeze towel roll to help relax muscles so toes can be reached  
ii. If above step does not work begin to bend knees slightly until toes can be reached

3) Repeat steps 1-2
   a. If small knee bend was used, try to bend knees less during each repetition but still make it close to your toes.
   b. There may be tightness in your calves, backs of knee, hamstrings, and low back

Phase 2:

The only difference with phase 2 is the positions of the 1-2 inch board. Place the board under your heels. Place towel roll in same position as phase 1. Repeat steps 1-3 from phase 1.
ABSTRACT

Background: The stabilizing action of the serratus anterior (SA) muscle is vital in maintaining normal scapulothoracic rhythm. This warrants investigation of exercises to discern which are best to activate the SA muscle. Recruitment of the muscles in the trunk and lower extremity kinetic chain during exercises has demonstrated increased SA activation due to the myofascial connections between various segments of the body. Variation of surfaces during an exercise has also been shown to alter the muscle recruitment patterns.

Purpose: The primary purpose was to determine the effects of trunk and lower extremity kinetic chain muscle recruitment on the SA muscle activity while on an unstable surface. The secondary purpose was to determine if the SA muscle activity would change when the surface stability during the exercises was reduced.

Study Design: Descriptive, within-subject repeated measures.

Methods: Surface electromyographic activity of the SA, latissimus dorsi (LD), external oblique (EO) on the dominant, and femoral adductor (FA) muscles on the non-dominant side and gluteus maximus bilaterally was analyzed during forward punch plus (FPP) and two of its' variations: FPP with closed chain serape (CS), FPP with open chain serape (OS) on stable and unstable surface in twenty-one healthy males. A two-way repeated measure ANOVA was used to determine the difference in the muscle activation between exercises, surfaces, and interaction between these two variables. A separate one-way repeated measures ANOVA with Sidak post hoc test was used for comparisons between stable and unstable surfaces. (p≤0.05).

Results: Muscle activity was statistically significantly higher for the CS and the OS exercises compared to the FPP for all the muscles except for the LD within the same surface. There was no significant difference in muscle activity for any of the muscles when compared between stable and unstable surfaces.

Conclusions: Incorporating the trunk and lower extremity kinetic chain during the FPP exercise increased the SA activation on both stable and unstable surfaces. However, the type of surface did not influence the activation of any muscle across exercises. The results of this study further strengthen the benefit of the kinetic chain exercises but also caution that adding an unstable surface to an exercise does not always imply higher muscle activation.

Level of Evidence: 2b

Key Words: Kinetic chain, serratus anterior, movement system, myofascial chains
INTRODUCTION

Normal scapulothoracic kinetics and kinematics are essential for proper function of the upper extremity. Due to its anatomical location, the scapula acts as a connecting link between the upper extremity and the trunk. Abnormal scapular kinematics such as decreased scapular upward rotation, posterior tilting, and external rotation have been related to various mechanical dysfunctions at the shoulder such as subacromial impingement. Chronic and repetitive shoulder impingement could lead to rotator cuff pathologies such as tendinopathies or tears. Abnormal scapular kinematics could represent a dysfunctional link in the chain that connects the upper extremity to the rest of the body. In the absence of a normal scapular kinematics, all of the muscles that attach to the scapula cannot function efficiently. This muscular imbalance may contribute to scapular dyskinesis.

Although several muscles attach to the scapula and are responsible for the normal three-dimensional scapulothoracic motion, the serratus anterior (SA) has been shown to be one of the primary muscles responsible for normal rhythm. The SA commonly presents as weak in patients with shoulder dysfunction. Reduced SA muscle activation could lead to abnormal scapular motion during all the motions of the shoulder complex. Therefore, the SA plays a key role in regulating the normal scapulothoracic rhythm by stabilizing the scapula over the thoracic cage. Hence, motor control and/or strengthening of the SA is an important intervention in patients with various shoulder dysfunctions.

Researchers have suggested several exercises to strengthen the SA muscle. Since the shoulder complex depends on the synchronous movement of multiple segments in the body, kinetic chain recruitment during various exercises has shown to increase the SA muscle activation. The use of the kinetic chain model during rehabilitation of patients with shoulder dysfunctions has been suggested to be more effective than traditional exercises that include upper extremity muscles alone. Kinetic chain model exercises engage multiple segments and muscles of the body simultaneously. This treatment approach also takes into consideration the entire neuromuscular system rather than isolating the different segments of the body while treating common shoulder and upper extremity (UE) dysfunctions.

One explanation why incorporating the kinetic chain during various UE exercises may result in higher SA muscle activation is due to various myofascial connections between the trunk and the limbs. The SA muscle is part of what has been described as “the serape effect” which highlights the myofascial connections between the SA, ipsilateral rhomboids, external oblique (EO), and contralateral internal oblique, and femoral adductor (FA) muscles. Additionally, SA has myofascial connections to the ipsilateral latissimus dorsi (LD) near the inferior scapular border. Due to its myofascial connection with the LD, the SA muscle has indirect connections with bilateral gluteus maximus (GM) muscles via thoracolumbar fascia. Increased activation of the SA has been achieved when all the other muscles in a kinetic chain have been activated along with the SA during various exercises.

With an intent to increase the muscle activation and improve proprioception, use of different surfaces has been advocated. For this reason, unstable surfaces such as balance boards, inflatable discs, and exercise balls are commonly used during rehabilitation exercises. Although there is evidence supporting an increase or decrease in the muscle activation when the exercise was performed on unstable rather than a stable surface, no change in the muscle activation by addition of the unstable surface has also been documented.

Hence, researchers have not reached a consensus regarding the benefits of adding unstable surfaces during the performance of various exercises. Various electromyographic studies have been conducted to investigate the best exercises for the activation of the SA. Forward punch plus (FPP) has been one of the previously documented exercises to best activate the SA muscle in an open chain. Kaur et. al found that the extremities and trunk kinetic chain recruitment increased the SA muscle activation on a stable surface during the FPP exercise. Previous studies have reported increased SA activation with the extremities and trunk kinetic chain recruitment on an unstable surface during a closed
chain exercise. There are no studies that have examined the effects of the kinetic chain on the SA activation on an unstable surface during an open chain exercise. Thus, the primary purpose was to determine the effects of trunk and lower extremity kinetic chain muscle recruitment on the SA muscle activity while on an unstable surface. The secondary purpose was to determine if the SA muscle activity would change when the surface stability during the exercises was reduced.

**METHODS**

**Subjects**
Twenty-one healthy males with fair to very lean body composition (low percentage body fat), as reported in ACSM's Guidelines for Exercise Testing and Prescription completed the study. The body composition of the participants was assessed to achieve most accurate surface electromyography (EMG) signal by reducing the effects of body fat on the EMG signal. The subjects mean age was 26.7 ± 2.6 years, mean height, 177.2 ± 5.6cm, mean weight, 79.5 ± 7.8 kg, and mean percentage body fat, 12 ± 3.6%. The study was approved by the Institutional Review Board of the University of St. Augustine for Health Sciences, Austin, TX. Sample size of 19 subjects was needed using conventional values for a medium effect size (f = 0.25); degrees of freedom = 6, power = 0.80; alpha = 0.05. Twenty-one subjects completed the study.

**Procedures**
The subjects provided informed consent and then were screened regarding inclusion and exclusion criteria (Table 1). Skin fold measurements were taken using the guidelines provided in the ACSM's Guidelines for Exercise Testing and Prescription. Lange* skin fold calipers (model # 68902, Fitness Mart*, division of Country Technology, Inc., Gays Mills, Wisconsin) and the three site formula regression equations for men (chest, abdomen, and thigh) were used to assess the body composition. Leg length was measured by the principal investigator to standardize the step length during exercises to allow for the accurate comparisons of performance among participants. The leg length was measured from the anterior superior iliac spine (ASIS) to the end of the medial malleolus with the subject lying supine while not wearing shoes.

The Trigno wireless EMG system (Delsys Inc. Boston, MA, USA) was used to collect all the EMG data. Wireless electrodes (37mm x 26mm x 15 mm ) and a four bar (99.9% silver) contact area, with an inter-electrode distance of 10 mm (Delsys Inc. Boston, MA, USA) were used in conjunction with a hard-wired single differential amplifier. The skin was prepared before the electrode placement using vigorous cleaning of the area with an alcohol pad. The subjects shaved the area if body hair was present. EMG electrodes were applied using the double sided hypoallergenic adhesive tape to the lower muscle fibers of

<table>
<thead>
<tr>
<th>Table 1. Inclusion/Exclusion Criteria</th>
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<tr>
<td><strong>Inclusion Criteria</strong></td>
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<tr>
<td>• Males</td>
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<tr>
<td>• Age 18-40 years,</td>
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<tr>
<td>• Age-related body composition (% body fat) between fair to very lean, as reported in ACSM’s Guidelines for Exercise Testing and Prescription</td>
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ACSM= American College of Sports Medicine
the SA, LD, and EO muscles on the dominant side, GM bilaterally, and FA of the contralateral side of the subjects according to the procedure described by Cram et al. The electrode placement for each muscle was as follows: for the SA the electrodes were placed below the axillary area, at the level of the inferior tip of the scapula, and just medial to fibers of the latissimus dorsi; for the LD, the electrodes were placed approximately 4 cm below the inferior tip of the scapula, half the distance between the spino processes and the lateral edge of the torso; for the EO, the electrodes were placed lateral to the rectus abdominis and directly above the anterior superior iliac spine, halfway between the crest and the ribs at a slightly oblique angle so that they were parallel to the muscle fibers; for the GM, the electrodes were placed half the distance between the greater trochanter and the sacral vertebrae in the middle of the muscle on an oblique downward angle at the level of the trochanter or slightly above; and for the FA muscle, the electrodes were placed on the medial aspect of the thigh in an oblique direction 4 cm from the pubis. After placing the electrodes, subjects performed light jumping jacks for 30 seconds to warm up.

For normalization of the EMG data, maximum voluntary isometric contractions (MVCs) were established for each muscle. Test positions were consistent with those described by Kendall and previous research. For the SA muscle, participant was asked to sit at the edge of the bed with feet touching the floor. The arm of the testing side was elevated to 125°. The investigator placed one hand on the upper arm and the other hand was placed on the lateral border of the scapula. The participant was asked to resist downwardly directed force. For the LD muscle, participant was asked to lie prone. The arm was positioned in adduction, extension and internal rotation. The investigator provided resistance just below the elbow in the combined direction of shoulder abduction and flexion. For the FA muscles, the participant was placed in the side lying position with testing side down. The top leg was cradled by the investigator while providing resistance to the lower thigh, just above the knee. While the participant was instructed to lift the leg towards the ceiling. For the GM muscle, participant was in prone position with hip extended and knee flexed beyond 90°.

The resistance was applied in the downward direction on the posterior thigh just above the knee. For the EO muscle, the participant while in hook lying was asked to perform an oblique sit up to move the resisted shoulder towards the opposite knee.

The MVCs were performed over a five-second period using a metronome involving a gradual build up to maximum muscle activity. Each muscle test was repeated three times, with a 15-second rest between contractions. Between MVIC measurements of different muscles, a two minute of rest period was provided. Verbal feedback was provided for each subject for the MVIC procedures.

**Exercises**

The exercises under investigation were either based on the previous recommendations to best activate the SA muscle or based on the myofascial connections reported in the literature. The following exercises were performed on the ground (stable surface) and the BOSU® Balance Trainer (Ashland, OH, USA), (unstable surface) with the subject wearing shoes. The order of the exercises was randomized using a computerized random sequence generator.

**Exercises 1 and 4: Forward punch plus (FPP)** (Figure 1 and 4): Subject stood in a parallel stance, and the exercise started with subject's dominant arm at the side of the body with elbow flexed to 90° and radio-ulnar joint in the midway between pronation and supination. The investigator placed one hand on the upper arm and the other hand was placed on the lateral border of the scapula. The participant was asked to resist downwardly directed force. For the LD muscle, participant was asked to lie prone. The arm was positioned in adduction, extension and internal rotation. The investigator provided resistance just below the elbow in the combined direction of shoulder abduction and flexion. For the FA muscles, the participant was placed in the side lying position with testing side down. The top leg was cradled by the investigator while providing resistance to the lower thigh, just above the knee. While the participant was instructed to lift the leg towards the ceiling. For the GM muscle, participant was in prone position with hip extended and knee flexed beyond 90°.

The subject then returned to the initial position by extending the shoulder, flexing the elbow in the same forearm position, and standing in a parallel stance.

**Exercises 2 and 5: FPP with closed chain serape effect (CS)** (Figure 2 and 5): Subject performed FPP with the dominant arm as he rotated the trunk to the opposite side with simultaneous contralateral leg flexion and adduction in a closed chain. The subject stepped forward and crossed the midline of the trunk as marked by the white tape on the ground. The subject then returned to the initial position by extending the shoulder, flexing the elbow in a neutral position and standing in a parallel stance. The
The length of the forward step was standardized for each subject by placing the tapes on the floor at a distance of 75% of their leg length (± 3 cm on either side of the 75% of the leg length).

**Figure 1.** Exercise 1- Forward Punch Plus (FPP), stable.

**Figure 2.** Exercise 2- Forward Punch Plus (FPP) with closed chain Serape effect (CS), stable.

**Figure 3.** Exercise 3- Forward Punch Plus (FPP) with open chain Serape effect (OS), stable.

**Figure 4.** Exercise 4- Forward Punch Plus (FPP), unstable.

Exercises 3 and 6: FPP with open chain serape effect (OS) (Figure 3 and 6): Subject performed FPP with the dominant arm as the trunk was rotated to the opposite side and performed simultaneous contralateral
The subject swung the contralateral leg in front and crossed the midline of the trunk as he maintained his balance. The subject then returned to the initial position by extending the shoulder, flexing the elbow in neutral position, and standing in a parallel stance.

The subjects were verbally instructed to punch as hard as possible with maximum force to reach a stand with a visual marker placed at the maximum reach distance to ensure adequate protraction of the scapula with the exercises. The subjects were required to bring their fist close to the marker with each exercise trial. The subjects were asked to stand with feet at their hip width apart on both surfaces while maintaining their balance. The positions of the feet were marked to make sure that the subjects returned to their previous foot positions in case they moved between trials. Practice trials were provided to the subjects, and three trials of the exercises were performed with at least five seconds rest between repetitions. The speed of the trials was regulated by a metronome set to 50 beats per minute, where each phase (starting position to maximum reach and maximum reach to the ending position) was performed during one beat.9,11,26 The subjects were given verbal commands to begin and end each exercise trial for proper technique during the training and data collection. A minimum of two minutes of rest was provided between different exercises to prevent the influence of fatigue on muscle activation.9,11

**Data processing**

The data were collected at a sampling frequency of 1926 Hz, CMRR > 80 dB@60 Hz; signal to noise ratio of > 750 nv, and no gain was applied to the signal. All collected signals were subsequently band pass filtered (between 20 and 450 Hz) with a 2nd order filter on the high-pass, and a 4th order filter on the low-pass then rectified and finally smoothed by using a root-mean-square (RMS) calculation. RMS was calculated using a default window length of 0.125 s with a 0.0625s window overlap. For all subjects, MVIC was averaged across the three intermediate seconds for each muscle to calculate the mean of the peak RMS value of the three trials. The mean RMS EMG activity of each muscle was calculated across the three trials of every exercise, for all the subjects. The mean RMS value of the three trials for each muscle was normalized to its respective MVIC value and represented as

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**Figure 5.** Exercise 5-Forward Punch Plus (FPP) with closed chain Serape effect (CS), unstable.

