ABSTRACT

Background. Methods of measuring lower extremity function is limited for those with partial weight bearing (PWB) status in early phases of a lower extremity rehabilitation program.

Objectives. The purpose of this study was to measure intra-rater reliability of two lower extremity PWB performance measures using an incline exercise apparatus and to evaluate the concurrent validity and responsiveness to change of these two measures.

Methods. Thirty-seven adult patients with lower extremity injuries were measured on two PWB measures (PWB20 and PWB30) of lower extremity performance as well as several common measures of LE function. After initial testing, subjects were asked to return for retesting, following four to six weeks of rehabilitation intervention. Reliability of the data from the measures was tested using intraclass correlation coefficients (ICC); validity was based on bivariate correlations of the measures. The minimal detectable change (MDC) value and limb symmetry index (LSI) were used to study the responsiveness of the PWB measures.

Results. The ICC for the PWB20 and PWB30 were 0.95 and 0.98, respectively. The bivariate correlations of the PWB20 with stair climbing and walking speed were greater than those of the PWB30. Correlations ranged from $r = 0.49$ to 0.72 between the PWB measures and the functional measures. For most patients, their change in score between initial testing and follow-up exceeded the MDC; the LSI improved for all patients.

Conclusion. Using the incline apparatus yielded reliable PWB data. In addition, performance on the PWB measures correlated fairly well with common measures of function.

Key words: partial weight bearing, incline apparatus, reliability, validity

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INTRODUCTION

Functional performance tests (dynamic full weight bearing tests) are useful predictors of lower extremity performance, which in turn allows for development of a realistic prognosis. Functional performance tests include the single legged hop for distance tests, stair climbing tests, and walk tests, among others. Each of these tests is supported by research in terms of the reliability of the measures and the validity of the inferences made from these tests. The common denominator is that the patient must have full weight bearing status in order to perform these tests. Currently few options exist to measure lower extremity performance of individuals with less than full weight bearing ability. For instance, individuals recovering from surgery (lower extremity total joint replacement, anterior cruciate ligament reconstruction, fixation after fracture, etc.) frequently initiate rehabilitation under weight bearing restrictions. In other cases, because of pain or weakness, performing traditional functional weight bearing tests is not feasible early in the recovery. A useful measure of lower extremity performance ability is essential for rehabilitation, treatment progression, and development of accurate prognoses of individuals with limited weight bearing status (i.e., partial weight bearing, PWB). Unfortunately, clinicians are limited to either subjective evaluation, self-report, or non weight bearing measures to estimate performance in individuals with restricted weight bearing ability.

Common forms of measurement of non weight bearing performance include manual muscle testing, joint range of motion (ROM), joint integrity measures (e.g., ligament laxity testing), and isokinetic testing. While these traditional clinical examination techniques provide reliable data, their reported predictive validities are low, as tests generally demonstrate poor correlation to lower extremity functional performance. For example, Kea et al examined the relationship between isokinetic testing of hip abduction and adduction movements to a lateral hop test for distance in elite hockey players. The relationship between isokinetic measures of hip strength and the hop tests was slight to poor (r = -.26 to .27). Kea et al concluded that function should not be predicted by joint-specific strength tests. Additional studies reported a wide range of correlations between isokinetic test measures and functional performance measures ranging from r-values of 0.26 to 0.63, with most of these studies testing the correlation of isokinetic measures to hop tests measures. In general, the authors concluded that care must be exercised when interpreting isokinetic measures of muscle performance in terms of functional performance.

Indirectly measuring the responsiveness of various lower extremity performance measures, Worrell et al used isokinetic testing, along with maximum lateral step-up repetitions, a leg press test, and two hop tests to measure changes in subjects following a six week lower extremity strengthening protocol. The protocol involved lateral step-up exercises in full weight bearing. At the conclusion of the study, all lower extremity performance measures improved with the exception of the isokinetic test measures. Worrell et al concluded that the non weight bearing isokinetic measure was not responsive to the changes gained in a weight bearing exercise program.

While isokinetic tests provide reliable measures of muscle strength, these tests do not show evidence of predictive validity for weight bearing functional performance ability. The manual muscle test, while being an accepted measure of leg strength, only measures static muscle strength and does not predict dynamic activity of the lower extremity. Hence, clinicians have limited options to measure lower extremity performance in individuals with PWB status.

An option worth consideration for measuring lower extremity performance in PWB is a sliding incline device, called the Total Gym, that was originally designed for partial weight bearing exercise. Using the Total Gym, Munich et al examined two lower extremity performance measures in a PWB position. The two lower extremity performance tests evaluated by Munich et al included the following: 1) the number of one-legged squats performed in 20 seconds on the Total Gym; and 2) the time required to perform 50 one-legged squats on the Total Gym. The intention of these two measures was to evaluate lower extremity performance, using the one-legged squat test as the definition of performance, in partial weight bearing. According to Munich et al, the test of one-legged squats in 20 seconds was designed to indirectly measure power of the lower extremity, and the 50 one-legged squats test was designed to indirectly measure local muscle endurance. All subjects were healthy young adults.

Munich et al concluded that the sliding incline apparatus was able to yield reliable data, with ICC values for intratester reliability exceeding 0.80. However, the test-retest reliability and inter-tester reliability of these measures, on
a non-healthy population, has not been evaluated. In addition, the validity or application of this protocol to an injured population has not been studied.

In the rehabilitation setting, clinicians are limited in their ability to measure lower extremity PWB performance of individuals with limited weight bearing ability. The PWB tests studied by Munich et al\(^2\) may provide an option for the clinician in order to provide early assessment of lower extremity performance in individuals with limited weight bearing. However, before test efficacy can be assumed, further data regarding the reliability and validity of these tests in an injured sample needs to be determined. Therefore, the purpose of this study was to measure the intratester reliability of the partial weight bearing tests described by Munich et al\(^2\) with individuals recovering from lower extremity injuries or surgery. In addition, this study evaluated the validity of these PWB performance tests, in terms of concurrent validity evidence and responsiveness to change, in patients with lower extremity dysfunction.

**METHODS**

**Subjects**

Subjects were recruited from area orthopaedic surgery offices and physical therapy offices by way of information flyers that were distributed to these offices. Inclusion criteria for this study were adult individuals, 21-65 years of age, with a unilateral lower extremity dysfunction resulting from an injury or surgery. Subjects needed to be currently involved in some form of physical therapy or a home program for rehabilitation. In addition, subjects needed to be willing to report to the University's research laboratory for all data collection, on at least two separate occasions, at least four weeks apart. Subjects were excluded if they were not able to walk independently and ascend/descend stairs with full weight bearing, or if subjects were non weight bearing on the involved lower extremity. In addition, subjects were excluded if at least 0-90 degrees of knee flexion range of motion was not available at the time of testing. All subjects signed an informed consent document, and this study was approved by the University of San Diego State Institutional Review Board for Human Subjects Research. Subjects were compensated monetarily for the time and expenses required to participate in this study.

**Apparatus**

For the PWB performance tests, this study used a Total Gym 26000 (Engineering Fitness International, San Diego, CA). This device consists of a sliding board apparatus that is mounted to a rail system. The rail system is fixed to a vertical upright stand and the rail can be positioned at angles of 10 degrees to 50 degrees to the horizontal (floor surface). Positioning the sliding board at an angle of 50 degrees to the horizontal provides approximately 65% of the individual's body weight as resistance (*Figures 1 and 2*) according to manufacturer's specifications and based on the following.

The slide distance regulator (Engineering Fitness International, San Diego, CA) was used to restrict the displacement of the sliding board apparatus in the downward direction. The slide distance regulator was also used in order to control the total knee ROM during a single squat repetition. A standard stop watch was used to record time for all tests. A standard goniometer was used to record...
knee joint ROM during the PWB performance tests. A standard tape measure was used to measure linear distance of the one-legged hop tests.

**Procedures**

Prior to any testing, subjects first performed single knee squat repetitions on the Total Gym device with the involved lower extremity, in order to determine an appropriate level for testing (i.e., angle of inclination and, therefore, appropriate body weight resistance), as well as to assure that subjects could perform a knee squat through a range of 0-90 degrees of knee flexion. The criteria for inclination level was an ability to perform ten consecutive one-legged squats without pause, through a ROM of at least 0-60 degrees of knee flexion (Figures 1 and 2). This ROM was selected because the range is necessary for normal stair climbing. However, the preferred test range of motion was 0-90 degrees of knee flexion, in accordance with Munich et al.21 Ten repetitions were chosen for the screening based on the investigators’ clinical experience and the opinion that this would be a safe level for testing. Once the appropriate inclination level, and the comfortable knee ROM were determined, the slide distance regulator was secured to the sliding board in order to assure that knee flexion ROM did not exceed the maximum knee flexion available for that patient. Knee ROM was measured with the goniometer using accepted procedures.22 Subjects were then randomly assigned to a sequence of lower extremity performance tests. The tests included the following:

1) Repetitions completed during the 20 second test of single leg squats on the Total Gym (PWB20)
2) Time (seconds) to complete the 30 repetition test on the Total Gym (PWB30)
3) Time (seconds) to ascend a flight of stairs
4) Time (seconds) to descend a flight of stairs
5) Time (seconds) to walk 15 meters
6) Distance (centimeters) of a single one-legged hop

The sequence of tests were randomly determined using a 5 x 5 design; the stair climbing tests were considered as one test in this design, given that subjects would naturally need to descend and ascend stairs during a test. However, for the purpose of data analysis, ascent and descent scores were considered separately. Prior to testing, subjects were provided warm-up times with either walking or performing two-legged squat exercises, as appropriate, on the Total Gym apparatus. Subjects were provided three to five minutes of rest between each test. On day one, subjects performed all tests in random order. A subset of 15 subjects was selected randomly to perform the tests a second time, on the first testing day, for test-retest reliability analysis. All subjects were asked to return for follow-up testing four to six weeks following the first day of testing. The follow-up testing was to examine the responsiveness, of the PWB performance tests, change in status of the subjects. It was expected that changes would occur in the patients, following four to six weeks of physical therapy or home exercise intervention. Given these improvements, the PWB performance tests should also reflect this improvement. While this study did not control the interventions that were provided, it is reasonable to expect that patients would improve over time. The incline level and knee ROM of the PWB20 and PWB30 tests were maintained for the follow-up testing. The same licensed physical therapist (20 years outpatient clinical experience), trained in the administration of the PWB20 and PWB30 tests, performed all the measures of all the patients.

**Measures**

**Twenty-second Squat Repetition test on the Total Gym (PWB20)**

This test involved the subject performing as many single-leg squat repetitions as possible in a 20 second time period. The subject squatted from 0 degrees of knee extension to a maximum of 90 degrees of knee flexion (Figures 1 and 2). If the subject was unable to flex the knee to 90 degrees the subject was asked to flex to a comfortable position. This position was measured with a 12-inch goniometer, using standard procedures as described by Norkin and White,22 for knee ROM measurement, and the slide distance regulator was used to assure that knee ROM did not exceed the maximum comfortable level of knee flexion. The subject was instructed on how to perform the proper squatting technique and he/she was asked to practice the squatting technique prior to beginning the test. Subjects were instructed to move from an extended knee position into a flexed knee position until the subject felt minor resistance from the slide distance regulator. After becoming familiar with the test, the subject rested for one minute before starting the actual test. Subjects were encouraged to squat at the fastest pace they felt safe performing. During the test, the researcher counted the number of squats performed by the subject in a 20-second time period.
Timed 30 single leg squat repetition test (PWB30)
This test required the subject to perform 30 single leg squat repetitions on the Total Gym. Thirty repetitions were chosen in place of the original 50 repetitions because pilot testing demonstrated that 50 repetitions required too much effort from a patient in the early stages of recovery. The actual procedures are identical to the PWB20, with the exception that subjects were instructed to continue squatting until 30 full repetitions were completed. The time (seconds) required to complete 30 repetitions was recorded by the investigator. In the event that a subject needed to stop and rest or slow down, the time continued to be recorded until all 30 repetitions were completed. Five subjects needed to stop and rest momentarily during the first day of testing; rest was not needed for any subject during the follow-up testing four to six weeks later. Subjects were encouraged to squat at the fastest pace they felt safe performing.

Timed ascending stair test (Stair UP)
This test required the subject to ascend a single flight of stairs (24 steps). The subject was instructed to ascend the stairs as rapidly as possible while remaining safe. The researcher used a stopwatch to determine the amount of time (seconds) the subject took to ascend the flight of stairs. Subjects could use an assistive device (straight cane or quad cane) and the railing, if needed.

Timed descending stair test (Stair DOWN)
This test required the subject to descend a single flight of stairs (24 steps). This test followed the Stair UP test for all participants. On completion of the Stair UP test, the subject was then instructed to descend the stairs as rapidly as possible while remaining safe. The researcher used a stopwatch to determine the amount of time (seconds) the subject took to descend the flight of stairs. Subjects could use an assistive device (straight cane or quad cane) and the railing, if needed.

Walk test
For this test, the subject was asked to walk 30 meters at a comfortable pace. During the 30-meter walk, two distinct points, 15 meters apart, were used for measurement of walking speed. When the subject's heel reached the first mark, the researcher started the stopwatch. The stopwatch was stopped when the subject's heel reached the second mark, and the time (seconds) was recorded.

Single-leg hop test
To complete this test, subjects performed a maximal single-leg hop. The subject was instructed how to properly perform the test. Prior to the test, the subject performed two practice hops. The subject began the test with toes behind a starting line, and a maximal hop was performed. Upper extremity movement and position were not controlled by the researcher. The researcher then measured the distance from the starting line to the subject's heel. The single-leg maximal hop was conducted two separate times during the actual test. The maximal distance of these two, or best score, was used for data analysis.

Additional data
The subject's age, gender, diagnosis, onset of injury (i.e., time since injury), and treatment type (i.e., home program or formal clinical physical therapy) were recorded. This information was self-reported by the subject.

Data Analysis
Reliability study
Relative and absolute reliability of the data from the PWB performance tests (PWB20 and PWB30 tests) and functional tests was estimated using the test-retest data of day one. Relative reliability measures the test-retest consistency of the data by establishing a coefficient value (intraclass correlation coefficient). This coefficient value is then compared to an established criteria for acceptable reliability. Absolute reliability involved estimating the actual error in the measure, in the original units of measure. The absolute reliability provides information regarding the expected error in the measure. Re-testing occurred approximately 30 minutes following the initial test. In order to evaluate the relative reliability of the data the Intraclass Correlation Coefficient (ICC 3,1) was used to estimate intrarater reliability.23,24 A lower one-sided 95% confidence value was constructed using SPSS version 11.0. It is the lower bound value of the 95% confidence interval that is of clinical importance for the ICC, because this represents the lowest possible relative reliability. In order to estimate absolute reliability of the measures, the standard error of measurement (SEM) was estimated based on:
sx is the standard deviation of the measure and rx was the ICC derived in the test-retest portion of the study. An upper one-sided 95% confidence value was constructed for the SEM. It is the upper bound value of the 95% confidence interval that is of importance clinically for the SEM, because this represents the highest possible value of error in the measure. The SEM was then used for the calculations of the minimal detectable change (MDC) with a 95% level of confidence, based on the procedures described by Stratford et al. The MDC is an estimate of the absolute change in a measure that is required to be clinically meaningful. The MDC95 was estimated using the following formula:

In this case, z = 1.96 is the z-score associated with a 95% confidence interval, and the value of 2.0 is a correction factor accounting for error over two testing occasions. The MDC was used to estimate the 95% confidence in the data that a clinically significant change occurred over time.

