ABSTRACT

Background. Sport specific ergometers are important for laboratory testing (i.e. peak oxygen consumption (VO₂)) and out of season training.

Objectives. The purpose of this study was to compare cardiorespiratory variables during exercise on a double poling ergometer to a field test in elite sit skiers.

Methods. Three male and four female athletes from the Canadian National / Developmental team (17-54 years of age, six with complete paraplegia and one with cerebral palsy) completed a field test and a double poling ergometer protocol separated by at least 24 hours. Both protocols consisted of three maximal trials of skiing of three minutes duration separated by 1.5 minutes of rest. A wireless metabolic system and heart rate monitor were used to measure cardiorespiratory responses [peak heart rate, peak VO₂, and peak respiratory exchange ratio (RER)] during each test. Arterialized blood lactate was measured before the beginning of exercise, after each trial and at 5, 10 and 15 minutes post exercise.

Results. No significant differences existed between the field and ergometer tests for peak oxygen consumption (VO₂) (field = 34.7 ± 5.5 mL·kg⁻¹·min⁻¹ vs. ergometer = 33.4 ± 6.9 mL·kg⁻¹·min⁻¹). Significantly higher peak heart rate and RER were found during the ergometer test. Significantly higher lactates were found during the ergometer test after trial 2 and trial 3.

Conclusion. The double poling ergometer is similar to a field test for evaluating peak VO₂ in elite cross country sit skiers; however, the ergometer test elicits a higher heart rate and anaerobic response.

Key Words: spinal cord injury, aerobic power, lactate.

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INTRODUCTION
Sit-skiing is an event at the Paralympics which involves the athlete sitting in a sled on skis and propelling with poles over race distances ranging from 2.5 to 15 km (Figure 1). Physiological responses to sit skiing have never been evaluated.

Regular cross country skiing is characterized by repeated dynamic contractions over an extended period of time and requires a high level of sustained power output by both the upper and lower body.1-4 One physiological trait that has been associated with cross country skiing success is maximal oxygen consumption (VO\(_2\) max).5-8,10,11 The VO\(_2\) max is often measured in a laboratory setting on an ergometer, due to the technical problems related to testing in the field.12 The most common ergometers used to evaluate all types of athletes include treadmills, cycle ergometers, and arm crank ergometers.4,13 Testing for sports other than running or cycling lack specificity when using these ergometers;4,14 therefore, a variety of sport specific ergometers is required. Recently, a double poling cross country ski ergometer has been modified to accommodate cross country skiers with disabilities (sit skiers) and is often used during training during seasons without snow. The purpose of this study was to compare the cardiorespiratory and metabolic responses in elite sit skiers during simulated skiing on this ergometer in a laboratory setting with the same responses during an outdoor field test. The hypothesis was that no significant differences would exist between the laboratory and field tests for the cardiorespiratory and metabolic responses evaluated in this study.

METHODS
Subjects
Seven (three male and four female) subjects, aged 17 to 54 years, volunteered for this study. The subjects were recruited from the developmental and national Canadian Nordic ski teams. Subjects must have competed for a minimum of two years at an elite level which included national and international competitions. Four of the athletes were previously Paralympians, and one athlete was a multiple Paralympic medalist. Subject characteristics are shown in Table 1. The study was approved by the University of Saskatchewan Biomedical Research Ethics Board for research in human subjects. Written, informed consent was obtained prior to the start of the study.

Experimental Design
Throughout the study, all subjects were encouraged to undertake their normal training and diet. They were instructed to continue to be adequately hydrated, not eat two hours prior to the test, avoid strenuous exercise, and limit caffeine intake within six hours of testing. Prior to testing, body weight, height, and body composition were measured. Body weight was measured on a Toledo scale, accurate to the nearest 0.1 kilogram. Standing height was estimated based on arm span, age, and gender (Height = 0.75 (arm span) - 0.05 (age) + 4.04 (gender) + 40.91).15 Body composition was estimated with bioelectrical impedance. Briefly, the electrical impedance measurements (RJL instruments, Quantum II, Lincoln, MI) were undertaken with the subject lying in a supine position on a plinth. Any metal objects (bracelets, watches) that were known to affect these measurements were removed from the patient.

Four sets of electrical impedance measurements were taken between the following combinations of limbs on each subject as previously described by Desport et al.16 right upper and right lower limbs, right upper and left lower limbs, left upper and right lower limbs, and left upper and left lower limbs. For each hand-foot combination, the two receiving electrodes were placed at the level of the malleoli and proximal to the phalanges. The resistance and reactance for the four combinations were averaged and entered along with the patient’s age, height, and weight into the Cypress software available with the instrument for the calculation of percent body fat. Bioelectrical impedance is reliable (r=0.96) and valid.

Figure 1. A sit skier during the field test.
with good correlation to hydrostatic weighing ($r=0.95$).\textsuperscript{13}

Each subject then completed a field test (Figure 1) and a double poling ergometer protocol (Figure 2) in random order on separate days (separated by at least 24 hours). Each subject used their customized sit ski for both these test protocols. Both protocols consisted of three maximal trials lasting three minutes each, separated by 1.5 minutes of rest. A three-by-three minute repeat was deemed acceptable to achieve VO\textsubscript{2} peak based on previous research on able-bodied subjects.\textsuperscript{17,18}

Following each exercise protocol, each subject passively recovered for 15 minutes. Temperature and wind conditions were monitored during the field test, and laboratory temperature was constant at 21 degrees Celsius. Wind conditions were minimal during the field tests ($<1$ m/sec) and temperature varied between -4$^\circ$C to -15$^\circ$C. The field-testing track was designed by the national team coaches to simulate an actual race. Blood lactate was monitored before beginning testing, after each trial, and after exercise at 5, 10, and 15 minutes. Heart rate was monitored during and after exercise with a Polar heart rate monitor (Polar, Levittown, United States). A wireless metabolic system (Sensormedic VmaxST, Conshohocken, United States, or Cosmed K4B\textsuperscript{2}, Rome, Italy) was used to monitor gas exchange variables (oxygen uptake, respiratory exchange ratio, breathing frequency, and minute ventilation) during exercise. Although two different metabolic systems were used, all but one subject used the same metabolic system for both the field and ergometer protocols. The instrument was calibrated using 16% oxygen and 4% carbon dioxide prior to and after each test to ensure accuracy of the data. The volume transducer was calibrated using a 3 L syringe. The breath-by-breath measurements were recorded on to the wireless metabolic system during the test, downloaded to a computer after the test, and subsequently averaged over 20-second intervals for analysis.

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**Table 1. Subject characteristics.**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Injury</th>
<th>Age (Years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>%Body Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
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<td>171</td>
<td>61.0</td>
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<tr>
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<td>14.4</td>
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<tr>
<td>F3</td>
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<tr>
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</tr>
<tr>
<td>F5</td>
<td>CP</td>
<td>23</td>
<td>146</td>
<td>44.0</td>
<td>27</td>
</tr>
<tr>
<td>F6</td>
<td>L1-complete</td>
<td>45</td>
<td>165</td>
<td>63.2</td>
<td>37.5</td>
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<tr>
<td>M7</td>
<td>T11-complete</td>
<td>54</td>
<td>181</td>
<td>77.2</td>
<td>19</td>
</tr>
</tbody>
</table>

| Mean    | 37      | 165        | 64.5        | 21.6        |
| St. Dev.| 13      | 17         | 14.8        | 9.3         |

St. Dev. = Standard deviation  
M = Males  
F = Females  
T = Thoracic  
L = Lumbar  
CP = Cerebral Palsy  
*Subject was unable to attend body composition analysis.
The VO₂ peak was determined by the highest 20-second average from the three trials. Peak oxygen pulse was calculated as VO₂ peak (mL/min) divided by peak heart rate and was considered to be an indirect estimate of stroke volume.

**Statistical Analyses**

Data are expressed as means ± standard deviations. Intraclass correlation coefficients were calculated between variables on the field and ergometer tests. A repeated-measures analysis of variance (ANOVA) was used to determine if differences existed between means for the double poling ergometer and field test protocols for VO₂ peak, peak heart rate, peak oxygen pulse, peak respiratory exchange ratio, peak minute ventilation, and peak respiratory rate. A 2 (field vs. ergometer) x 7 (baseline, after each repeat, and 5, 10, and 15 minutes post-exercise) repeated-measures ANOVA was used to assess differences between conditions for blood lactate concentrations. A Tukey’s post-hoc test was used to determine differences between pairs of means on this last ANOVA. Statistical significance was set at p<0.05. Statistical analyses were carried out using Statistica, version 5.0 (StatsSoft Inc., Chicago).

**RESULTS**

Typical VO₂ responses during the two tests are shown for a single subject in Figure 3. During the three maximal intervals, the subjects consistently achieved a high VO₂ response. No significant differences existed in the peak responses of the relative or absolute VO₂ (Figures 4 and 5), oxygen pulse, respiratory rate, and minute ventilation between the double poling ergometer and the field test. However, the peak respiratory exchange ratio (field = 1.19±0.14 vs. ergometer = 1.35±0.11; P=0.02) and peak heart rate (field = 173±5 bpm vs. ergometer = 178±4 bpm, P=0.05) were significantly higher during the double poling ergometer protocol when compared to the field test (Table 2). A significant protocol by time interaction occurred for blood lactate levels.

The post-hoc analysis indicated significantly higher lactate levels for the ergometer protocol after trial 2 and trial 3, as shown in Figure 6. The intraclass correlation coefficients between protocols were 0.84 (p=0.023) for relative peak VO₂, 0.86 (P=0.015) for absolute peak VO₂ (Figure 7), 0.95 (P=0.005) for minute ventilation, 0.87 (P=0.012) for oxygen pulse, and 0.85 (P=0.019) for peak blood lactate. The intraclass correlation coefficients for peak heart rate (0.52; P=0.197) and respiratory rate (0.70; P=0.082) were not significant.

**DISCUSSION**

This study is the first to evaluate the cardiorespiratory responses of skiers with disabilities during sit-skiing, an event at the Winter Paralympics. The major finding of this study was the similar VO₂ peak values on the modified double poling ergometer compared to the field test. Wisloff and Helgerud performed research on able-bodied skiers and they also had similar VO₂ peak values on a field test compared to values on the double poling ergometer. In the current study peak heart rate was significantly higher during the ergometer protocol when compared to heart rate during the field test. Wisloff...
and Helgerud found similar heart rate results in able-bodied skiers.

A potential mediating factor that may have affected the subjects’ peak heart rate during the double poling ergometer protocol is the continuous resistance as compared to the varying speeds and tempos that occurred during the field test. The field testing course was designed to simulate an actual race with varying inclinations and turns, while the ergometer protocol maintained a constant resistance to the athlete. Therefore, the athletes may not have been able to reach their peak heart rate during the field tests due to short recovery periods (down hills and turns) throughout the testing course. There are two possible explanations for the similar VO2 responses and a lower heart rate response during the field test. There may be a difference in oxygen extraction at the muscle (arterial-venous oxygen difference; (a-v)O2 difference) or stroke volume responses between protocols.

Oxygen pulse, which denotes the oxygen utilization per heart beat is strongly correlated with stroke volume (r=0.84) but not with (a-v)O2 difference (r=0.15). The authors of the current study found no significant difference in peak oxygen pulse between protocols; therefore, it is likely that stroke volume was not significantly different between the two protocols. Therefore, a similar peak VO2 accompanied by a lower peak heart rate during the field test compared to the ergometer test was most likely due to higher (a-v)O2 difference during the field test. As mentioned above, the field test involves intermittent effort during the skiing course as one skis and then recovers during down hills and turns, whereas the ergometer test involves more continuous muscle contraction against the resistance of the ergometer. This may allow for greater blood flow to the muscles during the field test (as muscle recovers between contractions during down hills or turns), permitting a greater extraction of oxygen at the muscle from the blood, which would be reflected as a greater (a-v)O2 difference. Future research is needed with direct measures of arterial and venous blood across the exercising muscle to test this hypothesis.

The results indicated significantly higher lactate and RER values during the double poling ergometer protocol as compared to the field test, which suggest an increased anaerobic cost during the ergometer protocol. Although diet composition was not controlled before tests, this most

Figure 4. Mean values for relative VO2 ± standard deviations.

Figure 5. Mean values for absolute VO2 ± standard deviations.

Figure 6. Mean blood lactate values during various time points ± standard error. Ergometer test was significantly (P<0.05) greater after trial 2 and trial 3 compared to field test.

Figure 7. Correlation for absolute peak VO2 measured on the ergometer vs. field test.
likely had minimal influence on RER or lactate because all subjects belonged to the same training center where nutrition and hydration of athletes were carefully managed. Athletes at camp were supplied with and ate a similar breakfast each morning before testing. As mentioned earlier, the field test allowed small recovery periods which may have affected lactate results, by allowing increased lactate clearance through increased blood flow which could account for the lower lactate and RER.

One mediating factor that may have had an effect on all metabolic and cardiovascular values measured is environmental temperature. The average temperature was 21°C during the laboratory test and -8°C during the field test. Previous studies have demonstrated an increase in venous return, stroke volume, VO2, and a decreased heart rate in cold environments, while others have found contradictory results. The present study found no significant difference between the two protocols for the peak VO2 or oxygen pulse, suggesting little or no effect of the cold on these athletes.

The major limitation of the current study was the small sample size due to the uniqueness of this population. The small sample size increased the likelihood of a type II error (i.e. finding no difference between conditions when in fact there is a difference). Another limitation was the multiple comparisons which increased the likelihood of a type I error (i.e. finding a difference when in fact there is no difference). However, controlling for the type I error (i.e. use of a Bonferroni correction) was deemed too conservative with the lack of power from the small sample size.

CONCLUSION

In summary, the results suggest that a double poling ergometer protocol performed in the laboratory is comparable for measuring the peak VO2 to a field test in elite cross country sit skiing athletes. However, the field test elicits a significantly lower peak heart rate and a lower blood lactate and RER. This difference is most likely due to the continuous nature of the ergometer test compared to the more intermittent nature of the field test where the athlete alternates between periods of skiing and gliding depending on the section of the course.

REFERENCES


ABSTRACT

**Background.** Athletes often utilize compensatory movement strategies to achieve high performance. However, these inefficient movement strategies may reinforce poor biomechanical movement patterns during typical activities, resulting in injury.

**Objectives.** This study sought to determine if compensatory movement patterns predispose female collegiate athletes to injury, and if a functional movement screening (FMS™) tool can be used to predict injuries in this population.

**Methods.** Scores on the FMS™, comprised of seven movement tests, were calculated for 38 NCAA Division II female collegiate athletes before the start of their respective fall and winter sport seasons (soccer, volleyball, and basketball). Seven athletes reported a previous history of anterior cruciate ligament reconstruction (ACLR). Injuries sustained while participating in sport activities were recorded throughout the seasons.

**Results.** The mean FMS™ score and standard deviation for all subjects was 14.3±1.77 (maximum score of 21). Eighteen injuries (17 lower extremity, 1 lower back) were recorded during this study. A score of 14/21 or less was significantly associated with injury (P=0.0496). Sixty-nine percent of athletes scoring 14 or less sustained an injury. Odds ratios were 3.85 with inclusion of all subjects, and 4.58 with exclusion of ACLR subjects. Sensitivity and specificity were 0.58 and 0.74 for all subjects, respectively. A significant correlation was found between low-scoring athletes and injury (P=0.0214, r=0.76).

**Discussion:** A score of 14 or less on the FMS™ tool resulted in a 4-fold increase in risk of lower extremity injury in female collegiate athletes participating in fall and winter sports. The screening tool was able to predict injury in female athletes without a history of major musculoskeletal injury such as ACLR.

**Conclusion.** Compensatory fundamental movement patterns can increase the risk of injury in female collegiate athletes, and can be identified by using a functional movement screening tool.