**Figure 6.** Exercise 6-Forward Punch Plus with open chain Serape effect (OS), unstable.
a percentage of MVIC (%MVIC) using the following equation:9,11

\[ %MVIC = \left( \frac{\text{Average RMS value of the three repetitions}}{\text{average peak RMS value}} \right) \times 100 \]

**Data Analysis**

A two-way repeated measure analysis of variance (ANOVA) with two repeated factors, surface (two levels) and exercises (three levels), was performed on the %MVIC EMG activity for each of the six muscles (SA, LD, EO, FA, and bilateral GM) to determine significance between surfaces, between exercises, and interaction between surface and exercises. In the event of significant results, a separate one-way repeated measures ANOVAs was performed to compare the normalized EMG values of the same muscle during three exercises for both the stable and the unstable surfaces. Separate ANOVAs were performed on each muscle tested to determine if the change in the SA activation was due to the recruitment of the trunk and LE muscles and if there were any significant differences among the three exercises. In the event of a significant ANOVA, Sidak post hoc test was used for the pairwise comparison of exercises. The level of significance was set at 0.05 for all analyses, and 95% confidence intervals (CIs) were reported around the %MVIC for each exercise. The Statistical Package for the Social Sciences (SPSS Inc, 24.0, Chicago, IL, USA) was used for the analyses.

**Results**

The two-way repeated measures ANOVA was not statistically significant for the surface (F = 0.045, p = 0.835) and for the interaction between surface and exercises (F = 0.237, p = 0.714). This indicates that the change in the surface from stable to unstable did not significantly change the muscle activity for any of the muscles during each exercise.

However, the muscle activity was statistically significantly different between the exercises for all the muscles except for Latissimus Dorsi (F = 12.7, p < 0.001). One-way repeated measures ANOVA was statistically significant for the main effects for both surfaces among the three exercises for the SA (Table 2) (stable: F = 12.2, p < 0.001; unstable: F = 9.3, p = 0.002), EO (Table 3) (stable: F = 20.8, p < 0.001; unstable: F = 13.6, p < 0.001), FA (Table 4) (stable: F = 20.3, p < 0.001; unstable: F = 12.726, p < 0.001), contralateral gluteus maximus (cGM) (Table 5) (stable: F = 9.5, p < 0.001; unstable: F = 3.4, p = 0.041), and ipsilateral gluteus maximus (iGM) (Table 6) (stable: F = 17.3, p < 0.001; unstable F = 12.8, p = 0.001).

Results of the pairwise comparisons indicate that the EMG activity (% MVIC) of the SA, EO, FA, and iGM during both the stable and the unstable surfaces for the CS and the OS was significantly higher than the EMG activity of the FPP. However, cGM activity was significantly higher for the CS but not for the OS (Tables 1 - 6). There were no statistically significant differences between CS and OS for any muscle for the either surface (p > 0.05) except for the FA (stable: p = 0.003 and unstable: p = 0.025). There was no statistically significant difference for the activation of the LD (Table 7) (stable: F = 2.1, p = 0.146)

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Mean (%MVIC)</th>
<th>SD</th>
<th>95% CIs (Lower bound - Upper bound)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stable Surface</strong></td>
<td></td>
<td></td>
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<tr>
<td>FPP</td>
<td>85.50</td>
<td>43.17</td>
<td>65.85 -105.15</td>
<td></td>
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<tr>
<td>CS</td>
<td>132.54</td>
<td>86.97</td>
<td>92.95 -172.13</td>
<td>0.034*</td>
</tr>
<tr>
<td>OS</td>
<td>160.65</td>
<td>100.95</td>
<td>114.70 -206.60</td>
<td>0.001*</td>
</tr>
<tr>
<td><strong>Unstable Surface</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>84.98</td>
<td>37.70</td>
<td>67.819 -102.14</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>138.40*</td>
<td>94.33</td>
<td>95.46 -181.33</td>
<td>0.03*</td>
</tr>
<tr>
<td>OS</td>
<td>157.39*</td>
<td>110.23</td>
<td>107.21 -207.57</td>
<td>0.007*</td>
</tr>
</tbody>
</table>

SD= standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.

*p value statistically significant at p≤0.05.
Table 3. Mean EMG activation of the External Oblique for the three exercises.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Mean (%MVIC)</th>
<th>SD</th>
<th>95% CIs (Lower bound - Upper bound)</th>
<th>p-value</th>
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<tr>
<td>Stable Surface</td>
<td></td>
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</tr>
<tr>
<td>FPP</td>
<td>52.08</td>
<td>21.81</td>
<td>42.15 - 62.01</td>
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<tr>
<td>CS</td>
<td>78.75</td>
<td>32.61</td>
<td>63.90 - 93.59</td>
<td>0.001*</td>
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<tr>
<td>OS</td>
<td>92.68</td>
<td>34.04</td>
<td>77.18 - 108.17</td>
<td>0.001*</td>
</tr>
<tr>
<td>Unstable Surface</td>
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<td></td>
<td></td>
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<tr>
<td>FPP</td>
<td>53.83</td>
<td>25.87</td>
<td>42.05 - 65.60</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>85.87</td>
<td>33.99</td>
<td>70.40 - 101.34</td>
<td>0.001*</td>
</tr>
<tr>
<td>OS</td>
<td>87.79</td>
<td>37.94</td>
<td>70.52 - 105.06</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

SD = standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.
*p value statistically significant at p≤0.05.

Table 4. Mean EMG activation of the Adductor muscles for the three exercises.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Mean (%MVIC)</th>
<th>SD</th>
<th>95% CIs (Lower bound - Upper bound)</th>
<th>p-value</th>
</tr>
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<tbody>
<tr>
<td>Stable Surface</td>
<td></td>
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</tr>
<tr>
<td>FPP</td>
<td>14.87</td>
<td>13.11</td>
<td>8.90 - 20.834</td>
<td></td>
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<tr>
<td>CS</td>
<td>67.34</td>
<td>67.06</td>
<td>36.82 - 97.87</td>
<td>0.002*</td>
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<tr>
<td>OS</td>
<td>111.52</td>
<td>101.71</td>
<td>65.21 - 157.81</td>
<td>0.001*</td>
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<tr>
<td>Unstable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>33.92</td>
<td>52.57</td>
<td>9.99 - 57.85</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>73.00</td>
<td>88.76</td>
<td>32.60 - 113.41</td>
<td>0.003*</td>
</tr>
<tr>
<td>OS</td>
<td>110.82</td>
<td>140.68</td>
<td>46.78 - 174.86</td>
<td>0.003*</td>
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</tbody>
</table>

SD = standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.
*p value statistically significant at p≤0.05.

Table 5. Mean EMG activation of the contralateral Gluteus Maximus for the three exercises.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Mean (%MVIC)</th>
<th>SD</th>
<th>95% CIs (Lower bound - Upper bound)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>12.27</td>
<td>12.93</td>
<td>6.39 - 18.16</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>16.27</td>
<td>13.38</td>
<td>10.18 - 22.36</td>
<td>0.001*</td>
</tr>
<tr>
<td>OS</td>
<td>13.41</td>
<td>10.07</td>
<td>8.82 - 17.99</td>
<td>0.549</td>
</tr>
<tr>
<td>Unstable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>10.12</td>
<td>5.78</td>
<td>7.49 - 12.75</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>14.07</td>
<td>9.02</td>
<td>9.97 - 18.18</td>
<td>0.04*</td>
</tr>
<tr>
<td>OS</td>
<td>12.53</td>
<td>7.34</td>
<td>9.19 - 15.87</td>
<td>0.223</td>
</tr>
</tbody>
</table>

SD = standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.
*p value statistically significant at p≤0.05.
and unstable: $F = 4.8, p = 0.074$) among the three exercises across the two surfaces.

**Discussion**

To effectively rehabilitate a patient with shoulder complex dysfunction, it is vital to choose the exercises that are best in recruiting the SA muscle due to its role in the normal scapulothoracic rhythm. In the current study, EMG activation of the SA during the FPP exercise and its two variations, CS and OS, that incorporated the muscles (LD, EO, FA, GM) in the kinetic chain linkages on various surfaces was investigated. The SA muscle activation was significantly increased with the integration of the extremities and trunk kinetic chains on both surfaces, but there was no statistically significant difference in the mean EMG activation of the SA between the stable and the unstable surfaces.

**Comparison of the three Exercises**

This study is not the first to investigate the effects of the kinetic chain recruitment on the activation of the SA muscle. The SA muscle activation was significantly greater during the CS and the OS exercises as compared to the FPP (only) exercise. Therefore, simultaneous recruitment of various trunk and lower extremity muscles during the CS and the OS exercises probably facilitated the SA muscle activation. To authors’ knowledge, no other researchers have compared the effects of the stable and the unstable surfaces on the recruitment of the SA muscle activation in the FPP exercise. This study is in agreement with the previous research that has investigated the effects of kinetic chain recruitment on the activation of the SA muscle.9–11,15 Maenhout et al.11 and Kim et al.10 proposed that kinetic chain recruitment via the ipsilateral leg extension activated the muscles

### Table 6. Mean EMG activation of the ipsilateral Gluteus Maximus for the three exercises.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Mean (%MVIC)</th>
<th>SD</th>
<th>95% CIs (Lower bound - Upper bound)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>15.91</td>
<td>7.00</td>
<td>12.72 - 19.09</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>25.16</td>
<td>12.63</td>
<td>19.41 - 30.91</td>
<td>0.002*</td>
</tr>
<tr>
<td>OS</td>
<td>33.20</td>
<td>19.69</td>
<td>24.23 - 42.16</td>
<td>0.001*</td>
</tr>
<tr>
<td>Unstable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>16.70</td>
<td>7.47</td>
<td>13.30 - 20.10</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>22.46</td>
<td>9.69</td>
<td>18.05 - 26.87</td>
<td>0.002*</td>
</tr>
<tr>
<td>OS</td>
<td>31.18</td>
<td>20.50</td>
<td>21.85 - 40.51</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

SD= standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.

* p value statistically significant at $p \leq 0.05$.

### Table 7. Mean EMG activation of the Latissimus Dorsi muscle for the three exercises.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Mean (%MVIC)</th>
<th>SD</th>
<th>95% CIs (Lower bound - Upper bound)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>41.63</td>
<td>28.03</td>
<td>27.69 - 55.57</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>43.8</td>
<td>29.3</td>
<td>29.24 - 58.39</td>
<td>0.957</td>
</tr>
<tr>
<td>OS</td>
<td>57.27</td>
<td>42.27</td>
<td>36.24 - 78.29</td>
<td>0.146</td>
</tr>
<tr>
<td>Unstable Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPP</td>
<td>37.03</td>
<td>18.07</td>
<td>28.05 - 46.02</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>39.79</td>
<td>20.62</td>
<td>29.53 - 50.05</td>
<td>0.785</td>
</tr>
<tr>
<td>OS</td>
<td>54.32</td>
<td>42.56</td>
<td>33.15 - 75.79</td>
<td>0.074</td>
</tr>
</tbody>
</table>

SD= standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.

* p value statistically significant at $p \leq 0.05$. 

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in a myofascial chain that connects the SA muscle to the GM muscles via the LD and thoracolumbar fascia, which in turn resulted in higher SA activation during a push-up plus exercise.

The present and the previous investigations supported the hypothesis that by engaging the adjacent muscles in a kinetic chain, there was improved activation of the primary muscle of interest.9-11,15,17 Based on the results, it may be reasonable to choose exercises (exercises 2, 3, 5, and 6) that utilize the muscles incorporated in various myofascial chains (serape effect that connects SA to the EO, FA, and the SA connections to the bilateral GM via thoracolumbar fascia and the LD) connected to the SA if the aim is to achieve higher SA activation than a traditional FPP exercise. Yamauchi et al.15 investigated the effects of trunk rotation on the activation of the scapular muscles and concluded that incorporating diagonal movement patterns could be more beneficial than engaging the scapular muscles in isolation. Similar results were reported by De Mey et al.17 as they investigated the effects of kinetic chain on the muscle recruitment during various scapular retraction exercises and found increased activation of the proximal muscles as they recruited the distal muscles in the chain.

Comparison of the stable versus the unstable surfaces
To compare the effects of different surfaces on the SA muscle activity exercises 1 and 4, 2 and 5, and 3 and 6 were compared with each other. There was no change in the muscle activation between the stable and the unstable surfaces. The amount of muscle activation on an unstable surface has been documented to be dependent on the extent of instability.21,25 The BOSU® Balance Trainer may not have created enough instability to increase the SA muscle activation. Other types of unstable surfaces such as balance boards and inflatable discs need to be investigated in the future in order to identify their effects on SA activation. Therefore, the current findings cannot be generalized to all types of unstable surfaces. The type of exercises investigated in the present study may be another reason for no statistically significant differences in the activation of the SA muscle between different surfaces. More dynamic exercises than the FPP and its variations may result in higher SA muscle activation on the unstable surface. The authors of the present study chose not to incorporate any other type of unstable surface or other exercises due to the risk of injury to the subjects while performing the exercises. The non-significant differences in the SA muscle activation between the stable and the unstable surfaces are supported by several investigations secondary to various factors such as subject's characteristics and their response to various types of unstable surfaces used, the nature and intensity of exercises performed, and the type of unstable surface used.17,20,22,24,25,38

No significant change in the muscle activation on the unstable surface could also be attributed to the additional demands placed on the body in maintaining stability in the unstable environment.19,21,39-41 To maintain the balance, antagonists, synergists, and stabilizing muscles may play a bigger role in maintaining posture and stability.19,23,42 In addition, these muscles have been documented to cause either facilitation or inhibition of the agonist muscles. The SA muscle acts more as a prime mover/agonist in performing the FPP exercise used in this study. Therefore, previous researchers support the results of the present study that there was no change in the SA muscle activation with the addition of LE instability. Additionally, a muscle group may show no change in the muscle activation by adding unstable surface because unstable surfaces may result in a lower muscle force output to provide more stabilization. Hence, no change in muscle activation was observed on an unstable surface for the other muscles (LD, EO, FA, and GM) in the present study could be because these muscles are not the prime stabilizers of the body. It may be a possibility that the muscle activation of the prime stabilizers may have increased when the exercises were performed on the unstable surface. The authors of the present study did not measure the force production and the EMG activation of the prime stabilizers of the body during these exercises. Future studies are recommended to investigate these variables when performing these exercises on different surfaces.

A significant decrease in SA activation while performing a push up plus exercise on the unstable surface was found by Lehman et al.,22 Maenhout
et al.,11 and De Mey et al.25 Those authors concluded that the lack of increased muscle activation on the unstable surface could be due to subject variability to the exercise performance and the type of unstable surface used. Lehman et al.,43 compared the push-up plus exercise on stable and the unstable surfaces and concluded that the vertical distance between the center of mass of the subject and the unstable surface might have a role to play in the amount of muscle activation. They further stated that greater the distance between the subject’s center of mass and the unstable surface the higher the muscle activation. This study did not measure the position of the center of mass, but the insufficient distance between the subject's center of mass and the center of the BOSU® Balance Trainer could be another reason why the authors did not find any significant change in the SA muscle activation across two surfaces. However, caution should be exercised when generalizing such phenomenon because research also exists supporting a change in the muscle activation of various muscles with the addition of the unstable surfaces.18-20,42,44 Further investigation on the effects of various surfaces on the muscle activation among different exercises and what factors could lead to increase, decrease, or no change in the muscle activation on the unstable surfaces is warranted. Lastly, since the width of the base of support was standardized for each subject across both surfaces, it would be interesting to see if changing the width of the base of support has any effect on the activation of the SA muscle between the two surfaces.

