ABSTRACT

This clinical commentary outlines a new clinical model for anterior cruciate ligament (ACL) rehabilitation, the Knee Symmetry Model. This model has been developed by clinical observation, patient interaction, and by analyzing outcome measures derived from prospective follow-up of patients. More specifically, the best outcome scores occurred in patients with symmetric range of motion and strength. A thorough discussion of the details involved in the development and implementation of this rehabilitation program for this patient following ACL reconstruction is described. Included in this description is the supporting evidence and clinical rationale behind pre-operative and post-operative ACL rehabilitation. Preliminary results from a recent group of patients are presented. When using the Knee Symmetry Model 100% of patients achieved normal knee extension and 97% of patients achieved normal knee flexion.

Key Words: ACL rehabilitation, pre-operative rehabilitation, post-operative rehabilitation

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INTRODUCTION
Rehabilitation of patients following anterior cruciate ligament (ACL) surgery has evolved dramatically over the last several decades. During this time, clinicians have gradually changed their approach from absolute immobilization and no muscle activity to minimal range of motion (ROM) restrictions with immediate muscle activation following surgery.\textsuperscript{1,3,4,6,7} Although ACL post-operative rehabilitation has continued to evolve, relatively minimal literature is available outlining the precise nature of ACL rehabilitation. The authors of this report have focused their clinical practice entirely on knee injuries and, through this focus, have developed a new model for ACL rehabilitation, the Knee Symmetry Model.

Current articles on ACL rehabilitation are few or lack the proper detail necessary for a practicing clinician to fully implement the rehabilitation program. Even those articles where rehabilitation is the primary focus of the study do not give full descriptions of the details involved with ACL rehabilitation.\textsuperscript{1,3,4,6,7} Therefore, clinicians are left with insufficient detail when attempting to implement a rehabilitation program outlined in the literature. More specifically, most articles in the current literature focus on the details involved with strength training while ROM is not focused upon.\textsuperscript{1,7} Through research and data collection, ROM appears to be the primary issue involved in excellent outcomes following ACL reconstruction. To date, other articles within the literature are infrequent that specifically focus on the ROM part of the rehabilitation process.

The authors have been able to develop the Knee Symmetry Model for ACL rehabilitation in part due to the utilization of the same graft with the same surgical approach and the same graft fixation for the past 25 years. Therefore, because the surgical procedure has been constant, the primary variable observed in patient outcomes is the rehabilitation. The surgical procedure used in this center is an ACL autograft with bone-patellar tendon-bone. While most surgeons have changed their surgical procedure, this center has maintained the same graft source, the same graft fixation, and the same surgical approach, thus, allowing changes in patient outcomes to be observed as a result of changing the rehabilitation program. Given that the graft source, fixation, and surgical approach have not changed, the focus has been on refining the rehabilitation program.

Outcomes have helped identify that patients who achieve symmetrical ROM and strength have better subjective and objective outcomes, regardless of meniscal or articular cartilage damage found at the time of surgery.\textsuperscript{9} Physical therapists do not have control over the surgeon or patient's choice of graft selection, but do play an important role in the patient's ability to achieve symmetrical ROM. Understanding the importance of symmetrical ROM makes it the most important factor in the rehabilitation process, regardless of graft choice or the surgical procedure. The Knee Symmetry Model provides an outline to achieve this goal of full ROM. The goal of the rehabilitation program should be symmetrical ROM and the surgical procedure performed should allow the physical therapist the best opportunity to restore the patient's knee to symmetrical ROM and strength. Although the basic principles of rehabilitation outlined in this report apply to all grafts, the specific details of rehabilitation along with the outcomes reported are based on the knee symmetry model following an ACL reconstruction performed with a patellar tendon graft.