Validity study

Two elements of validity evidence were examined: concurrent validity evidence and responsiveness to change validity evidence. Concurrent validity evidence was assessed by comparing the PWB performance tests of the involved leg with known measures of function that included walking speed, stair ascending/descending speed, and hop performance. The values of all tests were evaluated using the Pearson’s product moment correlation coefficient for bivariate correlations. Responsiveness validity evidence was examined using two procedures: 1) a two-factor (2x2) analysis of variance (ANOVA) compared the rate of change of the involved leg with the uninvolved leg (i.e., known groups method) on the PWB performance tests; and 2) a simple repeated measures ANOVA compared the relative change scores of the involved leg on the PWB performance tests with the relative change scores of the known measures of function (walking speed, stair ability speed, and hop distance). Paired t-tests, comparing the initial measurement values with the follow-up values, were also used to test whether subjects improved on the four measures of function.

Finally, the limb symmetry index was calculated, by obtaining the ratio of the involved leg raw score with the uninvolved leg score on the PWB performance tests, for the PWB performance tests. The limb summary index is a useful measure in that it accounts for changes in both lower extremities (i.e., involved and uninvolved) over time, to estimate the relative performance of the involved limb compared with the uninvolved limb. The limb summary index at initial test was then compared with the limb summary index at follow-up using a simple repeated measures ANOVA, and planned repeated contrasts were used to test for differences between the PWB20 and PWB30 limb symmetry index (LSI) values.

RESULTS

Subject Demographics

Forty-four subjects originally volunteered to participate in this study. Seven subjects were excluded because they presented with bilateral lower extremity symptoms. Thirty-seven subjects completed the initial testing. Fifteen of these subjects were retested on the initial day to assess reliability of the data. Data from the 15 subjects were used for the reliability study and data from the 37 subjects were used for the correlation matrix. Of the original 37 subjects, only 23 subjects completed the second phase of testing after four to six weeks for follow-up. Data from the 23 subjects who completed both the initial and follow-up testing were used for the responsiveness to change analysis. The 14 subjects who did not complete the follow-up were excluded because they were not involved in any form of rehabilitation (i.e., formal clinical therapy or home therapy, n = 12) or they did not return for follow-up (n = 2). The two subjects who did not return for follow-up did not want to travel the distance for the follow-up test. Data of the remaining 23 subjects were then used for the responsiveness to change analysis. Eight of these 23 subjects maintained a regular physical therapy rehabilitation program, while 15 subjects continued with a home exercise program.

Table 1 provides the demographic information of the subjects, including age, sex, and time since original injury/dysfunction. Table 2 provides a distribution of the self-reported diagnoses of the subjects.
as a list of the physical diagnoses by self-report of all subjects. Knee joint pain refers to those subjects who reported either “arthritis” or “internal knee pain” as their reason for physical therapy consultation. The time, in days, of onset was estimated by each subject. For surgical cases (i.e., knee joint replacement, ACL surgery, etc.), the date of surgery served as the time since onset. For all other conditions, acute and chronic, the subject provided a best estimate of duration of symptoms.

Finally, an insufficient number of subjects completed the hop test (n = 8), prohibiting any meaningful statistical analyses. Hence, findings on the hop tests are not included.

Reliability Study
The ICC’s for the PWB performance tests, walking time, stair times, and hop test are reported in Table 3. All point estimates for the ICC’s were greater than 0.90, and the lower bound of the 95% confidence interval exceeded 0.70 for all measures.16 In addition, Table 3 provides the SEM for the PWB performance tests. Based on the SEM, the MDC90 is also presented in Table 3 for the two PWB performance tests.

Validity Study
Concurrent validity
The results of the bivariate correlation analysis testing between the two PWB performance tests and the four measures of function, on the initial day of testing, are presented in Table 4. All correlation coefficients were significant at p < 0.05. Negative correlations were identified between the number of one-legged squat repetitions that a subject could perform in 20 seconds with the time needed to walk or ascend/descend stairs (r = -0.72 to -0.60). Hence, repetitions were inversely related to time; more repetitions in 20 seconds were related to less time needed to walk or ascend/descend. Similarly, a positive correlation was identified between the time required to complete 30 one-legged squat repetitions and the time needed to walk and ascend/descend stairs (r = 0.61 to 0.49). In all cases, the PWB20 test had slightly higher bivariate correlation coefficient values than the PWB30 test, with the three measures of function. As expected, the two PWB performance tests were correlated with each other (inversely), and the stair climbing tests were correlated with each other. Walking was also correlated with stair climbing.

Responsiveness to change
Follow-up testing of the four performance tests and the two PWB performance tests occurred on average 30.27 days (sd = 2.94 days) post initial test with a minimum and maximum of 27 and 36 days, respectively. Subjects were tested at the same level on the Total Gym as their initial test Total Gym level. All subjects were initially tested at either level 8, 9, or 10, which coincided with 50-65% of body weight, on the Total Gym. Follow-up testing was performed at the same level. Average knee flexion for all PWB performance tests was 70.22 degrees (sd = 4.07 degrees) with a minimum and maximum of 60 degrees and 83 degrees. The results of the two-way

<table>
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<tr>
<th>Self-Report Diagnosis</th>
<th>Initial (n)</th>
<th>Follow-up (n)</th>
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<tbody>
<tr>
<td>Knee joint pain</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Patella-femoral dysfunction with/without lateral release</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Anterior cruciate ligament reconstruction</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Total knee arthroplasty</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Achilles tendon rupture and repair</td>
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<td>2</td>
</tr>
<tr>
<td>Iliotibial band syndrome</td>
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<td>0</td>
</tr>
<tr>
<td>Tibial plateau fracture</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hamstring tear</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>37</strong></td>
<td><strong>23</strong></td>
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Table 2: Distribution of diagnoses, by self-report, at initial test of study and at follow-up.
repeated measures ANOVA for the PWB20 test and for the PWB30 test revealed that the involved leg demonstrated significantly greater changes in performance compared with the unininvolved leg (p < .05 for the interaction term in both PWB performance tests). Table 5 provides the mean values at initial and at follow-up for the two PWB performance tests. In addition, pairwise t-tests revealed that all subjects improved in walking speed, stair climbing speed, and hop distance (p < .05). Mean measures for initial and follow-up are also displayed in Table 5 for these measures. Finally, the absolute change values are reported, for comparison to the MDC95.

Relative change of each of the functional tests was similar to the relative change in the PWBP tests for the involved lower extremity. Simple repeated measures to test these values revealed no significant differences in relative change scores (p > .05). Table 5 provides the relative change for each measure, expressed as a percentage. The uninvolved limb relative changes were significantly less than the other relative change scores (p < .05). Finally, the limb symmetry index for the PWB performance tests changed significantly when tested with a simple repeated measure ANOVA (p < .05). Based on the planned repeated contrasts, the LSI increased from initial test values to the follow-up values (Table 5), for both the PWB20 test and the PWB30 test (p < .05). The LSI of the PWB20 was greater than the LSI of the PWB30 at both the initial test and at follow-up (p < .05).

DISCUSSION
The purpose of this study was to evaluate the measurement properties of two PWB measures of lower extremity performance. The two tests, both involving a single legged squat, were performed on a Total Gym, a device that allowed the measures to be performed at less than 100% of the subject's body weight. In fact, all subjects performed the PWB tests at approximately 65% of body weight. The measurement properties evaluated included absolute and relative reliability, as well as validity evidence in the form of concurrent validity and responsiveness to change. A heterogeneous sample of patients participated in this study, with lower extremity conditions ranging from patellofemoral dysfunction to total knee arthroplasty surgery.

The relative intratester test-retest reliability of the two PWB measures assures reliability, with ICC values exceeding 0.90. In addition, the absolute reliability, as estimated with the SEM, was also excellent, with upper 95% SEM values less than 2.0 for either measure (i.e., PWB20 or PWB30). The ICC values exceed those reported by Munich et al. It is likely that the heterogeneous sample in this current study contributed to the improved ICC values. Munich et al used a homogeneous sample of college-aged healthy adults. In addition, the test-retest ses-

<table>
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<tr>
<th>Table 4. Correlation matrix for all measures. (n = 37)</th>
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<tr>
<td></td>
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<tr>
<td>PWB20</td>
</tr>
<tr>
<td>PWB30</td>
</tr>
<tr>
<td>Stairs UP</td>
</tr>
<tr>
<td>Stairs DOWN</td>
</tr>
<tr>
<td>Walk</td>
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<table>
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<tr>
<th>Table 5. Mean measures for the partial weight bearing performance tests and the measures of function (sd).</th>
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<tr>
<td>Test</td>
</tr>
<tr>
<td>PWB20 Uninvolved</td>
</tr>
<tr>
<td>PWB20 Involved</td>
</tr>
<tr>
<td>PWB30 Uninvolved</td>
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<tr>
<td>PWB30 Involved</td>
</tr>
<tr>
<td>Stair UP</td>
</tr>
<tr>
<td>Stair DOWN</td>
</tr>
<tr>
<td>Walk</td>
</tr>
<tr>
<td>LSI PWB20</td>
</tr>
<tr>
<td>LSI PWB30</td>
</tr>
</tbody>
</table>

PWB20 = repetitions
PWB30, Stair, Walk = time (sec.)
LSI = limb symmetry index (%)
* Significantly different from initial values, p < .05.
† Significantly less than all other relative change estimates, p < .05.
sion for this current study was separated by only 30 minutes, whereas the Munich et al study performed re-testing one full week later. Regardless, the ICC values and the low SEM suggest that the two PWB performance tests provide reliable data in terms of intra-tester reliability.

Concurrent validity evidence was estimated by correlating the PWB performance test measures with measures of walking speed, stair climbing and descending speed, and maximum one-legged hop distance. The data from the initial test were used to evaluate these relationships. This study found correlations between the PWB performance tests and the functional tests. In fact, the correlation coefficients were higher than those found for isokinetic testing. This finding is not surprising given that the PWB performance tests involve the entire lower extremity (ankle, knee, hip), whereas the isokinetic tests used in previous studies were measures of isolated lower extremity muscle group function. The PWB performance tests more closely replicate the interaction between multiple joint systems during a functional activity, and hence the measures of the PWB performance tests better correlate with walking and stair climbing speed, compared with single joint system tests. In addition, as noted by Aasa et al, body size influences muscle strength assessment. Isokinetic tests are dependent on leg/limb mass whereas the PWB performance tests are dependent on total body mass.

The direction of the correlations for the PWB performance tests with the functional measures of walking and stair climbing also make sense. For instance, the PWB20 test, which is a measure of maximum repetitions, demonstrated negative correlations with walking speed and stair climbing speed. The more repetitions a person could complete in 20 seconds, the less time that person would need to walk the established walk distance and to ascend/descend a flight of stairs. Conversely, the PWB30 test positively correlated with these functional measures. The less time needed to complete 30 repetitions of the PWB30 test, the less time needed to also walk a set distance and ascend/descend a flight of stairs.

This study was not able to evaluate the relationship between the PWB performance tests and one-legged hop ability. Only eight subjects were able to complete the hop trials. The hop tests were considered too advanced by most of the subjects, at their present stage of recovery.

Additional validity evidence was estimated in the form of responsiveness to change. Worrell et al noted that isokinetic testing may not be responsive to changes in lower extremity function, when weight bearing exercise protocols are involved in the rehabilitation. The two PWB performance tests demonstrated good responsiveness to change. The MDC values of 3.74 and 3.41, respectively, of the PWB20 and PWB30 were exceeded by the average absolute changes on both measures (4.8 and 9.2, respectively). Hence, the PWB performance tests are able to measure improvement/change in patients’ lower extremity function, if indeed changes have occurred because of rehabilitation and/or time. Initial test and follow-up test measures on the PWB performance tests were significantly different from each other, as were walking speed and stair climbing speed. All measures improved significantly. In fact, relative changes for all measures were similar (p > .05).

Additional responsiveness evidence is provided by the change in the limb symmetry index (LSI). It was expected that the LSI would improve, given that the uninvolved lower extremity was not expected to improve as well as the involved lower extremity. In this study, the uninvolved lower extremity did not demonstrate any significant changes on the one-legged tests (PWB performance tests). Thus, the LSI improved significantly, based on both PWB performance tests. The initial test LSI of our subjects are comparable with those reported by Wilk et al, when testing leg strength isokinetically. In their study, the LSI based on isokinetic testing was less than 85% in the majority of their subjects. Following four to six weeks of time, the subjects in this study demonstrated improved performance of the involved lower extremity, greater than the changes in the uninvolved lower extremity, as evidenced by the improved LSI.

Several limitations exist to this current study. The type of rehabilitation that each patient received was not controlled. In addition, the influence of rehabilitation approaches and lack of formal rehabilitation in terms of the outcomes achieved was not accounted for. In fact, as noted in the results, only eight of the 24 returning subjects received formal physical therapy. The majority performed physical therapy prescribed home exercise programs. Another limitation is the wide range of diagnoses included in this study. Given that the average time since onset was nearly four months, whether the PWB performance tests are better suited for acute or chronic conditions could not be determined. Future research should evaluate the PWB perform-
ance tests on individuals with acute conditions separately from chronic status, as well as analyze patients by diagnostic groups. Finally, even though the PWB performance tests are intended for the early stages of recovery and for individuals with PWB status, the subjects in this study had full weight bearing (FWB) status. The FWB status was necessary in order to test walking speed and stair climbing speed for the concurrent validity evaluation. Yet, even with FWB status, only eight of the original 37 subjects were willing to perform the hop tests. The hop tests were either considered too aggressive or subjects were afraid to try to hop. While this is a limitation to our study, it is also evidence of the need for a controlled weight bearing measure of performance.

Hence, in order to determine if the PWB performance tests are appropriate for a patient population with acute presentation or PWB status, future research is needed that involves this population. Our study included individuals with lower extremity pathology, however, all were FWB. Further research is needed on a sample of patients with actual PWB limitations.

CONCLUSION
Two partial weight bearing one-legged squats tests were evaluated for measurement properties of reliability and validity. The two partial weight bearing performance tests, the PWB20 and PWB30, demonstrated sufficient intrarater test-retest reliability. In addition, this study provides evidence of validity of these measures to estimate lower extremity performance. The two tests correlate with walking and stair climbing speed. In addition, the two tests are responsive to changes in condition and provide an indication of leg symmetry. These partial weight bearing performance tests might be suitable for the orthopaedic setting, as a means of patient examination of function in a partial weight bearing position. Clinicians should use caution in interpreting the findings of an evaluation with the partial weight bearing performance tests until further research with specific patient populations and acute status have been completed.

REFERENCES


CASE REPORT

THE USE OF PATELLAR TAPING IN THE TREATMENT OF A PATIENT WITH A MEDIAL COLLATERAL LIGAMENT SPRAIN

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Michael Masaracchio, PT, DPT, OCS

ABSTRACT

Background. The medial collateral ligament (MCL) is one of the most frequently injured ligaments in the knee. The purpose of this case report is to describe conservative management of a 13 year-old soccer player with a one year history of untreated intermittent bilateral anterior knee pain who sustained a grade II MCL sprain while playing soccer and returned to competitive play within four weeks. The use of patellar taping as an adjunct to treatment will be introduced.

Case Description. Based on the physical examination findings, the patient’s injury was classified as a grade II MCL sprain. The patient was treated successfully with a combination of modalities, manual therapy, and therapeutic exercise. Specifically, patellar taping was added to the traditional physical therapy regimen. Pain scale ratings, strength assessment, and a variety of functional outcome assessment tools were used to determine progression and outcomes.