Limitations and Future Scope
The present study recruited young healthy males which limits the generalization of the results to other populations that are not similar to the subjects in the present investigation such as people with shoulder dysfunction, of a different age group, and females. Use of surface EMG to record motor recruitment of specific muscles during dynamic exercises has limitations such as consistency and security of electrode placement, motor unit recruitment by participants, crosstalk among various muscles in the vicinity, and amount of effort given by the subjects.31 Several testing positions have been recommended for measuring the MVIC activity of the SA muscle across various participants.45 For EMG normalization purpose, MVIC data for the SA muscle was collected with participants shoulder flexed to 125˚ as recommended by Cram et.al19 and as per another study.8 Caution is warranted in extrapolating the results of our study due to the variability in the MVIC positions for the SA muscle activation. Significant variation in the SA MVIC positions across subjects may also explain why the SA muscle activation was higher than the MVIC with exercises that incorporated the additional muscles in the kinetic chain that have connections with the SA muscle (exercises 2,3,5, and 6). Future studies are warranted to compare the activation of the SA muscle in the kinetic chain exercises with other MVIC positions that could produce maximum EMG amplitudes for various fibers of the SA muscle across subjects.EMG data for all the muscles that have myofascial connections with the SA muscle was not collected due to the limited ability of the surface EMG in evaluating the deeper muscles accurately. It could be interesting to see the role of all the muscles in a kinetic chain that could influence the recruitment of the SA muscle during these dynamic exercises, perhaps using kinesiological needle EMG. Future studies could also look at the kinetic and kinematic data while performing these dynamic exercises. It would be beneficial to compare various rehabilitation exercises that have demonstrated high SA recruitment including the ones in the present study and develop a continuum of exercises from a lower to higher recruitment of the SA that could assist clinicians in rehabilitating the patients with shoulder dysfunctions in progressive training regimes.

CONCLUSION
Given the SA's pivotal role in controlling scapular rhythm during various shoulder movements, finding the best exercises for higher SA muscle activation is crucial for effective rehabilitation of various shoulder dysfunctions. In light of the current inclination towards utilization of the kinetic chain during rehabilitation due to its clinical efficacy, this study further investigated the effects of various surfaces on the SA muscle activation in a kinetic chain model. Consistent with the previous research, LE and trunk kinetic chain utilization resulted in higher activation of the SA muscle regardless of the surface. Further
research is required to substantiate any additional benefit of adding unstable surfaces to achieve higher muscle activation.

REFERENCES


ABSTRACT

Background and Purpose: Multi-ligament knee injuries (MLKI) can be debilitating and often career ending injuries for athletes. Current literature reports on outcomes following these injuries for return to activities of daily life; however, there is a paucity of evidence evaluating the return to sport following a MLKI. The purpose of this case report is to describe the treatment and outcome following a MLKI and novel meniscus radial repair technique in which the athlete returned to compete in the 2018 Winter Olympic Games 14 months postoperatively.

Study Design: Case Report.

Case Description: A healthy 28-year-old female Olympic alpine skier who sustained a deep knee flexion with varus force injury to her right knee during a competitive skiing event. Examination and imaging revealed a completely torn anterior cruciate ligament (ACL) and lateral collateral ligament (LCL), complex radial tear of the lateral meniscus, medial meniscus tear, popliteofibular ligament tear, proximal tibiofibular joint ligament tear, and a common peroneal nerve neuropraxia. The athlete underwent an anatomic single-stage, multi-ligament knee reconstruction surgery which consisted of a novel meniscus radial repair technique.

Outcomes: A return to snow progression was initiated at seven months postoperatively. At 10 months postoperatively, a physical exam revealed trace effusion, no joint line tenderness, and negative stability tests. A repeat MRI revealed adequate healing of the lateral meniscus radial repair. The athlete passed a functional sports test at 10-months postoperatively and was cleared to return to ski with no restrictions. At 12 months postoperatively, the athlete placed in an Olympic qualifying ski race. At 14 months postoperatively, the athlete competed in the 2018 Olympic Winter Games.

Discussion: This case report highlights the ability of an athlete to return to elite level of competition following an anatomic single-stage, multi-ligament knee reconstruction surgery which consisted of a novel meniscus radial repair technique.

Level of Evidence: 4

Key Words: Meniscal repair, Multi-ligament knee injury, Olympics, return to sport
INTRODUCTION

The management of multi-ligament knee injuries (MLKI) can be a complex progression that depends on a multitude of factors. Current literature reports on outcomes following these injuries, but there is a paucity of evidence evaluating the return to sport following a MLKI. Multi-ligament knee injuries commonly occur during high-energy sports such as downhill skiing. These highly debilitating injuries can be career-ending and are often complicated with associated injuries such as complex meniscus tears. Anatomical surgical reconstruction and return to sport rehabilitation are key to optimal outcomes and return to pre-injury levels of activity following MLKI. The purpose of this case report is to describe the treatment and outcome following a MLKI and novel meniscus radial repair technique in which the athlete returned to compete in the 2018 Winter Olympic Games 14 months postoperatively.

CASE DESCRIPTION AND EXAMINATION

This case report describes a 28-year-old female who is an alpine skier on the U.S. Olympic ski team. The athlete sustained an acute right knee injury during a competitive skiing event (giant slalom). She described a noncontact mechanism at the time of injury which included deep knee flexion with a varus force. She began to experience immediate anterolateral knee pain with an associated knee effusion. The patient provided informed consent for this case report. She presented to the orthopedic clinic three days following her skiing injury. Her chief complaint was right knee pain and instability. She denied any previous history of injury to her right knee. Her left knee had a previous anterior cruciate ligament (ACL) reconstruction performed three years prior. Upon examination, there was moderate effusion and swelling globally around the right knee. Patellar mobility was two quadrants medially and laterally with no crepitation appreciated. She was tender to palpation along the medial and lateral joint lines. Right knee extension was 7 degrees of hyperextension compared to 3 degrees of hyperextension on the left knee. Right knee flexion was limited to 90 degrees due to swelling and pain. Ligamentous exam revealed a 3+ Lachman's test with a soft endpoint, 3+ pivot shift, and 3+ varus stress test at 30 degrees. The athlete's posterior cruciate ligament (PCL) and medial collateral ligament (MCL) were stable with a negative posterior drawer and a negative valgus stress test. The dial test was 1+ at 30 degrees of knee flexion with rotation occurring from the anterolateral tibia. The proximal tibiofibular joint had increased anteroposterior motion at 90 degrees of knee flexion compared to the contralateral limb. Neurovascular exam revealed mild decreased sensation throughout the common peroneal nerve distribution with intact motor function.

INTERVENTION

Plain radiographs were obtained and revealed no acute bony fractures or evidence of osteoarthritis. Bilateral varus stress radiographs were obtained and revealed a significant increase of 3.0 mm in lateral compartment gapping of the right knee compared to the uninjured left, consistent with a complete lateral collateral ligament (LCL) tear.1 An MRI was obtained and demonstrated a complete tear of the ACL and LCL (Figure 1). The PCL, MCL, and popliteus tendon were intact. There was a possible tear noted in the posterior horn of the medial meniscus evidenced by increased signal between the posterior horn and the posterior capsule and a posterior medial tibial bone bruise. The lateral meniscus displayed a complex radial tear near the root attachment. In addition, the popliteofibular ligament appeared torn and there was increased swelling around the posterior ligamentous complex of the proximal tibiofibular joint.

Examination under anesthesia of the right knee revealed complete grade III ACL and LCL tears. Prior to the start of surgery, bone marrow aspirate was harvested from the left posterior superior iliac crest and whole blood was drawn intravenously. Both blood products were processed in a centrifuge to isolate bone marrow concentrate (BMC) and platelet-rich plasma (PRP), which were injected into the athlete's right knee at the end of the surgery for biological healing augmentation.2 Surgery was performed next which consisted of an open common peroneal nerve neurolysis, LCL reconstruction with hamstring tendon autograft, proximal tibiofibular joint reconstruction with hamstring autograft, popliteofibular ligament repair, medial meniscus ramp repair, (novel) lateral meniscus two-tunnel transtibial radial
repair, and ACL reconstruction with patellar tendon autograft (Figure 2). This novel meniscal repair technique allows for the approximation of the two ends of the radial tear that would otherwise be irreparable.

**REHABILITATION PROGRESSION**

Following surgery, the athlete was non-weight bearing for six weeks with limited knee flexion range-of-motion (ROM) of 0 to 90 degrees for two weeks. Walking was initiated at six weeks postoperatively and the athlete was able to wean off of crutches at eight weeks postoperatively. Stationary cycling began at seven weeks postoperatively, followed by a generalized strengthening program which focused on muscular endurance. Blood flow restriction (BFR) training began at three months postoperatively to stimulate muscle hypertrophy with low-level resistance exercises (Table 1). The rationale for BFR was to stimulate an anaerobic environment in order to promote muscle hypertrophy while continuing to protect the surgical reconstructions and meniscus repairs. By limiting the load placed across the knee with no or low resistance, BFR allows postoperative patients to utilize the physiological adaptations of moderate to high resistance training without the risk of compromising the healing structures.

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**Figure 1.** MRI appearance of grade III tears of the anterior cruciate ligament (ACL) and lateral collateral ligament (LCL) and radial tear of lateral meniscus. A) Sagittal view demonstrating complete tear of the ACL (white arrow, right) with increased anterior tibial translation as a secondary sign of ACL injury (white arrow, left) and floating appearance of lateral meniscus (black arrow). B) Posteromedial tibial bone bruise, indicative of secondary sign for posterolateral corner injury (white arrow). C) Coronal view demonstrating wavy appearance and thickening of LCL (white arrow, right), indicative of a complete tear; this was confirmed on clinical exam. Complex radial tear of the posterior horn of the lateral meniscus (white circle) with significant meniscal extrusion. This example highlights the difficulty in repairing radial tears as there is a significant gap (white arrow, up) and approximation of the two tissues must be restored for successful repair.

**Figure 2.** Intraoperative images demonstrating the novel two-tunnel transtibial radial repair technique. First, a tunnel is drilled (transtibial) aiming for the lateral side of the torn meniscus (A). This step is repeated with a second tunnel which is drilled in the same manner but aimed at the medial side of the torn meniscus (B). After both sutures are placed, the first into the free edge of the lateral side of the torn meniscus (C) followed by a second suture which is placed into the adjacent free edge of the medial side of the torn meniscus (D). After both sutures are secure in the meniscus, they are shuttled down the tibial tunnels in a crisscross fashion, thus successfully approximating the two torn edges inferiorly (D). Lastly, horizontal sutures are placed utilizing an inside-out meniscus repair technique which allows for the approximation of the two torn edges superiorly (E and F).
within the knee.\textsuperscript{3,4} The athlete was instructed to avoid deep knee flexion activities (i.e. squats), resistive hamstring exercises, and sitting cross-legged for four months postoperatively. These restrictions were placed on the athlete to avoid overloading the meniscal repairs during the first four months of the recovery period. Jogging and light agility exercises began at four months postoperatively.

A return to snow progression was initiated at seven months postoperatively (Table 2). At 10 months postoperatively, a physical exam revealed trace effusion,

**Table 1. Blood flow restriction training protocols.**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Frequency</th>
<th>Duration</th>
<th>Pressure</th>
<th>Intensity</th>
<th>Rest Periods</th>
<th>Volume</th>
<th>Exercise Progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resisting Muscle Atrophy</td>
<td>3-6 days per week</td>
<td>6-12 weeks</td>
<td>Personalized, 80% total LOP</td>
<td>Body weight with minimal to no resistance</td>
<td>15-30 seconds with cuff inflated</td>
<td>4 sets of 30/15/15/15 repetitions</td>
<td>Resisted weight bearing exercise when treatment focus is muscle strength</td>
</tr>
<tr>
<td>Building Muscle Strength</td>
<td>3-6 days per week</td>
<td>6-12 weeks</td>
<td>Personalized, 80% total LOP</td>
<td>≤ 30% 1 RM</td>
<td>30-45 seconds with cuff inflated</td>
<td>4 sets of 30/15/15/15 repetitions</td>
<td>Discontinue BFR when treatment focus is muscle power</td>
</tr>
</tbody>
</table>

LOP: limb occlusion pressure; RM: repetition maximum; BFR: blood flow restriction.

**Table 2. Return to snow progression following multi-ligament knee reconstruction with lateral meniscus radial repair. Program specific for Olympic-level competitive skiing athlete.**

| Day 1: Easy free-skiing on slalom skis. Mostly sliding on skis, no arcing/carving (~4 runs) |
| Day 2: Easy free-skiing on slalom skis. Mostly sliding, no arcing (~6 runs) |
| Day 3: Rest day |
| Day 4: Begin with easy sliding/drills on slalom skis (~3 runs). Incorporate arcing (~3-4 runs). Light intensity |
| Days 5-7: Start on Slalom skis, work into giant slalom. Arcing and slalom drills (~6-7 runs). Light intensity |
| Day 8: Rest day |
| Day 9: Slalom free-skiing, work into giant slalom drills with stubby gates (shorter, lighter, softer gates) (7-8 runs). Light to moderate intensity |
| Day 10: Giant slalom drills and stubby course (~8 runs). Moderate intensity |
| Day 11: Rest day |
| Day 12: Giant slalom free skiing/drills, stubby course mixed with tall gates (~8 runs). Moderate intensity |
| Day 13: Giant slalom free skiing/drills, giant slalom gates (8-9 runs). Moderate to high intensity |
| Day 14: Giant slalom drills and giant slalom full gate course, about 20 gates (9-10 runs). Moderate to high intensity |

*Rest for ~5-7 days, continue off-snow physical therapy program *

*Return to skiing with team for on-snow camp. Duration = 3 weeks. Goal is to initiate normal skiing maneuvers with intensity dictated by proper technique (e.g. if poor technique, decrease intensity) *

Days 1-3: Work on transitioning from free-skiing into giant slalom gates

Days 4-8: Begin focusing on speed skiing with technical drills

Days 9-21: Slowly increase distance of courses, with goal of returning to skiing full-length speed courses by day 21

*Continue on and off snow training with rest days as needed. Returned to competitive skiing with first race 3 weeks from this point in progression*

*Time points are specific for individual athlete of this case report.*
no joint line tenderness, a negative Lachman's test, negative pivot shift, and a negative varus stress x-ray test evidenced by a < 1 mm side-to-side difference on varus stress radiographs (Figure 3). A repeat MRI revealed adequate healing of the lateral meniscus radial repair as well as the medial meniscus ramp repair (Figure 3). The athlete did complain of mild anterior knee pain while training but not with skiing. Exam revealed mild patellar tendinopathy; therefore, a leucocyte rich PRP injection was directed into the patellar tendon to help decrease inflammation and pain.

The athlete passed a functional sports test at 10 months postoperatively and was cleared to return to ski with no restrictions. The functional performance tests utilized were specific to skiing and have previously been demonstrated as reliable and valid measures for assessing function following ACL reconstruction.5 The test consists of four main components with an overall composite score based upon the sum of the four individual scores. The individual components of the functional sports test include single leg squat with resistance (3 minutes), lateral bounding (90 seconds), forward jogging (2 minutes), and backward jogging (2 minutes). A designated physical therapist graded the patient on technique and movement quality according to predetermined scoring criteria.5 At 12 months postoperatively, the athlete placed in an Olympic qualifying ski race. At 14 months postoperatively, the athlete competed in the 2018 Olympic Winter Games and placed 15th overall in super G and downhill skiing events. Details of the individualized exercise protocol with timeline for specific exercise interventions are reported in Figure 4.