SURGICAL APPROACH
Both contralateral (CBPTB) and ipsilateral (IBPTB) bone patellar bone ACL autografts are utilized in this center. The CBPTB and IBPTB surgical procedures have been described in depth elsewhere.\textsuperscript{10,11} The CBPTB can be used as a primary procedure or to revise a previous ipsilateral reconstruction. Critical elements of the CBPTB and IBPTB surgical procedures include proper graft placement in the tibial and femoral tunnels, full knee ROM (hyperextension and flexion) after the graft has been placed and tensioned in the tibial and femoral tunnels, and accommodative fixation (sutures tied over buttons) of the graft in the tibial and femoral bone tunnels. The graft needs to be tight enough to provide stability but loose enough to allow for full knee ROM in the operating room. If the knee is not able to go through a full ROM once the graft is tensioned, post-operative rehabilitation programs designed to restore symmetric ROM may result in decreased knee stability or leave the patient with the inability to achieve symmetrical ROM. Therefore, the authors recommend a thorough discussion with the referring surgeon when implementing this program.

REHABILITATION PHILOSOPHY
As our knowledge of the patient's response to this surgery has grown, an increased emphasis has been placed on restoring the surgical knee to the pre-injury status.\textsuperscript{8,10} To fully accomplish this goal, the clinician is asked to restore
bilateral knee symmetry. Most clinicians believe that early elimination of pain and inflammation in the injured knee is critical to achievement of knee symmetry in patients. However, the rehabilitation approach should also include bilateral knee symmetry in terms of ROM, strength, stability, and function as soon as symptoms allow. Principles of treatment begin pre-operatively and continue until complete knee symmetry is achieved post-operatively. Once knee symmetry is achieved post-operatively, the patient is discharged from formal rehabilitation; however, each patient is followed closely after discharge from formal rehabilitation. It is only through patient follow-up that the long-term results of surgery and rehabilitation have been observed and rated. Failure to perform follow-up evaluations on patients leads to an inaccurate understanding or a misinterpretation of results.

Therefore, our rehabilitation philosophy has been shaped by frequently analyzing the patient’s post-operative status. Each and every patient is strongly advised to follow up on regular intervals including 1, 2, 4, and 6 months and at the first, second, fifth, tenth, and twentieth year post-operatively. This information is entered into the center’s database so that all patient outcomes can be analyzed together. The understanding gained from the long-term follow up of patients has guided the establishing principles of rehabilitation within this program. This program has developed based on long-term research and data collection that recognizes the importance of obtaining knee symmetry, most importantly symmetrical ROM, as a means to provide the patient with optimal short and long-term outcomes.

**PRE-OPERATIVE REHABILITATION**

Patients are evaluated by the physician and physical therapist at the time of their initial appointment. The physician makes the medical diagnosis, and the physical therapist performs an initial examination by observing and measuring all elements of knee symmetry. Patients are taught a home rehabilitation program for each component of the knee symmetry model. Although an emphasis on a home program requires fewer visits to physical therapy, each visit is quite comprehensive. Emphasis is placed on educating patients and their families about the goals of rehabilitation. The primary goal, knee symmetry, is stressed repeatedly during the pre-operative period. Once the patient has achieved the specified goals and is able to demonstrate the ability to perform the exercises, they are approved for surgery.

Patients are required to reduce the inflammation and swelling in the involved limb prior to surgery. They are instructed to utilize ice, compression, and elevation 3-4 times per day until the inflammation and swelling are eliminated. During the pre-operative period patients are instructed to refrain from competitive sports; however, they are not specifically restricted from their normal daily activities.