**Key Words.** female athlete, sports injury, Functional Movement Screen™, injury risk factors

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INTRODUCTION
A variety of intrinsic factors predisposing athletes to injury have been documented in the literature, including agonist/antagonist muscle ratios for strength and endurance, structural abnormalities, female gender, pre-training fitness level, and history of prior musculoskeletal injury. More recently, neuromuscular control, core instability, and contralateral muscular imbalances have been suggested as other important intrinsic risk factors for injury. Contralateral imbalances may also present after injury has already occurred, resulting in muscular inhibition, compensatory strategies, or both. Much of the published literature on causative and contributing factors to sports injuries are retrospective, as well as demonstrate inconsistencies in definitions, populations, and methodology. In addition, many studies focus on impairments surrounding a single joint or involving individual muscles.

In an effort to bridge the gap between the pre-participation medical screening and performance testing, Gray Cook et al. developed the Functional Movement Screen™ (FMS™). The FMS™ consists of seven movement tests that are intended to quickly and easily identify restrictions or alterations in normal movement. According to Cook et al., the tool was designed to challenge the interactions of kinetic chain mobility and stability necessary for performance of fundamental, functional movement patterns. Such movements require controlled neuromuscular execution in a variety of occupational and athletic tasks. By adopting inefficient movement strategies, individuals may reinforce poor movement patterns that, despite achieving high performance, may eventually result in injury.

Few studies have formally investigated the use of the FMS™ and its ability to predict injury in the athletic population. Peate et al. studied the correlation between FMS™ performance and history of prior injury, as well as the impact of core stabilization intervention on injury rates and lost work time in 433 firefighters. After adjusting for the age of subjects and dichotomizing to either passing (score >16/21) or failing (score < 16/21), the odds of failing the FMS were 1.68 times greater in firefighters with previous history of any injury. In an unpublished manuscript, Burton incorporated the FMS™ in testing of 23 firefighter candidates entering 16 weeks of firefighter academy training. Although results of this study could not determine the ability of the FMS alone to predict injury or performance due to a small sample size, a relationship did exist between using the FMS combined with selected performance tests to identify injury predisposition. Kiesel et al. examined the relationship between FMS™ scores of 46 professional football athletes and the incidence of serious injury. Results of the study concluded that a score of 14 or less on the FMS was associated with an 11-fold increase in the chance of injury and a 51% probability of sustaining a serious injury over the course of one competitive season.

While considering these promising results, none of these studies have implemented the FMS™ as a screening tool for female athletes despite consistently higher injury rates in this group. Therefore, the purpose of this study was to determine if compensatory movement patterns predispose female collegiate athletes to injury, and if the Functional Movement Screen™ could be used to predict injury in this population over the course of one competitive season.

METHODS
Thirty-eight female student-athletes (mean age 19.24±1.20 years) participating in women’s collegiate soccer, volleyball, and basketball at an NCAA Division II institution during the 2007-2008 season volunteered for the study. An exclusively female population was selected in order to potentially observe a higher number of injuries, as females frequently experience increased injury rates compared to males in sport. Inclusion criteria for this study included females 18-26 years old who had not sustained an injury within the previous 30 days that prohibited full participation in pre-season practice and/or conditioning programs. Exclusion criteria included an injury sustained within the 30 days preceding testing that excluded the athlete from participating in practice and/or competition, or recent surgical intervention that limited the athlete’s participation in sport due to physician-imposed restriction.

Prior to commencement, approval for the study was obtained through the University of Findlay’s Institutional Review Board. All participants were asked to provide informed consent and fill out a medical history form prior to their involvement in the study. A preliminary pilot study was performed to examine the inter-rater reliability between the lead investigator and an independent scoring investigator who scored subjects based upon video recording of their respective testing sessions.
Subjects were tested within two weeks of the beginning of their respective competitive sport seasons. Subjects were asked to perform a series of movements using directions for testing as described by the authors of the FMS™. Testing was conducted by two investigators experienced in using the FMS™ in daily practice and scored by the lead investigator, and via video recording by an independent investigator (based on the criteria described by Cook et al.). The FMS™ consists of seven movement tests, described by Cook et al. that include: Deep Squat, Hurdle Step, In-Line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push-Up, and Rotary Stability.

Injuries sustained by each subject during in-season practices and competitions were reported. Weekly follow-up with the certified athletic trainers overseeing the respective sports of the subjects were used to track and monitor any injuries that occurred. The definition of injury that was utilized for the purpose of this study was a musculoskeletal injury that met the following criteria: (1) the injury occurred as a result of participation in an organized intercollegiate practice or competition setting; (2) the injury required medical attention or the athlete sought advice from a certified athletic trainer, athletic training student, or physician.

Data Analysis

Interrater reliability between the lead investigator and an independent scoring investigator was determined in a pilot reliability study of eight University student volunteers (5 female, 3 male). The investigators were licensed physical therapists with clinical practice emphasis in orthopaedic rehabilitation. The investigators reviewed the FMS™ instruction manual and watched the accompanying instructional videos prior to scoring study participants. The lead investigator and the independent investigator scored each subject separately via digital video recording. Model 2 intraclass correlation coefficients (ICC) were calculated for each test of the FMS as well as the composite FMS score.

For this study, a cut-off score on the FMS of 14 (maximum score = 21) was utilized to determine relationships between lower FMS score and injury. Kiesel et al. utilized a receiver-operator characteristic (ROC) curve to determine a cut-off score of 14 that maximized both sensitivity and specificity. To maintain consistency with Kiesel et al.'s findings, the same cut-off score was employed in this study for data analysis. A 2 x 2 contingency table was created, dichotomizing those above and below the predetermined cut-off composite score on the FMS, and those who incurred an injury from those who did not. A Fisher's exact test with a one-tailed p value of <0.05 was performed. The Fisher's exact test was chosen due to its ability to calculate a more exact P value with smaller sample sizes than a Chi-square test. Sensitivity, specificity, odds ratios and likelihood ratios with confidence intervals set at 95% (CI95) were also calculated. Correlation and regression analysis was used to establish whether the relationship between the composite FMS score and injury was strong enough to utilize the FMS as a predictor of sustaining a reportable injury. The ability to predict outcomes or characteristics that may predispose an athlete to sustaining an injury can be useful both clinically and in applied settings.

RESULTS

Descriptive subject data including age, height, weight, and sport participation for all subjects is presented in Table 1. Interrater reliability between the lead investigator and an independent scoring investigator were determined via intraclass correlation coefficients (ICC), displayed by test in Table 2.

The mean FMS™ score and standard deviation (SD) for all subjects (n = 38) included in the study...
was 14.3 ± 1.77 (maximum score of 21). For those individuals that sustained an injury, the mean FMS score was 13.9 ± 2.12, while those who did not sustain an injury had a mean score of 14.7 ± 1.29. Of those individuals who had a composite FMS score of ≤14 (n = 16), 68.75% of those individuals sustained an injury throughout their respective competitive season. Additionally, 81.82% of subjects who scored at or below 13 and 48.28% of subjects who scored at or below 15 sustained injuries. Average FMS™ scores for subjects in their respective sports along with number of injuries are reported in Table 3.

Utilizing the cut-off score of 14, as described by Kiesel et al, a 2 x 2 contingency table (Table 4) was produced that was utilized to determine a sensitivity of 0.579 (CI95 = 0.335 to 0.798); specificity of 0.737 (CI95 = 0.488 to 0.909); positive likelihood ratio of 2.200 (CI95 = 0.945 to 5.119); and an odds ratio of 3.850 (CI95 = 0.980 to 15.130). Those with an FMS score of ≤14 were found to be significantly more likely to sustain an injury (Fisher’s exact test, one-tailed, P = 0.0496). A strong correlation existed between injury and FMS™ score (r = 0.761, P = 0.021). Linear regression analysis for the data from all subjects (n = 38) produced results (P = 0.0748, r² = 0.5892) that did demonstrate a statistically significant relationship between FMS™ score and risk of injury. Non-linear regression analysis also did not produce significant results that would allow the use of the FMS™ to predict injury in this sample of female collegiate athletes.

Further analysis of the data revealed a strong correlation (r = 0.952, P = 0.0028) between composite FMS score and lower extremity injury when the shoulder mobility test was removed from the calculation of the composite FMS™ score for all subjects (n = 38). This resulted in a maximum FMS™ score of 18 from six tests (e.g., Squat, Hurdle-Step, In-Line Lunge, Active Straight Leg Raise, Trunk Stability Push-Up, and Rotary Stability).

Data analysis with exclusion of subjects with a previous history of ACL injury (n = 31) revealed similar findings to results of the entire study sample. The mean FMS™ score and standard deviation (SD) for the non-ACL subjects (n = 31) was 14.0 ± 1.76. For those individuals that sustained an injury, the mean FMS™ score was 13.6 ± 1.91, while those who did not sustain an injury had a mean score of 14.6 ± 1.45. Of those individuals who had a composite FMS™ score of ≤14 (n = 15), 73.33% of those individuals also sustained an injury throughout their respective competitive season. Furthermore, 81.82% of subjects who scored at or below 13 and 56.0% of subjects who scored at or below 15 sustained injuries. Average FMS™ scores for non-ACL subjects in their respective sports along with number of injuries are reported in Table 5.

The 2 x 2 contingency table for the 31 non-ACL subjects (Table 6) produced a sensitivity of 0.647 (CI95 = 0.383 to 0.858), specificity of 0.714 (CI95 = 0.419 to 0.916), positive likelihood ratio of 2.265 (CI95 = 0.921 to 5.568), and an odds ratio of 4.583 (CI95 = 0.994 to 21.127). Those with a FMS™ score of ≤14 were found to be significantly more likely to sustain an injury (Fisher’s exact test, one-tailed,

### Table 3. Average FMS™ score and number of injuries per sport (n = 38).

<table>
<thead>
<tr>
<th>Sport</th>
<th>Average FMS™ Score</th>
<th># Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>13.4</td>
<td>8</td>
</tr>
<tr>
<td>Volleyball</td>
<td>15.3</td>
<td>5</td>
</tr>
<tr>
<td>Basketball</td>
<td>14.6</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 4. 2x2 contingency table for all subjects (n = 38).

<table>
<thead>
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<th>FMS™ Score</th>
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<tr>
<td>≤14</td>
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<td>5</td>
<td></td>
</tr>
<tr>
<td>≥15</td>
<td>8</td>
<td>14</td>
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### Table 5. Average FMS™ score and number of injuries per sport, subjects without history of ACL injuries (n = 38).

<table>
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<tr>
<th>Sport</th>
<th>Average FMS™ Score</th>
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</tr>
</thead>
<tbody>
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<td>13.2</td>
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<tr>
<td>Volleyball</td>
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<td>4</td>
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<tr>
<td>Basketball</td>
<td>14.3</td>
<td>5</td>
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</tbody>
</table>

### Table 6. Contingency table for subjects without history of ACL injuries (n = 31).

<table>
<thead>
<tr>
<th>FMS™ Score</th>
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<th>NO</th>
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<td>≤14</td>
<td>11</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>≥15</td>
<td>6</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>


A moderate correlation existed between injury and FMS™ score ($r = 0.726$, $P = 0.046$). Linear regressions analysis for non-ACLR ($n=31$) subjects reached statistical significance ($P=0.0450$, $r=-0.8214$, $r^2=0.6748$) demonstrating a relationship between FMS™ score and risk of injury (Figure 1). Non-linear regression analysis did not produce significant results to use the FMS™ as an injury predictor in non-ACL injured subjects. Results of the statistical analyses conducted for this study are summarized in Table 7.

**DISCUSSION**

This study was performed to determine if compensatory movement patterns predispose female collegiate athletes to injury, and if the FMS™ could predict injury in the sample population. The hypothesis that compensatory movement patterns were related to injury was supported in the present study. A lower score on the FMS™ was significantly associated with injury, with 69% of those scoring 14 or less sustaining an injury, and experiencing a 4-fold increase in injury risk. The cut-off score of 14 or less that was determined by Kiesel et al was also significant for this study, despite distinct differences in subjects and methodology. Kiesel et al tested professional male football players who, in addition to their elite athlete status, experienced different sport and training demands compared to their female collegiate athlete counterparts. In addition, Kiesel et al limited their data collection to “serious” injury, defined as membership on the injured reserve, and time loss of a minimum of three weeks from normal training and competition.

The authors of the current study chose to adopt a more broad definition of injury for several reasons. First, the authors anticipated that the number of female collegiate athletes available for observation would be less than that studied with a professional football team. Second, the contact but non-collision nature of the represented women’s sports studied were thought to be less likely to result in a large number of severe, traumatic injuries more prevalent in a sport such as American football. Third, the authors wanted to include overuse and repetitive microtrauma injuries that may not have been accurately represented under a time-loss injury definition, yet still contribute to compensatory movement patterns and increased risk of more severe musculoskeletal injury. The basis for use of the FMS™ by Cook et al is the hypothesis that repetitive microtrauma caused by adoption of inefficient movement strategies may predispose individuals to musculoskeletal injury. The effects of repetitive microtrauma include overuse pathologies that the athlete is initially able to work through despite his or her symptoms. However, the

![Figure 1. FMS™ score and injury relationship.](image)

Table 7. Statistical summary.

<table>
<thead>
<tr>
<th></th>
<th>Fisher’s Exact Test</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>LR</th>
<th>Odds Ratio (95% CI)</th>
<th>Spearman Correlation</th>
<th>Adjusted* FMS™ Spearman Correlation</th>
<th>Linear Regression Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Subjects (n=58)</td>
<td>0.0496</td>
<td>0.579 (0.335-0.798)</td>
<td>0.737 (0.488-0.909)</td>
<td>2.200</td>
<td>3.850 (0.980-15.130)</td>
<td>r = 0.7608</td>
<td>r = 0.9515</td>
<td>r = -0.7676</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P = 0.0214</td>
<td>P = 0.0028</td>
<td>r² = 0.5892</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P = 0.0748</td>
</tr>
<tr>
<td>Non-ACL Subjects (n=31)</td>
<td>0.0495</td>
<td>0.0647 (0.383-0.858)</td>
<td>0.714 (0.419-0.916)</td>
<td>2.265</td>
<td>4.583 (0.994-21.127)</td>
<td>r = 0.7261</td>
<td>r = 0.0458</td>
<td>r = -0.8214</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P = 0.0458</td>
<td></td>
<td>r² = 0.6748</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P = 0.0450</td>
</tr>
</tbody>
</table>

CI – Confidence Interval; LR – Likelihood Ratio

*Adjusted FMS™ included all tests except the shoulder mobility test.
current study’s lack of a longitudinal design spanning multiple sport seasons may decrease its sensitivity to injuries involving repetitive microtrauma that could later progress to a more severe acute injury, easily recognized under a time-loss injury definition.

Of the 38 study participants, seven had previously sustained anterior cruciate ligament injury with subsequent reconstruction (ACLR). This injury represented the most significant type of traumatic injury recorded in participants’ past medical history, which could have had a significant impact on FMS™ performance and subsequent injury, and therefore data were analyzed both with and without inclusion of the previously injured subjects. However, significant correlation between an FMS™ score less than or equal to 14 and sustaining an injury during the season existed with or without inclusion of ACLR subjects, and the average FMS™ score actually dropped slightly in non-ACLR subjects (14.3 +/- 1.77) versus all subjects (14.0 +/- 1.76). The odds ratio for injury increased from 3.85 to 4.58 when ACLR subjects were excluded from analysis, demonstrating that a lower FMS™ score in non-ACLR subjects resulted in a higher risk of injury in that group. Although history of previous injury is usually considered a strong predictor of future injury, it is possible that a significant emphasis on lower extremity strength and neuromuscular control was employed in the rehabilitation of subjects post ACLR, and that such training may have positively impacted their FMS™ scores.

The hypothesis that the FMS™ could be used to predict injury in female collegiate athletes was partially supported in the current study. Regression analysis using a linear model was able to establish a predictive relationship between a FMS™ score and the risk of injury, but only for subjects without history of ACLR. When expanded to include all subjects, the linear regression model failed to reach statistical significance, most likely due to a lack of power from a small sample size. The data for the non-ACLR group may have provided better predictive results due to the exclusion of subjects that had suffered serious musculoskeletal injury. As history of previous injury (ACLR) is a strong independent risk factor for future injury, the potential for interaction between FMS™ performance and changes to the neuromusculoskeletal system that may occur after ACLR are unknown in the present study. Further analysis using a non-linear model yielded no predictive capabilities.