**DISCUSSION**

The main finding of this case report was the ability of an athlete to return to elite level of competition following an anatomic single-stage, multi-ligament knee reconstruction with a novel meniscus radial repair. However, the current literature has mixed results on athletes' abilities to return to play (RTP) following MLKI's. In a recent systematic review of NFL players with MLKI's, Bakshi et al.6 concluded that athletes with MLKI's return to sport at a lower rate and lower level than pre-injury levels. Authors reported that those athletes with combined ACL and MCL tears had a 70.8% RTP rate, whereas those with ACL and PCL/LCL tears had a 55.6% RTP rate.6 In contrast, Everhart et al.7 conducted a systematic review of MLKI's including 21 studies and 524 patients with a median follow-up of 51 months. Authors reported that overall RTP to an elite level of competition following MLK reconstruction was between 22% and 78%; however only 33% of those returned to pre-injury levels.7 The authors believe prompt diagnosis and anatomic reconstruction/repair of all injured ligaments and menisci are vitally important and may directly impact an athlete's ability to return to the same pre-injury level of competition following a MLKI.

Cinque et al.8 reported comparable outcomes with a similar novel transtibial radial repair and inside-out
meniscus repair at a mean 3.5 years postoperatively. Authors concluded that the two-tunnel transtibial repair is a reliable and valid surgical solution for complex meniscus radial tears which may be considered irreparable otherwise. When comparing outcomes of meniscal radial repair versus meniscectomy, current research shows that outcomes favor radial repair due to increasing concern of long-term osteoarthritis after meniscectomy. In addition, meniscectomy has been shown as a strong predictor of not returning to play in athletics; therefore, an attempt of anatomic repair of all meniscal tears should be conducted to increase the likelihood of RTP and decrease the likelihood of post-traumatic osteoarthritis and failure of ligamentous reconstruction.
Clinical outcomes and returning to competition are highly dependent upon the postoperative rehabilitation protocol and timing of RTP.\textsuperscript{19} Physical therapy protocols focus on avoidance of overloading the newly repaired meniscus with weight bearing restrictions and range-of-motion restrictions.\textsuperscript{20} The RTP timing of a MLKI can be a longer course (9 to 12 months), as opposed to an isolated ACL reconstruction (7-9 months) or an isolated meniscus repair (4-6 months).\textsuperscript{21-23} While the rehabilitation protocol can be considered equally as important as the surgery—knee stability, swelling, and pain can be persistent following surgery which limits a patient’s ability to perform their rehabilitation directly. Thus, to have the best chance of success during a recovery from MLK surgery, anatomic single-stage MLK reconstruction with meniscal repair is preferred.\textsuperscript{24}

Muscle atrophy is a significant challenge during rehabilitation after multi-ligament knee surgery which can lead to prolonged recovery and diminished patient outcomes. Blood flow restriction therapy occludes venous outflow while maintaining arterial inflow by the application of an extremity tourniquet.\textsuperscript{25} When using BFR as an adjunct to postoperative rehabilitation, it has been suggested that exercises performed at lower loads (20% - 50% of 1RM) can promote muscle hypertrophy similar to traditional strengthening protocols, while reducing pain and adverse joint loading.\textsuperscript{26,27} Takarada et al.\textsuperscript{25} investigated BFR without exercise in patients immediately following ACLR with hamstring tendon autografts. After two weeks of knee immobilization and BFR therapy, patients demonstrated significantly less muscle atrophy than immobilized controls with non-inflated occlusion cuffs (sham).\textsuperscript{25} Similarly, Ohta et al.\textsuperscript{28} reported significant increases in both muscle circumference and strength following ACLR with hamstring tendon grafts. Training interventions were conducted from weeks 2 to 16 postoperatively and consisted of combined resistance training with BFR compared to a matched protocol without BFR. Between the control and BFR groups, there were no significant differences in knee range-of-motion or anterior knee stability between preoperative and postoperative training;\textsuperscript{28} thus supporting the use of BFR following ACLR without compromising ligamentous healing or graft integrity. In addition, it has been reported that BFR therapy can begin immediately after surgery because deep venous thrombosis (DVT) has not currently been associated with postoperative BFR use.\textsuperscript{3,4}

In the current case report, the patient underwent concomitant BMC and PRP intra-articular injections at the time of surgery in order to promote healing of the complex lateral meniscus radial tear repair. BMC and PRP are utilized in orthopaedic conditions to augment the healing process and decrease inflammation and have been used following knee injury and/or surgical repair.\textsuperscript{2,29} Specifically, BMC is used for the treatment of avascular tissue (e.g. articular cartilage) or tissue that has a limited blood supply (e.g. meniscus) due to the reported presence of mesenchymal stem cells (MSCs).\textsuperscript{30,31} However, contrary to the public’s belief, MSCs comprise only a very limited number of the cells present in BMC. Other clinically relevant factors and cytokines in BMC, including interleukin-1 receptor antagonist (IL-1Ra), are theorized to promote the anti-inflammatory and regenerative processes.\textsuperscript{32,33} Moreover, IL-1Ra is thought to be responsible for the beneficial effects of pain relief with use of BMC.\textsuperscript{34} Despite the lack of evidence supporting the definitive role of BMC or PRP to regenerate or heal musculoskeletal tissue injuries\textsuperscript{35,36}, the growth factors within these blood products make them a viable adjunct for potentially improving the healing environment following complex musculoskeletal injuries.\textsuperscript{30,31}

LIMITATIONS
There are limitations inherent to a case report. It involves only the report of a single individual and thus outcomes cannot be extrapolated to entire study population or athletic group that undergo the same or similar surgical procedures. While this single athlete was able to return to full activity in their respective sport and competition level, these results cannot be inferred for athletes in other sports or at other levels of competition. Furthermore, the specific injury pattern and respective surgeons experience may limit the global interpretation of these outcomes.

CONCLUSIONS
This case report describes the ability of an Olympic athlete to return to elite level of competition
following an anatomic single-stage, multi-ligament knee reconstruction with a novel meniscus radial repair in a safe but timely manner. These results highlight the importance of a prompt diagnosis and anatomic surgical reconstruction and the use of adjunctive orthobiologic therapies (BMC, PRP) and BFR during rehabilitation in order to increase potential to return to elite pre-injury levels of competition in athletes with multi-ligament knee injuries.

REFERENCES


ABSTRACT

**Background:** Musculoskeletal injuries are recognized as the leading health problem and primary source of injury, disability, and financial burden across the military. Special Operations Forces are at an increased risk of musculoskeletal injury due to increased physical demands, precipitous deployments, and continual training and deployment cycles. Multiple injury screening tools exist, yet decisions to return to duty are frequently deferred to individual institutional protocol or provider clinical decision making, with no accepted gold standard.

**Purpose:** The purpose of this case report is to describe the application of a system to return a Special Operations Forces candidate to duty following an ankle injury sustained during a military static line airborne operation while in the Special Forces Qualification Course.

**Case Description:** The subject was a 34-year-old male with surgical fixation of a left distal fibular fracture with syndesmotic tear after landing from a static line airborne jump during the Special Forces Qualification Course. This case report provides a system to determine return to duty following an ankle fracture and provides a guide to returning a subject to participation, duty, and tactical performance training.

**Outcomes:** Outcome measures recorded were vast, as the use of multiple measures are more indicative of overall function than any single measure. Impairment based measures included Global Rating of Change Scale (GROC), Numeric Pain Rating Scale (NPRS), lateral step down and Closed Chain Dorsiflexion (CCDF). Functional outcome measures included: the Functional Movement Screen™ (FMS™), Lower Quarter Y-Balance (LQYB), three hop tests for distance, and physical performance metrics.

**Discussion:** The most substantial challenge to this process was the lack of standardized and validated military return to duty testing and guidelines in the literature. Ideally, pre-injury assessment would provide a baseline; however, compared to peers, the subject was well within acceptable ranges for all physical performance metrics at final Return to Duty testing. The subject was returned to duty 10 months after initial injury being physically comparable to his cohorts and being able to complete all military requirements.

**Keywords:** Military, movement system, return to duty, tactical athlete

**Levels of Evidence:** 5
BACKGROUND AND PURPOSE
Without question, musculoskeletal injuries are recognized as the leading health problem and primary source of injury, disability, and significant financial burden across the military. Musculoskeletal injuries cost over $548 million annually and are the single most common reason for discharge from service, costing additional hundreds of millions of dollars in continued medical expenses. In addition, musculoskeletal injuries are responsible for nearly half of the restrictive work-days annually. Special Operation Forces are at an increased risk of musculoskeletal injury due to increased physical demands, precipitous deployments, and continual training and deployment cycles. Physical requirements within Special Operations Forces are considerably more taxing and remarkable than those of General Purpose Forces – the core and main group of the armed forces – potentially leading to increased incidence of injury. When comparing all military personnel, Special Forces have the highest incidence of injury rate at 12.1 per 100 soldier months. Although these injuries occur at an alarming frequency, previous research has found 76.9% of musculoskeletal injuries are preventable. The lower extremity is the most common anatomical location injured, accounting for 50% of all musculoskeletal injuries and 60% of all preventable injuries. The most common causes of lower extremity injury in Special Operation Forces include running (23.1%) and lifting (19.2%) usually occur during physical training. Among Airborne soldiers, ankle injuries account for 30 – 60% of all military parachute injuries, with 7 – 23% classified as fractures.

Among General Purpose Forces, only 50% of soldiers suffering a musculoskeletal injury returned to duty within 90 days. Sixty eight percent of Special Operations Forces who had rehabilitation for recent orthopedic injuries were unable to deploy with their units despite compliance with prescribed rehabilitation activities over a 6-month time frame. Since previous injury and fitness levels are leading risk factors for sustaining a subsequent injury within the military, return to duty decision making needs to be comprehensive prior to discharging a soldier to unrestricted activity. Multiple screening tools exist, yet decisions to return to duty are frequently deferred to individual institutional protocol or clinical decision making, with no accepted gold standard. Clinicians working in the military need an efficient, objective, cost effective, and reliable system for determination of return to duty status.

Arden et al. defined a return to sport continuum that has been adapted and applied to the military population in order to provide a system to return Special Operations Forces to duty while also assessing injury risk and determining operational readiness (Figure 1). The three elements applied to the military context are return to participation, return to duty, and return to tactical performance. This system emphasizes a graded, criterion-based progression in the rehabilitation process. Return to participation is defined when the military tactical athlete is physically active, but not yet ready medically, physically or psychologically to return to duty. Return to duty is defined as when the military tactical athlete has returned to duty but is not yet performing at their desired tactical performance level. In this stage, the emphasis is placed on injury risk reduction strategies while improving performance. Return to tactical performance is the last element where specific attention is placed on returning to operational readiness within the military context. The decision to return Special Operations Forces to duty following a musculoskeletal injury is multifaceted with both self-report and performance-based criteria being utilized in clinical practice to modify decisions.

The purpose of this case report is to describe the application of a system to return a Special Operations Forces candidate to duty following an ankle injury sustained during a military static line airborne operation while in the Special Forces Qualification Course.

CASE DESCRIPTION
The subject was a 34-year-old Caucasian male who presented for evaluation after surgical fixation of a left distal fibular fracture with syndesmotic tear after...
landing from a static line airborne jump during the Special Forces Qualification Course. A static line refers to a cord tethered between the aircraft and the soldier’s parachute, when upon exiting the aircraft, will automatically deploy the parachute for a safe landing.\textsuperscript{14} The Special Forces Qualification Course consists of five phases over approximately 61 weeks. Each phase cultivates expertise in small unit and Special Forces tactics, survival skills, language and cultural training, unconventional warfare, survival, escape, resistance, evasion, and advanced combat survival tactics.\textsuperscript{15}

During the airborne operation, the subject collided with another soldier before landing. Due to the mid-air collision, the subject's landing position was compromised, which contributed to his resultant fracture upon landing.\textsuperscript{16} Despite fracture, the subject completed the remainder of the four-week austere training event. The subject underwent surgery one month prior to evaluation for internal fixation and syndesmotic wire, without a syndesmotic screw (Figure 2). At initial evaluation, the subject was in the process of completing a six-week prescribed non-weight bearing status. The subject had no significant past medical history or red flags. The subject's perceived level of function out of 100 was assessed and reported to be 20%. Although not found in the literature, this was used to assess daily perceived function. Informed consent was obtained including that the data concerning the case would be submitted for publication and institutional review board approval was obtained from Womack Army Medical Center, Fort Bragg, North Carolina.

**CLINICAL IMPRESSION 1**

This subject's diagnosis was a left distal fibular fracture and syndesmotic tear. Due to the unstable nature of the fracture and mortise disruption, open reduction and internal fixation (ORIF) was required. Typically, ORIF is performed secondary to an initial and temporary closed reduction stabilization to allow soft tissue swelling to decrease.\textsuperscript{16} Due to this subject's occupational requirements and continued trauma post fracture an ORIF was the initial repair. ORIFs typically have a side effect of decreased functional outcome due to hardware placement\textsuperscript{16}. However, due to lack of syndesmotic screw, physical activity prior to injury, high availability of physical therapy services, and motivation to return to duty, he had a good prognosis for full recovery. Examination details are described below. This subject is an ideal candidate for the purpose of this case report as the subject fits the demographics of being an active duty military soldier who sustained an injury while training. The subject was otherwise healthy; therefore, eliminating comorbidities/secondary injuries from affecting his progress. Lastly, due to his job description, will need to have achieved optimal pre-injury function before full return to duty.

**EXAMINATION**

The subject ambulated into the clinic using bilateral crutches non-weight bearing on the left lower extremity wearing an immobilization boot. A lower quarter screen consisting of dermatomes, myotomes, and reflexes were all within normal limits. Range of motion and strength of the hips and knees were equal and within normal limits. The left ankle demonstrated markedly restricted range of motion with 15 degrees plantarflexion and 3 degrees open chain dorsiflexion. Ankle joint mobility, balance/proprioception, strength, ligamentous integrity and functional testing were all deferred at this time due to healing constraints and precautions.

**Test and Measures**

Tests and measures assessed on this subject for general screening purposes included Kendall manual muscle testing (MMT) and range of motion measurement via goniometry. Although manual muscle testing has questionable reliability and validity, since gross lower extremity strength was not a major

![Figure 2. Post-Operative Radiographs.](image)
impairment and testing was performed by one examiner, it was considered suitable in this situation. Similarly, screening the range of motion of the lower extremities was performed for monitoring maintenance and performed predominantly by one examiner increasing reliability in this instance. The only non-goniometric ROM measurement performed was closed chain dorsiflexion (CCDF). Detailed testing procedures are described in the subsequent section.

**Outcome Measures**

Outcome Measures recorded included: Global Rating of Change (GROC), Numeric Pain Rating Scale (NPRS), Lateral Step Down, Lower Quarter Y-Balance (LQYB), Functional Movement Screen (FMS™), Closed Chain Dorsiflexion (CCDF), Human Performance Program Metrics (5-10-5, broad jump, 3RM deadlift, 300-yard shuttle repeat), and three hop tests for distance (single hop, triple hop, and crossover). The subject subjectively reported GROC and NPRS at every treatment session. The Lateral Step Down, LQYB, FMS™, and CCDF were measured approximately three months from initial evaluation and again at four months from initial evaluation. Four months after initial evaluation, hop tests were administered; followed by Human Performance Program metrics at final RTD testing. (Table 1)

The subject was not functionally safe to perform single leg jumping and agility tests at the four-month evaluation; therefore, the lateral step down was utilized to provide similar lower extremity functional information in a safe manor. It served as a bridge from impairment-based measures to functional measures and provided valuable information regarding dynamic strength and lower extremity alignment with moderate reliability (ICC = 0.67) and high (80%) Kappa agreement. Instructions for administration and scoring can be found in the references.