Outcomes. Following one session of modalities, manual therapy, patellar taping, and education in a home exercise program (HEP), the patient reported decrease overall left knee pain and increased comfort with knee active range of motion (AROM). Throughout the four weeks of treatment, the patient was compliant with the HEP. During this time, the patient continued to demonstrate improvement in pain, strength, AROM, and functional activities.

Upon discharge, the patient was cleared for full return to sports.

Discussion. The novel intervention in this case report was the taping of the patella medially. This patient returned to sports two weeks earlier than the average athlete with a grade II MCL sprain.

Key words: MCL sprain, soccer injuries, knee rehabilitation, patellar taping

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INTRODUCTION
The medial collateral ligament (MCL) is one of the most frequently injured ligaments in the knee. Injuries to the MCL are classified into grades I, II, and III based mostly on clinical examination. Currently, treatment of isolated MCL injuries, especially grades I and II, are managed nonoperatively. Injuries to the MCL are especially common in young athletes involved in sports which place valgus loads on the knee. Physical therapists who treat these injuries have the challenging task of returning these athletes to their sport as quickly and as safely as possible. The purpose of this case report is to describe the conservative management of a grade II MCL sprain, which included patellar taping as an intervention technique.

Anatomy of the MCL
The medial aspect of the knee joint is quite complex in terms of its functional anatomy. To assure a good understanding of the MCL, the anatomy of the medial aspect of the knee needs to be briefly discussed. Warren and Marshall have identified three distinct layers along the medial aspect of the knee. The first layer consists of the fascia covering the sartorius muscle. The second layer consists of the superficial MCL, and the third layer consists of the knee joint capsule. Since this case report is dealing with an isolated injury to the MCL, only the detailed anatomy of this particular structure will be reviewed. For a more comprehensive detailed anatomy review of the medial aspect of the knee, readers are referred to the article by Jacobson et al.

Based on the work by Warren and Marshall, the MCL can be subdivided into superficial and deep components. The superficial MCL has a proximal attachment along the medial femoral epicondyle and runs distally to the proximal medial tibia. The deep MCL has a proximal attachment along the medial femoral epicondyle and runs distally to insert on the tibia, just below the joint line. Additionally, the deep MCL has an attachment to the medial meniscus. Other authors have described the MCL as having an attachment to the fibers of the medial patellar retinaculum.

Biomechanics of the MCL
Given the various anatomical components of the MCL, researchers and clinicians have extensively studied the biomechanics of this important medial stabilizer of the knee. The superficial MCL functions as the primary stabilizer of the medial knee joint against valgus stresses. Brantigan et al have further subdivided the superficial MCL into an anterior parallel bundle of fibers along with a more posterior oblique bundle of fibers. Both Brantigan et al and Mains et al have argued that the superficial MCL fibers remain tight throughout knee flexion. Other authors have suggested that the fibers of the superficial MCL are on slack in knee flexion. Still other authors, such as Horowitz and Warren et al, have argued that the anterior fibers of the superficial MCL are tight in flexion, while the posterior oblique fibers remain tight in extension.

Mechanism of MCL Injury
The typical mechanism of injury to the MCL involves a valgus stress to the knee joint. This valgus stress can result from a contact injury such as those seen in football or soccer, or from a non-contact injury secondary to cutting, pivoting, or a sudden change in direction as is prevalent in basketball and soccer. When valgus forces are combined with rotatory forces, other structures such as the anterior cruciate ligament (ACL) or the posterior medial corner of the capsule may potentially be damaged. However, even though this case report involved a non-contact, valgus force with a rotatory component to the knee, the result was an isolated grade II MCL sprain.

Classification of MCL Injuries
Clinicians may be called upon to diagnose MCL injuries, which can be detected by physical examination. Various classification systems for MCL injuries based on physical exam exist in the literature. For this case report the authors used the clinical classification system developed by Indelicato (Table I), which is also described by Giannotti et al when discussing classification of MCL sprains.

Given the complex anatomical nature of this ligament, it is impossible to isolate...
deep MCL injuries using special tests, therefore requiring the aide of diagnostic imaging. In addition to the clinical classification just described, another classification of MCL injuries based on magnetic resonance imaging (MRI) has been discussed in the literature. Stoller et al have discussed three grades of MCL injuries based on findings observed following an MRI. Grade I sprains are represented by an increased signal intensity medial to the MCL. Grade II sprains are identified with similar characteristics of grade I sprains with additional increased signal within the MCL itself. Grade III sprains are identified as complete loss of fiber orientation with fluid between the torn ligament ends. This classification system can assist with definitive diagnosis if clinical examination techniques are unclear secondary to potential swelling or inflammation.

**Outcome Measures**

Pain scale ratings, strength assessment, and a variety of functional outcome assessment tools were used to determine progression and outcomes. The Numeric Pain Rating Scale (NPRS) is an 11 point scale ranging from 0-10, with 0 representing no pain and 10 representing the worst pain imaginable. Patients rate the highest pain level over the last 24 hours. Research has shown the NPRS to be both reliable and valid, with a change of two points being clinically significant.

The Lower Extremity Functional Scale (LEFS) is a scale on which patients score their ability to perform functional activities. The LEFS consists of 20 items scored on a five point scale ranging from 0-4. The highest possible score is 80, which represents a high functional level. The literature has demonstrated the reliability of the LEFS and its construct validity has been supported in comparison to the SF-36. Both the minimal clinically important difference and the minimal detectable change is a nine point difference in the total score.

Additionally, functional activities were used to assess patient progression. These included shuttle runs, hopping, and figure-8 running drills. These activities mimic some of the stresses and functional demands on the knee during soccer.

**CASE DESCRIPTION**

**History**

The patient was a 13 year old soccer player who reported left medial knee pain after planting her left foot and turning right during a soccer game. The patient reported icing her knee immediately after the injury with no significant improvement in pain or function. The patient was seen by a sports medicine physician three days post-injury and was diagnosed with an MCL sprain. Physical therapy was prescribed and the patient was evaluated by a physical therapist five days after the injury.

**Activity Level**

The patient lived with her family in a private house, with a bedroom on the third floor. She was a member of a soccer travel team and attended practice 4-5 times per week for 1.5-2 hours a practice session.

**Numeric Pain Rating Scale (NPRS)**

The patient subjectively rated her pain level at a 6/10.

**Chief Complaints/Functional Level**

The patient reported difficulty with ambulation, dressing (donning and doffing pants, socks, and shoes), stair negotiation (descending more than ascending), transferring in and out of a tub, sitting, squatting, balance, and anything required to play soccer. The patient reported an inability to fully extend her left knee due to extreme pain. A specific NPRS score for the pain experienced during end-range active knee extension was not obtained.

**Lower Extremity Functional Scale (LEFS) Score**

The patient’s LEFS score was 31/80.

**Past Medical History**

The patient reported a previous ankle fracture on the ipsilateral side about eight months prior to injury, and intermittent bilateral knee pain for one year, which the patient was not experiencing at this time.

**PHYSICAL EXAM**

**Girth/Edema**

Mid-patella circumferential measurement revealed a 0.3 cm difference in girth, with the right circumference measured at 33.8 cm, and the left circumference measured at 34.1 cm. This 0.3 cm difference may have been due to swelling; however, the difference could also have attributed to measurement error.

**Active Range of Motion**

Knee AROM was measured with the patient positioned prone on a plinth, with the trunk and femur supported by the plinth, and the lower leg unsupported by the plinth.
Knee flexion on the right was 5°-0°-136°, and on the left was 4°-110° (with pain).

**Strength Testing**
The patient's overall lower extremity strength was assessed to be in the good to normal range with manual muscle testing (Table 2). The patient complained of pain with resisted hip adduction, knee flexion, and ankle plantarflexion.

**Positive Special Tests**

**Valgus Stress Test**
This test is designed to assess the integrity of the MCL as well as other medial stabilizers of the knee. Based on the patient's history and description of her mechanism of injury, the treating clinician performed this test. The test was painful at both 0 degrees and 30 degrees of knee flexion, with a firm end-feel without gapping at 0 degrees, and a firm end-feel with mild gapping at 30 degrees. According to Dutton, a positive test at 30 degrees indicates at least a grade II MCL sprain.

**Apley’s Compression Test**
This test assesses for potential meniscal tears. Given the rotary component of the mechanism of injury and the patient's complaint of inability to fully extend her knee, the treating clinician performed this test to evaluate the integrity of the meniscus. The test was positive only with tibial external rotation. Given the denial of catching or clicking in the knee by the patient, in combination with the poor diagnostic accuracy of the Apley’s compression test and negative findings of other meniscal tests, the treating clinician did not suspect a torn meniscus.

**Step-down test**
This test has been used in patients with patellofemoral pain to objectively measure knee pain while descending stairs. It should be noted that this test is not specific to the patellofemoral joint and is useful following knee ligamentous injuries or other sports-related injuries.

The intra-rater reliability of this test has been determined to be high (intraclass correlation coefficient 0.94) by Loudon et al. To the best of the authors' knowledge, research documenting the validity, as well as the specificity and sensitivity of the step-down test have not been reported. The treating clinician also used this test to assess eccentric quadriceps muscle control, which is a necessary component of many functional and sports activities. The test was positive based on the patient's report of pain and inability to control knee flexion while descending a standard clinic 8 inch step-stool.

**Tenderness to Palpation**
The following structures were tender when palpated: left MCL (mid and distal/tibial portions), distal quadriceps muscle and quadriceps tendon (suprapatellar tissues), left distal medial hamstrings muscle, and left proximal medial gastrocnemius muscle.

**Posture**
In standing, bilateral subtalar joint pronation (left more than right) was observed. In addition, decreased left lower extremity weight-bearing and less left knee flexion were present when compared to the right.

**Gait**
The patient was ambulating with one axillary crutch, decreased left stance time, decreased left knee flexion during swing phase, and without full knee extension during terminal swing phase.

**Neurological Screening**
Since the patient presented with no significant past medical history and did not report any radicular or neurological symptoms, a complete neurological exam was not conducted.
Diagnosis
Based on the grading system of Indelicato,17 the treating therapist diagnosed this patient with a grade II MCL sprain.

INTERVENTION
Session 1/Initial evaluation (5 days post-injury)
The patient's treatment consisted of medial patellar glide taping (Figure 1) as described by McConnell26 and ice to the left knee with the patient positioned supine while rolling a physioball by moving the involved leg in and out of hip and knee flexion and extension (pain-free range) (Figure 2). For the patient's home exercise program (HEP), see Table 3. The patient was instructed to wear the tape until the night prior to the next scheduled session unless skin irritation, discomfort, or an increase in symptoms was experienced.

Session 2 (10 days post-injury)
The patient's pain level was a 3-4/10 on the NPRS at the beginning of the session, and the patient reported being able to straighten her knee into full extension. The patient presented with AROM 0º-135º with minimal discomfort, and 0º-138º with pain; and continued tenderness to palpation to the mid- and distal portions of the MCL. For treatment session details, see Table 3. Immediately following the session, the patient rated her pain level with ambulation at a 1/10.

Session 3 (13 days post-injury)
The patient rated her pain in general at a 0/10, with “occasional twinges” with excessive or sudden activity. The patient presented with continued, though decreased, tenderness to palpation to the MCL, and continued poor eccentric quadriceps muscle control (step-down test). For treatment session details, see Table 3.

Session 4 (16 days post-injury)
The patient continued to rate her pain at a 0/10 with “occasional twinges” at 4/10.

The patient presented with AROM 8º-0º-138º; continued tenderness to palpation to the MCL, decreased postural control with rotatory and multi-planar movements compared to the uninvolved side, a positive left valgus test (at 30º only), a positive left step-down test (though patient demonstrated improved quadriceps control). For treatment session details, see Table 3.

Session 5/Last Visit (30 days post-injury)
The patient rated her pain at 0/10 and reported an increase in her activity level without difficulty or pain. The patient presented without swelling in the left knee. Her AROM was 6º-0º-143º. Manual Muscle Test of the left hip flexors was a 4+-5/5; knee flexion, extension, and dorsiflexion were 5/5; and plantarflexion was a 4+/5. Special tests revealed a positive left valgus test at 30º yielding laxity without pain and a negative step-down test. There was mild tenderness to palpation to the proximal and distal portions of the MCL. The patient's LEFS score increased to 77/80. The patient was able to run figure-8's and shuttle runs without difficulty, but had a mild decrease in balance while hopping clock-wise and counter clock-wise.

Figure 1. Medial patellar glide taping
Figure 2. Ice with ball rolling
For treatment session details, see Table 3. The patient returned to her physician two days after the last visit and was cleared for full return to sports.

**Treatment Techniques (Table 3)**

Musculoskeletal injuries require a variety of treatment interventions. Interventions are selected by the clinician based on the patient's presentation that session, being mindful of the goals of the rehabilitation program. Modalities and Manual Therapy Modalities, such as heat and ice, were used as adjuncts to the rehabilitation program. The treating clinician selected the appropriate modality based on the patient's presentation during each session.

Transverse-friction massage was performed to the MCL in an effort to decrease pain, improve blood flow, and promote desired collagen alignment. In addition, joint distraction of the tibiofemoral joint was performed to decrease pain and improve joint mobility. Rhythmic stabilization was used by the treating clinician to facilitate neuromuscular control of the knee.

**Therapeutic Exercises**

Various therapeutic exercises were implemented into the rehabilitation program for this patient. These exercises are described in complete detail in the discussion section of the paper. For a list of exercises, their parameters, and time of implementation, please see Table 3.

**OUTCOMES**

At the conclusion of the first session, the patient reported decreased overall left knee pain, less pain with movement, and improved total knee AROM. By the beginning of the third session, the patient reported no pain except “occasional twinges” with excessive or sudden activity. However, the patient continued to demonstrate poor eccentric quadriceps muscle control. At the last session, 25 days after the initial examination, the patient's pain had improved from a 6/10 to 0/10 (NPRS), her LEFS had increased from 31/80 to 77/80, and her overall functional capacity had improved (Table 4).

**DISCUSSION**

Sports involving valgus loading of the knee contribute to the frequent occurrence of MCL injuries. Annually, tremendous growth in pediatric soccer participation occurs in the United States, estimated by the American Academy of Pediatrics to be between 11.4%-21.8%. It is logical to conclude that as the participation in sports that yield a high incidence of MCL injuries increases, so will the absolute number of MCL injuries. Given the assumed increase of MCL injuries, physical therapists

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**Table 3: Exercises and Treatment Techniques**

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 3</th>
<th>Session 4</th>
<th>Session 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td></td>
<td></td>
<td>Left knee 15 minutes</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cold</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse friction massage MCL</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Patellar taping</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Distraction knee joint in sitting with Mulligan strap</td>
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<tr>
<td>Rhythmic stabilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Left lower extremity</td>
</tr>
<tr>
<td>Retro treadmill 5 minutes</td>
<td>1.1mph</td>
<td>1.4mph with grade 3 incline</td>
<td>1 minute warm up and 2 minute run</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral leg press with ball squeeze</td>
<td>40lbs 10 x 3 (90°-45°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wall squats</td>
<td>10 x 3</td>
<td>Left unilateral 10 x 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left lateral dips 4” step</td>
<td>5 x 3 with a mirror</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Left LAQ with ball squeeze</td>
<td>10 x 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitter</td>
<td>Contact guard 10 x 2</td>
<td>Independent 10 x 3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Single limb stance (SLS)</td>
<td>SLS on a balance pad with ball catch (to fatigue)</td>
<td></td>
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<tr>
<td>Home Exercise Program</td>
<td></td>
<td></td>
<td>Add 1x/day right hip adduction with red theraband 10 x 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Initial Examination</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPRS</td>
<td>6/10</td>
<td>0/10</td>
</tr>
<tr>
<td>LEFS</td>
<td>31/80</td>
<td>77/80</td>
</tr>
</tbody>
</table>

**Table 4: Outcome Measures**

<table>
<thead>
<tr>
<th>Functional Activities</th>
<th>Ambulation with axillary crutches, sports activities unable to be assessed</th>
<th>Normal gait, figure-8 shuttle runs no difficulty, mild decreased dynamic balance with hopping activities</th>
</tr>
</thead>
</table>
must identify efficient treatment techniques to minimize lost playing time.