The population for this study, a sample of convenience, was limited to fall and winter sports (soccer, volleyball, basketball) that were primarily lower-extremity dominant in nature. Although volleyball players are overhead athletes, the number that participated (n = 11) may not have been sufficient to detect upper extremity injuries, as no injuries to the upper extremity were reported.

A trend was noted regarding the performance of the Shoulder Mobility and Trunk Stability Push-Up in female subjects. The majority of subjects (74%, n = 28) obtained the highest score of 3 on the Shoulder Mobility test, with many greatly exceeding the required measurements for shoulder/thoracic flexibility indicating joint hypermobility. Conversely, only 5% (n = 2) of female subjects scored a 3 on the Trunk Stability Push-Up. As females are more likely to exhibit glenohumeral joint laxity and symptomatic instability as well as decreased upper body strength compared to males, these factors are likely influential in upper-extremity focused tests of the FMS™ in female athletes. With exclusion of the Shoulder Mobility test, the remaining FMS™ test cluster demonstrated improved correlation, from 0.761 (P = 0.021) to 0.952 (P = 0.0028) with the lower extremity/core injuries observed. However, additional removal of the Trunk Stability Push-Up had a negative effect (r = 0.698, P = 0.136). This demonstrates that the Trunk Stability Push-Up may indeed be more sensitive to core stability issues versus upper extremity strength, via the established connection between core instability and lower extremity injury.

A lower score on the FMS™ has previously demonstrated predictive ability in the male athletic population, and was shown to be a predisposing factor for injury in females in the present study. Although this study was only partially successful in establishing a predictive utility for the FMS™ in female athletes, observation of a limited sample size over a single season may not have provided the appropriate framework from which to draw conclusions. Future studies incorporating a larger, more diverse sample of female collegiate athletes, including those participating in upper extremity-dominant sports (e.g. softball, tennis, field events) are warranted in order to determine if the FMS™ can be used to predict injury in a more diverse population of female collegiate athletes. Future studies may also find that certain components of the FMS™ may be used independently to predict injury in various athletic subgroups. However, the concept of energy transfer throughout the kinetic chain underscores the appropriateness of adminis-
tering the entire test battery within the FMS™, as the complex interaction of core stability with distal extremity control is required in most sporting activities.

CONCLUSION
Compensatory fundamental movement patterns can increase the risk of injury in female collegiate athletes, and can be identified by using the Functional Movement Screen™. A score of 14 or less on the FMS™ resulted in an approximate 4-fold (3.85-4.58) increase in risk of lower extremity injury over the course of a competitive season in female collegiate athletes participating in fall and winter sports including soccer, volleyball, and basketball. The FMS™ may be able to predict injury in a subgroup of female collegiate athletes without a history of major musculoskeletal injury such as ACL reconstruction.

REFERENCES


ABSTRACT

**Background.** Many sports involve movements during which the lower extremity functions as a closed kinetic chain, requiring weight-bearing (WB) range of motion (ROM). Assessment of the capacity for internal and external rotation motion at the hip is typically performed with the individual in a prone, supine, or seated position. Such measurements represent ROM in a non-weight bearing (NWB) position, and, as a result, may not appropriately assess the capacity of the joint to meet the demands of the athlete’s sport. To date, no research exists which documents WB hip ROM in golfers relative to the ROM demands of the golf swing or the symmetry of weight-bearing hip rotation ROM in female golfers.

**Objectives.** Weight-bearing hip rotation ROM was measured in female golfers and compared to the actual hip rotation ROM that occurred during a full golf swing.

**Methods.** Fifteen right-handed, female collegiate golfers participated in the study. The WB hip rotation ROM was measured during three different stance conditions and during full golf swings using a custom-built testing device. These actions were captured using a 3-D motion analysis system.

**Results.** The golfers WB ROM was symmetrical for external rotation and internal rotation, $p = 0.648$ and $p = 0.078$, respectively. During the backswing, the golfers used approximately 20-25% of their available WB right internal rotation, and 50-75% of their available WB left external rotation. For the downswing, the golfers used approximately 34-37% of their available WB right external rotation and 84-131% of their available WB left internal rotation. The golfers used significantly more external and internal hip rotation ROM on the left (lead) hip during both phases of the full golf swing ($p < 0.001$), demonstrating an asymmetrical movement pattern.

**Discussion.** In general, golfers did not exceed the measured WB ROM limits during the golf swing but did demonstrate decreased WB internal rotation on the lead hip.

**Conclusion.** Clinicians need to pay special attention to functional (WB) hip rotation ROM in female golfers in order to assess injury risk related to the rotational hip asymmetry present during the golf swing.

**Key Words:** golf, hip rotation ROM, symmetry

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INTRODUCTION

Several studies\(^1\)\(^-\)\(^8\) have examined hip range of motion (ROM) in athletes and other healthy adults, but the normative values that they report appear to be somewhat different. Part of the reason for such discrepancies may be that there have been different methodologies employed regarding the type of motion measured (active vs. passive), as well as in the position used during the measurement (prone, supine, or seated). Despite this variability, common agreement exists that passive ROM is greater than active ROM\(^9\).

Interestingly, most activities of daily living, as well as sports, occur with a majority of the time spent in weight-bearing (WB). However, when assessing available joint ROM, measurements are frequently performed in non weight-bearing (NWB). Currently, no published normative data exists regarding available WB hip rotation ROM’s. For the athlete, a more functional assessment in the WB position may be required to determine if there is an adequate amount of hip rotation ROM necessary for a particular sport, skill, or motion.

Golf is a non-contact sport; however, injuries do occur. The leading site of injury among both professional and amateur golfers is the spine\(^10\)\(^-\)\(^12\). Interestingly, of the available injury survey studies, very few report hip injuries\(^12\)\(^-\)\(^18\). Although a small number of reported cases of hip injuries in golfers exist, Cibulka\(^1\) has described an association between low back pain and hip rotation ROM asymmetry in the non-golfing population. Currently, the normal or typical amount of hip rotation the lead and trail hip each undergo during the full golf swing is unknown.

If the repetitive motion of the golf swing occurs in an asymmetrical movement pattern, then asymmetrical hip rotation ROM may develop. Thus, a critical link may exist between golfers' available hip rotation ROM and their susceptibility to low back pain.

One recent investigation examined the association between low back pain and hip rotation ROM in Professional Golf Association (PGA) golfers\(^19\). The authors found a decreased amount of internal rotation on the lead hip in those with low back pain and a similar, although non-significant trend, in healthy golfers. As a result of that study, whether playing golf repetitively alters side-to-side hip rotation ROM symmetry or if low back pain creates the asymmetrical measurement is unknown. But, due to the fact that there was a similar trend in healthy golfers, this may suggest that playing golf repetitively could alter side-to-side hip rotation ROM. Further support for side to side asymmetry exists in a recent study published by Gulgin et al.\(^20\). They found almost one-fourth of a group of Ladies’ Professional Golf Association (LPGA) golfers showed a side-to-side asymmetry of more than five degrees in IR. Thus, these previous investigations provide an indication that a golfer's hip rotation ROM may adapt to the demands placed upon the hip.

Currently, no data exist documenting WB hip rotation in golfers or data that illustrates the actual amount of hip rotation ROM that occurs during the full golf swing. Thus, the purpose of this study was to measure WB hip rotation ROM in female golfers during the full golf swing and compare this to their available WB hip rotation ROM as measured in varied stance positions.

METHODS

Fifteen female golfers (mean age 19.6 ± 1.4 yrs; ht. 163.3 ± 6.5 cm; wt. 59.5 ± 6.6 kg; hdcp 5.2 ± 3.3) participated in the study. All subjects were right-hand dominant, played right-handed, and were screened to exclude those with a history of any hip or back pain within the past six months. Prior to participation, subjects signed a written consent form as approved by the University of Toledo Human Subjects Research Review Committee.

The subjects reported to the laboratory on one occasion. Prior to the WB ROM measurements, all subjects pedaled for five minutes on a stationary bicycle as a general warm-up. The available WB ROM of hip rotation was measured under three stance conditions, and then subjects performed approximately ten full golf swings with a driver. Video data of all the trials (WB ROM and golf swing) was collected. A three-dimensional (3D) motion capture system (Motion Analysis Corporation, Santa Rosa, CA) was used to quantify the hip rotation movements of each subject (Figure 1). The EVa 7.0 and KinTrak software (Motion Analysis Corporation, Santa Rosa, CA) were used for all data acquisition and processing. Eight Falcon High Resolution cameras (Motion Analysis Corporation, Santa Rosa, CA), sampling at 120 Hz were used for capturing the movement of the reflective markers on each subject. The various markers were placed on all subjects by the same investigator over the anatomical landmarks listed in Table 1. For obtaining WB hip rotation measurements, subjects stood on a custom-built wooden base so that one foot was fixed (stable), while the other foot (the involved leg...
The subjects were asked to maintain equal weight distribution on the right and left lower extremities during the measurement. All subjects were measured in three different WB conditions. For Condition A (WBa), the subject stood erect (hips and knees extended) with the stance width equal to the distance between the greater trochanters. Reliability for repeated measurements of hip rotation ROM measured in Condition A (WBa) was 0.819 (Cronbach’s Alpha), and thus, the set up was used for the remainder of conditions as well. For Condition B (WBb), the subjects stood erect (hips and knees extended) with stance width equal to the distance between the lateral border of feet when using a self-selected golf set-up position (for a driver). For Condition C (WBc), subjects were positioned in the same stance width as Condition B, but also with the amount of hip and knee flexion used during the self-selected golf set-up position (for a driver). For each condition, the rotating foot was aligned on the center of the board (with a tape line down for alignment). However, the starting angle of the entire rotating board was positioned to represent the subject’s natural toe-in or toe-out position. Depending on which direction was being measured, the subject was asked to rotate the foot externally (or internally) as far as possible, and then return to the start position. Measurements of maximum hip IR and ER were performed bilaterally, repeating the full movement six times in each direction. In order to maintain the level of flexion in the hip and knees during data collection (WBc), the subject’s initial start position was reset (using a goniometer) after every two trials. The three trials that required the least editing to produce complete marker paths were selected, tracked, processed, analyzed and the ensemble was averaged to examine the available WB hip rotation ROM. When processing the available WB ROM, any pelvic movement (ASIS vector) that occurred during the trial was subtracted from the maximum amount of foot rotation.

**Table 1. Anatomical landmarks for marker placement**

<table>
<thead>
<tr>
<th>Marker Location</th>
<th>WB ROM Trials</th>
<th>Full Golf Swing Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B) anterior superior iliac spine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>sacrum</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) greater trochanter</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) anterior thigh (mid)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) lateral femoral condyle</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) tibial tuberosity</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) mid tibia (medial)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) low tibia (lateral)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) lateral malleolus</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) calcaneus</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) 5th metatarsal</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) 3rd toe</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(B) acromion</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>(B) lateral humeral epicondyle</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>(B) wrist (dorsum)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>anterior forehead</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>clubhead</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>club shaft (distal to grip)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>ball</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

B = bilateral

For the assessment of the golf swing, an expanded marker set (Figure 3, Table 1) was placed on each golfer (by the same investigator), and ten golf swings were recorded. Practice swings were allowed for warm-up, as well as to allow the subject to feel comfortable performing a golf swing with the marker set in place. Each golfer...
assumed their natural stance width (as measured previously) and performed the swing with a standard 45° driver. As with the WB ROM trials, the full golf swings were captured at 120 Hz. For each subject, the three trials were selected (all by same investigator) in the same manner as previously mentioned to determine for each hip the maximum internal rotation and external rotation that occurred during the golf swing.

Statistical data analysis was performed using Statistical package SPSS version 14.0 (SPSS Inc., Chicago, IL). The significance level was set at an alpha level of 0.05. Two separate two way (side x condition) repeated measures ANOVA’s were utilized, one for internal rotation and one for external rotation. A post-hoc analysis was performed to verify where significant differences occurred across the conditions. For comparison of rotational hip motion ROM during the backswing and downswing phases a two way ANOVA (side x rotation) was run to test for a difference in the amount of rotation present in each hip.

RESULTS

The means and standard deviations for subject demographics are shown in Table 2. The mean stance width for WBa was less than WBb & WBc (43.0 ± 2.6 cm vs. 59.5 ± 4.6 cm respectively, Table 3). The mean hip and knee flexion used in WBc was 38.7 ± 6.0 degrees and 24.7 ± 7.0 respectively (Table 3).

For external rotation WB ROM, no significant difference occurred between sides (p = 0.648), a non-significant interaction (p = 0.908), but a significant difference existed between conditions (p < 0.001). Post-hoc analysis reveals that WBb ROM was significantly greater than WBa in the right hip (p = 0.013, Table 4) and was approaching a significant difference in the left hip (p = 0.055, Table 4). The ER rotation measured in the WBc was significantly greater than that measured in WBb in the right hip (p < 0.001, Table 4), but was not significantly greater in the left hip (p = 0.12, Table 4). The right and left hip demonstrated symmetrical WB external rotation. However, the external rotation increased significantly in the right hip (and not the left hip) by first increasing stance width, and increased even more by adding hip and knee flexion into the measurement posture. Although the left hip experienced the same amount of increase in external rotation ROM across the three stance conditions, the standard deviations were larger on this side, potentially keeping them from the significant finding on the left hip.

For internal rotation WB ROM, no significant difference existed between sides (p = 0.078), a non-significant interaction (p = 0.890), but significant difference existed between conditions (p < 0.001). The means and standard deviations (Table 4) revealed that the left hip has approximately two degrees less internal rotation ROM in all conditions which is not statistically nor clinically significant. Post-hoc analysis revealed that WBa ROM was not significantly different from WBb in either the right hip, p = 1.0 or the left hip, p = 1.0 (Table 4). However, the WBc group was significantly greater than WBb in the right hip, p = 0.002 and the left hip, p = 0.001 (Table 4). Thus, for WB internal rotation, widening the stance did not significantly alter available ROM, but adding hip and knee flexion did.

When examining the amount of WB ROM the golfers used during the full golf swing compared to the WB values obtained during the three WB conditions, they did not exceed the available internal rotation or external rotation WB ROM on the right (trail) hip at any point during the golf swing (Table 5). However, during the downswing, the mean left (lead) hip internal rotation was 34.8 ± 11.7 degrees, which exceeded the golfers WB ROM available as measured during two of the WB stance conditions (WBa, WBb, Table 5). But, when the

<table>
<thead>
<tr>
<th>Descriptives</th>
<th>Mean ± SD (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>19.7 ± 1.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163.3 ± 6.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.6 ± 6.6</td>
</tr>
<tr>
<td>Handicap</td>
<td>5.2 ± 3.3</td>
</tr>
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</table>
golfer’s WB ROM was measured in a similar position to that used during the golf swing (condition WBc), the golfers did not exceed the available internal rotation WB ROM (Table 5).

During the backswing phase of the golf swing, the maximum right hip internal rotation was 8.9 ± 4.8 degrees, which was significantly less than maximum external rotation, 29.7 ± 11.3 degrees; p < 0.001 (Table 5), of the left hip that was occurring at the same time. During the downswing, the subjects demonstrated the same pattern, as right hip external rotation of 14.9 ± 9.6 degrees was significantly less than left hip IR, 34.8 ± 11.7 degrees; p < 0.001 (Table 5). Thus, it would appear that the left (lead) hip experienced more rotation than the trailing hip throughout the backswing and downswing phases of the golf swing, demonstrating an asymmetrical movement pattern.

DISCUSSION
Since the position of the hip joint during measurement influences the results, it may be inferred that tension on the hip capsule affects this measurement. When the hip is flexed, the capsule and ligaments have more laxity, which should allow for more movement relative to a neutral hip joint (more taut hip capsule and ligaments). However, the literature refutes this line of thought, showing more hip rotation in a prone position when compared to measurements taken in a seated position. These hip rotation ROM values may then suggest that muscle length, as a result of the joint position, could be the limiting factor.