The LQYB was chosen due to its established reliable and valid ability to assess asymmetry and poor performance, as well as predicting non-contact injuries in athletes. Reliability intraclass correlation coefficient (ICC) for the LQYB test is 0.89. The minimal detectable change (MDC) when studied in service members is 8.7, 10.3, and 11.5 for the anterior, inferomedial, and inferolateral directions respectively.

The FMS™ was designed to assist in screening active individuals during the performance of seven full body functional movements to identify impairments. The FMS™ has been proven a reliable tool for use within (ICC = 0.869) and between (ICC = 0.843) clinicians. It is suggested to have a positive relationship between scores and occupational measures of performance and has excellent agreement among athletic populations. The FMS™ has shown excellent reliability (0.91) for predicting future injury. When tested in active duty service members, the minimal detectable change is 1.0. The traditional cutoff score less than or equal to 14/21 is the guide for which increased risk of injury is established. Detailed instructions for the Y-Balance and FMS™ can be found through numerous sources for mastery in administration.

Closed chain dorsiflexion range of motion was one of the primary impairments affecting this subject. This test was highly predictive of injury among U.S. Army Rangers. Range of motion is measured with the subject in half kneeling, with the affected lower extremity close to a wall. With the foot in full contact with

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Table 1. Timeline of Treatment and Outcome Assessments.

<table>
<thead>
<tr>
<th>Date</th>
<th>Day 0</th>
<th>Month 1</th>
<th>Months 2 - 3</th>
<th>Month 4</th>
<th>Month 5</th>
<th>Month 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>Surgery</td>
<td>Initial Evaluation</td>
<td>Treatment</td>
<td>Functional Reassessment</td>
<td>Functional Reassessment</td>
<td>Return to Duty Testing</td>
</tr>
<tr>
<td>Tests/Measure and Outcome Assessments</td>
<td>N/A</td>
<td>GROC, NPRS</td>
<td>GROC, NPRS, ROM, MMT</td>
<td>GROC, NPRS, Lateral Step Down, LQYB, FMS™, CCDF</td>
<td>GROC, NPRS, Lateral Step Down, LQYB, FMS™, CCDF, 3 hop tests</td>
<td>Month 5 assessment measures, Human Performance Program Metrics</td>
</tr>
<tr>
<td>WB Status</td>
<td>6 weeks NWB</td>
<td>Full WB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GROC= Global Rating of Change Scale; NPRS= Numeric Pain Rating Scale; MMT= Manual Muscle Test; LQYB= Lower Quarter Y-Balance; FMS™= Functional Movement Screen™; CCDF= Closed Chain Dorsiflexion
the floor, the subject shifts forward until the knee touches the wall. The maximum distance from the distal great toe to the wall is measured in centimeters. This method was chosen over other techniques due to its high reliability (ICC = 0.98 – 0.99) and low SEM (0.4 – 0.6cm). The MDC for this method is between 1.1 – 1.5cm. The criteria of 10cm distance from the wall was the standard for this clinic when describing full closed chain dorsiflexion range of motion.

Human Performance Program metrics included the 5-10-5 pro-agility, the broad jump, a 3-rep max trap-bar deadlift, and 300m shuttle repeat. See Appendix 1 for further description of these metrics. Additionally, the 300m shuttle repeat is also included in the Military Power, Performance, and Prevention algorithm aimed at developing predictive models for return to duty. The MP³ algorithm was the first attempt to develop a prediction model for military musculoskeletal injuries prior to injury and inform return to duty decisions.

Due to lack of ankle region specificity among aforementioned tests, three hop tests used in other ankle examination studies were also added to this subject’s return to duty testing regime. These tests included the single hop, triple hop, and crossover hop and are all measured for distance. Each hop test has excellent reliability (ICC = 0.92 – 0.97) and SEM ranging from 4.61 – 17.74cm.

Evaluation
Overall, the subject presented with no gross lower extremity deficits aside from the left ankle, which aligned with the traumatic mechanism of injury. Strength, joint mobility, balance/proprioception, and functional testing were assessed according to management guidelines. At baseline performance, all were impaired compared to the contralateral side and were addressed during course of treatment. The subject demonstrated a need for skilled physical therapy to increase mobility for gait, motor control, balance, and power to return to full active duty.

CLINICAL IMPRESSION 2
The initial impression of diagnosis was correct as well as the subject’s appropriateness for this case report. The timeline for this subject’s plan of care was initially thought to be 3 – 4 visits/week for 10 – 12 weeks from initial evaluation (one-month post-operation) then a re-evaluation to determine further rehabilitation. In addition to following bone healing timelines, extra time was allotted for progression beyond a typical outpatient orthopedic plan of care due to the occupational requirements of this subject. One potentially negative contributing factor to the subject’s prognosis was the unknown, yet likely, cortical damage imposed on the distal fibula due to persistent weight bearing while completing the austere training event prior to seeking medical treatment. Due to no additional limiting factors and availability of high physical therapy frequency, the subject continued to be appropriate for treatment and was expected to return to duty with full function. Based on outcome measures chosen, the subject’s functional abilities were scheduled to be tested on a monthly basis until function improved enough to return the subject to participation, duty, and finally return to tactical performance.

INTERVENTION
Treatment focused on pain reduction; regaining ROM, strength, and balance; and gradually loading the ankle. Isolated ankle plantarflexion and dorsiflexion exercises with resistance bands were initiated at initial evaluation and continued through the 2 weeks of non-weight bearing status to promote safe movement; in addition to use of a cooling and compressive garment to manage edema and pain. During this stage, the subject also received education on supportive nutrition from performance dieticians as well as performance training for the upper extremity combined with cardiovascular conditioning from Human Performance Program strength coaches and athletic trainers as part of an interdisciplinary approach for optimal performance and recovery.

Once full weight-bearing was allowed, traditional physical therapy exercises were progressed weekly and as tolerated by the subject until the surgical site and healing timelines allowed for manual therapy to be added in conjunction with traditional exercises. Manual therapy included many techniques such as: talocrural joint anterior to posterior (AP) in supine and tall kneeling with and without mobilization with movement, talocrural joint posterior to anterior (PA) in prone, distal and proximal fibular AP in
tall kneeling, and general talocrural joint distraction in supine. Techniques were performed throughout grades 1 through 4 as tolerance allowed for durations typically last 30 seconds per technique, repeated as necessary. Exercises included, but were not limited to, single leg balance, double and single leg squatting with variations, and subject-controlled ankle mobility activities. Throughout exercise progressions, the subject did not experience any lasting increase in pain, symptoms, or decrease in function.

Dorsiflexion range of motion was the limiting factor behind most progressions. Therefore, in-clinic management was heavily manual based, geared toward gaining range of motion and reinforced by supervised and independent workouts. Manual therapy included grade 3 and 4 generalized talocrural distraction, talocrural anterior to posterior mobilizations, distal fibular anterior to posterior mobilizations, and mobilization with movement. Hand placement was typical with the exception of distal fibular mobilizations, in which care was taken not to shear the surgical site on the lateral fibula. Since pain free range is requirement of mobilization with movement, this was the last manual technique to be added.

Once ankle range of motion reached 5 cm in CCDF, jumping and running progressions were initiated. This stage marked the initiation of return to participation as described by Arden et al (2016). The subject tolerated all progressions well with no increase in symptoms and continued to slowly improve ankle range of motion. Impact progression was crucial to this subject's rehabilitation due to the mechanism of injury, occupational physical requirements, and detrimental consequences of re-fracture. As a pre-requisite to the run progression, the subject had to demonstrate walking one mile in less than 15 minutes with no increase in pain or symptoms for three sessions in one week. Upon completion, a timed run/walk progression was initiated. In order to advance through the phases, no pain, swelling, or altered gait pattern could be present (Appendix 2). The subject completed two phases of the run/walk progression then was transitioned to strength coaches to improve overall tactical performance including military specific activities.

While the run progression was performed independently outside of clinic, the jump progression was performed under direct supervision. Bilateral landing exercises began the loading process in conjunction with more dynamic and full body warm up activities. The subject advanced through landing activities and multidirectional jumping on bilateral lower extremities while maintaining form before progressing to single leg activities. Adjustments including theraband around bilateral knees and use of a mirror for tactile and visual cues were utilized temporarily to address dynamic valgus. Single leg impact progression followed a similar pattern, while simultaneously increasing the height of bilateral lower extremity landing. Emphasis was on “soft” landings with appropriate impact absorption and unaltered biomechanics during each phase. Jump count gradually increased, as well as the intensity and impact involvement of all dynamic warm up activities. (Table 2)

OUTCOME

Self-Report Measures

The Global Rating of Change (GROC) and Numeric Pain Rating Scale (NPRS) were recorded at each treatment session; however, since they did not play a major role in the return to duty decision, they were not considered key outcomes for this case report. All self-report measures improved from initial to final evaluation. (Table 3)

Impairment Based Measures

The lateral step down was administered at the initial reassessments due to the subject's inability to perform the physical performance metrics safely. It served to bridge a gap between assessment but is not a factor in return to duty testing due to the higher challenges posed by other key outcome measures. Initial impairments noted on the lateral step-down score included trunk lean, rotated pelvis, and overall unsteady motion; resulting in an initial score of +3. At the second reassessment, the lateral step-down score improved to a zero; an optimal score which indicated no impairments. No information exists regarding the minimally detectable change for the lateral step down due to its ordinal properties. (Table 4) Closed chain dorsiflexion improved from 5cm to 10cm throughout the course of treatment which is equal to the contralateral limb and exceeds the minimal detectable change.23 (Table 4)
Functional Outcome Measures

From initial to final outcome administration, the subject improved FMS™ scores from 13/21 to 16/21, surpassing the MDC and threshold for increased risk of injury.22 (Table 4)

Initial anterior and inferolateral differences in the LQYB were both greater than the 4cm side-to-side cut off value, with 5 and 10cm differences respectively.25 These measures both improved by the final evaluation, each measuring within normal limits for side-to-side differences. Due to the subject's phase of rehab and inability to meet physical criteria required for hop testing during initial reassessment, the final scores were compared to male college athletes due to their analogous demographics, rather than tracking this subject's progress.28 Among initial trials involving the unaffected limb, subject was 21 – 108cm below the average distance, depending on the test. Additionally, limb symmetry indexes in the context of hop distance were assessed. The threshold used for this study was for the affected limb distance to be 90% of the unaffected limb distance. This ratio has been commonly reported in ACL rehabilitation among similar subject demographics.30 The subject reached this threshold for all three hop tests by his final return to duty testing. (Table 5). In addition, among peers the subject fell within the standard deviation for all Human Performance Program metrics including the 5-10-5 pro-agility, the broad jump,
a 3-rep max trap-bar deadlift, and 300m shuttle repeat (Table 6).

**DISCUSSION**

The purpose of this case report is to describe the application of a system to return a Special Operations Forces candidate to duty following an ankle injury sustained during a military static line airborne operation while in the Special Forces Qualification Course. The largest challenge to this process was the lack of standardized and validated military return to duty testing and guidelines in the literature. An extensive collection of outcome measures was utilized in this RTD decision and included: CCDF, LQYB, FMS™, single leg, triple hop, three hop crossover for distance, and Human Performance Program metrics. Positive changes in functional performance from initial to final assessments were observed in all outcome measures. Improvements in CCDF, FMS™, and LQYB exceeded the minimal detectable change.22,23 After the first reassessment, the subject was returned to participation as he trained with Human Performance Program strength coaches and athletic trainers on an upper body resistance training program combined with cardiovascular training.

Returning a soldier to unrestricted duty without adequate motion, strength, or motor control will merely perpetuate the situation, leaving them at a high risk for re-injury and reinitiate a massive sequela of negative physical, operational, and financial consequences. However, there is insufficient evidence of a standardized return to duty protocol or testing procedures to aid these clinical decisions among military populations. Pronouncements to return a
soldier to full duty rely on the clinical decision making of the health care team.

With the contribution of expert opinion in the field of military physical therapy and evidence from other musculoskeletal studies, the FMS™, LQYB, CCDF, Human Performance Program metrics, and three hop tests were chosen to assist in the return to duty decision making process of an U.S. Army Special Forces student status post distal fibular fracture with ORIF. The FMS™, LQYB, and CCDF were administered at the first and second reassessments, four and five months from surgical date respectively. (Table 1) Final values were compared to mid-point evaluation values, as well as clinically accepted standards, to gauge progress and performance. The hop tests were administered at the final evaluation and compared to cutoff values established for male college athletes for reference.

The subject demonstrated functional improvements in the FMS™, Y-Balance, and CCDF. The FMS™ score enhancement brought the subject to the positive side of the threshold for risk of injury and exceeded his peers’ averages. Lower Quarter Y-Balance scores also improved, meeting the MDC criteria. By decreasing side-to-side differences, the subject demonstrated an increased symmetry between each lower extremity and therefore may have reduced his overall risk of re-injury. The improvement in anterior reach direction may be partially explained by the improved closed chain dorsiflexion range of motion. Improvements in CCDF were also noted by the isolated measurement which adds to the overall reduction in injury risk for this subject. For the purpose of this case report, the lateral step down served as an objective way to quantify quality of motion into simplified categories. While not directly related to risk of injury, the lateral step down tests lower kinetic chain kinematics in a functional weight bearing position until increased load could be applied. With this subject’s improvement in quality of movement, as tested by the lateral step down, it is reasonable to extrapolate a carry over for reduction in injury.

When compared to male college athletes, the subject was deficient across all three hop tests during the initial administration, suggesting a lack of lower extremity power and balance due to residual lower limb asymmetries. However, upon final testing, limb symmetry for all hop testing surpassed the set 90% limb symmetry index threshold reaching 94 - 98% depending on the test.

All aforementioned outcome measures demonstrated improvement in lower extremity function and provided valuable information regarding the remaining deficits which assist in the discharge planning. To return to the intense and rigorous physical activity of a Special Forces student, the subject needed to perform at least as well as the average in his cohort. Ideally, pre-injury assessment would provide a baseline; however, compared to peers and as demonstrated by Table 6 above, the subject was well within acceptable ranges for all physical performance metrics at final RTD testing 10 months post injury. At this point, the subject was returned to duty and entered the return to tactical performance stage 10 months after initial injury - being physically comparable to his cohorts and being sound to complete all military requirements. One month later, the subject completed Robin Sage - the austere training phase where the initial injury was sustained - successfully and graduated the Special Operations Forces Qualification Course.

This case report provides an example of return to duty decision making with the use of functional tests chosen from evidence available for similar athletic

<table>
<thead>
<tr>
<th>Test</th>
<th>Class Averages</th>
<th>Standard Deviation</th>
<th>Patient Scores</th>
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</thead>
<tbody>
<tr>
<td>FMS™</td>
<td>15.5</td>
<td>1.8</td>
<td>16</td>
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<tr>
<td>Deadlift</td>
<td>351 pounds</td>
<td>58 pounds</td>
<td>335 pounds</td>
</tr>
<tr>
<td>Broad Jump</td>
<td>93 inches</td>
<td>8.5 inches</td>
<td>92 inches</td>
</tr>
<tr>
<td>300 yd Sprint</td>
<td>64.6 sec</td>
<td>3.4 sec</td>
<td>65 sec</td>
</tr>
<tr>
<td>5-10-5 Agility</td>
<td>4.95 sec</td>
<td>0.30 sec</td>
<td>5.25 sec</td>
</tr>
</tbody>
</table>

FMS™= Functional Movement Screen™
populations and their interpretation to assess performance. Due to lower extremity asymmetries, certain tests initially selected for return to duty testing were not performed at every assessment to ensure the safety of the soldier being tested. This case may assist physical therapists who need to make similar decisions for military athletes.