A thorough search of the literature did not yield any articles discussing the relationship between MCL sprains and patellar taping. To the best of the authors' knowledge, this case report is the first paper that evaluates the effects of patellar taping when implemented into the rehabilitation of an athlete with an MCL sprain. While the healing time frame for a grade II MCL sprain is variable, a range of 3-8 weeks is average. The consensus seems to be a minimum of 6-8 weeks for sports, such as soccer, that place more stress on the MCL. The patient in this case report was cleared for full participation in soccer in just four weeks. The authors recognize that while currently no evidence exists to support the use of patellar taping in individuals with MCL sprains, the implementation of this technique may potentially increase the rate of recovery in these individuals. Additional research is required to thoroughly investigate the potential positive effects of patellar taping.

As discussed in the literature, the initial phase of MCL injury rehabilitation focused on the elimination of pain and swelling. Additionally, emphasis was placed on normalizing quadriceps muscle function. During this phase, some clinicians are of the opinion that the knee should be braced, though this is not necessarily recommended across the board. When bracing is utilized, debate exists regarding the position of the knee in the brace – whether the knee should be in full extension or in 15°-30° of flexion. This difference may be due in part to differences of opinion regarding the biomechanics of the MCL. Slocum and Larsen, as well as Last, state that the superficial fibers of the MCL are on slack in positions of knee flexion. If this is the case, following principles of tissue healing and biomechanics, bracing the knee in flexion should place the healing tissue on slack, and prevent further stress to the collagen and connective tissue that comes with immobilizing the MCL in positions of terminal extension.

As the goals of minimizing pain and swelling, and achieving full weight-bearing were met, the focus shifted to achieving full pain-free ROM and lower extremity strength. In the final phase of rehabilitation, the patient was progressed to higher-level functional activities. Plyometric exercises, as well as sport-specific activities, were implemented to prepare the athlete for return to play.

Several therapeutic exercises were included in the program for this patient (Table 3). Retro-treadmill walking was utilized to improve concentric quadriceps muscle strength. Additionally, since the patient had a history of intermittent PFPS, and research has documented the decrease in patellofemoral joint compressive forces when compared to forward walking, the treating clinician felt this exercise was appropriate for this patient. Unilateral leg press with a ball placed between the knees was used to increase co-contraction of the quadriceps, hamstrings, and hip adductor muscles. The range of motion was restricted to a range of 90-45° to decrease stress to the MCL during the acute phase of healing.

Other closed-kinetic chain (CKC) strengthening exercises were incorporated in an effort to improve both strength and motor control of the knee. When necessary, visual feedback was given with the use of a mirror. The Fitter™ was used to incorporate a complete lower extremity strengthening program to enhance neuromuscular control and dynamic stability. Single limb stance (SLS) activities were incorporated to improve lower extremity balance and proprioception. A program consisting of both CKC and open kinetic chain (OKC) exercises was implemented, although greater emphasis was often placed on CKC exercises. The OKC exercises of long arc knee extension with hip external rotation and an adductor ball squeeze was used to simultaneously target adductor and quadriceps muscles firing with emphasis on the vastus medialis oblique muscle (VMO).

Plyometric exercises are generally implemented into the rehabilitation program in preparation for return to sport as previously described. This progression was not appropriate for this patient by the fourth session. A two week gap occurred between the fourth and fifth treatment sessions due the patient being away. The patient continued to perform her HEP during this time. Therefore, at the beginning of the fifth session, a reassessment was performed in preparation for the patient's upcoming appointment with her physician. Sport-specific tasks were used to evaluate her functional status, which were satisfactorily performed. Plyometric exercises were not implemented since she was returned to full competitive participation by her physician and physical therapy was discontinued.

While the basic rehabilitation guidelines were followed while treating this patient, the component of patellar taping was implemented. The primary author's hypothesis was that the taping would accelerate the initial phase of the
healing process, thereby minimizing the overall recovery time. The theoretical constructs for this intervention were to minimize the stress on healing tissues and to improve VMO firing.\textsuperscript{30,31}

**Rationales for Patellar Taping**

**Minimizing Tissue Stress**

Although the literature presents inconsistent findings, some research has shown that patellar taping can be utilized to affect patellar positioning.\textsuperscript{32} While the authors recognize the current gap as to the exact mechanism patellar taping has in rehabilitation of PFPS, sufficient acknowledgement exists in the literature that patellar taping does decrease anterior knee pain immediately upon application.\textsuperscript{33,31,34}

The recent study by Herrington\textsuperscript{32} demonstrated with the use of MRI, a small, but potentially important change in patella position with the use of patellar tape. In addition, Crossley et al\textsuperscript{35} in their review article found a change in patella position radiographically following the application of patellar tape. This change in patella position will place fibers of the medial patellar retinaculum on slack. An argument can be made that this, in turn, will place fibers of the MCL on slack due to the anatomical attachment of some of its fibers into the medial patellar retinaculum.\textsuperscript{10} This slack could take some of the stress off those fibers of the MCL, thus creating a better healing environment for the injured MCL fibers.

**Vastus Medialis Oblique (VMO) Muscle Activity**

Patellar taping is commonly used by clinicians to treat patients with patellofemoral pain.\textsuperscript{33,34} In the past few years, studies utilizing electromyography (EMG) have demonstrated that taping improves the timing of the firing of the VMO.\textsuperscript{30,31,36-38} It has been established that capsular distension due to effusion inhibits muscular contraction, and can lead to a long-term shut down of the quadriceps muscle.\textsuperscript{39,40} The VMO is particularly sensitive, requiring less joint effusion to be present before it shuts down than is required for the rest of the muscles in the quadriceps muscle group.\textsuperscript{39} Keeping the effects of swelling on the VMO in mind and extrapolating from the findings of these studies on EMG firing patterns, the treating clinician decided to utilize patellar taping to improve the timing of VMO firing. Although not specifically measured in this case report, research has documented the importance of restoring correct firing patterns to the VMO as quickly as possible. This enhancement in firing pattern may help achieve the appropriate balance between medial and lateral structures of the knee, thereby restoring correct biomechanics to the knee.\textsuperscript{41} It is especially imperative for anyone involved in higher level activities, such as sports, to have correct biomechanics restored.

Improved firing of the VMO may have an added benefit. The improved firing may help reduce the present edema. Voluntary muscle contraction will produce an increase in muscle pumping which can improve venous return.\textsuperscript{42} Any decrease in swelling can potentially decrease the reflexive inhibition of the quadriceps muscle. The increased quadriceps muscle activity will, in turn, continue to decrease the swelling via muscle pumping.

The patient’s immediate change in pain and functional levels during the first session can be attributed to factors other than the effects the tape had on the MCL. Two potential causes are the effects the tape had on her PFPS or those that ice can have on the inflammatory response. The authors recognize the immediate effect patellar taping is reported to have on patients’ pain and functional levels due to PFPS.\textsuperscript{33,31,34} With a potential co-morbidity of bilateral PFPS causing similar limitations, it is plausible that the application of patellar tape may have caused these positive changes in the patient. However, even though this argument cannot be completely ignored, two counter arguments can be made. First and foremost, the patient reported that her bilateral PFPS was intermittent, and she was not currently experiencing an exacerbation. Second, her symptoms were not severe enough for her to seek medical intervention since their onset. Given the patient’s improvement with unilateral taping, pain and functional limitations secondary to bilateral PFPS would not have changed as drastically.

Even though the application of ice could have influenced pain and functional levels in a positive manner, the immediate application of ice by the patient following the injury did not produce similar results of increased pain-free active knee extension, an overall decrease in pain levels, and improved weight bearing tolerance. Therefore, even though an argument can be made that the application of ice improved pain and motion during the first session, it is just as likely that the application of patellar tape yielded similar results. With a case report design, determining the true cause of the improvement is not possible.
CONCLUSION
This case report provides a novel component for the treatment of isolated MCL injuries. However, the results are a reflection of the treatment of one patient. For this treatment to be considered efficacious, more research needs to be conducted in this area. Future studies should consist of a case series approach with progression to a randomized clinical trial. This process will establish any cause and effect relationship that this component may have on MCL treatment.

While this patient's return to play time was shorter than the average time frame, no conclusion can be made as of yet of the effects of patellar taping on the rehabilitation time frame for patients with MCL sprains. This case is a starting point into the investigation of the effects of patellar taping on isolated MCL rehabilitation.

REFERENCES
18. Stoller DW, Tirman PF, Bredella MA. *Diagnostic Imaging Orthopaedics.* Salt Lake City, Utah: Amirsys; 2004


ABSTRACT

Rolling is a movement pattern seldom used by physical therapists for assessment and intervention with adult clientele with normal neurologic function. Rolling, as an adult motor skill, combines the use of the upper extremities, core, and lower extremities in a coordinated manner to move from one posture to another. Rolling is accomplished from prone to supine and supine to prone, although the method by which it is performed varies among adults. Assessment of rolling for both the ability to complete the task and bilateral symmetry may be beneficial for use with athletes who perform rotationally-biased sports such as golf, throwing, tennis, and twisting sports such as dance, gymnastics, and figure skating. Additionally, when used as intervention techniques, the rolling patterns have the ability to affect dysfunction of the upper quarter, core, and lower quarter. By applying proprioceptive neuromuscular facilitation (PNF) principles, the therapist may assist patients and clients who are unable to complete a rolling pattern. Examples given in the article include distraction/elongation, compression, and manual contacts to facilitate proper rolling. The combined experience of the four authors is used to describe techniques for testing, assessment, and treatment of dysfunction, using case examples that incorporate rolling. The authors assert that therapeutic use of the developmental pattern of rolling with techniques derived from PNF is a hallmark in rehabilitation of patients with neurologic dysfunction, but can be creatively and effectively utilized in musculoskeletal rehabilitation.

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INTRODUCTION
As humans develop from small, relatively immobile infants at birth into fully developed, amazingly mobile adults, they pass through many predictable patterns of body control and movement. In motor development, these patterns can be described as both reflexive and intentional movements, both of which serve as developmental milestones.1 These concepts are familiar to the therapists who treat pediatric clientele with neurodevelopmental diagnoses. Many therapists who treat adult patients and clients may fail to remember the principles of developmental postures and their sequence. In settings where patients with orthopedic and sports injuries predominate, the therapist can easily become focused on discrete local problems (or impairments) and miss the global effects (functional limitations) these problems create. In mature movement strategies/motor programs, the presence of developmental skills are not readily identifiable, but may in fact be a part of movement. An example of this principle is the movement of rolling. Although most adults do not consider the act of rolling to be an important part of complex movement skills, rolling may be a novel method to assess for, and intervene with, inefficient movements that involve rotation of the trunk and body, weight shifting in the lower body, and coordinated movements of the head, neck, and upper body.

The developmental milestones through which humans progress are related to developmental postures.2 Human infants are initially able to exist in sidelying, prone, or supine and are unable to move between these positions without assistance. These postures offer the infant the greatest amount of support/contact from the surface, and are the beginning of the developmental sequence and the development of motor control. As the infant matures, head control is achieved by four months of age leading to the ability to transition from one posture to the other, also known as rolling.3 Rolling is defined as “moving from supine to prone or from prone to supine position”1 and involves some aspect of axial rotation. Rotational movements are described as a form of a righting reaction because, as the head rotates, the remainder of the body twists or rotates to become realigned with the head.1,2 Rolling can be initiated either by the upper extremity or the lower extremity, each pattern producing the same functional outcome: movement from prone to supine or supine to prone.

The authors propose four variations of rolling which can be used to accomplish movement from prone to supine and supine to prone. Movement from the start position (either supine or prone) can be accomplished by using one upper extremity or one lower extremity to initiate movement. These four variations will be described in detail in the assessment section of this article. Each of the four variations is performed first with one upper extremity or lower extremity and then with the contralateral upper extremity or lower extremity in order to assess for symmetry, control, quality, and the ability to complete the roll.

When using rolling as an intervention, the upper extremity patterns make use of the fact that movements of the neck facilitate trunk motions3-5 or stated more simply, “where the eyes, head, and neck go, the trunk will follow.” By applying the proprioceptive neuromuscular facilitation (PNF) principle of irradiation (defined later in this article), the following can be utilized therapeutically: neck flexion facilitates trunk flexion, neck extension facilitates trunk extension, and full neck rotation facilitates lateral flexion of the trunk.3,4 Neck patterns can even be used to achieve irradiation into distal parts of the body, for example, neck extension can facilitate extension and abduction of the hip.3,4

Typically an infant can perform basic log rolling, with the body moving as a unit at four to five months of age, typically moving from prone to supine at four months of age, followed by moving from supine to prone (although the order varies in infants). Finally, segmental or “automatic” rolling occurs at six to eight months of age, which involves deliberate, organized progressive rotation of segments of the body.1 Some children actually combine multiple rolls, performed consecutively, as a method of locomotion across a floor. Adults use a form of rolling that is segmental, but has also been described as “deliberate.” Adult rolling described by Richter and colleagues4 found that normal adults use a variety of movement patterns to roll, most likely related to the flexibility and strength (or lack thereof) in the individual performing the movement. Several of the movement patterns described by Richter et al.4 were similar to the original patterns of rolling movement described by Voss et al6 in their original text on PNF. The variability of movement patterns used by adults to roll gives therapists multiple options to use when training or retraining adults in the task of rolling.8
Although the skill of rolling is an early developmental task that continues to be used throughout a lifetime, rolling may become altered or uncoordinated due to muscular weakness, stiffness or tightness of structures, or lack of stability in the core muscles. Several potential dysfunctions and assessments for these problems that affect rolling in adults will be addressed in detail in a subsequent section. Adults often use inefficient strategies to complete the task of rolling, some of which are compensatory and disorganized, serving to perpetuate the dysfunction(s) associated with the movement. The authors assert that when rolling is asymmetrical, the client demonstrates a break in normal patterning (symmetry), which can help the clinician visualize the interplay between the local (impairment level) problem and the global effect (functional limitation).

Developmentally important positions, such as kneeling and quadruped, are useful to the breakdown of complex motor patterns. While these two postures are used commonly by the sports physical therapist in interventions for orthopedic pathology by addressing muscular strength, core control, balance, and coordination, rolling is not. Although this article deals with the movement of rolling, these other postures are still important to the examination and training of athletes whose sports involve the use of rotation (tennis, golf, swimming, baseball).

Once a human is upright for motor tasks, rolling becomes less important for movement or access to the environment and, thus, is used less. Adults generally only use rolling to transition from prone to supine, as if turning over in bed. Most adults do not consciously make use of rolling in everyday mobility tasks, exercise routines, or as a part of more difficult rotational movements/skills. Rolling is a good choice for assessment and training because rolling is not commonly practiced. Therefore, compensation and incorrect performance can be easily observed. Rolling can be used as both a functional activity and an exercise for the entire body. It is the assertion of the authors of this article that many sports physical therapists forget or ignore rolling as an assessment and rehabilitative technique.