The current study revealed that less WB ROM occurred when standing erect or in hip neutral (WBa & WBb) than when hip and knee flexion were added, which places the joint capsule on slack. Thus, the results of the current study conflict with Bierma-Zienstra et al and Simoneau et al, in that, when in WB, the tautness of the hip capsule and ligament structures appear to have more of a limiting role than when measured in non-weight bearing (NWB). The studies by Bierma-Zienstra et al and Simoneau et al measured hip rotation ROM actively (NWB), which was similar to this study, as the WB measurement required active ROM. However, several factors contribute to joint ROM, such as the capsule, ligaments, surrounding muscle length, and bony congruency, making it difficult to identify the factor that was the greatest contributor to the rotational limitation.

In order to further examine the role that muscle length might play in hip rotation ROM, altered stance positions...
were used during data collection. Among the three stance conditions used in this study, there was variation in length of the surrounding hip musculature. For example, comparing WBA to WBB, an increase in stance width occurred in WBB, resulting in greater hip abduction. This increase in hip abduction shortens the adductors and lengthens the adductors, which may have limited the active tension that these muscles could generate to contribute to internal rotation or external rotation, limiting the WB ROM. For example, the gracilis muscle is considered an internal rotator of the hip and becomes stretched in condition WBB as hip abduction is increased. The gluteus minimus muscle can contribute to internal rotation when the hip is abducted, which could make up for the lengthened gracilis muscle. No change in WB internal rotation occurred between condition WBA and WBB on either hip (Table 4).

As for WB external rotation, a significant difference in ROM existed between condition WBA and WBB (increase in hip abduction) for the right hip, while for the left hip the difference approached a significant difference (p = 0.055). The WBB stance condition was associated with approximately 8-9 degrees more of external hip rotation than when measured in WBA condition (Table 4). When increasing the stance width and hip abduction, the gluteus medius, gluteus minimus, and tensor fascia latae muscles (all capable of producing external rotation) become shortened. But, the adductor brevis, adductor magnus, and pectineus muscles (all capable of external rotation) are lengthened. For WB external rotation, the change in muscle length of the involved musculature appeared to allow for more external rotation.

When going from a stance with an erect posture (WBA and WBB) to a stance with added hip and knee flexion (WBC), an 11-12 degree increase in WB external rotation and a 13-14 degree increase in WB internal rotation occurred (Table 4). In addition to the increased laxity in the hip capsule, most of the internal rotators are put on slack in the position of hip flexion (anterior gluteus medius, and tensor fascia latae muscles) and thus are not limiting the measurement, allowing for such an increase. However, the external rotators would be lengthened with the additional hip flexion, but not at such a length that would limit the significant increase in WB external rotation.

Prior to this study, the characteristics of weight bearing internal and external hip rotations during a golf swing had not been documented. The results of the current study demonstrate that significantly more external and internal rotation occurs on the left (lead) hip during both the backswing and downswing phases (Table 5) than on the right (trail) hip. Thus, the golf swing necessitates an asymmetrical pattern of internal rotation and external rotation between the two hips. Previous research has shown that golfers do present with side-to-side differences in their hip internal rotation ROM, which would appear to be linked to this repetitive movement pattern. When examining golfers in a prone, NWB condition, Vad et al found a significant difference in side-to-side internal rotation in a sample of professional golfers. In that study, the lead hip demonstrated less internal rotation than the trail hip. Although the significant difference was only evident in the golfers with low back pain, the trend was present for healthy golfers as well. Further supporting Vad et al, was the recent study by Gulgin et al that found almost one-fourth of a sample of female professional golfers had side-to-side asymmetry between the lead and trail hip of more than five degrees in internal rotation. Vad et al measured active hip rotation ROM and Gulgin et al measured passive hip rotation ROM. Although these previous investigations measured hip rotation ROM in a NWB condition, it appears that golfer's hip rotation ROM adapts to the demands placed on it by the dynamic asymmetry of the golf swing. In the current study, WB internal rotation was approximately two degrees less, although not significant, on the left (lead) hip in comparison to the right (trail) hip (Table 4). This result adds to the body of evidence of the adaptation in the golfer's lead hip internal rotation ROM, regardless of the measurement technique (NWB or WB) used.

The clinical relevance for asymmetrical hip rotation ROM between the right and left hip is that the function of the body's kinetic chain may be altered. In particular, there is a link with the spine, pelvis, and hip. When ROM is limited in one of the movement regions, the others may also be affected. In order to maintain function, when ROM is limited in one of these segments, adaptation in the movement of others is generally necessitated. The investigation of Cibulka et al have shown that an association exists with asymmetrical hip rotation ROM and low back pain. This finding suggests that golfers who development asymmetrical hip ROM as a result of the mechanics of the swing may be at an increased risk for low back pain over the course of their career. Interestingly, low back conditions have been
reported to be the leading injury complaint among both professional and amateur golfers.10-18

Another important clinical consideration involving hip ROM is that involving the influence of hip ROM on excessive stress on the surrounding soft-tissue of the hip, which would appear to be of particular concern when the available WB ROM is not adequate to accommodate the demands of a full golf swing. The results revealed that the golfers tested did not exceed their available WB external rotation ROM on either the backswing or downswing phases (Table 5). However, the golfers averaged 34.8 ± 11.7 degrees of internal rotation on the left (lead) hip during the downswing, which exceeded their available WB ROM as measured in condition WBa and WBb. For WBa condition, the golfers required 131.3% of their available internal rotation WB ROM on the lead (left) hip, and for condition WBb, they required 127.9% of their available internal rotation WB ROM (Table 5). However, when the internal rotation WB ROM used during the golf swing is compared to a condition most similar to that used during the golf swing (WBC), the subjects did not exceed their available internal rotation WB hip rotation ROM on the lead (left) hip (Table 5). Thus, if golfers become fatigued or change their address posture (do not set up with enough flexion in the hip and knees) during a round of golf, they may begin to exceed their available WB internal rotation ROM and risk injury.

While this study provides important information about WB hip ROM and the associated hip ROM during the golf swing, several limitations exist that should be considered. First, the amount of the subject’s hip torsion (anteversion or retroversion) was not taken into consideration. Participants who have a greater anteversion or retroversion angle might show limitations in one of the hip rotation measurements, while possibly having more in the opposite rotational direction. Second, tibial motion, or other kinematic contributors, may have acted differently when the knee was not flexed (condition WBC) compared to when the knee was not flexed (condition WBa). The transverse plane movements of the knee or foot was not measured, because this study only focused on hip motion; thus, the influence of these other factors cannot be directly assessed for their relative contributions. The separate contributions of the lower extremity joints and anatomic factors during a transverse plane movement are areas that need to be addressed in future research. Third, the WB ROM measurements were assessed while each subject maintained equal weight distribution between the right and left sides. During the golf swing, weight shifts to the right (trail) hip during the backswing and toward the left (lead) hip during the downswing. Alterations in weight distribution may influence hip joint kinematics.

CONCLUSION

The female golfers demonstrated symmetrical WB hip rotation ROM for IR and ER, but did demonstrate a slight decrease in WB internal rotation on the lead hip. In general, golfers did not exceed the measured WB ROM limits during the golf swing, but used significantly more hip rotation ROM on the lead hip, creating an asymmetrical movement pattern. Thus, for the athlete, WB assessment of hip ROM may be more functionally relevant than traditional NWB or more appropriate for the determination of adequate ROM for a particular sport task. Future research should focus on examination of the association between the required ROM demands of a specific sport and the amount of WB ROM available in athletes who participate in those sports. An athlete who does not have the available WB ROM needed for their sport movement may increase their risk of injury by placing excessive stresses on the relevant soft-tissues associated with the involved joint.

REFERENCES


ABSTRACT

Background. The transversus abdominis (TrA) is a spine stabilizer frequently targeted during rehabilitation exercises for individuals with low back pain (LBP). Performance of exercises on unstable surfaces is thought to increase muscle activation, however no research has investigated differences in TrA activation when stable or unstable surfaces are used.

Objective. The purpose of this study was to investigate whether TrA activation in individuals with LBP is greater when performing bridging exercises on an unstable surface versus a stable surface.

Methods. Fifty one adults (mean ± SD, age 23.1 ± 6.0 years, height 173.60 ± 10.5 cm, mass 74.7 ± 14.5 kg) with stabilization classification of LBP were randomly assigned to either exercise progression utilizing a sling bridge device or a traditional bridging exercise progression, each with 4 levels of increasing difficulty. TrA activation ratio (TrA contracted thickness/TrA resting thickness) was measured during each exercise using ultrasound imaging. The dependent variable was the TrA activation ratio.

Results. The first 3 levels of the sling-based and traditional bridging exercise progression were not significantly different. There was a significant increase in the TrA activation ratio in the sling-based exercise group when bridging was performed with abduction of the hip (1.48 ± .38) compared to the traditional bridge with abduction of the hip (1.22 ± .38; p<.05).

Conclusion. Both types of exercise result in activation of the TrA, however, the sling based exercise when combined with dynamic movement resulted in a significantly higher activation of the local stabilizers of the spine compared to traditional bridging exercise. This may have implications for rehabilitation of individuals with LBP.

Trial Registration: NCT01015846

Key Words. Core stability, rehabilitation, Rehabilitative Ultrasound Imaging

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Redcord, AS provided the exercise equipment necessary for this study.
BACKGROUND

Low back pain (LBP) is a significant problem that affects approximately 50% of the population.¹ The majority of individuals with recurrent episodes of LBP do not have an identifiable structural diagnosis.² A treatment-based classification system has been developed to identify similarities among subsets of individuals with LBP so that clinicians can select appropriate interventions to improve outcomes.³, ⁴ One subset of the classification system includes individuals who are thought to benefit from spine stabilization exercises.⁵-⁷

The stabilization classification is a subgroup of patients who experience LBP as a result of faulty neuromuscular control, rather than from true ligamentous instability.⁸, ⁹ Muscular injury, fatigue, or facet or disc degeneration can compromise the stabilizing effects resulting in shearing forces that cause the pain.¹⁰ A decrease in muscular control can have damaging effects on postural control and intersegmental stability which may lead to degeneration of spinal structures.¹⁰ Therefore, this subgroup of patients would likely respond to a spinal neuromuscular rehabilitation program that targets the spinal stabilizers.

The abdominal drawing-in maneuver (ADIM) has been described as the best way to activate the TrA¹¹-¹⁴ and is often a fundamental exercise in a traditional stabilization program for LBP.¹⁵, ¹⁶ The ADIM is an inward movement of the lower abdominal wall in which the patient is instructed to draw the umbilicus toward the spine.¹⁵, ¹⁶ A key feature is to teach the patient to preferentially activate the TrA while maintaining relaxation of the more superficial musculature (rectus abdominus, external oblique). The ADIM is often used to facilitate the re-education of neuromuscular control mechanisms provided by the local stabilizing muscles.¹⁸ This training of the TrA has been shown to improve pain and function in patients with chronic LBP¹⁷-¹⁹ because activating these muscles is thought to assist in dynamic spine stabilization during functional tasks.²⁰

Once the motor skill of the ADIM is taught, it is combined with varied postures including supine or prone and advancing from stable to increasingly unstable surfaces.²⁶, ²⁷ The traditional stabilization exercise interventions have been successful at treating LBP²⁷, ²⁸-³⁴ however there is often recurrence of LBP that has been illustrated in several studies.²⁰, ²⁵-³⁰ This recurrence rate may be an indicator that patients may be performing these exercises without properly activating the TrA or that a timing dysfunction exists. Hodges et al.²⁵ proposed that the TrA contracts prior to limb movement in healthy individuals, while the pre-activation is poor in those with LBP. Exercise intervention should focus on the best method to target the stabilizing musculature, and therefore the recruitment of the TrA during specific exercises should be examined.

Sling exercise therapy has been proposed to activate local spine stabilizers during the activity in a pain free manner without substitution of global muscles.²⁶ Sling therapy exercise is performed while the pelvis or lower extremities are supported or suspended in a sling (Figure 1). The exercises can be made easier by providing assistance with a sling and elastic cord to offset body weight, or made more difficult by providing an unstable surface to perform the exercises. The patient must bear weight through the cords and balance him or herself during the exercise. Stuge et al. found that doing specific stabilization exercises using sling exercise therapy in post-partum women with pelvic pain was effective in reducing pain, improving functional status, and improving health-relating quality of life after a 20 week intervention²⁷ and at a 2 year follow up.²⁸ However, the underlying mechanism for improvement in their outcomes was unknown. Stuge proposed that increased activation of local stabilizer muscles with the sling exercise therapy may have contributed to improved outcomes compared to traditional therapy.

Rehabilitative Ultrasound Imaging (RUSI) is a non-invasive method to visualize the lateral abdominal wall and qualitatively and quantitatively assess deep muscular activity with exercise. Muscle thickness change during the ADIM has been validated with EMG studies²⁹, ³⁰ and is an indicator of muscle activation.¹⁶, ³¹ The TrA

Figure 1. Sling exercise.
activation ratio has been developed to examine the recruitment of the TrA during an active contraction, thus normalizing the measurement to the resting thickness of the muscle. Therefore, comparisons in the TrA activation ratio during specific therapeutic exercise interventions can help identify those exercises that preferentially recruit the local stabilizers. The purpose of this study was to compare the TrA activation ratio during a progression of traditional stabilization exercise to a similar progression of sling based exercise.

Methods
Study Design
A randomized trial with one between factor, exercise group (standard bridge, sling bridge) and one within factor, level of exercise (decreasing support) was used to examine the effects of exercise on TrA activation ratio. The main outcome variable was the ratio of TrA thickness during the exercise versus in the relaxed position (TrA activation ratio).

Sample size calculations indicated the number of participants required was 24 per group in order to detect a 0.3 difference in TrA contraction ratio between groups. This was based on standard deviations (0.36) from a previous study, an a priori significance level of P= 0.05 and a power of 0.80.

Subjects
Fifty-one adults aged 18-53 with a current episode of LBP were recruited to participate in this study (males=8; females=33). Demographic information is found in Table 1. Subjects were recruited from the university community and from an athletic therapy clinic. The subjects met either 3 out of 4 criteria that categorized them in the lumbar stabilization classification or 6 criteria for best-fit categorization (Figure 2). The criteria for the lumbar stabilization classification clinical prediction rule were patients that are a younger age (<40), greater flexibility including hamstring range of motion of 91º, positive prone instability test, and an instability catch or aberrant movements in flexion/extension motions.

Subjects that did not meet 3 out of these 4 criteria were further evaluated to see if they met at least 6 of the following best fit criteria: spring test hypermobility, increased episode frequency, more

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**Table 1. Subject demographics.**

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Traditional Exercise Group</th>
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<tr>
<td>Age (years)</td>
<td>23.1 ± 6.0</td>
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<tr>
<td>Height (cm)</td>
<td>173.6 ± 10.5</td>
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<td>175.7 ± 10.2</td>
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<tr>
<td>Mass (kg)</td>
<td>74.7 ± 14.5</td>
<td>72.7 ± 12.9</td>
<td>76.7 ± 15.8</td>
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<tr>
<td>BMI</td>
<td>24.6 ± 2.8</td>
<td>24.6 ± 2.4</td>
<td>24.6 ± 3.2</td>
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<td>Oswestry Score</td>
<td>12.8 ± 5.0</td>
<td>13.3 ± 5.4</td>
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<td>FABQ Score (physical activity)</td>
<td>14.9 ± 5.9</td>
<td>15.2 ± 6.4</td>
<td>14.7 ± 5.5</td>
</tr>
<tr>
<td>FABQ Score (work)</td>
<td>5.5 ± 7.3</td>
<td>7.0 ± 8.8</td>
<td>4.0 ± 7.6</td>
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<tr>
<td>Duration of Symptoms (months)</td>
<td>30.0 ± 41.0</td>
<td>44.55.2</td>
<td>33.3 ± 9.2</td>
</tr>
<tr>
<td>TrA Contraction Ratio</td>
<td>1.58 ± 0.27</td>
<td>1.55 ± 0.22</td>
<td>1.61 ± 0.30</td>
</tr>
</tbody>
</table>

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**Figure 2. Inclusion criteria.**
than 3 previous episodes, positive posterior pelvic pain provocation test, active straight leg raise range motion of 60-90º, modified Trendelenburg, or pain with palpation of the long dorsal sacroiliac ligament or pubic symphysis. If they met 6 of these criteria, then they were considered a best fit for the stabilization classification (Figure 3). The study was approved by the Institutional Review Board of the University of Virginia, and written informed consent was obtained from all the participants before testing.