The outcome measures discussed in this case report provided objective and salient information regarding this soldier’s performance ability which assisted in the return to duty decision making. A limitation of this case report research is the inability to extrapolate results and decisions to all military personnel. Future research needs to be geared towards establishing baseline cutoff values for these and other outcome measures for various military occupational specialties to further guide decision making. This research would be best formatted using a large sample size using either a prospective or retrospective design with outcomes related to successful return to duty. Lack of testing among military populations using these outcome measures is a limitation of this case report. Additionally, there may be other measures that reflect occupation specific requirements.

CONCLUSION

Return to duty testing is lacking in research, thus leaving such decisions up the discretion of the medical team involved in the soldier’s recovery. This case report provides a system to determine readiness to return to duty following an ankle fracture. Similar methods could be used for other lower extremity injuries, as few of the aforementioned tests are exclusively used for evaluation of the ankle. One valuable lesson learned throughout this process was to keep the subject’s safety as a top priority. Although certain functional tests were initially selected to be tested, when the subject did not display a sufficient functional capacity, these tests were deferred until later when deemed safe. This further supports the need for sound clinical decision making for return to duty determinations. This case report also provides a guide to returning a subject to participation, duty, and tactical performance training with a core background in clinical decision making that is supported by evidence-based outcomes. This system should be considered for all military personnel returning to duty and other tactical athlete populations.

REFERENCES


APPENDIX 1

Table 1. Physical Performance Metrics

<table>
<thead>
<tr>
<th>Activity</th>
<th>System Tested</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10-5 Pro-Agility</td>
<td>Agility</td>
<td>Start at in the middle of a 10m line. When told to do so, sprint to the right 5m, back to the left 10m, then back to the starting position 5m to the right as fast as possible. Repeat, starting from the left.</td>
</tr>
<tr>
<td>300m Shuttle Repeat</td>
<td>Anaerobic</td>
<td>Sprint 300m for time. Allow 1 min rest. Sprint 300m again for time.</td>
</tr>
<tr>
<td>3RM Trap-Bar Deadlift</td>
<td>Strength</td>
<td>Perform a deadlift using a trap-bar equivalent to a 3 rep-max.</td>
</tr>
<tr>
<td>Broad Jump</td>
<td>Lower Body</td>
<td>With both feet evenly planted behind the start line, jump as far forward as possible. The jumper must stick the landing without losing balance or taking steps forward to count attempt. Record farthest distance jumped on 3 attempts.</td>
</tr>
</tbody>
</table>

*Allow proper warm up prior to all activities.

APPENDIX 2

Table 2. Phase 1 and 2 of 4-Phase Running Program

Phase 1: Impact Tolerance/Running for Appreciation (2-4 weeks)

Perform a walking warm up/light dynamic warm up and proper recovery. Perform every other day with a maximum of 2 consecutive days pending soreness. Guidelines: <60% max HR or 6/10 RPE

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Duration</th>
<th>Total Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 min jog/2 min walk x 5 reps</td>
<td></td>
<td>20 min total: 10 min running</td>
</tr>
<tr>
<td>3 min jog/2 min walk x 5 reps</td>
<td></td>
<td>25 min total: 15 min running</td>
</tr>
<tr>
<td>4 min jog/2 min walk x 5 reps</td>
<td></td>
<td>30 min total: 20 min running</td>
</tr>
<tr>
<td>5 min jog/2 min walk x 5 reps</td>
<td></td>
<td>35 min total: 25 min running</td>
</tr>
<tr>
<td>5 min jog/2 min walk x 6 reps</td>
<td></td>
<td>42 min total: 30 min running</td>
</tr>
</tbody>
</table>

Criteria to Progress: No pain, no swelling, normal mechanics.

Phase 2: Endurance Building/Volume Tolerance (2-4 weeks)

Perform a walking warm up/light dynamic warm up and proper recovery. Perform every other day with a maximum of 2 consecutive days pending soreness. Gradually build pace with each step below and repeat 2 – 3 sessions prior to progressing. Guidelines: <75% max HR or 7/10 RPE [Finish 8/10 RPE as able]

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Duration</th>
<th>Total Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min jog/1-2 min walk x 3 reps</td>
<td></td>
<td>36 min total: 30 min running</td>
</tr>
<tr>
<td>2 miles consecutive x 1 rep</td>
<td></td>
<td>Pace dependent</td>
</tr>
<tr>
<td>2.5 miles consecutive x 1 rep</td>
<td></td>
<td>Pace dependent</td>
</tr>
<tr>
<td>3 miles consecutive x 1 rep</td>
<td></td>
<td>Pace dependent</td>
</tr>
</tbody>
</table>

Criteria to Progress: No pain, no swelling, normal mechanics. Able to run 30 minutes continuously at least 2x/week.
ABSTRACT

**Background:** Isokinetic testing of the trunk is ubiquitous in the literature and with training, however, there is a lack of normative data for adolescents and adult athletes.

**Purpose:** The purpose of the current review is to present and summarize data about isokinetic trunk strength assessment relative to young, adolescent and adult athletes. Testing position variations, reliability values by age groups, utilization of strength measures and normative data by age groups have been discussed. The information presented within this review are of practical importance for assessment of isokinetic trunk strength to appraise the athlete's current strength level and provide suitable conditioning program.

**Study design:** Literature review

**Methods:** NCBI-PubMed, Web of Science, and SPORTDiscus were searched to identify relevant correlation and intervention studies/trials related to isokinetic testing of the trunk. Forty-two studies meeting the inclusion criteria were included in this literature review.

**Evidence synthesis:** The validity of isokinetic trunk measures (i.e. peak torque; flexion/extension ratios) can be affected by a number of factors including whether the individual is tested in seated or standing position, which can alter the muscle length–tension relationship. Reliability is excellent for some strength measures and moderate to high for muscle endurance. Extension and concentric measures tend to have better reliability than flexion and eccentric measures respectively, while females show typically higher reliability scores than men due to the difficulty in controlling men's body position when testing. Normative data for various populations are provided.

**Conclusions:** Muscle assessment methods using an isokinetic dynamometer are considered reliable with high correlations to peak strength values and flexor/extensor ratios over age groups. However, caution should be exercised when interpreting position-specific isokinetic test results that measure trunk flexion (standing vs seated position). Still, there are indications that low-velocity movements are more reliable for measuring trunk strength. In adolescence, boys appear stronger than girls, with higher values for trunk extensors. Trunk flexors and extensors ratios decrease with growth. Data of isokinetic trunk muscle performance seems to be correlated not only to anthropometric parameters but also to sports discipline and training volume. The effects of sport on the muscular strength of the trunk may have both a preventive factor and a possible risk factor for low back pain. There is evidence for an association between high physical workloads and back injury.

**Level of Evidence:** 5

**Key words:** core, endurance, isokinetic reproducibility, trunk strength testing, sport
**INTRODUCTION**

Trunk flexion is ubiquitous in daily activities, such as walking or sit-to-stand, and in different sports performance actions, such as overhead throwing or hitting a ball. Authors have demonstrated the importance of trunk strength for preventing injuries in the spine and knee, such as the low back pain and anterior cruciate ligament injuries that frequently occur in sports and the workplace.

Strength testing of the trunk muscles plays an important role in functional evaluation. Initial discussion on trunk strength testing dates back to the 1940s and since then numerous testing procedures have been introduced into clinical practice. One of these procedures is isokinetic testing. Although isokinetic dynamometers are commonly used in clinical practice for testing of the extremities, only a few findings regarding the reproducibility of trunk strength testing exist. Isokinetic measurements are based on the principle of testing strength capacity under constant rotational or linear motion velocities and are considered the ‘gold standard’ for assessing strength capacity. Current dynamometers are capable of measuring isometric, concentric and eccentric contraction modes for clinical, performance and scientific applications. Isokinetic dynamometry is a well-accepted tool for assessing strength of the upper and lower extremities as well as trunk muscles, and isokinetic strength testing is a useful approach to assess trunk extension and flexion in healthy individuals as well as in patients with low back pain. In order to assess isokinetic trunk strength, many different devices have been developed for standing or sitting positions. Isokinetic (peak torque (PT) and work (W)) and isometric parameters (PT and rate of force development or rate of torque development) can be assessed. Furthermore, isokinetic measurements can be used to identify strength deficits in individuals with and without pathologies. In addition, the evaluation of the outcomes of preventive and rehabilitative interventions is important. The measurement of PT is commonly used as a proxy measurement of trunk strength and serves as a valid outcome parameter for reporting trunk extension and flexion strength in both healthy subjects and patients with low back pain. Moreover, it is used to define deficits in specific pathologies, as well as to evaluate effectiveness of training and therapy.

Strength is essential for stability (ability to compensate for perturbations to balance) in healthy individuals and those with back conditions (i.e. low back pain [LBP]) and performance of the core (trunk). Research on isokinetic assessments of lateral flexion and rotation are quite rare and reproducibility in these two planes (lateral flexion/rotation) has not been sufficiently analyzed.

The functional applicability of isokinetic measurement still remains questionable. Some scientists agree that isokinetic movements are “unnatural” and the motion involved is not related to that which occurs during sporting performance. In addition, it has to be emphasized that what is being measured is not internal muscle tension but the torque/force output of complex muscle systems especially when assessing the spine. Isokinetic dynamometry is considered a valid and reliable device used to determine the force, or torque, generated by a muscle group for a specific action, having good-to-excellent reliability. Isokinetic dynamometry, however, is not universally accessible and is rarely used clinically owing to its high cost, requirement for considerable user expertise, and protracted testing time.

There is great benefit in using trunk isokinetic dynamometry to reliably assess strength parameters. There is a lack of normative data of trunk flexors and extensors muscle strength in the literature. Particularly, there is a lack of normative data from asymptomatic adolescent and adult athletes. Unlike the arms and legs that can compare or normalize the strength of a limb to the contralateral limb, the trunk does not present this possibility. In this way, the comparison of the trunk strength of an individual always will need to be compared with population normative data or parameters of normality.

The purpose of the current review is to present and summarize data about isokinetic trunk strength assessment relative to young (children), adolescent and adult athletes. Testing position variations, reliability values by age groups, utilization of strength measures and normative data by age groups have been discussed. The information presented within this review are of practical importance for assessment of isokinetic strength of trunk and conditioning professionals in appraising their athlete’s current
strength level and providing accurate conditioning training programs. Typically, isokinetic trunk assessments examine joint range of motion, muscular strength, power and balance between agonists and antagonists muscles, as all of these variables are considered crucial for optimal performance whilst playing a role in reducing an athlete’s risk of injury. Muscle strength ratios are commonly tested to describe unilateral antagonist to agonist strength properties, functionality and imbalances.

METHODS
The present literature review was conducted in accordance with the recommendations of the “Preferred Reporting Items for Systematic Reviews and MetaAnalyses” (PRISMA).20

Literature Search
The literature review was performed with the databases of PubMed, Web of Science, and SPORTDiscus; for correlation and for intervention studies. The following search terms were included in search strategies: “isokinetic and trunk”, “isokinetic and low back pain”, isokinetic and trunk and healthy”, “isokinetic and trunk and athletes”, “isokinetic and trunk and adolescent”, “isokinetic and trunk and therapy”, “isokinetic and trunk and prevention”, “isokinetic and trunk and training”, “isokinetic and trunk and exercise”, “isokinetic and trunk and validity”, “peak torque and trunk”, “peak torque and trunk and healthy”, “peak torque and trunk and athletes”, “peak torque and trunk and adolescent”, “peak torque and trunk and prevention”, “peak torque and trunk and training”, “peak torque and trunk and exercise” and “peak torque and trunk and validity”. By using the filter criteria of the respective databases, the search was limited to full-text availability, publication dates (2000 to 2018), humans, ages (i.e., 16-44 years), and English language. Further, the reference lists of the included studies as well as relevant review articles were screened for titles in order to identify additional suitable studies for inclusion.

RESULTS
The search strategy revealed 224 references among which 42 presented relevant isokinetic strength measures derived from testing of healthy subjects without pathologies, athletes and/or adolescents. Most frequently, data for trunk extension and flexion strength were evaluated with cross-sectional designs (31 papers for flexion/extension, three for rotation, and none for lateral flexion). Nine out of the 31 ‘sagittal’ studies reported isokinetic measures for patients with low back pain (PLBP), 29 for healthy subjects/others and seven involved both healthy subjects and PLBP. Studies investigating prevention, therapy or training effects (eight total) or using isokinetics as an intervention were rare.

Results revealed that standing flexion elicited significantly greater PT, W and power (P) values than sitting, at both velocities tested, whereas no differences were noted in trunk extension. When testing sagittal plane trunk strength in the upright posture, Guilhem et al13 found torque values ranging between 152 and 453 N.m in trunk extension, and between 99 and 263 N.m in trunk flexion, which is in accordance with the values reported for healthy subjects tested in similar conditions.21 Previous studies demonstrated a 30% increase of flexor torque from supine to standing position, which is closer to the functional configuration of daily or sport tasks.22 Moreover, the upright configuration has been shown to reduce the contribution of muscles crossing the hip joint, thus leading to lower torque variations compared to the supine position.23

In a recent review on pediatric strength testing, De Ste Croix24 stated that test-retest-variability in isokinetic strength testing in children ranges between 5 and 10% regardless of joint tested. Furthermore, De Ste Croix24 deduced in his review that extension movements were more reliable than flexion movements, concentric muscle action was more reliable than eccentric work and that reliability was reduced with increased testing velocity. With adolescents, Carvalho et al.25 reported questionable as well as clinical acceptable to excellent reproducibility in adolescent basketball players for isokinetic strength testing (ICC: 0.72-0.99). Lindsay et al.26 reported an acceptable reproducibility in the adolescent cohort with isokinetic trunk rotation and endurance at a testing velocity of 30°/s (ICC: 0.86-0.87). Müller et al.11 found excellent reliability (0.91-0.94) with adolescents’ isokinetic trunk strength testing.

Test–retest reliability of isokinetic PT measurements for trunk flexors and extensors data exhibited
very low mean differences (610 N·m), and excellent ICC and SEM values. Although trunk extensor concentric torque showed slightly lower ICC and higher SEM values than eccentric, reliability was comparable between 60°/s and 120°/s angular velocities. Test–retest reliability results were also excellent for trunk flexor muscles, with ICC above 0.90 and SEM values below 8% for all the experimental conditions, which are similar to or better than previous reliability analyses conducted with other studies. Concerning endurance variables, studies found moderate-to-high ICC values for the drop in the performance within sets (0.57 < ICC < 0.82), in healthy young male and female volunteers. Recently, Roth et al. found very good ICC's ranging from 0.85 to 0.96 in adults for isokinetic trunk extension and flexion.

Ben Moussa Zouita et al. found that mean of the trunk extension and flexion torques is 208 Nm (range: 121–360 Nm) and 176 Nm (range, 111–296 Nm), respectively with a ratio of trunk flexion to extension of 0.84 (range, 0.54–1.16). Also, the average trunk flexion to extension ratios varied between 52.6% to 69.7% and 43.9% to 58.6% respectively, in the non-athlete and athlete groups.

DISCUSSION
The purpose of the current review is to present and summarize data about isokinetic trunk strength assessment relative to young, adolescent and adult athletes. Testing position variations, reliability values by age groups, utilization of strength measures and normative data by age groups have been discussed. The information presented within this review are of practical importance for assessment of isokinetic trunk strength and conditioning for professionals in appraising their athlete’s current strength level and providing accurate conditioning training programs that correlate with physical performance. Also this data, may serve as reference for prevention of low back pain.