The Relationship of Rolling to Rotation
Frequently, even highly functional patients demonstrate dysfunctional sequencing or poor coordination during active rotational movements that are part of their functional demands/tasks. Rolling patterns can easily illuminate rotational movement pattern dysfunction, especially when comparing between sides. It should be noted that the movement dysfunction is usually a problem with sequence and stabilization rather than a deficiency in strength of a prime mover. Theoretically, a person should be able to roll (rotate) equally easily to either the right or the left. Frequently athletes have a typical pattern or habitual “good side” for rotational activities. Consider the gymnast, thrower, or golfer; each of whom rotates to the same direction repeatedly, according to the demands of their sport. Examples include the twisting and spinning motions used during tumbling, the unidirectional rotation used during the throwing motion, and the same-side rotational motions that comprise the golf swing. In each of these examples, the athlete has a preferential side, and a pattern of rotation (e.g. always to the left in a right handed thrower or golfer) which is typical for the performance of their sport, and may have asymmetry in rolling to the opposite side.

The Relationship of Rolling to Other Movement Tasks
Although described in relationship to rotational tasks and movements, rolling is not only related to rotational tasks. The rolling patterns can function as a basic assessment of the ability to shift weight, cross midline, and coordinate movements of the extremities and the core. Abnormalities of the rolling patterns frequently expose proximal to distal and distal to proximal sequencing errors or proprioceptive inefficiency that may present during general motor tasks. Finally, many adults have lost the ability to capture the power or utilize the innate relationship of the head, neck, and shoulders to positively affect coordinated movements.

Rolling as Assessment
As indicated previously, many high level tasks performed are often in a prescribed and unilateral motion. Even though a task or sport specific skill may be demonstrated by patients and clients at high levels, the fundamentals of the task of rolling should not be altered when compared bilaterally. Whether rolling is initiated by the upper or lower extremities, the state of optimal muscle recruitment, coordination, and function is reached when symmetry is present. For example, a right handed thrower should be able to complete all four variations of rolling, with equal ease regardless of direction. If during assessment the different rolling tasks are not symmetrical and equal, the clinician should consider that foundational
mobility or neuromuscular coordination may be compromised.

Because rolling precedes other locomotion activities in the developmental postures of infants and children, rolling can be used as a discriminatory test that uses regression to a more basic developmental task to locate and identify dysfunction in the form of poor coordination and stability of rotation. Without a doubt, mobility, core stability, controlled mobility, and properly sequenced loading of the segments of the body are required to perform these rolling tests correctly. Assessment of necessary precursor abilities should always precede common measurements of function which include strength, endurance, balance, gait, etc. Simply stated, movement quality appraisal should precede movement quantity appraisal.

Patients or clients who are being asked to perform the rolling tests must have sufficient trunk, upper extremity, and lower extremity mobility. An example of this principle is the use of the seated trunk rotation test that is designed to identify how much rotational mobility is present in the thoracolumbar spine. To pass this screen the patient must demonstrate sufficient mobility to ensure greater than 30 degrees of rotation bilaterally (Figure 1). If a patient or client cannot roll, it may simply be due to a mobility impairment in the thoracic spine. A mobility problem should not be addressed by a stability exercise. It is imperative that potentially contributory mobility problems are addressed prior to assessing the functional rolling motions. Figures 2a and 2b depict an example intervention for a patient or client who fails the rotation screen secondary to diminished thoracic rotation. Note how the anteriorly tilted position of the pelvis in the quadraped position locks the lumbar spine in extension which allows for a targeted stretch of the thoracic spine. Once the rotation motion is equal bilaterally (patient can pass the rotation screen test) or has significantly progressed toward appropriate mobility, interventions for assisted rolling may begin. In this case, rolling may be viewed as an adjunct exercise to encourage mobility.

Rolling tasks occur about diagonal axes. Figures 3a and 3b depict the two diagonals that comprise the axes of movement used by humans during the task of rolling. These graphics also demonstrate the starting positions for supine to prone rolling and prone to supine rolling movements, respectively. Typically, the axis for rolling does not involve the extremity that leads the movement.

Several neurophysiologic principles of PNF can be applied to the assessment and enhancement of the task of rolling. During treatment, the therapist may use visual, verbal, and tactile techniques to cue and resist the neck, trunk, or extremities to promote a maximal response from muscle groups used during rolling. These cues serve to enhance the quality of the skilled motion and to move the patient toward functional gains. Verbal cues will be described with each variant of rolling, as well as suggestions for visual and tactile cues to enhance overflow or irradiation.

Overflow or irradiation can be defined as the increase in facilitation that alters the excitatory threshold level at the anterior horn cell. By facilitating the stronger portions of a pattern, the motor unit activation of the involved or weaker portions is enhanced, thereby strengthening the response of the involved segments. Normally, overflow occurs into those muscles that offer synergistic support for the prime movers used during a motor task. Overflow can occur from proximal to distal or vice versa. The increased peripheral feedback that occurs when more than the involved segment participates in the activity may enhance the ability to respond and to learn the motor task.

For example, when using tubing for axis elongation facilitation, the patient’s upper extremity or lower extremity is placed and held in a traction or elongated position,
Figure 2A. Example mobility technique for lower thoracic rotation, note pelvic position to ensure locking of lumbar segments. Therapist can use an interlocked arm to assist patient into rotation.

Figure 2B. Example mobility technique for upper thoracic rotation. Again, note pelvic position to ensure locking of lumbar segments.

Figure 3A. (Left) Diagonal axes of rotation shown in supine, and beginning position for supine to prone rolling.

Figure 3B. (Right) Diagonal axes of rotation shown in prone, and beginning position for prone to supine rolling.
thereby pre-activating the phasic Type II receptors and promoting stretching of the synergistic trunk musculature. These elongated muscles provide a stable base upon which rolling occurs and utilize multiple segments to enhance motor learning. Conversely, joint approximation by compression of joint surfaces stimulates the static Type I receptors that facilitate the postural extensors and stabilizers. This technique, applied to the upper extremity or lower extremity which are a part of the rolling axis, can be used to improve the performance of a person having difficulty with the rolling task.

Four different rolling tasks are described. Each description will include the axis of rotation, specific instructions for performance of the test, verbal cues, and potential tactile or resistance cues.

**Supine to Prone Leading with the Upper Body**

This pattern isolates shoulder flexion/horizontal adduction, which leads to trunk flexion/rotation, culminating in pelvic rotation/hip flexion that allows for completion of the roll. The patient lies supine with legs extended and slightly abducted; arms flexed overhead, also slightly abducted. Head is in neutral rotation (Refer to Figure 3a for the start position). When rolling to the left, the axis of rotation is formed by the upper extremity of the side that the individual is rolling towards and the lower extremity of the side the individual is rolling from.

Ask patient to actively roll his or her body to the prone position starting with his or her left arm by reaching obliquely across body.

- The patient’s head and neck should flex and turn toward the right axilla. Remember, the head and neck are connected to the core, therefore where the head and neck lead the body will follow. *(Figure 4)* Facilitation of rolling from supine to prone from the cranial end of the body involves activation of the flexor chain: the neck, trunk, and hip flexors sequentially.

- The lower body should not contribute to the roll. Cue the patient to resist the temptation to push with the left lower extremity.

- The therapist can also give visual reference by placing his or her body on the side toward which the rotation is occurring, in this case, on the right side.

- Evaluate for quality, ease of movement, synergy, and ability to complete the roll.

- Repeat to the opposite side, leading with the right arm. Evaluate carefully for symmetry between the rolling to the right and rolling to the left.

**Verbal cueing:**

- Look with the eyes and head

- Reach arm across body and turn head into shoulder

- Elongate the axis:
  - Make the axis (left) leg long – “reach”
  - Make the axis (right) arm long – “reach”
  - Stay long through the axis
  - Verbal sequence: “Reach-lift arm-look into shoulder-roll”

**Tactile/resistance cueing to assist rolling:**

- Use proximal manual contacts to facilitate protraction of the scapula by the therapist positioning him or herself on the side toward which the patient is rolling, while cueing the patient to “pull your shoulder down toward your opposite hip.”

- Use distal manual contacts to approximate the upper extremity of the axis arm to facilitate elongation of the axis. For example, in an upper body driven roll led with the left upper extremity, offer manual approximation through the right upper extremity at the wrist/hand to encourage the response of elongation.

- Use tubing to cue the patient/client to elongate the axis either through the lower or upper body. For example, in an upper body driven roll led with the left upper extremity, place tubing on
either the right distal upper extremity anchored lower on the body or on the left distal lower extremity to encourage the response of elongation.

**Prone to Supine Leading with Upper Body**

This pattern begins with isolated shoulder flexion, leading to trunk extension/rotation, culminating in pelvic rotation that allows for the completion of the roll. Patient lies prone with legs extended and slightly abducted; arms flexed overhead, also slightly abducted as depicted in Figure 3b. When rolling toward the left side of the body, the axis of rotation is formed by the upper extremity of the side that the individual is rolling towards and the lower extremity of the side the individual is rolling from, or in this case the left upper extremity and right lower extremity, respectively.

Ask patient to actively roll his or her body to the supine position starting with his or her left arm only. The head should extend and rotate toward the opposite side. Remember, the head and neck are connected to the core, therefore where the head and neck lead the body will follow.

- During this form of the test, the lower body should not contribute to the roll.
- The body will always follow the head. Facilitation of rolling from prone to supine from the cranial end of the body, involves activation of the extensor chain: the neck, trunk, and hip extensors, sequentially.
- The therapist can also give visual/auditory reference by placing his or her body on the side toward which the patient is rolling, using the verbal cue “lift and pull your shoulder blade down and in.” (Figure 6)
- Use proximal manual contacts to facilitate retraction of the scapula by the therapist positioning him or herself on the side toward which the patient is rolling, using the verbal cue “lift and pull your shoulder blade down and in.” (Figure 6)

**Verbal cueing:**

- Lift arm and look up and over the opposite shoulder.
- Elongate the axis (see tactile cues below):
  - Make the axis (right) leg long – “reach”
  - Make the axis (left) arm long – “reach”
  - Stay long through the axis
  - Verbal sequence: “Reach-lift arm-look over shoulder-roll”

**Tactile/resistance cueing to assist rolling:**

- Use proximal manual contacts to facilitate retraction of the scapula by the therapist positioning him or herself on the side toward which the patient is rolling, using the verbal cue “lift and pull your shoulder blade down and in.” (Figure 6)
- Use manual contacts to approximate the upper extremity of the axis arm to facilitate elongation of the axis. For example, in an upper body driven roll led with the right upper extremity, offer manual approximation through the left upper extremity to encourage the response of elongation.
- Use tubing to cue the patient/client to elongate the axis either through the lower or upper body. For example, in an upper body driven roll led with the right upper extremity, place tubing on either the left distal upper extremity anchored lower on the body or on the right distal lower extremity to encourage the response of elongation.

**Figure 5.** Intermediate position for rolling prone to supine, leading with left upper extremity, with therapist placed in visual field for cueing, also using auditory cueing by snapping fingers.

**Figure 6.** Intermediate position for rolling prone to supine, leading with right upper extremity, using manual contact on scapula for facilitation.
Supine to Prone Leading with the Lower Body
This pattern isolates hip flexion, which leads to pelvic rotation/lumbar flexion, and culminates in trunk flexion/rotation to allow for completion of the roll. The patient lies supine on the ground with his or her legs extended and his or her arms flexed over his or her head on the ground. The head is in neutral rotation. (Refer to Figure 3a for start position.) Like the upper extremity initiated supine to prone roll, this task utilizes a flexed posture and is often easier than the prone to supine task. When rolling to the left, the axis of rotation is formed by the lower extremity of the side that the individual is rolling towards and the upper extremity of the side the individual is rolling from, or in this case the left lower extremity and right upper extremity, respectively.

Ask patient to actively roll his or her body to the prone position starting with the right leg only.
• Lead with right hip flexion followed by the adduction of the extended leg.
• The upper body should and not contribute to the roll. During lower body initiated rolls, the head and neck play less of a role, and are therefore not cued.
• Evaluate for quality, ease of movement, synergy, and ability to complete the roll.
• Repeat to the opposite side, leading with the left lower extremity. Evaluate carefully for symmetry between rolling to the right and rolling to the left.

Verbal cueing:
• Elongate the axis:
  - Make the axis (right) leg long – “reach”
  - Make the axis (left) arm long – “reach”
  - Stay long through the axis
  - Verbal sequence: “Reach – lift leg across body – roll”

NOTE: The following techniques are not used during the initial assessment, rather, may be used when dysfunctional patterns of movement are identified. These facilitory techniques are intended to be used for short term assistance and then eliminated as soon as technique is improved and perfected.

Tactile/resistance cueing to assist rolling:
• Use proximal manual contacts to facilitate protraction of the pelvis by the therapist positioning him or herself on the side toward which the patient is rolling, using the verbal cue “pull your pelvis up and forward.”
• Use distal manual contacts to approximate the lower extremity of the axis leg to facilitate elongation of the axis. For example, in a lower body driven roll led with the right lower extremity, offer manual approximation through the sole of the foot to encourage the response of elongation.
• Use tubing to cue the patient to elongate the axis either through the lower body or through the upper body. For example, in a lower body driven roll led with the right lower extremity, place tubing on either the left distal lower extremity anchored higher on the body or on the right distal upper extremity to encourage the response of elongation.

Prone to Supine Leading with the Lower Body
This pattern begins with hip extension which initiates the roll and leads to pelvic rotation/lumbar extension and culminates in trunk extension/rotation, completing the roll. This pattern helps to identify weak gluteal muscles by isolating hip extension/lateral rotation. Patient lies prone with legs extended and slightly abducted; arms flexed overhead, also slightly abducted. Head is in neutral rotation. (Refer again to Figure 3b.) When rolling toward the left side of the body the axis of rotation is formed by the lower extremity of the side that the individual is rolling toward and the upper extremity of the side the individual is rolling from, or in this case the left lower extremity and right upper extremity, respectively.

Ask patient to actively roll his or her body to the supine position starting with the right leg only.
• Attempt to perform with a fully extended lower extremity, but if unable to complete the roll, the patient may flex the knee if needed in order to initiate the roll. Cue to extend at the hip and then at the knee.
• During this form of the test, the upper body should not contribute to the roll. During lower body initiated rolls the head and neck play less of a role, and are therefore not cued.
• Evaluate for quality, ease of movement, synergy, and ability to complete the roll.
• Repeat to the opposite side, leading with the left lower extremity. Evaluate carefully for symmetry between rolling to the right and rolling to the left.

Verbal cueing:
• Elongate the axis:
  - Make the axis (right) leg long – “reach”
- Make the axis (left) arm long – “reach”
- Stay long through the axis
- Verbal sequence: “Reach – lift leg across body – roll”

NOTE: The following techniques are not used during the initial assessment; rather, these may be used when dysfunctional patterns of movement are identified. These facilitory techniques are intended to be used for short term assistance and then eliminated as soon as the technique is improved and perfected.

Tactile/resistance cueing to assist rolling:

- Use proximal manual contacts to facilitate retraction of the pelvis by the therapist positioning him or herself on the side toward which the patient is rolling using the verbal cue “lift and pull your pelvis back” (Figure 7)
- Use distal manual contacts to approximate the lower extremity of the axis leg to facilitate elongation of the axis. For example, in a lower body driven roll led with the right lower extremity, offer manual approximation through the sole of the foot to encourage the response of elongation.
- Use tubing to cue the patient to elongate the axis either through the lower body or through the upper body. For example, in a lower body driven roll led with the right lower extremity, place tubing on either the left distal lower extremity anchored higher on the body or on the right distal upper extremity to encourage the response of elongation.