Instruments
Ultrasoundography
Resting ultrasound images of the TrA were obtained using a LOGIQ Book XP (GE Healthcare Products, Milwaukee, WI) with an 8 MHz linear transducer while the subject was in the supine hook-lying position. Ultrasound imaging is a reliable and valid technique to measure muscle thickness changes. It has been compared to MRI, which is considered the gold standard for the measurement of muscle geometry, and it has been compared to EMG as a standard technique for monitoring muscle activation.

The images were recorded in B mode with the transducer placed just superior to the iliac crest on the right side in the transverse plane along the mid-axillary line. To standardize the placement of the transducer among subjects, the hyperechoic interface between the TrA and the thoracolumbar fascia was the right most structure of the ultrasound image. The angle of the transducer was altered to ensure the best image was captured and the fascial layers of the abdominal muscles were parallel on the screen. Images were viewed ipsilateral to the side of LBP, or on the right side if the participant had central pain. The transducer was consistently placed transversely over the lateral aspect of the abdomen as previously reported with the medial edge of the transversus abdominis was visualized on the far right side of the screen. (Figure 4) The thickness of the TrA, Internal Oblique (IO), External Oblique (EO), and total lateral abdominal thickness were measured using Image J software (Version 1.41o, Wayne Rasband National Institutes of Health; USA). On each image, the scale was set for one centimeter using the numeric scale on the right side of the image. The thickness of the TrA, EO, and IO were then measured using the distance between the superior edge of the deep hyperechoic fascial line to the inferior edge of the superior fascial line. Then, the total lateral abdominal thickness was measured by the distance between the superior portion of the deep fascial border of the TrA to the inferior portion of the superior fascial border of the EO. The thickness measurements were then saved into Microsoft Excel where TrA activation ratios were calculated.

To minimize bias, the series of images were stored with no indication of which group the subject had been randomized. The images
were later measured by a blinded examiner with previously established intrarater reliability (ICC3,1) equal or greater than 0.99 for the TrA thickness measurements.

Prior to enrolling subjects, both examiners underwent a supervised training program for the RUSI by an experienced physical therapist. After training, a pilot study that consisted of 10 participants was used to establish intrarater reliability for the RUSI measurement technique. Two images were taken, one during rest and one during a single ADIM contraction. This sequence was repeated 3 times for a total of 6 images for each rater. This sequence was then repeated a second time. Measurements were taken of the lateral abdominal wall and the measurement values were then compared and it was found that the intraclass correlation coefficient (ICC) for intrarater, interimage reliability was greater than or equal to 0.99 for the TrA muscle thickness measure (at rest and contracted). Reliability for this rater was determined to be excellent compared to previous reports of this measurement technique.32,34,36

**Testing procedures**

**Pre-Testing Training**
The examiner utilized ultrasound imaging during pre-testing training in order to monitor all participant's progress while practicing the ADIM. The technique established by Teyhen et al.34 was used to train the subjects to perform an ADIM. Participants were instructed how to perform this contraction through traditional methods, without using visual feedback from the ultrasound image.16 Participants were given verbal cueing instructions to gently pull their navel to the spine at the end of a normal exhalation and to hold this contraction for 10 seconds while continuing normal respiration. A plateau in ADIM performance was thought to occur when the participant could perform 3 isolated TrA contractions without a specific increase in EO and IO muscle thickness.

**Initial Measurements**
After ADIM training was complete, three baseline, resting images were recorded at the end of exhalation. These images were stored for later measurement by a blinded investigator.

**Intervention Procedures**
Following baseline measurement of lateral abdominal muscle thickness, participants were randomly assigned to either a traditional bridging exercise group or the sling exercise bridging group using pre-printed cards enclosed in sealed envelopes.

There were four levels of bridging exercises in each group, each progressively more difficult. The investigator monitored success at each level prior to advancing to the next stage of the exercise. The investigator observed the pelvic alignment in the horizontal plane and or any compensatory movements and asked participants about whether the activity increased their pain. Once the exercise was performed properly, images during the exercises were recorded during a 5 second hold. The examiner positioned the ultrasound transducer on the lateral abdomen to appropriately view the TrA and at the completed position of each exercise, recorded the image for the contracted position. Five repetitions were performed at each level of the exercise and the investigators recorded the RUSI during repetitions 2-4. At least one contracted image was obtained during each of the four levels of exercise progression. The images were stored and saved according to the participant number and the level of exercise. The images were measured after data collection by an examiner who was blinded to the exercise condition.

**Traditional Bridge Exercise Progression**
Each exercise began with the participants in the supine hook-lying position on the treatment table with their knees bent to 90°, feet flat on the table, and arms crossed over the chest. The participants were then instructed to perform an ADIM and then push through the heels to lift their hips into the air while maintaining straight alignment of the knees, hips, and shoulders. In the first level, the participants held this position for 5 seconds and then were instructed to lower their back and hips back to the starting position. The second level consisted of the participants extending their right knee for 3 seconds, returning their foot to the ground, followed by left knee extension for 3 seconds and then lowering back to the starting position. In the third level, the participant had a DynaDisc™ placed between their scapulae to perform the exercise on an unstable proximal surface and in the fourth level they were instructed to alternately extend their knees (as in condition two) as well as abduct the hip 45°. Participants performed 5 repetitions on each level of the exercise (Figure 5).
Sling Bridge Exercise

The Redcord™ sling exercise therapy device (Redcord AS; Staubo, Norway) was used for the sling bridge exercise. There were four possible levels of the sling-bridging exercise (Figure 6). The participants in the sling exercise group began by laying supine on the treatment table with their hips and knees bent to 90º. The participant’s knees were placed in a sling that was suspended from the ceiling. The first level consisted of the participants lifting their hips into the air while maintaining straight alignment of the knees, hips, and shoulders. Participants were not instructed to perform an ADIM prior to sling exercise, as suggested in product literature (RedCord™). The participants held this position for 5 seconds while an image was recorded then lowered themselves back to the starting position. In the second level, the participants left knee remained in the sling and the right knee was not in the sling. The participant was instructed to hold their right leg at the same level as the left and to lift their hips into the air while maintaining straight alignment of the knees, hips, and shoulders. They held this position for 5 seconds and then lowered back to the starting position. In the third level, the participant had both knees placed in the sling and a DynaDisc™ was placed in between their scapulae to provide an unstable proximal surface upon which to perform the bridge. In the fourth level, the participants’ ankles were placed in two separate slings and they were instructed to perform the bridge and then abduct their legs one at a time before lowering back to the starting position. Participants performed 5 repetitions on each level of the exercise and US images were recorded on repetitions 2-4.

Results

The traditional exercise and sling exercise groups did not differ (P > .05) in terms of demographic stabilization classification criteria, or pre-intervention TrA activation ratio. It was not possible to obtain clear images for 2 participants; therefore the data for these participants was not included in the analysis. All participants were able to progress through the first two levels of their respective exercise progression in a pain free manner with correct technique. One individual was not able to progress to Level 3 of the traditional bridging exercise, while all individuals in the sling bridge progression were able to complete Level 3. Level 4 presented the greatest technical challenge with 18 (75%) individuals able to complete the traditional bridging exercise and 22 (88%) individuals completing the sling bridge progression. No individual in either group reported pain during the exercise intervention at any level.

Although consistently higher in the sling exercise group, there were no significant differences (P > .05) in TrA activation ratios between traditional bridging and sling bridging when comparing the first 3 levels of exercise.
levels of the exercise progression (Table 2). TrA activation ratio was significantly greater ($P = .04$) when performing sling bridging with hip abduction (Level 4) compared to traditional bridge with hip abduction (Table 2).

**Discussion**

The goal of a rehabilitation program for patients with LBP is often based on an ability to regain neuromuscular control of the TrA, in conjunction with other segmental stabilizers such as the multifidus. This treatment is the recommended plan for "stabilization" classification of LBP patients who may have poor motor control especially during dynamic tasks. These patients are typically young, have increased flexibility and experience recurrent episodes of LBP. On examination, there is typically a positive prone instability test or other provocative maneuvers that amplify abnormal motion in the spine. These individuals often present with subacute symptoms and may function at a relatively high level despite ongoing or recurrent LBP.

The TrA activation ratio has been proposed as an index to determine the ability of the local musculature to stabilize the spine. There is a preponderance of literature that has utilized ultrasound imaging to examine the function of the TrA reporting either muscle thickness during contraction or the difference in thickness during contraction compared to a resting state. The TrA activation ratio compares the muscle thickness during contraction to the thickness during a resting state in a similar manner to the method that reports strength measures as normalized to body weight. Although the terminology of "activation" ratio implies a neuromuscular influence, ultrasound imaging is only able to measure cross sectional thickness of the muscle rather than a true measure of the reactivity or excitability of the specific muscle being examined. Changes in thickness are thought to be representative of increased muscle activation. Although the TrA activation ratio seems to be the most consistent and representative measure, normative data for the TrA activation ratio in both normals and individuals with LBP is lacking.

Average TrA activation ratio during the ADIM for both groups prior to the intervention was 1.58. This ratio seems low compared to a previous study by Teyhen et al who observed TrA activation ratios of approximately 2.0 during the ADIM. However, that study used active duty soldiers with non-specific LBP and utilized ultrasound imaging for biofeedback during the testing. The TrA activation ratio observed in the present study was consistent with the values reported by Kiesel et al. for those with stabilization classification LBP where there was a 50% increase in thickness during contraction.

![Figure 6. Sling-Bridge exercise progression.](image-url)
The authors of the current study examined a series of exercises performed in two different modes in order to determine which exercises had the greatest effect on changes in thickness of the deep spinal stabilizers. The rehabilitative exercises using the sling based therapy resulted in the highest value in TrA activation ratio of the dynamic exercises that were examined, but only in the most challenging exercise condition. As documented by other investigators, the authors also found that the ADIM in the hook lying position was an effective method to activate the TrA. This static task may contribute to the initial retraining of the neuromuscular control, however, the most complex task, bridge with hip abduction with sling support comparatively resulted in a thickness change in the TrA, without volitional contraction of the abdominal musculature. Since the role of local stabilizers is reflexive in nature, the use of exercises, which activate these muscles, without conscious contraction, may translate to other functional activities.

The use of unstable surfaces for exercise training and rehabilitation has been hypothesized to challenge the motor control system more than a stable surface and therefore increase the contraction speed, intensity and muscle activity levels of the stabilizers of the spine. Using unstable surfaces also improves the coordination of neuromuscular reflexes reaction responses in movement. Vera-Garcia et al. found that doing curl-ups on a labile surface challenged the motor control system which increased abdominal muscle activity and co-activation because of the increased demand on the stabilizing muscles. They found that this increase in activation of these muscles would challenge the endurance capacities which would lead to a better training approach although the exercise also recruited the global muscles rather than just the spinal stabilizers. Although their study showed evidence that the use of labile surfaces is beneficial, the research still has mixed results on whether those exercises better results than traditional exercise.

A large percentage of the participants were able to perform all levels of the traditional (75%) and sling (88%) bridging progression. Completion of an exercise, however does not necessarily translate into an ability to concurrently stabilize the spine during the task.

The exercise progressions that were chosen for this study were thought to be equal tasks that could be comparable in terms of difficulty and muscular demand. The clinician’s goal with exercise intervention is to find the most challenging exercise level that patients perform correctly, without causing pain. Both progressions were nearly identical in terms of limb positions and movements. However, the sling exercise group had an unstable surface in every level. The authors believe that this factor contributed to the increased muscular demands in this group compared to the traditional group, particularly to maintain balance and alignment during the exercise. Furthermore, a higher percentage of subjects in the sling exercise group were able to complete all levels of progression suggesting that sling exercise programs provide an alternative exercise modality in patients with LBP.

A limitation of this study was the individuals with LBP who met stabilization classification criteria were not actively seeking medical care for their pain. Although, subjects in the present study did demonstrate a level of dysfunction as measured by the Oswestry and Fear Avoidance Beliefs Questionnaire (FABQ) self report measures, it is possible that individuals with greater dysfunction may have TrA activation ratios that are different with this exercise progression. Additionally results for other exercise progressions on stable or unstable surfaces (i.e. side-bridge or front plank) are unknown. Additional research is necessary to determine the contribution of sling exercise therapy in acute muscle activation as well its effect on long term patient oriented outcomes.

**Conclusions**

Activation of the TrA is a commonly used in rehabilitation exercise because of its ability to actively stiffen the spine, maintain safe spinal orientation prior to movement, and control shearing forces on the spine. Both types of exercise that were studied in this investigation were capable of recruiting the TrA. However, the results of

**Table 2.** *Transverse abdominis activation during bridging exercise.*

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<td>Hip Abduction</td>
<td>1.22 ± .38</td>
<td>1.48 ± .38</td>
<td>.04*</td>
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*Significant P < .05
this investigation indicate that sling based exercise is equivalent to traditional mat based exercise in increasing the TrA activation ratio. Our findings further suggest that individuals with LBP may be better able to recruit the TrA during the more complex sling based task. Clinically, sling-based therapy can be used to train the neuromuscular system of the deep spinal stabilizers in subjects with low back pain.

REFERENCES


ABSTRACT

Background. There is no consensus among the existing published evidence as to whether closed kinetic chain (CKC) or open kinetic chain (OKC) exercises should be the intervention of choice following an anterior cruciate ligament (ACL) injury or reconstruction. The commonly held belief has been that OKC exercises cause increased strain on the ACL as well as increased joint laxity and anterior tibial translation.

Objective. To investigate the effects of OKC and CKC exercises on the knees of patients with ACL deficiency or reconstruction.

Data Sources. MEDLINE, ProQuest Medical Library, and CINAHL.

Study Selection. Six articles were chosen for inclusion in the systematic review. The authors narrowed 50 articles down to 6 by review of titles and abstracts. Included articles were randomized controlled trials written in English, published during 2000-2008, that evaluated the effects of OKC and CKC exercises on ACL deficient or reconstructed knees.

Data Extraction. Quality of the included studies was defined by the PEDro scale, which has been found to be reliable.2

Data Synthesis. Scores on the PEDro scale ranged from 4-6/10. One article found positive significant effects with inclusion of OKC exercises in the rehabilitation program and another found significant benefits with combining OKC and CKC exercises. CKC exercises alone were not found by any studies to be superior to OKC exercises.

Conclusion. These studies reveal favorable results for utilization of both open and closed kinetic chain exercises for intervention with ACL deficient or reconstructed knees. However, further research needs to be completed.

Key Words. open/closed kinetic chain exercise, ACL

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We would like to express sincere gratitude to Gordon J. Alderink, PT, PhD and John R. Stevenson, PT, PhD for their help and guidance with this systematic review.
INTRODUCTION
Over the years, debate has persisted regarding what type of exercise is most appropriate after an anterior cruciate ligament (ACL) injury. Specifically, the question arises about what kind of forces the ACL deficient or reconstructed knee is able to withstand during exercise and function. The ACL is the primary restraint to anterior translation of the tibia on the femur. In addition, the ACL serves as a secondary restraint to tibial rotation and any varus/valgus angulation that occurs when the knee is at full extension. Because the bony relationship between the tibia and femur offers little bony stability, the ACL is of primary importance as a stabilizer of the knee.