VALIDITY OF ISOKINETIC TRUNK MEASURES
Isokinetic dynamometry can measure trunk flexion and extension strength at various angular velocities and contraction modes (isometric, concentric, and eccentric), and has been found to be safe, reliable, valid and sensitive enough to detect muscle weakness. Findley et al. postulated that isokinetic trunk extension and flexion have traditionally been measured in either the sitting or standing position. However, these positions may produce dissimilar levels of PT, work, and power of isokinetic concentric trunk extension and flexion at 60°/s and 120°/s in the sitting and standing positions. They suggested that trunk musculature, including some synergist muscles can partly contribute to external torque differences seen during trunk flexion or extension between sitting and standing positions. Between positions there is likely different recruitment of hip muscles and variation in range of motion.

Although the angle of the hip joint was much different, the anatomical ROM measured in the sitting position was from 100° of extension to 30° of flexion whereas in the standing position ROM was from 190° of extension to 120° of flexion. Changes between sitting and standing isokinetic exercise in the sagittal plane alters the muscle activation-performance relationship, thereby shifting the zone of optimal performance, described as the inverted-U torque production curve. In essence, data are being produced in two completely different ROM's in the different positions.

Szpala et al. compared trunk extensor’s torques and spinal muscles activity during sitting and lying body positions. They found significantly higher electromyographic (EMG) activity in erector spinae muscles during lying, whereas PT values were higher during the sitting position. Therefore, caution should be exercised when interpreting position-specific isokinetic test results that measure trunk flexion.

Reliability of isokinetic trunk measures (Table 1)
Due to the importance of trunk strength, clinicians and coaches must know whether changes in strength over time reflect a real gain or loss, or are the result of the measurement error. Therefore, the validity and reliability of data are important when assessing strength. The validity of data concern how an individual’s test performance reflects true performance.
### Table 1. Previously reported reliability statistics of isokinetic trunk measures.

<table>
<thead>
<tr>
<th>Study</th>
<th>Characteristics</th>
<th>Subjects</th>
<th>Weight (kg)</th>
<th>Contraction mode</th>
<th>Test velocity °/s</th>
<th>Ext</th>
<th>Flex</th>
<th>F/E</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Youth</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Merati et al. (2004)</td>
<td>Adolescents</td>
<td>F H</td>
<td>40</td>
<td>Con</td>
<td>60 90 120</td>
<td>101 79 59 68</td>
<td>94 80 68 80</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M H</td>
<td>44</td>
<td></td>
<td>60 90 120</td>
<td>135 118 107</td>
<td>109 105 96</td>
<td>0.81</td>
</tr>
<tr>
<td>Mueller et al. (2011)</td>
<td>Adolescent athletes</td>
<td>F H</td>
<td>22 63</td>
<td>Con</td>
<td>60</td>
<td>161 60 30 146</td>
<td>111 117 219 146</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>48 67</td>
<td></td>
<td></td>
<td>219 30 30 81 81</td>
<td>146 146 146 146</td>
<td>0.71</td>
</tr>
<tr>
<td>Muller et al. (2014)</td>
<td>Adolescents athletes 15.9 year, Judo=10, Soccer=1, Swimming=1, Gymnastics=1</td>
<td>F H</td>
<td>13 69</td>
<td>Con, Flex/Ext, Rot</td>
<td>30 60 120</td>
<td>211 214 282</td>
<td>147 138 146</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td></td>
<td>Ecc</td>
<td>30 R: 81 L: 87</td>
<td>147 138 129 129</td>
<td>147 138 146 129</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>All M/F</td>
<td>377</td>
<td></td>
<td>Flex/Ext, 60°/s</td>
<td>140 97 30 30 30</td>
<td>97 97 97 97 97</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>233</td>
<td></td>
<td></td>
<td>149 219 30 30 30</td>
<td>102 102 102 102 102</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>144</td>
<td></td>
<td></td>
<td>125 125 30 125 125</td>
<td>89 89 89 89 89</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td><strong>Adults</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yahia et al. (2011)</td>
<td>Normal adults</td>
<td>M/F H LBP</td>
<td>30 30 30 76</td>
<td>Con</td>
<td>60 90 120</td>
<td>145 90 120 123</td>
<td>76 67 132 112 102</td>
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</tr>
<tr>
<td>Baur et al. (2010)</td>
<td>Normal active adults</td>
<td>M H</td>
<td>13 73</td>
<td>Con</td>
<td>60 90 120</td>
<td>260 237 283 248</td>
<td>212 207 218 218 288</td>
<td>0.82</td>
</tr>
<tr>
<td>Race car driver</td>
<td></td>
<td>M H</td>
<td>13 71</td>
<td></td>
<td>60 90 120</td>
<td>260 237 283 248</td>
<td>212 207 218 218 288</td>
<td>0.82</td>
</tr>
<tr>
<td>Muller et al. (2011)</td>
<td>Normal adults</td>
<td>M/F H</td>
<td>26 66</td>
<td>Con</td>
<td>60 90 120</td>
<td>249 211 237 140</td>
<td>211 173 184 164 184</td>
<td>0.89</td>
</tr>
<tr>
<td>Ben Moussa Zouita et al. (2018)</td>
<td>High-level Athletes (mean 23.3 years) Boxing Wrestling Weightlifters Nonathlete control (mean 22.3 years)</td>
<td>M H</td>
<td>18 74.1 74.1</td>
<td>Con</td>
<td>60 90 120</td>
<td>440.05 365.46 344.10</td>
<td>297.34 261.53 211.98</td>
<td>58.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M H</td>
<td>n=8 n=5 n=5</td>
<td>Ecc</td>
<td>60 90 120</td>
<td>373.01 365.46 344.10</td>
<td>249.23 261.53 211.98</td>
<td>43.9</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>74.1</td>
<td>373.01 365.46 344.10</td>
<td>249.23 261.53 211.98</td>
<td>58.6</td>
</tr>
<tr>
<td>Bervisevic et al. (2001)</td>
<td>Normal adults</td>
<td>M H</td>
<td>27 78</td>
<td>Con, Ecc</td>
<td>30 60 30 60</td>
<td>211 201 249 256</td>
<td>128 116 249 256</td>
<td>0.61</td>
</tr>
</tbody>
</table>

F= female, M= male, H= healthy, LBP= Low Back pain, Con= concentric contraction, Ecc= eccentric contraction, Flex= flexion, Ext=extension, Rot= Rotation, L= left side, R= right side, F/E= Flexion/extension ratio;
and the reliability measures in tests and retests concern the repeatability of the data observed in a sample.36

Previous studies regarding the reproducibility of isokinetic trunk strength have focused mainly on the relative parameters, predominantly correlation coefficients.36 Relative reliability indicates how similar the rank orders of the participants in the test are to the retest.37 The main problem with relative reliability is that it depends on the variability of the sample. However, absolute reliability is related to the consistency of individual scores;38 the smaller the variation, the higher the reliability.39 In addition, they are not variance dependent. Among those indices, the most commonly used are the standard error of measurement, the coefficient of variation of standard deviation and Bland Altman plots.40 CV and SEM reflect the magnitude of the differences between two measures.41 Since they are expressed in units that are readily interpretable, extrapolation to new individuals as well as comparison between different measurement tools is possible.39 Blande Altman plots showed no systematic biases when most of the points are very close to the line of equality. Ultimately, there was good agreement between results from different equipment, without any identifiable trend.

From a practical standpoint, muscle assessment methods using an isokinetic dynamometer are considered reliable and reproducible, with correlation coefficients between 0.93 and 0.99 for peak force values and between 0.91 and 0.96 for total workload values.42 Isokinetic trunk flexion/extension strength reliability with adults has been reported to be clinically acceptable to excellent with testing velocities of 60°/s and 120°/s (ICC 0.74 – 0.91)13 and 30°/s and 60°/s (ICC: 0.78-0.91).43 Müller and colleagues11 suggested that isokinetic trunk flexion and extension angular velocities higher than 120°/s could increase the error between sessions and large ranges of motion could result in a misalignment between the biological axis of the trunk and the mechanical axis of the dynamometer.

The high reliability of the isokinetic testing of the trunk (high ICCs) is presumably related to several factors, including the standardization of the instructions, the adoption of familiarization procedures, the adjustment of the fixed seat platform according to the size of the members of each individual, the fixed order of the tests, and the supervision of experienced evaluators. Overall, the results of all these studies indicate the robustness of isokinetic measures in assessment of trunk muscle strength.

Despite the efforts made in the field of isokinetic trunk assessment, there is no evaluation protocol to determine the appropriate velocity and through what range of movement the evaluation should be performed,44 even though there have been attempts.45 Still, there are indications that low-velocity movements are more reliable for measuring trunk strength.13,29 Different authors have analyzed the test reliability using peak force,29,46,47 but it has not been shown which strength manifestation (peak force or mean force) is more reliable for assessing trunk strength. However, the reliability of strength test results is crucial to assess the level of adequate performance and develop a successful rehabilitation or training program36 for all age groups.

**Youth**

Trunk isokinetic torque of youth has been measured in a few studies.48,49 The use of isokinetics for studying muscle torque in children and adolescents is fully accepted and reliable.50,51 Studies on the extension/flexion torque ratio in limbs and trunk as well as upper and lower body (knee vs. elbow) extension and flexion torque ratios with increasing age in both sexes seem to be sparse.52 Godhe et al.49 suggest that from the youngest ages to adolescence, peak absolute (N.m) and normalized (N.m/kg body mass) torque increases in all measures with highest increase in the trunk activities. For trunk activity, the sex differences start at age 14 years. However, trunk extension/flexion ratios are mainly unchanged with increasing age with no differences between sexes. Normalizing data (N.m/body mass) reduces the rate of increase in all measurements in both sexes but does not change the rank order.

Choice of isokinetic testing protocols with pediatric populations may be influenced by participants, test equipment availability, cost and specificity of testing. There are numerous generic protocol considerations
specific to paediatric groups such as adaptation of equipment, stabilization and technique, habituation and learning effects, and safety. Some dynamometers can be ordered with paediatric specifications such as adjustable seat length to accommodate the short femurs of children and short attachments.53

In a recent review on pediatric strength testing, De Ste Croix24 stated that test-retest-variability in isokinetic strength testing in children ranges between 5 and 10%. Furthermore, De Ste croix24 deduced in his review that extension movements were more reliable than flexion movements, concentric muscle action was more reliable than eccentric work and that reliability was reduced with increased testing velocity, regardless of joint tested. With adolescents, Carvalho et al.25 reported questionable as well as clinically acceptable to excellent reproducibility in adolescent basketball players for isokinetic strength testing (ICC: 0.72-0.99). Lindsay et al.26 reported an acceptable reproducibility in the adolescent cohort with isokinetic trunk rotation and endurance at a testing velocity of 30°/s (ICC: 0.86-0.87). Müller et al.5 found excellent reliability (0.91-0.94) with adolescents’ isokinetic trunk strength testing.

Sex differences
Isokinetic strength variables in flexion and extension efforts showed high ICC values in both males and females (0.74 < ICC < 0.91).34 These results differ from those by Dvir and Keating45 and Keller et al.55 who found higher isokinetic trunk extension reliability values for females and males, respectively. Dvir & Keating45 found partially clinical acceptable reproducibility of an isokinetic test protocol (concentric/eccentric; 10°/sec, 40°/sec) measuring trunk extension strength in healthy men and women with women (ICC: 0.70-0.87) showing higher ICCs than men (ICC: 0.52-0.78). The test-retest correlation coefficients were generally lower in males (0.52–0.78) than in females (0.70–0.87) probably as a result of a higher difficulty in controlling the males body position during the protocol. Hence, the greater anthropometric dimensions and the higher experience in maximum efforts of some males may have allowed them to exert higher forces.55 So inappropriate strapping could have changed the initial position, affecting the pelvic axis alignment.43

Normative data (Table 2)
Children and adolescents
With children and adolescent athletes, isokinetic testing is often applied to describe and evaluate individual and population specific characteristics like age- or sex-related changes in strength over growth and maturation.24 However, there are difficulties in assessing maximum strength in adolescents due to their inexperience with producing maximal strength.24,56,57

Balague et al.48 observed that peak low back torque extension is at its maximum level in 12-year-old girls and in boys, from the age of 14 years it increases constantly. Among the 14 to16-year-olds, on the other hand, whether they are healthy or not, the boys appear stronger than the girls, with higher values for the trunk extensors and flexors. In a study involving 62 school children with an average age of 12 years. Mériti et al.58 found that isokinetic performances pertaining to peak torque, total workload and mean power for trunk extensors at 60°/s and at 90°/s were higher for boys.

Bernard et al.59 suggests that in populations of children and adolescent (11-16 years), they could not deduce reference values for the trunk isokinetic parameters; all they could do in this respect was establish frameworks for values that would be adjusted as the series of tests increase in number. For girls, the maximum moment of force (MMF) and mean power (MP) values for the trunk flexors and extensors ranged from 1.7 to 2 and 2 to 2.8 times body weight respectively. For 11 to 13 year old boys, MMF and MP values for the trunk flexors and extensors ranged from 1.4 to 2 and 1.7 to 2.7 times body weight respectively, and for 14 to 16-year old boys 2.4 to 2.8 and 2.4 to 3.5 times the body weight, respectively. In boys, trunk flexors and extensors ratios normalized to body weight, decreased with growth from 0.72–0.91 to 0.67–0.77. While, the girls show more elevated trunk flexors and extensors ratios, ranging from 0.81-0.94 to 0.75-0.95 for the controls. Bernard et al.59 observed that values for trunk concentric peak moment were higher than those found by Delitto et al.60 An accurate comparison of these values between studies is hampered by the lack of data on range of motion and age groups of the individuals.
It has been shown that growth and the resulting anthropometric parameters are directly related to motor performance in young people and that the latter stabilizes at the end of growth.\textsuperscript{61} Philippaerts et al.\textsuperscript{62} followed prospectively for five years, the growth in size and weight of 33 young footballers, initially aged 12.2 (± 0.7) years and found a correlation between peak growth and trunk muscle strength, the endurance of the upper body muscles, balance and speed of running among other measures of physical performance.

However, Godhe et al.\textsuperscript{49} presents a complete set of different ratios trunk activities in both sexes and all age groups from 8 to 15 years. For the trunk, a sex difference is only seen at 15 years for extension and at 14 and 15 years of age for flexion. For trunk extension and flexion higher PT normalized values are found in boys compared to girls only at three points with regard to age groups; at the 12th and 15th year age groups for flexion and in the 12th year age group for extension. The increase in average absolute (N.m) values from the 8th to the 15th year age group is highest in the trunk.