Dysfunctional Patterns of Rolling and Contributory Factors

Knowledge of typical functional movement patterns of the body enables the therapist to identify dysfunctional patterns of motion. As each of the four described rolling tasks are performed, the therapist should carefully observe and document the qualitative differences between upper and lower body initiated rolls and side to side differences. Outcomes that display less than optimal performance include: inability to complete the roll, use of inertia or swinging of the extremities to complete the roll, use of extremities not being tested during the roll, and pushing or bracing with the opposite lower or upper extremity in order to artificially supply stability during the attempt. Many contributory factors may play a role in a patient’s ability or inability to roll in a smooth, coordinated, and controlled manner. These factors include: strength of the pelvis and scapula (proximal links) and the extremities, length/stiffness of important muscle groups, and insufficient coordination of all the moving parts of the system.4 The ideal is for the individual to be able to roll easily and symmetrically while adjusting to various demands.

Patients with many diagnoses may demonstrate difficulty with attempts to roll. Some examples of these diagnoses include: poor neuromuscular control and stability of the core muscles, low back pain of multiple origins, sacro-iliac pain/dysfunction, and various upper and lower extremity mobility or stability problems. The following examples illustrate the power of rolling as an assessment strategy.

Case Example—Upper Extremity

Consider the pitcher has undergone a right rotator cuff repair and has progressed through the rehabilitation process, as prescribed by the therapist, regaining full active range of motion in all planes, manual muscle test scores for the muscles of the shoulder complex of 4+/5 or better, and functional abilities to perform all activities of daily living with 10 pounds at shoulder height without dysfunctional movement. He still complains of “fatigue and lack of endurance” with the initiation of a return to throwing program. When assessed using the rolling tasks, the patient was able to roll from supine to prone leading with each of the extremities, but was unable to roll from prone to supine when leading with the right upper extremity.

Case Example—Lower Extremity

Consider the recreational soccer player who has undergone a partial medial meniscectomy on the left knee. The patient has progressed well throughout the rehabilitation process and has full active and passive range of motion, normal manual muscle test scores of the lower quarter, and knee flexion/extension isokinetic scores that demonstrate less than 10% difference in peak torque when compared bilaterally to the uninjured lower extremity.
The patient can perform a full, painfree functional squat and can jump and land without difficulty (single limb hop for a given distance is within 90% of uninvolved lower extremity). Functionally, this soccer player still has difficulty with performance of cutting and lateral movements. When assessed using the rolling tasks, the patient was able to perform all upper extremity initiated rolls without difficulty. Lower extremity initiated rolls by the right lower extremity were also achieved without difficulty. He was unable to roll from supine to prone to the right (initiating movement with the left lower extremity) and also was unable to roll prone to supine to the right (also initiating with the left lower extremity). The patient had difficulty crossing the midline of the body with the left lower extremity initiated rolling task.

Although impairments had been addressed and quantitative performance tests were essentially symmetrical to the uninvolved extremity, qualitative performance assessment of rolling revealed a deficiency in each of the two case examples. This assessment indicated the inability to effectively coordinate, time, and sequence the movements of the extremities and the trunk during a lower level developmental task. Normal impairment measures and quantitative functional measures do not necessarily imply normal function.

ROLLING AS INTERVENTION
Rolling has thus far been described as an assessment. After the assessment is complete, the therapist must draw conclusions about bilateral symmetry and rolling ability, as well as possible causes for less-than-optimal rolling. Multiple interventions exist that can assist the patient or client to enhance the ability to roll, and thereby enhance core stability, rotational function, and overall function of the upper and lower extremities. Many alternate exercise postures and modifications to the task of rolling exist, each attempting to begin to elicit core control of the scapula and pelvis or diminish the demands of the task.

The quadruped posture can be used to recruit and facilitate underutilized proximal musculature such as the scapular stabilizers and gluteal muscles (Figures 8 and 9). Another example that could be used for a patient who is unable to complete the roll is the use of assistance in the form of a rolled airex mat or foam roller behind the trunk or pelvis to place him or her in an easier starting position when rolling from supine to prone (Figure 10), referred to as assisted or facilitated rolling.

Recall the patient that underwent a rotator cuff repair who demonstrated the inability to roll from prone to supine leading with the involved upper extremity. For this patient, an exercise progression might include the following:

- Quadruped position stabilization for the scapula (Figure 8)
- Resisted rolling with manual contact on the scapula (Figure 6)
- Axis elongation using manual contact or tubing applied to the uninvolved upper extremity

Early exercises encourage the use of the scapula in a facilitated, stabilized position, and then subsequent exercises progress to the recruitment of the scapular prime movers, which serve to facilitate coordinated upper extremity and trunk movement as well as to pro-
vide opportunities to cross the midline. Although the patient in this case had all of their impairments addressed (range of motion, manual muscle test, etc.), the qualitative assessment of the task of rolling revealed an alteration of timing and coordination between the involved upper extremity and the trunk. This examination of a lower level developmental task revealed another area for potential intervention. Rolling was an effective low-level functional intervention because of its requisite demands of timing and reflex stabilization between the extremities and trunk which serve to “reset” the timing and coordination necessary for higher level function, such as throwing.

Now return to the patient who underwent the partial medial meniscectomy of the left knee and was unable to roll from supine to prone or prone to supine when leading with the involved lower extremity. This patient might use a similar exercise progression, including the following:

- Bridging exercises for stabilization of the pelvis/gluteals, using a tubing loop for abduction resistance
- Quadruped stabilization of pelvis/gluteals, core, and scapula, using tubing (Figure 9)
- Hip abduction with core stabilization might follow to address both proximal lower extremity strength and stability (through gluteus medius and minimus muscles) and core stability (Figure 11) or the side plank with abduction for same (Figure 12)
- Proximal stabilization/manual contacts during rolling via pelvic resistance (Figure 7), (Note that this principle could also be applied to the supine to prone task by utilizing anterior pelvic contact.)
- The rolling task itself, facilitated with tubing in the form of the Starfish 1 drill for supine to prone (Figures 13A & B) and the Starfish 2 drill (Figures 14A & B)

Early exercises encourage the use of the pelvic and core muscles in a facilitated, stabilized position, and then progress to the recruitment of the movements of the hip/pelvis to facilitate coordinated lower extremity and trunk movement, as well as to provide opportunities to cross the midline. Again, although the patient in this case had all of their impairments addressed (range of motion, manual muscle test, isokinetic scores, etc.), the qualitative assessment of the task of rolling revealed an alteration of timing and coordination between the involved lower extremity and the trunk. This examination of a lower level developmental task revealed another area for potential intervention. Rolling was an effective low-level functional intervention because of its requisite demands of timing and reflex stabilization between the extremities and trunk. The task of rolling serves to “reset” the timing and coordination necessary for higher level function, such as lower extremity movements that cross the midline and require high proprioceptive acuity.

In the two case examples, rolling was being used for its impact on neuromuscular time and coordination of movement, as well as recruitment of important muscles of the proximal extremities and core. It is important that the patient be instructed to perform the tasks associated with rolling with precision and perfection. When attempting to determine dosage for the previously described exercises, it is important to dose below the threshold of the inappropriate motor pattern domination. If the patient has difficulty with more than one rolling pattern, begin with the component parts of the roll that are most dysfunctional. Select an exercise that is achievable for the patient (may be a lower developmental posture or assisted rolling exercise) and select the number of repetitions based upon the ability to perform the repetitions with precision and accuracy. A simple pneumonic for this is “PMRS”, Position, Movement, Resistance,
Speed. Begin the intervention by choosing the position in which the patient can successfully challenge muscles that are weak/dysfunctional in movements that address the dysfunction. This movement may be isolated (scapula, pelvis, or limb) or a functional movement such as rolling. It is entirely possible that resistance, the next element, could be minimal to none, but subsequent sessions may build upon it. Finally, the addition of speed to a carefully selected posture, movement, and resistance exercise can make the activity more difficult, noting that speed masks substitution and requires a base of strength to be effective as a training parameter.

For example, the patient with rotator cuff dysfunction described previously might be able to perform quadruped stabilization with scapular movement without any resistance 18 times before a form break. Start with that number of repetitions, and have the patient attempt to perform two or more sets. Progress the quadruped exercise by adding the resistance of tubing, again determining the number of repetitions that can be performed with precision. Next, progress to the roll itself; using an assisted or facilitated technique, yet again determining the number of repetitions that can be performed properly, without substitution or compensation, and dose accordingly. Eventually the assistance will not be needed and resistance (manual contacts or tubing) can be added to the roll. Finally, the speed at which the exercise is being performed can be altered to mimic more functional motion demands.

Figure 13A. Start position for “Starfish 1” pattern, used for training of supine to prone rolling, leading with the lower extremity. Note tubing loops have been placed around both feet, with the length of the band around both upper extremities. To start, the lead hip is flexed, abducted, and slightly internally rotated while the knee is flexed. The rolling movement is initiated by extending, adducting, and externally rotating the hip while extending the knee. Note that the patient is concurrently elongating the opposite lower extremity (axis lower extremity) against the tubing.

Figure 13B. Intermediate position “Starfish 1.” Patient will finish in the prone position with all four extremities extended and slightly abducted.

Figure 14A. Start position for “Starfish 2” pattern, used for training of prone to supine rolling, leading with the lower extremity. Tubing placed as described previously, the lead leg then is flexed, abducted, and externally rotated. The rolling movement is initiated by extending, adducting, and internally rotating the hip, while extending the knee. Note that the patient is concurrently elongating the opposite lower extremity (axis lower extremity) against the tubing.

Figure 14B. Intermediate position “Starfish 2” pattern. Patient will finish in the supine position with all four extremities slightly abducted.
Learning the building blocks of a motor sequence and the control of the rolling movement is paramount to perfecting the task. The rolling task maximally challenges the core muscle stabilizers and extremities during a developmental, atypical movement. As motor learning occurs, the patient or client accomplishes the control and skilled use of mobility to accomplish the task of rolling. The authors of this article believe that rolling can facilitate enhanced use of the trunk, core musculature, and the extremities during a wide variety of functional tasks.

CONCLUSION
The human body is built on and relies upon symmetry. During static postures and dynamic functional tasks, length, strength, and stability/mobility must exhibit delicate integration or balance. Side-to-side and anterior-posterior balance are both important to healthy, normal function. Without symmetry, a state of asymmetry occurs which may eventually lead to injury, imbalance, and dysfunction. Normal functional activities are rhythmic and reversing, which both establishes and depends upon balance and interaction between stabilizers, agonists, and antagonists. Often, athletes become “stuck” in patterns of movement that do not promote symmetry and reversal, such as tasks that require rotation in one direction, including pitching, tennis, and golf. Determining alterations in symmetry or the inability to reverse a movement is the first step to successfully addressing dysfunction. Treatment must facilitate movement in both directions in order to enhance normal functional movement and provide adequate postural responses to motion. Improvement of motor ability depends on motor learning which can be enhanced by auditory, tactile, and visual stimuli. During intervention, specific developmental postures may be used to enhance the use of the head, neck, and trunk as important parts of the movement. The use of the skill of rolling as an assessment and intervention technique can serve as a possible method by which symmetry, reversal, and motor learning can be achieved.

REFERENCES
ABSTRACT

**Background.** Although anterior cruciate ligament (ACL) sprains usually occur during the initial phase of the landing cycle (less than 40° knee flexion), the literature has focused on peak values of knee angles, vertical ground reaction force (VGRF), and muscle activity even though it is unclear what occurs during the initial phase of landing.

**Objectives.** The objectives of this study were to determine the effects of sex (male and female) and fatigue (pre-fatigue/post-fatigue) on knee flexion angles at the occurrence of peak values of biomechanical variables [knee valgus angle, VGRF, and normalized electromyographic amplitude (NEMG) of the quadriceps and hamstring muscles] during a bilateral drop landing task.

**Methods.** Knee valgus angle, VGRF, and NEMG of the quadriceps and hamstring muscles were collected during bilateral drop landings for twenty-nine recreational athletes before and after a fatigue protocol.

**Results.** Peak values of knee valgus, VGRF, and NEMG of medial and lateral hamstring muscles occurred during the late phase of the landing cycle (>40° of knee flexion). Females in the post-fatigue condition exhibited peak VGRF at significantly less knee flexion than in the pre-fatigue condition. Males in the post-fatigue condition exhibited peak lateral hamstring muscles NEMG at significantly higher knee flexion than in the pre-fatigue condition.

**Discussion and Conclusion.** Peak values of biomechanical variables that have been previously linked to ACL injury did not occur during the initial phase of landing when ACL injuries occur. No biomechanical variables peaked during the initial phase of landing; therefore, peak values may not be an optimal indicator of the biomechanical factors leading to ACL injury during landing tasks.

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INTRODUCTION
Sprains of the anterior cruciate ligament (ACL) are often season-ending injuries that cause significant physical and emotional burden on the injured athlete. These ACL injuries also create substantial financial impact with costs related to orthopaedic care and rehabilitation in the US reaching approximately $850 million each year.1

Research efforts aimed at the prevention of ACL sprains have focused on improving the understanding of the biomechanics at the moment of injury. Previous researchers have analyzed ACL sprains captured on video tape in a variety of sports such as team handball, basketball, soccer, and volleyball. These studies reported that the majority of ACL injuries occur during the initial phase of landing when the knee is flexed less than 40°.2-4 Additional evidence suggesting that the initial phase of landing (less than 40° of knee flexion) represents the most vulnerable range for ACL tears comes from cadaveric,5,6 “in vivo,”7,8 and computer simulation9,10 studies of ACL strain or force. These studies form a remarkable consensus within the literature, suggesting that the initial phase of landing from a jump may be the most appropriate focus of biomechanical studies attempting to clarify the mechanism of ACL injury. Despite this consensus, current biomechanical studies11-15 have focused analysis on variables without verifying that these variables occur in the initial phase of landing.

Landing from a jump has been cited as one of the most common athletic maneuvers to cause ACL injuries,1,3,4,16-20 and several researchers have investigated the biomechanics of landing.11,15 Although studies have used different methodological approaches,11,12 many studies have used analysis of peak values of lower extremity joint angles and vertical ground reaction force (VGRF) without regard to the degree of knee flexion.13,14,16 This approach assumes that peak values are valid indicators of important biomechanical events regardless of the degree of knee flexion at which they occur. Consequently, existing studies have not described when peak values occur within the landing cycle relative to the natural progression of knee flexion from initial contact to peak knee flexion. It is unknown if the peak values reported in the previous literature11,13,16 occur during the initial phase of landing when injury risk and ACL strain are greatest, or during the latter stages of the landing cycle, when studies suggest ACL injury risk2-4 is decreased. If peak values occur during the initial stages of landing, previous studies would be supported by sug-
Given this information presented, the objectives of the present study were:

1. To describe the knee flexion angles at which peak biomechanical variables (knee valgus, VGRF, and NEMG of the rectus femoris, vastus medialis, medial hamstring, and lateral hamstring muscles) occur during bilateral drop landings from a 40 cm platform.

2. To statistically evaluate the difference between sex and fatigue status on the knee flexion angles at which peak biomechanical variables occur.

METHODS

Subjects

Twenty-nine recreational athletes (14 females and 15 females) between the ages of 20-40 years were recruited. The inclusion criteria were willingness to participate in the study and participation in recreational sports at least twice/week for a minimum of 45 minutes per practice session. Exclusion criteria were: obesity (body mass index greater than 30 kg/m²); a history of injuries or diseases that would render unsafe the execution of the protocol; and a history of injuries or diseases that could affect the biomechanics of landing, such as lower extremity fractures. Subjects were excluded if they had received specialized training in jumping and landing techniques as could occur through participation in gymnastics or dance.