Recently, treatment after ACL injury has been focused on closed kinetic chain (CKC) exercises. CKC exercises have been used preferentially because of the belief that they are safer for the patellofemoral joint, replicate functional tasks, and do not contribute to increased risk of anterior tibial displacement.3,5 CKC exercises are mainly used to train the quadriceps muscle group to improve muscle strength, coordination, and proprioception, while putting the least amount of tensile strain on the ACL.6 For these reasons, it has been suggested that CKC exercises are safer than open kinetic chain (OKC) exercises for rehabilitation of both ACL deficient and reconstructed knees, decreasing the likelihood of injurious stresses being placed on the injured or reconstructed ligament. The use of OKC exercises with ACL pathologies has been proposed to increase the anterior shear forces at the knee, to a greater extent than CKC exercises.9 With an increased demand placed on the ACL by greater shear forces, the injured or reconstructed ACL graft undergoes a substantial amount of strain due to the anterior translation of the tibia on the femur, which may result in increased damage to the ligament.5 However, there is not consistency among results of research regarding this belief. The question remains: whether CKC or OKC exercises are more harmful to the overall structure of the knee joint, through increased strain on the ligament, increased joint laxity, or increased anterior tibial translation, and whether either should be preferentially used or discontinued.

By conducting a systematic review of the literature, data can be compared from past studies to examine whether the evidence or lack thereof offers insight on the appropriateness of OKC versus CKC exercises when dealing with patients who have ACL pathology. The clinical relevance of this review encompasses the all-important paradigm of function. Some researchers have found both closed kinetic chain and open kinetic chain exercises to be important for return to function following an injury to the ACL.7,8 Rehabilitation of the knees of ACL injured and reconstructed patients must include interventions that are both safe and effective with the goal of returning patients to their activities at a high functional level as quickly as possible. The aim of this systematic review is to compare the clinical and statistical outcomes of published studies that compare OKC and CKC interventions for ACL rehabilitation.

METHODS

Literature Search
MEDLINE database searches were performed using keywords: “kinetic chain”, “ACL”, “chain”, “knee”, and “laxity”. A ProQuest Medical Library search was performed using keywords: “knee” and “closed kinetic chain”, and a CINAHL database search was completed using keywords: “closed kinetic chain” and “ACL”. All search results were limited to full text, peer reviewed articles.

Study Selection Criteria
In order for an article to be included in this systematic review it had to have been published between 2000-2008, written in English, evaluate open kinetic chain and closed kinetic chain exercises on an ACL deficient or reconstructed population, and be a randomized control trial. The reason for inclusion of research regarding rehabilitation of subjects with ACL deficiency and ACL reconstruction is that both need to be protected from undue stress and shear, either during healing or during exercises in order to decrease the risk of stretching forces which could produce further injury.

Review Criteria
All studies included were categorized as Sackett evidence level Ib, individual randomized controlled trials (with narrow confidence interval).

Interpretation of the Evidence
According to the scoring used by Physiotherapy Evidence Database (PEDro) scale1, a study that received a “1” rating in any given category indicates that the study sufficiently met the criterion. The authors of this systematic review agree with the PEDro ratings given for most categories1 in the included articles. However, Perry et al4 and Perry et al5 both received a score of “0” for criterion 8: “Measures of at
least one key outcome were obtained from more than 85 percent of the subjects initially allocated to groups and the authors of this systematic review would contest this score due to the inclusion of at least 1 key outcome measure reported for over 85 percent of the subjects in each of these published reports.

Results of the Literature Search
The MEDLINE search discussed above yielded 31 results, which were then narrowed to 18 with a change of keywords. The described ProQuest Medical Library search yielded 7 results. The CINAHL database search yielded 19 results. Duplicate results were found during some of the searches. After further scanning the titles, 12 articles were selected for the initial review. After reading through the abstracts, 6 articles were chosen for inclusion in the systematic review for their relevancy and their ability to satisfy the selection criteria.

Methodological Quality of Reviewed Studies
Scoring the strength of the articles was performed using the 11-point PEDro scale (Table 1) developed by physiotherapists at the University of Sidney. A higher score on the PEDro scale suggests a stronger quality study. This scale has been found to be acceptable for use in scoring when a consensus rating is used. A consensus rating involves 2 independent raters scoring the study and a third rater being used to resolve any disputes. The PEDro scores reported in this systematic review were obtained from the Physiotherapy Evidence Database. The scoring was performed using a consensus rating (See Table 2 for results).

Table 1. PEDro Scale

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score*</th>
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<tbody>
<tr>
<td>1 † Eligibility criteria were specified.</td>
<td>Yes/No</td>
</tr>
<tr>
<td>2 Subjects were randomly allocated to groups (in a cross-over study, subjects were randomly allocated an order in which treatments were received).</td>
<td>Yes/No</td>
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<tr>
<td>3 Allocation was concealed.</td>
<td>Yes/No</td>
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<tr>
<td>4 The groups were similar at baseline regarding the most important prognostic indicators.</td>
<td>Yes/No</td>
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<tr>
<td>5 There was blinding of all subjects.</td>
<td>Yes/No</td>
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<td>6 There was blinding of all therapists who administered the therapy.</td>
<td>Yes/No</td>
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<tr>
<td>7 There was blinding of all assessors who measured at least one key outcome.</td>
<td>Yes/No</td>
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<tr>
<td>8 Measures of at least one key outcome were obtained from more than 85 percent of the subjects initially allocated to groups.</td>
<td>Yes/No</td>
</tr>
<tr>
<td>9 All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by “intention to treat.”</td>
<td>Yes/No</td>
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<tr>
<td>10 The results of between-group statistical comparisons are reported for at least one key outcome.</td>
<td>Yes/No</td>
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<tr>
<td>11 The study provides both point measures and measures of variability for at least one key outcome.</td>
<td>Yes/No</td>
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SUMMARY OF THE LITERATURE


**Purpose:** The purpose of this prospective matched follow-up study was to investigate the effects of CKC quadriceps exercises compared to OKC exercises following ACL reconstruction. Specifically, the researchers sought to determine the effects these exercises had on anterior knee laxity and isokinetic muscle torque. **Methods:** In order to be included in the study subjects had to have sustained their first unilateral ACL injury and they had to have a healthy contralateral leg. Subjects were excluded if they had any previous knee injuries or a concomitant injury that could influence their rehabilitation potential. Using this criterion, 44 men and women from the ages of 18-49 were included in the study. Each subject was randomized into one of two treatment groups each consisting of 22 subjects. Group 1 used CKC exercises to strengthen their quadriceps while group 2 carried out quadriceps strengthening through combined OKC and CKC. Subjects began their specific treatment protocol the day after their reconstruction. In addition to randomization, each patient was matched to another patient for age, gender and level of physical activity. The measurements in this study at baseline (6 weeks post-surgery) and at 6 months post-op included anterior knee laxity with the use of KT-1000™ arthrometer and isokinetic measurements of the quadriceps and hamstrings muscle torque using the Kin-Com® dynamometer. In addition to these tests and measures, patients were given a questionnaire on knee function and satisfaction that was returned at an average of 31 months post-surgery. **Results:** Statistical analysis with a Chi-Square test was used to determine if the outcomes were significantly different between groups. There was no significant difference between groups in regards to anterior knee laxity when compared both pre- and post-operatively between injured and healthy knees. Group 2 did show a significantly greater gain in quadriceps torque at 6 months post-op but the groups were similar in hamstring torque. Examination of the questionnaire data determined that group 2 returned to sports at the same level as before their ACL injury earlier than group 1. **Conclusion:** Based on the data from baseline and post-intervention measures, the researchers concluded that a

<table>
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<tr>
<th>PEDro Grading Criteria</th>
<th>Mikkelsen et al., 2000</th>
<th>Morrissey et al., 2002</th>
<th>Morrissey et al., 2000</th>
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**Level of Evidence*** Type Ib | Type Ib | Type Ib | Type Ib | Type Ib | Type Ib | Type Ib |
combination of CKC and OKC exercises for quadriceps strength was better than using CKC exercises alone. This combination approach to intervention improved muscle torque about the knee and returned patients to activity earlier than the use of CKC exercises in isolation.


**Purpose:** The purpose of this randomized control trial was to assess the impact of a distally fixed (CKC) exercise protocol versus that of a nondistally fixed (OKC) protocol on knee pain in subjects post-ACL reconstruction.

**Methods:** A convenience sample of subjects recovering from ACL reconstruction was utilized. The reconstruction used either a ligament augmentation device with a piece of patellar tendon or a bone-patellar tendon-bone graft. Forty-three subjects met the inclusion criteria which consisted of: no history of pathology requiring medical attention in the contralateral lower limb, at least 20 days between baseline measurements and surgery, 35 days between pre-test and post-test, ability to carry out 8 to 13 therapy sessions between pre-test and post-test, passive knee flexion to 90 degrees, and the ability to walk without an assistive device. Subjects were randomized by block randomization into different treatment groups. Twenty-one patients were placed into group C; who received CKC training and 22 subjects were placed into group O, who received OKC exercises. Baseline measures collected by the examiners included: knee laxity using a ligament arthrometer, the Hughston Clinic Questionnaire, knee girth, passive ROM for knee flexion and extension, isotonic OKC knee extensor muscle performance, isotonic CKC and OKC knee and hip extensor muscle performance, biomechanical analysis of knee function, and isometric and isokinetic performance of the knee flexors and extensors in OKC positions. The primary outcomes measured and analyzed from pre-test to post-test included: VAS scores from the Hughston Clinic Questionnaire, bilateral maximum isometric torque of the knee extensors, and VAS scores for pain during maximum isometric torque of the knee extensors. In addition, pain was further monitored in each treatment session and subjects were asked to report the amount and location of the pain, and the examiners reported the amount of peak torque generated by the knee extensors. **Results:** The researchers found a statistically significant difference between pre-test and post-test VAS scores for the 3 pain questions from the Hughston Clinic Questionnaire. However, the between group analysis did not show a significant difference in pain scores. In addition, the researchers determined that a significant relationship between groups did not exist in the data collected for isometric knee extension and change in knee pain. **Conclusion:** CKC exercises do not affect knee pain differently than OKC exercises in patients following ACL reconstruction. The researchers suggested that either training protocol can be used in subjects early after ACL reconstruction, specifically, to strengthen hip and knee extensors. However, they also suggested that until further evidence is provided clinicians should continue to use the more conservative approach consisting of CKC exercises for training after surgery.


**Purpose:** The purpose of this study was to evaluate the effects of OKC and CKC exercises on knee laxity immediately following ACL reconstruction.

**Methods:** The study consisted of 36 subjects (7 females, 29 males) who were less than 20 days post-ACL reconstruction. Other inclusion criteria included: no prior history of pathology requiring medical attention in uninvolved lower extremity, days between pre- and post-test was <35, and subjects that received 8 to 13 physical therapy sessions. Knee laxity measurements were taken with the Knee Signature System™ arthrometer pre-therapy and then the subjects underwent 4 weeks of therapy 3 times per week. Subjects were randomly assigned to either an OKC exercise group or a CKC exercise group. Laxity measurements were repeated at the end of the 4 week therapy session. Dynamic and isometric quadriceps and hamstring strength measurements were taken. Walking and stair use was analyzed using three cameras and a force plate system as an evaluation of function. Logarithmic transformation was used on anterior tibial displacement values to correct for the skew that was present. The researchers used the ANCOVA to statistically compare the laxity
between the 2 experimental groups. **Results:** The mean laxity values in the closed and open kinetic chain groups were 9.87 (pre-test), 9.98 (post-test) and 9.46 (pre-test), 10.25 (post-test) respectively. The post-test mean laxity in the OKC group was 9% greater than the CKC group but did not demonstrate a statistically significant difference (P=0.32) at the 95% confidence interval. **Conclusion:** There was not a statistically significant difference between patients who used closed kinetic chain and open kinetic chain exercises with regards to knee laxity (anterior tibial displacement). This study also found no difference in function or knee pain between groups.

**Purpose:** The aim of this study was to evaluate the effects of OKC and CKC knee extensor exercises on knee laxity and function in subjects who were 8 to 14 weeks post ACL reconstruction. **Methods:** 49 subjects were included in the study (37 males, 12 females). Inclusion criteria included: subjects being 18-60 years old, having no posterior cruciate ligament tear in the involved knee, and having required no medical services for the contralateral leg in the previous 6 months. The study involved training between weeks 8 and 14 following reconstructive surgery. Subjects were randomly assigned to either an OKC or CKC training group. Subjects filled out the Hughston Clinic questionnaire regarding their involved knee. Various measurements were taken at the start of the study by therapists blinded to group assignment, including: height, weight, active knee motion angles, knee circumference, and knee laxity values attained with the Knee Signature System™. Subjects also were asked to fill out an activity log. All subjects underwent therapy 3 times per week for 6 weeks. Exercises were performed at 3 sets of 20 for the first 3 weeks and 3 sets of 6 for the last 3 weeks. Specific training regimens for the two groups can be seen in Table 3. After 6 weeks of therapy the same measurements were taken and 3 jump tests were added. Statistical analysis utilized independent two sample t-tests, Mann-Whitney U test, Chi-Square tests, and univariate analysis to compare baseline values to post-test values. **Results:** Statistical analysis of baseline and training data showed similarity between the groups, except that the CKC group spent significantly more time on a bicycle and had a higher final quadriceps load (weight in kg used for resistance exercises). There were no statistically significant differences in any of the measured variables between the 2 groups. **Conclusion:** The results of this study revealed no significant difference in knee laxity between groups rehabilitated using open and closed kinetic chain exercise regimens. Additionally, no significant difference was found in patient reported or objectively measured function in subjects who were in the middle period (weeks 8-14) of ACL rehabilitation. The authors advised that CKC exercises be used for ACL rehabilitation because OKC exercises showed no advantage over CKC and there might still be risk involved with OKC exercises.

**Purpose:** The purpose of this randomized, single-blind clinical trial was to compare the effects of OKC and CKC exercises on knee laxity and knee function in patients with ACL deficiency. The null hypothesis of the study was that groups would not differ in terms of laxity of the injured knee, self-assessment of knee function, or injured/unjured leg jump ratios after training. **Methods:** The trial examined 64 patients, 49 males and 15 females. Subjects were assigned to either an OKC treatment group or CKC treatment group based on block randomization. Inclusion and exclusion criteria for this study were that subjects were deemed suitable if they had no previous history of pathology requiring medical attention in the contralateral lower extremity within the past 6 months, did not have a concurrent posterior cruciate ligament (PCL) injury, and their ACL diagnosis had to be confirmed by the use of an MRI or other clinical test. After informed consent was received, the patients went through a series of tests and measures conducted by physical therapists that were blinded to the subjects group assignments; including knee laxity testing with a ligament arthrometer, measurement of function based on the Hughston Clinic knee self-assessment questionnaire, and testing of the maximum effort during a single leg jump test. Each of the above named tests were measured at baseline and then again following 6 weeks of intervention, during which patients attended therapy 3 times per week. A general questionnaire was used to glean...

DISCUSSION/CONCLUSION
Six randomized controlled trials were analyzed for this systematic review. Each of these articles studied the effectiveness of and differences between OKC exercises and CKC exercises following an ACL repair or ACL injury with subsequent deficiency. Of the 6 articles, 4 articles investigated the differences within a population of patients who underwent ACL reconstruction and the other 2 investigated subjects who had ACL deficiency. Five of the 6 articles studied the effects of these exercises on knee laxity, examining both static and dynamic anterior tibial translation. Four of the 6 articles utilized measurements including knee girth, PROM of knee flexion and extension, muscle information regarding the dates of the patients’ arthroscopy and/or injury, activity impairments, and details of the injury. The Hughston Clinic questionnaire was used to understand how the patients’ felt regarding the condition of their knee. In order to test knee laxity examiners made use of the Knee Signature System™. The jump test methods used (single-leg horizontal hop and the vertical jump) have both been found to be reliable and valid. Aside from the test and measures, the researchers instructed the subjects to keep a diary, which allowed them to record the details of the therapy they received as well as activities they were participating in outside of treatment. Results: At the conclusion of this study the researchers were unable to reject their null hypotheses regarding all study variables. The researchers were not able to find a significant difference in the knee laxity measurements between groups from baseline when compared to the end of the intervention program. The subjects demonstrated a statistically significant difference between groups in the vertical jump test, which was greater in the OKC group at post-test. However, even with this finding, inferences can not be made for the other jump test because of the differences in muscular torques and motor performance variations that are required with each of the tests. Conclusion: The researchers concluded that OKC and CKC exercises of the knee extensors following ACL injury do not differ in their effects on knee laxity and function in the ACL deficient knee.
strength testing and biomechanical analysis of knee function during walking and stair use. Three studies\(^3,^4,^5\) utilized the Hughston clinic questionnaire to address patient self-assessment and two of these studies\(^4,^5\) also used a pre-test general questionnaire to describe injury and surgery dates, activity difficulties, and any current sporting activities. One study used a post-test questionnaire addressing knee function and satisfaction as well as physical activity.\(^7\) One of the 6 articles used other additional outcome measures including subjects’ 1 repetition maximum, anterior translation during single-leg squat, vertical jump ability, a Lysholm self-assessment tool, the Knee injury and Osteoarthritis Outcome Score (KOOS) and the Tegner questionnaire.\(^6\)

Of the 6 articles, 2 found positive significant effects with inclusion of OKC exercises in the rehabilitation program. Tagesson et al\(^6\) stated that their results supported the use of OKC exercises to regain proper muscle torque around an ACL deficient knee. Strengthening of the quadriceps through a treatment program using OKC quadriceps exercises (with exclusion of CKC exercises) led to significantly greater quadriceps strength over using CKC quadriceps exercises alone. Mikkelsen et al\(^7\) found that a combination of CKC and OKC exercises was better than using CKC exercises alone for regaining quadriceps strength following reconstruction of the ACL. This combined exercise method improved muscle torque about the knee and returned patients to activity earlier than the use of CKC exercises in isolation.