Isokinetic assessment in pediatric populations has been utilised to describe the age and sex associated changes in strength,\textsuperscript{63,51,24} to explore the growth and

### Table 2. Normative data.

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>Evaluation</th>
<th>Joint</th>
<th>Movement</th>
<th>Type of contraction</th>
<th>Velocity (%/sec)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delitto et al. (1991)</td>
<td></td>
<td>Extension</td>
<td>Flexion</td>
<td></td>
<td></td>
<td>60, 120, 180</td>
<td>0.74-0.88, 0.74-0.88</td>
</tr>
<tr>
<td>Dvir and Keating (2005)</td>
<td>Healthy Men and Women</td>
<td>Trunk</td>
<td>Extension</td>
<td>Concentric, Eccentric</td>
<td></td>
<td>10</td>
<td>acceptable reproducibility ICCs: 0.52-0.78 ICCs: 0.70-0.87</td>
</tr>
<tr>
<td>De Ste Croix (2012)</td>
<td>Children</td>
<td>Test-retest-variability</td>
<td>Extension</td>
<td>Concentric, Eccentric</td>
<td></td>
<td>Reduced with increased testing velocity, regardless of joint tested.</td>
<td>5 and 10% Extension movements were more reliable than flexion movements Concentric muscle action was more reliable than eccentric work</td>
</tr>
<tr>
<td>Carvalho et al. (2011)</td>
<td>14 to 16-year-old basketball players</td>
<td>Reliability</td>
<td>Trunk</td>
<td>Concentric, Eccentric</td>
<td></td>
<td></td>
<td>ICC from 0.72 to 0.99</td>
</tr>
<tr>
<td>Lindsay et al. (2006)</td>
<td>Adolescent</td>
<td>Trunk rotation</td>
<td></td>
<td></td>
<td></td>
<td>30 (ICC: 0.86-0.87).</td>
<td></td>
</tr>
<tr>
<td>Müller et al. (2014)</td>
<td>Healthy adolescents (N=13)</td>
<td>Twice</td>
<td>Trunk</td>
<td>Rotation, Flexion / Extension</td>
<td>Concentric, Eccentric and Eccentric</td>
<td>30, 120, 30 (between 0.65 - 0.90, (0.94, (0.91))</td>
<td></td>
</tr>
<tr>
<td>Dervisevic et al. (2007)</td>
<td>27 young healthy male (21.3±3.7\ yrs) Twice over a period of one week</td>
<td>Trunk</td>
<td>Flexion / Extension</td>
<td>Concentric/Eccentric</td>
<td>30, 60 (acceptable to excellent reproducibility (ICC between 0.78-0.91))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roth et al. (2017)</td>
<td>15 healthy sport students (8\ female and 7 male) aged 21 to 26</td>
<td>Trunk</td>
<td>Extension and Flexion</td>
<td></td>
<td>60, 150</td>
<td>Excellent Relative reliability (ICC: 0.85-0.96) very good ICC’s ranging from 0.85 to 0.96</td>
<td></td>
</tr>
<tr>
<td>García-Vaquero et al. (2016)</td>
<td>57 healthy and physically active young men (n=28) and women (n=29) 4 trials of 15 maximum</td>
<td>Trunk</td>
<td></td>
<td>Concentric</td>
<td>120</td>
<td>ICC&gt;=0.74 Moderate to high ICC values ((0.57&lt;ICC&lt;0.82))</td>
<td></td>
</tr>
<tr>
<td>Keller et al. (2001)</td>
<td></td>
<td>Trunk</td>
<td>Flexion</td>
<td>Extension</td>
<td></td>
<td>60</td>
<td>NA</td>
</tr>
</tbody>
</table>

\(F=\) female, \(M=\) male, \(H=\) healthy, \(LBP=\) Low Back pain, \(Con=\) concentric contraction, \(Ecc=\) eccentric contraction, \(Flex=\) flexion, \(Ext=\) extension, \(ROT=\) Rotation, \(L=\) left side, \(R=\) right side, \(F/E=\) Flexion/extension ratio.

\[\text{Table 2. Normative data.}\]
maturational effects on strength, to examine the effectiveness of training studies. Pediatric researchers are starting to move from beyond using isokinetic assessments in isolation, and for simply descriptive study, but are now trying to integrate isokinetic data with other forms of data to explore the complex changing mechanisms that are involved in the development of dynamic strength with age.

**Adults**

In healthy adult subjects, trunk strength is typically greatest with sagittal plane extension followed by sagittal plane flexion. It is clear that athletes tend to show the highest trunk strength values, but also the smallest ratio of trunk flexion to extension. Elite athletes show a capacity of between 150–240 Nm for trunk flexion and between 200–450 Nm for trunk extension. In this respect, adult athletes (rowers, wrestlers) have higher PT values compared to non-athletes and relatively higher trunk extension strength torques (reduced flexor/extensor ratio). Ratios of trunk flexion to extension in healthy untrained adults usually range between 0.7–0.9 but in athletes, the ratio tends to be between 0.5–0.7, which occurs in tandem with increased trunk extensor strength. However, few previous investigations have directly compared trunk flexion and extension strength and ratios between athletes and non-athletes, and explored the impact of angular velocity on trunk flexion and extension strength and ratios.

To summarize, previous studies indicate differences in isokinetic PT for trunk sagittal and transverse efforts as a function of age, subject populations (e.g. trained vs. untrained) and sex. Moreover, athletic subjects show more muscle capacity than sedentary subjects. A normal flexor/extensor ratio is lower than 1, ranging from 0.80 to 0.85 according to Greimion et al. without correction for gravity.

Recently Ben Moussa Zouita et al. compared maximal concentric isokinetic trunk extension and flexion torques, power and trunk extension and flexion torque ratios between high-level athletes and a control population. In general, there were trends for increasing trunk extension and flexion torques and power with increasing angular velocity in both groups, although the effect was more marked for trunk extension in the athlete group than in the non-athlete group. Additionally, it was found that the trunk extension torque of athletes was significantly higher than the non-athlete group at 60°/sec and 90°/sec but not at 120°/sec, and also that the trunk extension power of athletes was significantly higher than the control group at 90°/sec and 120°/sec but not at 60°/sec. In contrast, there was no difference between the athlete and control groups for trunk flexion power at any angular velocity.

Both athletes and non-athletes displayed greater torque and power in trunk extension, at all angular velocities versus trunk flexion. This is in accordance with previous reports that the trunk extensors are stronger than the trunk flexors. Athletes displayed greater trunk extension torque and power than non-athletes, but that there was no difference between athletes and non-athletes in relation to trunk flexion torque and power. In accordance with previous literature, athletic subjects display greater lumbar muscle capacity than sedentary subjects. Few studies have previously assessed the torque-angular velocity and power-angular velocity relationships for the trunk flexor and extensor muscles. Van Damme et al. found that the angular velocity of isokinetic trunk extension exercises influences the recruitment of the back muscles.

The ratio of the PT of the flexors to the extensors can serve as a parameter to assess the muscular balance of a joint. Simbala et al. assessed a group of asymptomatic sedentary individuals, and reported a ratio of the PT of the flexors to the extensors of 81% for males.

**Relation of isokinetic trunk strength, sport and performance (Table 3)**

The contribution of the trunk musculature to many sports (e.g. taekwondo, judo, tennis, golf, baseball, handball, rowing, etc.) and daily life activities, has aroused considerable interest in trainers, clinicians, and researchers. In the field of sports, it is thought that increases in the ability to exert the maximum trunk muscle force (trunk muscle strength), as well as the ability to exert trunk muscle force repeatedly or continuously over a long period of time (trunk muscle endurance), can improve athletic performance and help prevent and treat back disorders in individuals with trunk muscle weakness.
Table 3. Relation of isokinetic trunk strength, sport and performance.

<table>
<thead>
<tr>
<th>Study</th>
<th>Subject Characteristics</th>
<th>Contractile mode (con/ecc)</th>
<th>Test velocity °/s</th>
<th>Peak torque N.m Ext/Flex</th>
<th>Physical performance</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall et al. (1992)</td>
<td>M 23.1 years</td>
<td>23 Con</td>
<td>15° /s</td>
<td>146/169</td>
<td>Sit-up tests: Repetitions correctly performed in 1 min</td>
<td>Con/Robertson Curl-up: r=0.41</td>
</tr>
<tr>
<td></td>
<td>H 22.2 years</td>
<td>28 Ecc</td>
<td></td>
<td>95/111</td>
<td>- Kraus-Weber Test: 39</td>
<td>Con / Kraus-Weber Test: r=0.42</td>
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<td></td>
<td>F</td>
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<td>- Robertson Curl-up: 76</td>
<td>Ecc / Kraus-Weber Test: r=0.40</td>
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<td></td>
<td></td>
<td>- AAHPERD: 49</td>
<td>Ecc / AAHPERD: r=0.32</td>
</tr>
<tr>
<td>Roeter et al. (1996)</td>
<td>Elite level tennis players</td>
<td>60 Con</td>
<td></td>
<td>60/120</td>
<td>Measurements of strength, power, speed and agility, endurance and flexibility: The correlated measurements included the total distance thrown on a forehead, backhand, overhead, and reverse overhead medicine ball toss</td>
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<td>13 and 17 years</td>
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<td>Kals and Kurkaya (2013)</td>
<td>Voluntary Athletes from different sports 20-9 year</td>
<td>19 Con</td>
<td>30/90/120</td>
<td>Sprints (10m, 20m, 30m, and 40m) a non-motorized treadmill, V10m, V20m, V30m, V40m</td>
<td>Statistically highest significant correlations have been found between V40m and isokinetic trunk flexion-extension peak torques (30°, 90°, and 120°)</td>
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<td></td>
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<td></td>
<td></td>
<td>r= 0.845 There were significant relationships of horizontal ground reaction forces with isokinetic trunk flexion-extension peak torques at 30°, 90°, and 120°</td>
<td></td>
</tr>
<tr>
<td>Xiong et al. (2014)</td>
<td>Elite Weightlifters'</td>
<td>M H 12 Con</td>
<td>The relative peak torque of the trunk</td>
<td>Snatch and clean and jerk performance subjects’ snatch/weight, clean and jerk weight/height</td>
<td>Snatch/weight demonstrates moderate positive correlation significantly with back extensor</td>
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<tr>
<td>Kuniston et al. (2015),</td>
<td>International level</td>
<td>M H 9 Con</td>
<td>Trunk extensors and flexors at 60°/sec</td>
<td>Performed 100 meters monofoil surface swim</td>
<td>There was a strong correlation (p&lt;0.05) between swimming time and trunk flexors (r=.77) at angle 30° in male swimmers</td>
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<td></td>
<td>swimmers 16-17 years</td>
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<td>F 8</td>
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<tr>
<td>Barbado et al. (2016)</td>
<td>International Judokas National judokas</td>
<td>M H 11 Con</td>
<td>120</td>
<td>Sudden loading, to assess trunk responses to unexpected external perturbations, stable and unstable sitting, to assess the participants’ ability to control trunk balance</td>
<td>Few and low (r &lt; 0.5) significant correlations were found between strength endurance and stability parameters</td>
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<tr>
<td>Thevenon and Blanchard (2003)</td>
<td>Healthy subjects</td>
<td>M H 28.2 year</td>
<td>120/90/60</td>
<td>Finger to floor - Lumbar Schober index: - Dorsal Schober index: Assessment of hamstring extensibility - Assessment of hip flexors extensibility</td>
<td>A negative relation between finger to floor distance and maximal torque and work of trunk flexors at 30, 60 and 90°, r=-0.54</td>
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<tr>
<td></td>
<td></td>
<td>W 25 Con</td>
<td></td>
<td></td>
<td>A negative relation between lumbar Schober index and trunk extensors maximal torque and work at all speeds, r=-0.43</td>
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<td></td>
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<td></td>
<td>A positive relation between lumbar Schober index and flexors/extensors ratio at all speed, r=0.61</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>A positive relation between hamstring extensibility and work of trunk flexors at 30, 60 and 90°, r=0.53</td>
<td></td>
</tr>
</tbody>
</table>

F= female, M= male, H= healthy, LBP= Low Back pain, Con= concentric contraction, Ecc= eccentric contraction, Flex= flexion, Ext= extension, L= left side, R= right side, F/E= Flexion/extension ratio, AAHPERD= The American Alliance for Health, Physical Education, Recreation and Dance
For these reasons, many field and laboratory protocols have been developed to assess trunk muscle strength and endurance in sport, fitness, clinical and research settings.

Based on findings from 15 correlation studies, Prieske et al. observed only small-sized relationships between measures of trunk muscle strength and physical performance. In addition, the results of 16 intervention studies indicated only small-to-medium-sized effects of core strength training compared with no training or regular training on proxies of physical performance. Of note, Prieske et al. discussed a major limitation of their findings and questioned the external validity of the applied trunk muscle strength tests. Most included studies measured trunk muscle strength by means of a trunk muscle endurance test using an isometric plank test. Prieske et al. postulated that these tests do not appropriately evaluate maximal force production capacities in dynamic sport-specific activities.

Zinke et al. suggest that isokinetic trunk rotator training (8 weeks) in conjunction with canoe-specific training resulted in increased isokinetic trunk rotator torque (concentric) at slow and fast movement velocities. In addition, a strong relationship was found between peak isokinetic torque and peak paddle force (canoe-specific performance parameter).

**Isokinetic Assessment Relationship to Low Back Pain (LBP) Risk**

Typically, isokinetic trunk assessments examine joint range of motion, muscular strength, power and balance between agonists and antagonist muscles, as all of these variables are considered crucial for optimal performance whilst playing a role in reducing an athlete’s risk of injury. Muscle strength ratios are commonly tested to describe unilateral antagonist to agonist strength properties, functionality and imbalances. An increased antagonist/agonist imbalance may demonstrate failure of the antagonist muscles to produce enough strength to decelerate agonist maximal torque actions during a required movement, increasing the likelihood of muscle and ligament injuries during sports performance and functional activities. Therefore, unilateral imbalances have also been investigated as possible causes leading to a low back pain (LBP) condition. Some authors have detected an association between the episodes of BP and decreased trunk muscle strength. Some authors attributed this to the endurance of the trunk extensor muscles. However, other researchers failed to find any correlations between trunk muscles strength and back pain. Thus, the relation between trunk muscles strength and back pain occurrence need to be investigated. Trunk muscles strength cannot be accurately examined with conventional methods. The isokinetic dynamometer provides objective assessment of muscle function and can be used to study the relationship between the back pain and trunk muscles. Flexor/extensor imbalances have been tested as a possible cause of BP. The normal flexor/extensor ratio ensures that the flexor muscles produce sufficient contraction to decelerate the extensor muscles during trunk movements preventing ligament and muscle injuries during explosive or daily activities.

Gabr and Eweda obtained greater trunk flexor/extensor ratios at 120°/s among patients group, this means that trunk extension movements may result in more prominent trunk flexion strength than extension, resulting in a trunk strength imbalance. Likewise, Lee and his colleagues revealed a significant difference in the trunk flexor/extensor ratio between the healthy subjects and the BP sufferers. In contrast, Ripamonti and colleagues suggested that the flexor/extensor ratio cannot be considered as a predictive factor in patients with back pain.

**CONCLUSION**

Due to the importance of trunk strength, clinicians and coaches must know whether changes in strength over time reflect a real gain or loss, or are the result of the measurement error. Muscle assessment methods using an isokinetic dynamometer are considered reliable and reproducible, with high correlations to peak strength values and flexor/extensor ratios in children, adolescent, and adults. Therefore, the validity and reliability of data are important when assessing strength. However, caution should be exercised when interpreting position-specific isokinetic test results that measure trunk flexion (standing vs seated position). Still, there are indications that low-velocity movements are more reliable for measuring trunk strength.
In adolescence, boys appear stronger than girls, with higher values for trunk extensors. Trunk flexors and extensors ratios decrease with growth. Data of isokinetic muscle performance of the trunk seems to be correlated not only to anthropometric parameters but also to sports discipline and training volume. It seems that the effects of sport on the muscular strength of the trunk have both a preventive factor and a possible risk factor for low back pain. There is evidence for an association between high physical workloads and back injury.

For adults, trunk strength is usually greatest with sagittal plane extension versus flexion. Athletes displayed greater trunk torque and power than non-athletes. In terms of relationship to sports practice, the current literature has shown the principle of training specificity indicates that exercise choice should match the movement patterns and muscle actions of the sport as closely as possible if one is to achieve optimal levels of transfer. The sport-specific trunk motions involved in each sport can induce different muscular adaptations in the corresponding trunk muscles.

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