Instrumentation

Electromyographic data were collected with the Noraxon Myosystem 1400 (Noraxon USA, Inc., Scottsdale, AZ). The electrodes were disposable, surface, passive electrodes (blue sensor, Ambu, Inc., Linthicum, MD). The skin was prepared and the surface electrodes were placed on the rectus femoris, vastus medialis, lateral hamstring, and medial hamstring muscles as in previous research. These sites of electrode placement are consistent with established guidelines and are located between the motor point and the distal tendon in order to improve intra and inter-subject comparison reliability. Two electrodes were placed on each muscle at a 20 mm inter-electrode distance and parallel to fiber orientation. Athletic tape was used to fixate the electrodes and decrease movement artifact.

Kinematic data were collected with the use of eight Eagle cameras (Motion Analysis Corp. Santa Rosa, CA) and reflective markers were placed bilaterally as per established protocol on the second dorsal metatarsophalangeal joint, calcaneus, lateral malleolus, lateral femoral epicondyle, lateral mid-fibula (half way between the calcaneal and lateral femoral epicondyle markers), lateral mid-thigh (half way between the lateral femoral epicondyle and anterior superior iliac spine markers), anterior superior iliac spine, acromion, lateral humeral epicondyle, distal radioulnar joint, sacrum and left posterior superior iliac spine (offset) (Figure 1). The software for data collection was the EvaRT 4.0 (Motion Analysis Corp. Santa Rosa, CA).

The force plate was an OR6-5 AMTI biomechanical platform (AMTI, Watertown, MA). The force platform was time synchronized to the electromyography (EMG) and the motion analysis system. The kinetic and EMG data were sampled at 1200 Hz and the kinematic data were sampled at 240 Hz as appropriate for fast athletic maneuvers.

Experimental Protocol

Subjects were informed of the study protocol and total time needed for testing. All risks and possible harm as described in the consent form were verbally explained. All subjects completed a sports activity and medical history questionnaire, signed a consent form approved by the Institutional Review Board at New York University School of Medicine, and were measured for height, weight, foot width and length, and knee width.

Subjects completed the entire protocol (three landings pre-fatigue, fatigue protocol, and three landings post-fatigue) in a single session. The subjects were allowed two practice jumps and then performed three bilateral drop landings from a 40 cm platform. They were instructed to
drop directly down off the box and land with both legs on the force plate. Subjects did not receive any instructions on the landing technique to avoid a coaching effect. The effect of the arms was minimized by asking the subjects to keep their arms crossed against their chest. Trials were repeated when they were judged as non-acceptable (such as when subjects lost their balance or did not land with both feet on the force plate) by the primary investigator who was observing the real-time data on the monitor, the research assistant who was closely monitoring the jumps, or the subject. Upon completion of three successful landings, the wires were disconnected from the electrodes (but the electrodes were not removed). The subjects then followed the fatigue protocol: they jumped over five consecutive 5-7 cm obstacles. This was repeated 20 times for a total of 100 jumps. Then, the subjects jumped maximally vertically 50 times. After the fatigue protocol was completed, the wires were re-connected to the EMG electrodes and the same procedure of landing assessment was repeated for the post-fatigue part of data collection. All subjects completed all post-fatigue trials within six minutes after the completion of the fatigue protocol.

Data Processing

The analysis of the data was performed with Orthotrak 5.0 (Motion Analysis Corp. Santa Rosa, CA). Kinematic data were smoothed using a Butterworth fourth order low pass filter with a cut-off frequency of 6 Hz. The EMG data were filtered through a 6th order Butterworth filter (10-500Hz). The EMG amplitude was normalized to the maximum linear-enveloped EMG of each muscle exhibited during the landing phase of bilateral landings from a 20 cm platform (mean of three trials). The VGRF was normalized to body weight as in previous studies.

Statistical Analysis

This project utilized a repeated measures pre-fatigue and post-fatigue experimental design that used measures of NEMG, kinetic, and kinematic data. The knee flexion angles at which each biomechanical variable peaked were averaged for the three trials. The kinetic, kinematic, and NEMG data of the dependent variables relative to the different levels of the independent variables were entered into a statistical software package (SPSS 12.0, SPSS Inc., Chicago, IL, 60606). The independent variables were sex (male/female) and level of fatigue (pre-fatigue/post-fatigue). The dependent variables were knee flexion angle at the occurrence of peak values for the following biomechanical variables: knee valgus angles; VGRF; and NEMG amplitude of the rectus femoris, vastus medialis, medial hamstring, and lateral hamstring muscles. All NEMG and kinematic measurements were in reference to the right lower extremity (which was the dominant leg determined by leg used for kicking a ball) for all participants. Descriptive statistics (mean and SD) were produced for the values of knee flexion angle at the occurrence of peak values of the dependent variables (four NEMG amplitudes, VGRF, and knee valgus angle). The data were inspected and tested to ensure that the assumptions for data normality and sphericity of the univariate and multivariate repeated measures analysis of variance (MANOVA) were not violated.

A MANOVA procedure was used to evaluate the effects of sex (male/female), fatigue (pre-fatigue/post-fatigue) and their interaction on knee flexion angle at the occurrence of peak values. Follow up analysis of variance (ANOVA) tests were performed when the MANOVA reached significance (p<0.05) to determine which of the variables achieved significance. Significance was accepted at p<0.05.

RESULTS

No landing trial had to be repeated due to subjects losing their balance or failing to follow the instructions. No differences between males and females existed in respect to weekly number of sports participation hours as reported by the volunteers [mean hours/wk (SD): males: 6.6 (3), females 7.1 (6), p=0.77]. Peak values for all investigated biomechanical variables occurred when the knee was flexed more than 40° (Figures 2-5). The results of the MANOVA found that neither sex (df=7:21; F=2.44, p=0.053) nor fatigue (df=7:21; F=1.91, p=0.119) had a significant effect on knee flexion angle at occurrence of peak values of the biomechanical variables, however, the interaction of sex x fatigue was statistically significant (df=7:20; F=4.8, p<0.05). Univariate repeated-measures ANOVA tests were performed for sex x fatigue and determined that two of the variables were significantly different: 1) knee flexion at peak VGRF (p<0.05) - the knee angle increased in males by 1° but decreased by 5.6° in females in the post fatigue condition [mean (SD); non-fatigued males: 48.8° (±13), fatigued males: 49.6° (±15), non-fatigued females: 52.7° (±11), 47.1° (±11)] (see Figure 6); 2) knee flexion angle at peak lateral hamstring muscles NEMG (p=0.003) - the knee angle increased by 11° in
males but decreased in females by 3° in the post fatigue condition [mean (SD); non-fatigued males: 62.2° (±19), fatigued male: 73.7° (±21), non-fatigued females: 77.8° (±16), fatigued females: 75° (±15)] (Figure 7).
DISCUSSION

The present study examined knee flexion angles at the occurrence of peak biomechanical values. The peak values of all variables, (including variables that have been previously cited as contributors to ACL injury: knee valgus, VGRF, and quadriceps activity) did not occur during the initial phase of the landing cycle (knee flexion angle less than 40°) when ACL injury risk is increased. Given the literature cited in the introduction, these findings suggest that the methods used in previous studies focusing only on peak values measured across the entire landing cycle may have inadequately addressed an important factor in ACL injury risk, namely, the degree of knee flexion at which peak biomechanical values occur. These studies have provided insight with regards to biomechanical differences between males and females; they found that females land with greater peak knee valgus, greater peak quadriceps NEMG amplitude, and greater peak VGRF compared to males. Previous findings on peak values also suggest that females exhibit greater knee valgus and VGRF than males, however, the differences due to sex on the effect on quadriceps muscle NEMG did not reach statistical significance. Although peak values of biomechanical variables occur and can be analyzed after 40° of knee flexion, examining biomechanical variables at peak values may not be the optimal methodological approach given the potential for knee flexion to influence ACL injury risk.

The two variables that were significantly different due to the interaction of sex x fatigue were VGRF and NEMG of the lateral hamstrings muscles. Although contraction of the hamstring muscles can effectively decrease anterior tibial translation and prevent excessive stress on the ACL, it is unclear if the observed increase of 11° in knee flexion angle at the peak NEMG of the lateral hamstrings in males represents a finding that is related to the ACL injury mechanism. More likely, this study's findings relative to lateral hamstring muscle NEMG may not be clinically relevant as peak values of lateral hamstring muscles occur very late in the landing cycle (more than 60° of knee flexion) where ACL injury risk is less. An alternative explanation of the effect of fatigue on lateral but not medial hamstring muscles may be related to an effort to resist a frontal plane or rotary force.

However, the findings relative to VGRF may have clinical relevance as VGRF has been identified as a variable important to ACL injuries and the peak values occurred at knee flexion angles which are much closer to the angles known to demonstrate increased risk. In the current study, after a fatiguing protocol, females decreased the amount of knee flexion at which peak VGRF occurred by 5.6° to a value of 47.1°, while men increased the amount of knee flexion by 0.8° to a value of 49.6°. It appears that peak VGRF in men tends to occur in similar or slightly higher knee flexion angles in the post-fatigue condition while in women peak VGRF tends to occur in lower knee flexion angles, thereby, placing their knees closer to knee flexion values known to be related to ACL injury risk. This effect may be magnified with a fatigue protocol that is either more vigorous or ensures that all subjects are fatigued to the same level and potentially cause peak VGRF in fatigued females to occur when the knee is flexed less than 40° and the ACL more vulnerable to trauma.

In addition to finding that all peak variables occurred after the initial phase of landing and that the interaction of sex (male vs female) x fatigue (pre-fatigue/post-fatigue) was significant for VGRF and NEMG of the lateral hamstrings muscle, the current study also found that knee flexion angle at which peak values occurred was not significantly different relative to the difference between sex or fatigue (Figures 2-5). Therefore, the findings of the current study suggest that peak values of key biomechanical variables occur at similar knee flexion angles in non-fatigued male and female athletes and in pre and post-fatigued athletes of the same sex. However, caution should be taken in regard to this interpretation as two important issues that can potentially diminish the validity of sex and fatigue comparisons without regard for knee flexion. First, the use of peak values at degrees of knee flexion beyond 40° may not adequately describe biomechanical strain on the ACL. Second, as found in this study, the interaction of sex x fatigue produce significant differences in some variables and, therefore, knee flexion angles may have an influence on biomechanical strain of the ACL when examining differences between males and females using a fatiguing protocol.

This specific fatigue protocol was chosen because the combination of tasks simulates activities commonly performed in sports and because an eccentric-concentric fatigue protocol is more effective in producing fatigue than a concentric fatigue protocol. The fatigue protocol was designed in a way that the fatigue-induced pattern was applicable to functional activities outside the laboratory setting. The protocol used in the present study was similar to fatigue protocols used in previous research. Other research
has demonstrated that a fatigue protocol similar to the one used in the current study is sufficient to induce fatigue in a similar way to subjects of different training levels. Moreover, the demands of games such as soccer are very similar for males and females in terms of distance covered, sprint duration, and exercise intensity suggesting that laboratory fatigue protocols have greater applicability if they fatigue male and female athletes in a similar way as it occurs on the athletic field.

Implications for Future Research

As measurements of peak values occur late in the landing cycle when ACL injury risk is less, future biomechanical studies may be improved by examining biomechanical variables during the initial phase of landing. Future studies should determine if measurements at predefined knee flexion angles in the initial phase of landing are better predictors of ACL injury than peak values which occur after 40° of knee flexion. Future research should also investigate the differences between males and females using a more vigorous fatigue protocol in order to determine if increased fatigue may further alter the degree of knee flexion at which peak VGRF values occur. Considering the rapid proliferation of biomechanical studies of landing from a jump in recent years, the limited number of subjects in most studies, and the highly variable methodology across studies, methodology standardization may be needed to allow a meta-analysis investigation. The present study represents a first step towards standardization of methodology by suggesting that appropriate measures of biomechanical variables should occur during the initial phase of landing and by demonstrating that peak values do not occur until later in the landing cycle. Future studies should identify the variables that best predict ACL injury and the exact time in the initial phase of the landing cycle that the variable should be measured.

Limitations

Although all subjects were fatigued with the same fatigue protocol as opposed to normalizing the protocol to their athletic abilities, a specific measure of fatigue could have been used to ensure that all subjects had exceeded some minimum cut-off. Doing so might have allowed for a more meaningful interpretation of the effect of fatigue.

A general limitation of the present study is that the landing task may not adequately represent landing techniques on the athletic field because subjects were instructed to keep their arms crossed across their chest and jump down from a platform. Although these modifications were deemed necessary in order to have all subjects perform the same task with minimal variability, generalizability of the findings is decreased. In addition to drop landings, which have been used extensively in the literature of sports injury biomechanics, researchers have also used stop-jump and cutting maneuvers. Investigating both drop landings and continuous tasks such as cutting or stop-jump may have provided a more comprehensive picture of the effect of sex and fatigue on the biomechanical variables. Additionally, as with all biomechanics studies, direct implications to ACL injury cannot be made as no injuries occurred during the testing.

All subjects were recreational athletes who participated at least twice per week in a variety of sports that involved jumping. No differences existed between males and females in regards to hours of sports participation per week. However, this lack of a difference does not ensure equal proficiency in drop landings. Some subjects may have been more proficient than others in landing from a jump. A more homogenous group of subjects such as recreational basketball or volleyball players would make the findings of this study less generalizable but may increase its internal validity.

CONCLUSION

In summary, the present study demonstrated that peak values of the biomechanical variables that have been previously cited as contributors to ACL injury, such as knee valgus, VGRF, and quadriceps muscles activity did not occur during the initial phase of the landing cycle when ACL injury risk is greatest. This finding suggests that analyses based only on peak values may not be adequately addressing the influence of knee flexion on ACL strain which is higher when the knee is in less than 40° of flexion.

REFERENCES


ABSTRACT

Background. The Star Excursion Balance Test (SEBT) is a dynamic test that requires strength, flexibility, and proprioception and has been used to assess physical performance, identify chronic ankle instability, and identify athletes at greater risk for lower extremity injury. In order to improve the repeatability in measuring components of the SEBT, the Y Balance Test™ has been developed.

Objective. The purpose of this paper is to report the development and reliability of the Y Balance Test™.

Methods. Single limb stance excursion distances were measured using the Y Balance Test™ on a sample of 15 male collegiate soccer players. Intraclass Correlation Coefficients (ICC) were used to determine the reliability of the test.

Results. The ICC for intrarater reliability ranged from 0.85 to 0.91 and for interrater reliability ranged from 0.99 to 1.00. Composite reach score reliability was 0.91 for intrarater and 0.99 for interrater reliability.

Discussion. This study demonstrated that the Y Balance Test™ has good to excellent intrarater and interrater reliability. The device and protocol attempted to address the common sources of error and method variation in the SEBT including whether touch down is allowed with the reach foot, where the stance foot is aligned, movement allowed of the stance foot, instantaneous measurement of furthest reach distance, standard reach height from the ground, standard testing order, and well defined pass/fail criteria.

Conclusion. The Y Balance Test™ is a reliable test for measuring single limb stance excursion distances while performing dynamic balance testing in collegiate soccer players.

Key Words: Y Balance Test, lower extremity, postural stability

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BACKGROUND
Unilateral balance and dynamic neuromuscular control are required for sport. Dysfunctional unilateral stance has been prospectively identified as a risk for injury in sport. Recent discussion in the literature has occurred regarding the importance of assessing dynamic neuromuscular control for injury prediction using body relative movement testing. The Star Excursion Balance Test (SEBT) is a dynamic test that requires strength, flexibility, and proprioception. The goal of the SEBT is to maintain single leg stance on one leg while reaching as far as possible with the contralateral leg. The SEBT has been used to measure physical performance, compare balance ability among different sports, and identify individuals who have chronic ankle instability. Researchers have suggested using the SEBT as a screening tool for sport participation and as a post-rehabilitation test to ensure dynamic functional symmetry. Further, researchers have shown that SEBT performance improves after training.