Both of the studies by Perry et al\(^4,^5\) commented on the reliability and validity of various elements of their research design. Reliability of the therapists measuring laxity compared well with other published data, having significant difference values for knee laxity between 3.8 to 4.8mm.\(^1,^5\) The studies also used hop tests, which have been shown to be reliable and valid measures of knee function.\(^1,^2,^3,^4,^5\)

Studies that incorporated questionnaires to assess subjective information by patients about their knee function presented more detailed outcomes, accounting for multiple aspects of the rehabilitation process. For example, Mikkelsen et al\(^7\) used a questionnaire that assessed knee function and satisfaction. The results of this questionnaire were found to be significantly different in subjects in the combination group (CKC plus OKC exercises) as compared to CKC alone. Subjects believed their knee function was greater and reported earlier return to sports than those who received CKC exercises alone.

A weakness among some of the studies was a lack of statistical power due to inadequate subject numbers. For example, Morrissey et al\(^10\) conducted an analysis which reported the need of 60 subjects for statistical power. However, the study was carried out with only 36 subjects, demonstrating insufficient statistical power and thus the inability to make broad inferences with the resulting data. Four of the 6 articles had some of the same co-authors. Therefore, a weakness in these 4 studies is the fact that these authors may have been attempting to prove their personal ideas of what should be included in rehabilitation interventions in patients with reconstructed or deficient ACLs. Also, bias may be present in their inclusion and exclusion criteria. Based on the number of studies completed by this group of authors, the inclusion criterion for subjects and methodology choice for their studies may be based on past experiences and outcomes and therefore reflect bias. Lastly, a few of the articles had inadequate follow-up periods.\(^4,^5\) The results that were obtained may be further affected by increasing the amount of time between baseline and follow-up measurements. It may be that the subjects involved did not have enough time to develop significant changes in measured parameters, either positive or negative.

Five out of the 6 studies examined in this review provided a thorough description of therapeutic interventions that were utilized, in order to allow for replication of their methods.\(^3,^4,^6,^10\) Another strength of all of the studies was the use of strict therapeutic protocols to avoid the influence of confounding interventions.

Only randomized controlled trials were included within this systematic review, reflecting incorporation of strong, high level evidence based on Sackett’s criteria.\(^8\) The search completed by the authors of this systematic review yielded the same results as those listed on the Physiotherapy Evidence Database for this topic, suggesting that this systematic review provides a conclusive summary of the present evidence.\(^1\) It may be beneficial for future reviews to include other types of studies, such as systematic reviews in order to include a wider variety of the evidence. A limitation of this review is that some of the authors were collaborators in more than one of the studies, and therefore
this group of authors’ findings represents a majority of the data reviewed.

Implications for Clinical Practice
The results of these 6 studies offer the following recommendations for clinical application: closed kinetic chain and open kinetic chain exercises seem to have similar outcomes on knee laxity, knee pain, and function and therefore can both be used during the rehabilitation of a patient with ACL deficiency or post ACL reconstruction. However, it is important to keep in mind that 2 of the 6 studies showed favorable results for OKC exercises over CKC exercises. Mikkelsen et al7 found that using closed and open kinetic chain exercises together led to greater quadriceps torque return and a quicker return to sport than CKC alone. On a similar note, Tagesson et al6 reported that OKC exercises for quadriceps led to better gains in quadriceps strength than when using CKC exercises. The conservative approach would be to continue using closed kinetic chain exercises primarily, at least at the start of rehabilitation, due to the fact that there are not an adequate number of studies to completely refute the possible harm which may accompany the use of OKC exercises on the knee in this specific population. However, from the examination of the current research, it appears that an eclectic approach is warranted. Both closed and open kinetic chain exercises are beneficial for this patient population. Though it is common to think of many lower extremity functional tasks as being CKC, there are many that are performed in open kinetic chain. This is especially true for many complex movements that occur within the performance of sports. Many sporting movement patterns include both open and closed chain actions and could be considered “hybrids”. Therapists should not ignore the fact that the body performs many motions and actions in different contexts and it may be beneficial to retrain muscles and joints in those specific contexts, whether it is through OKC or CKC exercises.

In studies that showed superiority in outcomes with the use of OKC exercises, Mikkelsen et al7 and Tagesson et al6 began OKC exercises six or more weeks after reconstruction or injury respectively. The studies that began OKC exercises at four weeks or earlier following injury or surgery did not demonstrate any superiority in outcomes over CKC exercises.5,10 A study completed by Heijne and Werner11 found that beginning OKC quadriceps strengthening exercises at four weeks post ACL reconstruction produced greater anterior knee laxity as compared to beginning the same exercises at 12 weeks. Interpretation of these findings suggest that an optimal time for initiation of OKC exercises, accounting for both protection of the knee ligaments and reported positive benefits, is at least six weeks post reconstruction or injury.

Future Research
These studies reveal favorable results for both open and closed kinetic chain exercises when utilized during rehabilitation of knees in ACL deficient or reconstructed populations. However, in order to evaluate their effectiveness and the possible superiority of one approach over the other, further research needs to be completed. Looking at all phases of rehabilitation and having a longer follow-up period would yield more valuable and interesting evidence. Increasing the number of subjects in future investigations would increase the generalizability of results due to increased statistical power. Finally, another suggestion would be to ensure that the total dosage of exercises is comparable between experimental groups, thereby providing similar total volume of exercise intervention.

REFERENCES
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<th>INTERVENTIONS</th>
<th>CONCLUSION</th>
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<td><strong>7</strong></td>
<td><strong>OKC</strong> Week 6: Add isokinetic concentric and eccentric quadriceps exercises</td>
<td><strong>CKC</strong> See “Both”</td>
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<td><strong>3</strong></td>
<td><strong>OKC</strong> Ankle weights or hip &amp; knee extension machines (3x20) Excluded: step-ups, squats, leg press, calf exercises</td>
<td><strong>CKC</strong> Unilateral Leg press (3x20) Excluded: OKC hip &amp; knee extensions, step-ups, squats, calf exercises</td>
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<td><strong>4</strong></td>
<td><strong>OKC</strong> Unilateral OKC knee extensor exercises with ankle weights or machine Hip extensions with ankle weights Exercise dosage: wks 1-3: 3x20 wks 4-6: 3x6; increase load when pain level is &lt;5 and exercises completed correctly</td>
<td><strong>CKC</strong> Unilateral hip/knee extension on leg press Exercise dosage: wks 1-3: 3x20 wks 4-6: 3x6; increase load when pain level is &lt;5 and exercises completed correctly</td>
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</tr>
<tr>
<td><strong>6</strong></td>
<td><strong>OKC</strong> Seated knee extension on 1 leg Hip extension on 1 leg</td>
<td><strong>CKC</strong> Squat on 1 leg in a Smith machine</td>
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*See references for corresponding study

Note: Please reference the corresponding article for further description of interventions and progression of exercises.


ABSTRACT
Due to complex movements and high physical demands, dance is often associated with a multitude of impairments including pain of the low back, pelvis, leg, knee, and foot. This case report provides an exercise progression, emphasizing enhancement of strength and neuromuscular performance using the concept of regional interdependence in a 17 year old female dancer with patellofemoral pain syndrome.

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CASE REPORT
REHABILITATION OF A FEMALE DANCER WITH PATELLOFEMORAL PAIN SYNDROME: APPLYING CONCEPTS OF REGIONAL INTERDEPENDENCE IN PRACTICE
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INTRODUCTION
Dance often involves a complex sequence of movements and high physical demands of strength, stability, and flexibility. Due to intricate choreography and challenging performance schedules dancers are potentially at risk for injury. These physical requirements of dance, which include prolonged bouts of training and explicit physical control of their body, make physiologic training just as important as skill development for injury prevention.

The physical demands of dance often result in injury, which in turn limit a dancer's ability to perform. In a survey of 324 professional dancers, almost 50% reported missing between one and twenty-one days of exercise due to injury each year.1 Koutedakis and Jamuris1 reported that 90% of injuries in dancers involve the low back, pelvis, legs, knees, or feet. Prolonged bouts of training with inadequate rest, unsuitable floors, difficult choreography, and insufficient warm-ups are among the factors that contribute to dance injuries.2 In their paper, Koutedakis and Jamuris1 reviewed studies on male and female dancers, which suggested that supplement ary exercise training, beyond that of dance training, can lead to improvements in muscle balance and strength.

Strength training decreases incidence of dance injuries, without interfering with the key artistic and aesthetic requirements of a dancer.1 However, strength training has generally not been considered a necessary component of preparation for success in dance.1 This idea is supported by the view among dancers and choreographers that strength training may create a physique that is not complimentary to the typical dancer’s aesthetic appearance.1 MacDougal et al7 found increases in muscle strength were not necessarily accompanied by proportional changes in muscle size. This finding suggests that strength training is closely related to neural adaptations which increase muscle strength.3,4 These neural mechanisms responsible for strength development include alterations in agonist-antagonist co-activation, increases in motor unit firing rates (rate coding), and changes in descending drive to the motorneurons.3,4

Previous authors have suggested that proximal factors such as hip and core weakness may contribute to anterior knee pain.5,7 Additionally, authors have demonstrated that women exhibit movements associated with knee valgus and hip internal rotation when compared to men during specific movements.6,9 The ability of women to control these motions may depend on the strength of proximal muscle groups that are antagonistic to these movements.10 Proper hip strength and neuromuscular control, particularly of the gluteus medius and hip external rotators, enhances knee stability by controlling the pelvis and limiting hip adduction and internal rotation that result in increased knee valgus during activity.5 In the absence of sufficient proximal strength or muscular control, the femur may adduct and internally rotate, exaggerating lateral patellar contact due to the valgus moment.12-14 Repetitive activities with this mal-alignment may eventually lead to patellofemoral pain.10

Patellofemoral pain syndrome (PFPS), also known as anterior knee pain, remains a common orthopedic complaint occurring in approximately 1 in every 4 people.15 Those involved in athletics report an incidence of patellofemoral pain greater than 25%.10,15 The condition is more common in women than men and most often affects younger individuals between the ages of 10 and 35 years.16 Unfortunately, this pain often becomes a chronic condition that may fail to respond to conservative measures.17

Symptoms of PFPS typically include the following: pain while ascending and descending stairs, squatting, or prolonged sitting. Swelling, popping or grinding sensations may be present, as well as incidences of knee buckling or giving way.10,19 The spectrum of symptoms varies greatly among individuals, with complaints ranging from achy pain after activity to severe pain when rising from a chair or climbing stairs.10

Many patients with anterior knee pain are eventually referred to rehabilitation. Although PFPS is one of the most common clinical conditions treated by orthopedic and sports physical therapists, a consensus does not exist regarding how these patients should be managed.16 Differential diagnostic skills must be utilized to rule out a range of inflammatory conditions, mechanical problems, and other conditions such as ligamentous injury, tendinopathy, bursitis, and muscle strain.18-20 Identifying the origin of the inflammation is important for developing a treatment plan that will result in prompt resolution of symptoms.16 Failure to do so may result in suboptimal care and poor outcomes.16 Some of the various techniques commonly used to treat PFPS include non-steroidal anti-inflammatory medication, ice, quadriceps strengthening,
hamstring and gastrocnemius stretching, patella taping or bracing, and orthotics.\textsuperscript{15,20}

Vaughn\textsuperscript{21} highlighted the importance of a regional examination for a patient with non-specific knee pain, illustrating the concept of regional interdependence. With respect to musculoskeletal problems, regional interdependence refers to the concept that seemingly unrelated impairments in a remote anatomical region may contribute to, or be associated with, the patient's primary complaint.\textsuperscript{21} In some cases, knee pain may be the sole presenting symptom when a more proximal or distal structure such as the pelvis, hip, ankle, or foot is at fault.\textsuperscript{23} In such cases, the pain may be referred from a more proximal structure or be consequential to a remotely located impairment that produces excessive stress on structures of the knee, resulting in pain.\textsuperscript{21}

The purpose of this case report is to demonstrate the importance of strength and neuromuscular training in a female dancer who presented with PFPS and highlight the importance of a regional interdependence model of examination to identify the origin of knee pain.

**CASE DESCRIPTION AND HISTORY**

The patient was a 17-year-old female high school student who participated in dance activities up to 18 hours a week. Pain was initially reported in the anterior/medial aspect of the left knee in December 2007 with no specific mechanism of injury noted. The patient continued, despite pain in the left knee, to dance on a regular basis. She attempted to join the school cross-country team in the fall of 2008 but was unable to participate due to her knee symptoms.

An orthopedic surgeon evaluated the patient in December of 2008 with no significant findings related to fracture, dislocation, or meniscal involvement which is consistent with the presentation of PFPS. Further diagnostic testing with X-ray and MRI revealed a bone bruise on the medial femoral condyle and thinning cartilage. The patient opted for rest from dance and physical therapy.

**INITIAL EXAMINATION**

**Initial Presentation**

The patient was seen on December 31, 2008 for physical therapy examination with a chief complaint of left knee pain along the inferior and medial pole of the patella. The patient appeared to be a healthy and athletic 17 year old female. She presented with a slender build, as well as a low waist-hip ratio of 0.75\textsuperscript{24,25} that is typically seen in dancers. She had no swelling or erythema of her left knee with visual inspection. The history of her current injury was insidious onset of approximately one-year duration, as previously noted.

**Functional Status**

The patient had stopped dancing 3 weeks prior to examination, per the orthopedic surgeon's recommendation. She reported difficulty walking or running for periods longer than 10 minutes due to pain. She also reported that ascending and descending stairs at school caused an increase in pain, which forced her to take the elevator some days. The patient demonstrated unilateral squat with genu valgus collapse bilaterally with report of mild retro patellar discomfort.

**Systems Review**

At evaluation the patient was 5'6" and 125 lbs with a body mass index of 20.2 which is considered to be at the lower end of a normal range.\textsuperscript{26} She reported a history of fainting due to low blood sugar with no occurrences in the past two years. Also no previous injuries or surgeries were reported. An integumentary and neuromuscular screen revealed no gross deficits. Family medical history was unremarkable.

**Tests and Measures**

**Posture**

Standing postural assessment demonstrated the patient’s spine, hips, and knees were within normal limits (WNL) with exception of increased external rotation bilaterally in the lower quarter. Supine postural assessment revealing an increase in femoral anteversion, which lead to compensations in weight-bearing. The patient also presented with a Q-angle of 8 degrees bilaterally and the patella was hypo-mobile on the left with medial to lateral glides. In prone the patient presented with rear foot varus of 5 degrees bilaterally and a neutral forefoot when examined in subtalar neutral. Gait was assessed with the patient ambulating in bare feet at a self-selected pace for 30 feet and rapidly for 30 feet. No significant findings were found during gait analysis and the patient had no complaints of pain.