The test originally incorporated reaching in eight directions while standing on each foot, but factor analysis indicated that one reach direction (posteromedial) was able to accurately identify individuals with chronic ankle instability as well as performing all eight directions. Further, Plisky et al reported that the sum of three reach directions (anterior, posteromedial, and posterolateral), as well as asymmetry between legs in anterior reach distance, were predictive of lower extremity injury. Researchers have suggested using the SEBT as a screening tool for sport participation and as a post-rehabilitation test to ensure dynamic functional symmetry. Further, researchers have shown that SEBT performance improves after training.

Because this balance test is dynamic, difficulty can occur in attempting to accurately assess the farthest reach point and what criteria constitutes a successful reach (e.g. how much movement of the stance foot is allowed or if the reach foot is allowed to touch down). Thus, there have been many protocols utilized for the test (Table 1) with the primary variations in protocol being whether the reach foot touches the floor. Touching down with the reach foot introduces error by making it difficult to quantify the amount of support gained from that touchdown. If touchdown is not allowed, standardizing the distance from the ground that the person reaches is difficult, as well as instantaneously marking the farthest reach point. In addition, it is difficult for examiners to determine how much movement of the stance foot is allowed. Precise determination of the heel or forefoot lift off from the surface is difficult due to the contours of the foot and the rapid position changes due to co-contraction of the lower limb muscles during unilateral stance.

Another disparity in SEBT protocols is where the stance foot is aligned to determine starting position. The starting point has been reported to be at the bisection of the lateral malleolus, most distal aspect of the toes, center of the foot, and varied according to reach direction. The Y Balance Test™ (FunctionalMovement.com, Danville, VA) is an instrumented version of components of the SEBT developed to improve the repeatability of measurement and standardize performance of the test. The device utilizes the anterior, posteromedial, and posterolateral components of the SEBT. Therefore, a testing protocol was developed to address potential sources of error and to describe standard testing procedure so that results can be compared among studies as well as among clinicians. This device and protocol attempt to address the common sources of error and method variation including whether touchdown is allowed with the reach foot, where the stance foot is aligned, movement allowed of the stance foot, instantaneous measurement of furthest reach distance, standard reach height from the ground, standard testing order, and well defined pass/fail criteria.

METHODS
Subjects
Fifteen male collegiate soccer players (mean 19.7 ± 0.81 years) participated in the study. Subjects were excluded from participation in the study for lower extremity amputation; vestibular disorder; lack of medical clearance for

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<table>
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<th>Reach Foot Touch Down</th>
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<th>Average or Greatest reach</th>
<th>Testing Directions*</th>
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<td>AM, PM</td>
<td>Yes / ASIS to mid iliallateral medial malleolus</td>
<td>6 practice / 3 trials</td>
<td>Pictured with shoes off</td>
</tr>
<tr>
<td>Gribble and Hertel*</td>
<td>30</td>
<td>Yes</td>
<td>Center of grid</td>
<td>No</td>
<td>Mean of 3 trials (cm)</td>
<td>A, M, P</td>
<td>Yes / ASIS to mid medial malleolus bilateral</td>
<td>6 practice / 3 trials</td>
<td>Pictured with shoes off</td>
</tr>
<tr>
<td>Cote et al*</td>
<td>48</td>
<td>Yes</td>
<td>Center of grid</td>
<td>No</td>
<td>Mean of 3 trials (cm)</td>
<td>A, M, P</td>
<td>No</td>
<td>1 practice / 3 trials</td>
<td>Not specified</td>
</tr>
<tr>
<td>Lanning et al*</td>
<td>105</td>
<td>No</td>
<td>Center of Box</td>
<td>No</td>
<td>Greatest (cm)</td>
<td>AM, PM</td>
<td>Yes / ASIS to mid medial malleolus bilateral</td>
<td>6 practice / 3 trials</td>
<td>With the shoes on</td>
</tr>
<tr>
<td>Plisky et al*</td>
<td>235</td>
<td>No</td>
<td>Center of grid with most distal aspect of great toe at start line</td>
<td>No</td>
<td>Greatest of 3 trials (cm), sum of each direction greatest (composite)</td>
<td>A, PM, PL</td>
<td>Inferior aspect of ASIS to distal lateral malleolus, after clearing of the hip</td>
<td>6 practice / 3 trials</td>
<td>Great toe at line, pictured with shoes off</td>
</tr>
<tr>
<td>Hertel et al*</td>
<td>87</td>
<td>Yes</td>
<td>Geometric center of the foot on cross hairs in center of grid</td>
<td>No</td>
<td>Mean of 3 trials (cm)</td>
<td>AM, PM</td>
<td>Yes / ASIS to distal tip medial malleolus</td>
<td>6 practice / 3 trials</td>
<td>Geometric center of foot / pictured with shoes off</td>
</tr>
<tr>
<td>Gribble et al*</td>
<td>30</td>
<td>Yes</td>
<td>Foot bisected equally in all planes</td>
<td>No, Hands on iliac crests</td>
<td>Avg of 3 reaches (unit not specified)</td>
<td>A</td>
<td>Yes / ASIS to distal medial malleolus</td>
<td>6 practice / 3 trials</td>
<td>Pictured shoes off</td>
</tr>
<tr>
<td>Sawkins et al*</td>
<td>30</td>
<td>Yes</td>
<td>Varied to direction of reach</td>
<td>No</td>
<td>Greatest (cm)</td>
<td>A, P, PM</td>
<td>Not specified</td>
<td>6 practice (center to tapping) / 3 trials</td>
<td>Shoes off</td>
</tr>
<tr>
<td>Breslau et al*</td>
<td>34</td>
<td>Yes</td>
<td>Middle of grid with center of foot on small dot</td>
<td>Cited as Gribble et al*, cited as Gribble et al*, cited as Gribble et al*</td>
<td>Avg of 3 trials (cm &amp; mm used)</td>
<td>AM, PM</td>
<td>Yes / ASIS to medial malleolus (nearest mm) Both lower extremities</td>
<td>680 seconds of practice prior to testing, 3 trials</td>
<td>Not specified</td>
</tr>
<tr>
<td>Hubbard et al*</td>
<td>60</td>
<td>Yes</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Avg of 3 trials (cm)</td>
<td>A, PM, PL</td>
<td>Yes / &quot;Gribble&quot;*</td>
<td>6 practice / 3 trials</td>
<td>Not specified</td>
</tr>
<tr>
<td>Hubbard et al*</td>
<td>30</td>
<td>Yes</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Avg of 3 trials (cm)</td>
<td>A, PM, PL</td>
<td>Yes / &quot;Gribble&quot;*</td>
<td>6 practice / 3 trials</td>
<td>Not specified</td>
</tr>
<tr>
<td>Gribble et al*</td>
<td>30</td>
<td>Yes</td>
<td>Middle of grid</td>
<td>No, Hands on hips</td>
<td>Mean of 3 trials (unit not specified)</td>
<td>A, M, P</td>
<td>Yes / ASIS to distal medial malleolus</td>
<td>6 practice / 3 trials</td>
<td>Not specified (cinematic markers placed)</td>
</tr>
<tr>
<td>English and Howes*</td>
<td>3</td>
<td>Methods cited as Kinney et al*, with touchdown</td>
<td>Center of box</td>
<td>Not specified</td>
<td>Mean of 3 trials (cm)</td>
<td>Reported as Right anterior and posterior, Left anterior and posterior; (AM, PM)</td>
<td>Not specified</td>
<td>6 practice / 3 trials</td>
<td>Pictured with shoes on</td>
</tr>
<tr>
<td>Hale et al*</td>
<td>67</td>
<td>Yes</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Mean of 3 trials (unit not specified)</td>
<td>AM, PM</td>
<td>Not specified</td>
<td>6 practice / 3 trials</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

*A= Anterior, AM= Anterior Medial, M= Medial, PM= Posterior Medial, P= Posterior, PL= Posterior Lateral, L= Lateral, AL= Anterior Lateral, ASIS= Anterior Superior Iliac Spine,
† NA = Not Applicable
participation; injury; current or undergoing treatment for inner ear, sinus, upper respiratory infection, or head cold; or cerebral concussion within the previous three months. Prior to participation all subjects read and signed an informed consent form approved by the University of Evansville's Institutional Review Board.

**Testing Device**
The Y Balance Test Kit™ consists of a stance platform to which three pieces of PVC pipe are attached in the anterior, posteromedial, and posterolateral reach directions (Figure 1). The posterior pipes are positioned 135 degrees from the anterior pipe with 45 degrees between the posterior pipes. Each pipe is marked in 5 millimeter increments for measurement. The subject pushes a target (reach indicator) along the pipe which standardizes the reach height (i.e. how far off the ground the reach foot is), and the target remains over the tape measure after performance of the test, making the determination of reach distance more precise.

**Y Balance Test™ Protocol**
The subjects viewed an instructional video which demonstrated the test and testing procedure as explained by Plisky et al. Hertel et al found a significant learning effect with the SEBT where the longest reach distances occurred after six trials followed by a plateau. Therefore, the subjects practiced six trials on each leg in each of the three reach directions prior to formal testing. The subjects were tested within 20 minutes of practicing. All subjects wore athletic shoes during the performance of the test. The subject stood on one leg on the center foot plate with the most distal aspect of the athletic shoe at the starting line. While maintaining single leg stance, the subject was asked to reach with the free limb in the anterior (Figure 2), posteromedial (Figure 3), and posterolateral (Figure 4) directions in relation to the stance foot. In order to improve the reproducibility of the test and establish a consistent testing protocol, a standard testing order was developed and utilized. The testing order was three trials standing on the right foot reaching in the anterior direction (right anterior reach) followed by three trials standing on the left foot reaching in the anterior direction. This procedure was repeated for the posteromedial and the posterolateral reach directions.

The subject was instructed by one rater (PPG) to stand on the platform with toes behind the line and to push the reach indicator in the red target area in the direction being tested. These were the only instructions given to the subject during testing. All testing was observed and scored by two raters (inter-rater reliability) simultaneously that were blinded to each others scoring. Rater #1 was a physical therapist assistant and certified athletic trainer with 10 years of experience, and Rater #2 (BE) was a physical therapist with 7 years of experience. The raters independently determined if a successful trial was completed (i.e. that the foot was positioned correctly behind the line and that all of the criteria were met for a successful trial). To reduce bias, the rater recorded the reach distance regardless whether he thought the trial was successful. After three trials in one
reach direction, the raters were asked if they had at least one successful trial. If they did not, the subject was asked to perform an additional trial until a successful reach was completed. If the subject was unable to perform the test according to the above criteria in six attempts, the subject failed that direction.

The maximal reach distance was measured by reading the tape measure at the edge of the reach indicator, at the point where the most distal part of the foot reached. The trial was discarded and repeated if the subject: 1) failed to maintain unilateral stance on the platform (e.g., touched down to the floor with the reach foot or fell off the stance platform), 2) failed to maintain reach foot contact with the reach indicator on the target area while it was in motion (e.g., kicked the reach indicator), 3) used the reach indicator for stance support (e.g., placed foot on top of reach indicator), or 4) failed to return the reach foot to the starting position under control. The starting position for the reach foot is defined by the area immediately between the standing platform and the pipe opposite the stance foot. The process was repeated while standing on the other leg.

The specific testing order was right anterior, left anterior, right posteromedial, left posteromedial, right posterolateral, and left posterolateral. The greatest successful reach for each direction for each rater was used for analysis of the reach distance in each direction. Also, the greatest reach distance from each direction was summed to yield a composite reach distance for analysis of overall performance on the test. The testing procedure was repeated approximately 20 minutes later using a single rater (PPG) and measuring the same subject's right stance limb (to measure intra-rater reliability).

**Lower Limb Length**

On a mat table with the subject supine, the subject lifted the hips off the table and returned them to starting position. Then, the examiner passively straightened the legs to equalize the pelvis. The subject's right limb length was then measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial malleolus with a cloth tape measure.

**Data Analysis**

The data were analyzed for each subject for the right limb in the anterior, posterolateral, and posteromedial reach directions. Means and standard deviations were calculated for the reach distance in each direction and limb length. Paired sample t-test was used to determine if there was a difference between the performance of the right and left limb. Since reach distance is related to limb length, reach distance was normalized to limb length to allow future comparison among studies. To express reach distance as a percentage of limb length, the normalized value was calculated as reach distance divided by limb length then multiplied by 100. Composite reach distance was the sum of the three reach directions divided by three times limb length, and then multiplied by 100. An ICC (3,1) was used to evaluate intrarater reliability and ICC (2,1) was used to evaluate interrater reliability for each of the normalized reach distances.

**RESULTS**

Mean, standard deviation, median, and range of the average performance of the two limbs are reported in Table 2. Intrarater reliability for the
one tester ranged from 0.85 to 0.91 with anterior reach 0.91, posteromedial of 0.85, and posterolateral 0.90, and composite 0.91 (Table 3). Inter-rater reliability between the two testers ranged from 0.99 to 1.0 with anterior 1.0, posteromedial 0.99, posterolateral 0.99, and composite reach 0.99 (Table 4).

**DISCUSSION**

The intrarater reliability of the SEBT has been reported as moderate to good (ICC 0.67-0.97), and interrater reliability has been reported as poor to good (0.35-0.93). The variability in the ranges of previously reported reliability of the SEBT suggests the need to improve the accuracy of the testing methods and importance of a standardized testing protocol. The intrarater reliability improved over the traditional SEBT testing methods when using the Y Balance Test™. Because the intrarater reliability exceeds the intrarater reliability, the variability in subject performance on the test likely exceeds the variability in the measurement recorded by different raters (i.e. the precision in the device is greater than the precision in subject performance). This occurrence can be attributed to a more standardized scoring criteria and a more precise measurement device that also standardizes performance. Further, a standard testing order (i.e. right anterior, left anterior, right posteromedial, left posteromedial, right posterolateral, left posterolateral) allows for consistent performance of the test and attempts to minimize fatigue by alternating stance limbs.

The Y Balance Test™ was developed to address some of the limitations of the traditional SEBT testing methods. A reach indicator, standard reach height from the ground, well defined pass/fail criteria, and the ability of the reach indicator to remain over the tape measure after performance improve the reproducibility of the reach measurement. These features also allow the rater to focus more attention on observing the subject, and, therefore, better assess the subject's movement quality (Table 5). If examiners focused on monitoring stance foot movement, it was nearly impossible to simultaneously mark reach distance. In addition, during the development of the testing protocol for the device, it was difficult for examiners to determine how much movement of the stance foot was allowed in a successful trial (i.e. it was difficult to determine if/when the heel or forefoot actually lifted from the surface). Thus, the athlete was allowed to lift the heel off the ground to improve repeatability and standardize the testing procedures so that results can be compared among studies as long as the toe remained aligned with the start stripe at the front of the stance platform.

Some limitations to this study should be noted. Error could have been introduced by fatigue, practice effect, and re-measurement on the same day of initial testing. Future studies should be conducted with shoes off as many athletes attend...
A need exists to collect normative data using the Y Balance Test™ on varied populations (e.g., collegiate, high school, basketball, hockey, elderly, firefighters, etc.). With normative data and prospective studies, the Y Balance Test™ could be evaluated for prediction of injury in different populations and establish acceptable reach distances for each population.

**CONCLUSION**

The Y Balance Test™ has shown good to excellent reliability with the standardized equipment and methods. By establishing the reliability of the Y Balance Test™, sports medicine clinicians can better determine deficits and asymmetries in individuals, as well as assist in the return to play decision-making process.

**REFERENCES**