**Range Of Motion**

The patient's active range of motion (AROM) for all hip, knee and ankle, measurements were WNL and symmetri-...
cal bilaterally except for hip internal rotation with right internal rotation (IR) measured at 29 degrees and left IR measured at 39 degrees.

Pain
A 10 mm visual analog scale (VAS) was used to elicit an objective description of the patient's pain level. The patient reported 8/10 pain during dance class, which was the activity that most aggravated the symptoms. Pain was alleviated to 0/10 with sitting or resting. The patient reported 5/10 pain levels with walking more than 10 minutes on even or uneven ground, as well as ascending or descending 10 steps at school. Symptoms were localized to the medial aspect of the knee around the medial joint line. No tenderness to palpation occurred during examination.

Muscle Strength
The patient's strength was measured using manual muscle testing as described by Daniels and Worthingham. Abdominal (rectus abdominus and obliques) were measured at 4/5 in supine position with trunk flexion. The patient was unable to hold a prone plank greater than five seconds before increasing her lordotic curve suggesting weakness. All measurements were taken in a pain free manner.

<table>
<thead>
<tr>
<th>Tested Muscle Group</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexors</td>
<td>5/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Hip adductors</td>
<td>5/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Hip extensors</td>
<td>5/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Hip abductors</td>
<td>5/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Hip external rotators</td>
<td>5/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Hip internal rotators</td>
<td>5/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>5/5</td>
<td>5/5</td>
</tr>
</tbody>
</table>

Functional Outcome Measurements
At initial examination the patient scored a 49/80 on the Lower Extremity Functional Scale (LEFS). She also scored a 3.7/10 on the Patient-Specific Functional Scale (PSFS) in which the patient identifies specific functional tasks which are limited and rates them zero to ten with lower numbers reflecting greater levels of limitation.

ASSESSMENT
The patient's primary impairment was knee pain secondary to non-traumatic sports related injury. The physical therapy evaluation revealed an overall decrease in strength and muscle imbalances. This is particularly the case for her hip musculature which is needed to perform as a dancer. Weakness of the left hip abductor and external rotator muscles allowed for increased anteromedial vector forces and disproportionate stress on the anterior/medial left knee. Due to pain while dancing, her orthopedic physician placed the patient on activity limitations and no return to dance until after the first 4 weeks of treatment. The prescription was to evaluate and treat one time a week for 6 weeks due to unusually high co-pay and financial limitations. After the initial examination, the patient was treated once per week for three weeks, and then once every other week, for six total sessions.

Plan of Care Design
The rehabilitation program integrated aspects of a regional interdependence approach with a focus on improving muscular strength and coordination, correcting muscle imbalances, and enhancing neuromuscular control. Physical therapy interventions were initiated with a home exercise program (HEP) following initial examination. The patient's initial home program included single leg exercises for hamstring, gluteus medius and gluteus maximus muscle strengthening, single leg squats, side planks with knees flexed, as well as instruction for transverse abdominus muscle contraction with all exercises. The patient was instructed to perform exercises daily, completing two sets of ten for each exercise.

Special Tests & and Muscle Length Assessments
Based on the patient complaints of left knee pain several special tests were performed to rule out ligamentous and meniscal involvement. The patient tested negative bilaterally for the following tests: Lachman's and anterior drawer test for anterior cruciate ligament (ACL) stability, McMurray's test for medial and lateral meniscus, 90/90 test for hamstring muscle length, Thomas test for iliopsoas and rectus femoris muscle length, and Ober's test for iliotibial band length.
Assessment
The patient reported pain intensity of 6/10 VAS the week following the initial examination, with the symptoms most intense at night after performing exercises and normal activity at school. She had not returned to dance but had returned to teaching 3 children’s dance classes which were 30 minutes in duration within the past week. She performed her HEP every other day since examination and described the pain as intense and achy after the exercises.

The treatment focus was on simple strengthening exercises for hip and core muscles necessary for activities of daily living and progression to return to dance that could be carried over for home program due to limited visits. The patient externally rotated her lower extremities, a natural position for dancers, and demonstrated genu valgus during exercises. She also complained of pain with single leg exercises. When cued to maintain her foot in a neutral position with correct lower quarter alignment, the patient reported decreased knee pain during therapeutic exercises, especially with single leg exercises.

Table 2. Follow up visit 1 exercises performed in clinic.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Purpose and Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing unilateral hamstring curls</td>
<td>Hamstring strengthening</td>
</tr>
<tr>
<td>Bilateral squats on inverted BOSU to 30 degrees of knee flexion</td>
<td>Lower quarter strengthening and proprioception</td>
</tr>
<tr>
<td>Unilateral leg press with elastic tubing for abduction resistance (Figure 1)</td>
<td>Abductor cueing during squat</td>
</tr>
<tr>
<td>Monster walk with elastic tubing around distal thigh (Figure 2)</td>
<td>Hip and thigh strengthening and abductor cueing</td>
</tr>
<tr>
<td>Latissimus pull down</td>
<td>Core strengthening/stabilization</td>
</tr>
<tr>
<td>Side planks with knees flexed</td>
<td>Core strengthening/stabilization</td>
</tr>
<tr>
<td>Prone push up position with knee to chest at neutral and lateral and medial angles with lower extremity movement (Figure 3)</td>
<td>Core strengthening/stabilization</td>
</tr>
<tr>
<td>Cable cord bilateral squat with upper extremity row with elastic tubing and abduction resistance (Figure 4)</td>
<td>Core strengthening/stabilization, lower quarter strengthening and proprioception</td>
</tr>
</tbody>
</table>

Figure 1. Unilateral leg press with elastic tubing.
Figure 2. Monster walk with elastic tubing around distal thigh.

Figure 3. Prone push up position with knee to chest at neutral and lateral and medial angles with lower extremity movement.

Figure 4. Cable cord bilateral squat with upper extremity row with elastic tubing and abduction resistance.
Assessment

Upon return to treatment a week later the patient had minimal to no pain at rest or with activity with most intense pain measured at a 2/10 on VAS. She had not increased her activity but was able to ascend and descend stairs at school. Upon reassessment for strength the patient demonstrated better structural alignment of the lower quarter with demonstration of bilateral squat and unilateral squat and a decrease in pain during performance of each. She continued to demonstrate a genu valgus collapse with unilateral squat.

Due to a decrease in overall pain intensity with exercise, the treatment focus was progressed to functional movements with strengthening to mimic simple dance maneuvers. Elastic tubing was utilized for hip abductor muscle resistance during all single leg hip exercises to decrease severe genu valgus collapse due to lack of strength of abductor and external rotator muscles. The patient complained of fatigue and cramping in stabilizing hip during exercises performed with foot in neutral hip rotation position. The patient was able to climb stairs without any pain and had no reports of knee pain during treatment. The patient was instructed to use elastic tubing during HEP for proper recruitment of abductor and external rotator muscles and their ability to decrease vector forces on anterior/medial knee during closed chain activities. She continued HEP performance every other day during the week between treatments. HEP was expanded to include diagonal hops and single leg squats with ER of hip during squat and IR of hip with rising.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Purpose and Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leg body weight squat to 45 degrees of knee flexion</td>
<td>Eccentric quad control</td>
</tr>
<tr>
<td>Unilateral leg press with circle board (figure 5)</td>
<td>Reactive neuromuscular control</td>
</tr>
<tr>
<td>Forward step-ups with elastic tubing and abduction resistance on weight-bearing leg (figure 6)</td>
<td>Quadriceps muscle strengthening with abductor cueing</td>
</tr>
<tr>
<td>Bounding Stair climbs (2 Sets of 5 steps)</td>
<td>Quadriceps muscle strengthening</td>
</tr>
<tr>
<td>Single leg squat with IR of hip concentric motion and external rotation (ER) of hip with eccentric motion (figure 7)</td>
<td>Hip and quadriceps muscle strengthening with complex movement</td>
</tr>
</tbody>
</table>

Table 3. Follow up visit 2 exercises performed in clinic.

Figure 5. Unilateral leg press with circle board.

Figure 6. Forward step ups.
Figure 7. Single leg squat with internal rotation (IR) of hip concentric motion and eternal rotation (ER) of hip with eccentric motion.
Follow-up Visit 3

Assessment
Upon return to therapy a week later the patient reported having had no pain in her knee all week during ADL’s but that she had not returned to dance class. She did continue to teach a children’s class, which only required very simple dance moves, all of which were pain free. She no longer used the elevator at school and could ascend and descend stairs without pain.

Due to the patient’s report of no pain all week, treatment exercises were advanced to mimic dance moves with multiple planes and involvement of upper and lower extremities in a sport specific preparation for return to dancing. During treatment the patient demonstrated improved abduction/ER strength during sagittal plane activities by demonstrating decreased valgus collapse with unilateral squatting. The patient continued to lack proper control in coronal plane activities and movement with complaints of fatigue in hips. Over the next week the patient was allowed to return to tap class and jogging on pavement 1-2 miles a day. These activities were followed with return to ballet and contemporary dance class the following week. She returned to therapy after two weeks. Her HEP was advanced to include the complex activities she had performed during in-clinic treatment.

Table 4. Follow up visit 3 exercises performed in clinic.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Purpose and Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side planks with knees flexed and single leg abduction of top leg (figure 8)</td>
<td>Abduction/ER strength with core strengthening/stabilization</td>
</tr>
<tr>
<td>Unilateral leg press to 45 degrees of knee flexion with circle board</td>
<td>Lower quarter strengthening and proprioception</td>
</tr>
<tr>
<td>Crabwalk with squat and elastic tubing around distal thigh (figure 9)</td>
<td>Core strengthening/stabilization and hip abductor cuing</td>
</tr>
<tr>
<td>Bounding Stair Climbs (3 sets 10 reps)</td>
<td>Reactive neuromuscular control and proprioception</td>
</tr>
<tr>
<td>Single leg stance on even ground with contra lateral LE sagittal and frontal plane lower reaches to cone</td>
<td>Reactive neuromuscular control and proprioception</td>
</tr>
</tbody>
</table>

Figure 8. Side planks with knees flexed and single leg abduction of top leg.

Figure 9. Crabwalk with squat and elastic tubing around distal thigh.
Assessment
The patient reported a return to dance class 4 days a week for about 8 hours a week at 80% of pre-injury levels. She reported only minimal pain during ballet class with certain moves that required excessive external rotation. The patient was able run pain free on a treadmill for 2 miles for warm-up. For re-examination prior to treatment the patient performed bilateral jumps and unilateral hops on even and uneven surfaces to assess power and distance. She demonstrated proper form with jumps and no compensations. Following pre-treatment re-examination the patient had no complaints of pain or fatigue with treatment exercises. The HEP was advanced to focus on unilateral squats, jumps, and hops in an externally rotated position for return to sport training. The patient was to increase dance class hours and intensity and return to therapy in two weeks for discharge.

Table 5. Follow up visit 4 exercises performed in clinic.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Purpose and Rationale</th>
</tr>
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<tbody>
<tr>
<td>Fast paced walk and moderate jog on treadmill between 4.0 and 6.0 mph for 10 minutes</td>
<td>Endurance</td>
</tr>
<tr>
<td>Bilateral squats on balance board with AP instability to 45 degrees of knee flexion with elastic tubing proximal to knees</td>
<td>Reactive neuromuscular control, proprioception, and abductor cueing</td>
</tr>
</tbody>
</table>

Follow-up Visit 5

Assessment
Upon return to therapy two weeks later the patient reported being 100% better. She returned to dance 5 days a week for 9-10 hrs a week at 100% pre-injury level. She also reported jogging 3 miles twice a week on off dance days. Prior to physical therapy she could only perform one pirouette however now was able to perform three in succession. After re-examination for discharge the patient ran consecutive 40-yard dashes at maximum speed and performed repetitive jumping and skipping for 40 yards each. All activities performed on pavement, with no reports of pain with either activity.

Table 6. Follow up visit 5 exercises performed in clinic.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Purpose and Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jog on treadmill at patient’s selected 6.0 mph for 1 mile</td>
<td>Endurance</td>
</tr>
<tr>
<td>Double knees to chest jumps</td>
<td>Power</td>
</tr>
<tr>
<td>40 yd sprint on pavement</td>
<td>LE power</td>
</tr>
<tr>
<td>40 yd high skips on pavement</td>
<td>Speed, power, and agility</td>
</tr>
</tbody>
</table>
OUTCOMES
At the discharge examination all hip and knee manual muscle tests were graded as 5/5. Overall pain level was a 0/10 on VAS with all activities of daily living, school requirements, ascending and descending stairs, as well as with dancing. The patient scored a 74/80 on the Lower Extremity Functional Scale and an 8.7/10 on the PSFS. The one exception was a 1/10 pain on VAS, which the patient described with certain ballet plies and turnouts that required maximal external rotation on both extremities. This limitation did not limit her performance in ballet class. She reported gradually increasing the amount of time she spent dancing each week, but was able to perform at 100% of pre-injury level while in class. She was performing and teaching dance class 5 days a week for up to 10-12 hours a week at time of discharge.

DISCUSSION
Weakness of the hip abductor and external rotator muscle may be associated with poor eccentric control of femoral abduction and internal rotation during weight-bearing activities. This lack of control can contribute to malalignment of the patellofemoral joint as the femur medially rotates under the patella. To reduce excessive lateral patellar deviations during weight-bearing activities and potentially reduce anterior knee pain, physical therapy intervention was necessary to address hip muscle performance and control of the LE during activity. Decreased hip stability due to muscular weakness, especially that of the gluteus medius and external rotator muscles, may affect the patellofemoral joint position in some patients. Decreased hip abductor and hip external rotation muscle strength may allow the pelvis to collapse under the weight of the body during single-leg stance which is a common maneuver in dance. When a dancer drops their hip, a valgus stress at the knee can occur and that may aggravate a patellofemoral joint condition.

Robinson and Nee demonstrated that females between 12 and 35 years of age, presenting with unilateral PFPS demonstrate significant impairments in the isometric strength of their symptomatic limbs for hip abduction, extension, and external rotation when compared to uninjured control subjects. Additional researchers have shown that young females with PFPS demonstrate hip abduction and external rotation muscle weakness when compared to that of age-matched non-symptomatic females. Subjects with PFPS demonstrated 36% less external rotation muscle strength and 26% less hip abductor muscle strength than control subjects. Bogla et al also showed similar results for subjects with PFPS, who demonstrated 24% less hip external rotator muscle strength and 26% less hip abductor muscle strength than controls. These studies support the theory that hip abductor and hip external rotator muscle weakness may allow excessive hip adduction and hip internal rotation during activity, thus contributing to patellofemoral joint stress. More importantly, several authors have reported favorable outcomes in patients who participated in a rehabilitation program targeting the hip musculature for the treatment of anterior knee pain.

Authors have reported that female athletes land with less knee flexion, less time to peak knee flexion, greater knee valgus, greater vertical ground reaction forces, and less hamstring activation than male athletes which may lead to ACL injury. Jumping and landing is an integral part of dance. Lephart et al suggested that the neuromuscular characteristics of the lower extremity in female athletes can be improved with a basic exercise program of jumps and single leg stance exercises which may reduce the risk for injury. A reduction in injury rate after a strength-training program alone was reported in those after ACL injury. Elevated neuromuscular control may account for some of the strength gains. Improvements in a muscle’s ability to generate force, appears to be a way for dancers to enhance their performance. The dancer presented in this case study demonstrated significant functional improvements as reflected by the LEFS and PSFS scores with a primary intervention of strengthening. An awareness of these factors will assist dancers to improve training techniques and to employ effective injury prevention strategies.

CONCLUSION
This case report outlines rehabilitation guidelines, a therapeutic exercise program, functional training interventions, and outcomes utilized with a female dancer with PFPS. The patient achieved a successful outcome, returning to full participation of dance training and employment as a dance instructor. Critical to this case was implementing concepts associated with regional interdependence. Proximal weakness through the core and hip region of this female dancer likely contributed to deficits in neuromuscular control of the lower extremity kinetic chain during squatting, jumping, and hopping. Clinicians should consider the influence of proximal impairments when examining and treating a patient with dysfunction of the lower limb.
REFERENCES