Restoring complete passive ROM pre-operatively is a key to the entire rehabilitation program. Included in the knee ROM is bilaterally symmetric motion, which, in most patients, includes a component of hyperextension and knee flexion. Passive knee extension is measured with the patient lying supine with the heel propped on a bolster to allow the knee to fall into hyperextension (Figure 1). Passive knee flexion is also measured in supine (Figure 2). Both a quantitative (measurement) and qualitative (end

![Figure 1. Knee hyperextension measurement](image1)

![Figure 2. Knee flexion measurement](image2)
feel) approach is utilized for assessment of motion. Measurement is performed and recorded in a hyperextension/extension/flexion format. If a patient has 5 degrees of hyperextension and 135 degrees of flexion the measurement is recorded as 5/0/135. If a patient has lost 5 degrees of extension from 0 degrees neutral, the measurement is recorded as 0/5/135. Likewise, the end feel for hyperextension is observed quite meticulously by the physical therapist (Figure 3). It is not until both the end feel and the measurement of hyperextension are symmetrical that surgery is an option. Each physical therapist has performed a reliability test for both knee extension (hyperextension) and knee flexion. Previously the authors reported intrarater intra-class correlation (ICC) values for knee extension (.88) and flexion (.99) and intrarater reliability for knee extension (.95) and flexion (.99).

As the inflammation, swelling, and knee ROM are improved, neuromuscular re-training is initiated pre-operatively. Patients are taught leg control activities like quadriceps and leg raises, and instructed how to walk with a normal gait pattern. Patients may resume low impact activities and weight training if they desire, but these activities are not required pre-operatively. Before surgery, each patient is tested for quadriceps and hamstring muscle strength isokinetically at 60° and 180° per second. Both single leg hop and unilateral leg press are measured pre-operatively and used as post-operative strength goals as well. The strength measures obtained on the uninjured knee are utilized as a post-operative goal for both knees.

Knee function is measured with both the modified Noyes and International Knee Documentation Committee (IKDC) subjective outcome instruments. Each patient is given these instruments pre-operatively and at regular intervals post-operatively.

IMMEDIATE POST-OPERATIVE REHABILITATION

When CBPTB surgery is performed, both knees of the patient must be addressed in the rehabilitation process. Although a rehabilitation program must be applied to each patient's knee, the goals for each knee are somewhat different. On the graft-donor knee (contralateral knee), ROM is easily achieved and allows the clinician to focus on strength within the first 1-2 days post-operative. While on the ACL-reconstructed knee (ACL injured knee) the focus is on ROM, not strength. By performing surgery in this manner, the rehabilitation clinician is able to concentrate on the most important goals for each knee and minimize the post-operative complications. It is only through the process of performing surgery and rehabilitation on BOTH knees that the importance of goals and expectations for the two types of surgery (the ACL reconstruction and the graft-donor site) have been more completely understood. The rehabilitation program for each knee will now be outlined in detail.

ACL-Reconstructed Knee (ACL Injured Knee) – CBPTB or IBPTB

General Guidelines

During the immediate post-operative period, patients are hospitalized overnight to assure proper pain and swelling control is obtained. Patients are given ketoralac intravenously, placed on a continuous passive motion (CPM) machine, and provided with a cold/compression device (Cryocuff TM, DJ Orthopaedics, Vista, CA).

Ketoralac, a prostaglandin inhibitor, is used both pre-operatively and post-operatively. Patients are given 30mg intravenously pre-operatively and started on a continuous drip post-operatively. The continuous drip consists of 90 mg of ketoralac in 1L of normal saline solution over a 23-hour period. Ketoralac is combined with a local injection of .25% Marcaine and, when combined with the ketoralac, provides patients with excellent post-operative pain relief. A thin waterproof dressing is applied over the incision sites and drains are placed in bilateral knees for the first 23 hours to help minimize a hemarthrosis. Thromboembolitic compression stocking are placed on both legs and worn during the first week of bedrest. A cold/compression device is also immediately initiated in the operating room and utilized continually for the first week post-operatively.
The patient’s ACL-reconstructed knee is placed in a CPM machine immediately after surgery. The primary purpose of the CPM machine is to elevate the knee above the level of the heart to help minimize post-operative swelling. Secondarily, the CPM machine provides gentle passive ROM to the ACL-reconstructed knee and is set to move from 0-30 degrees of knee flexion continuously throughout the first week after surgery. The patient is instructed to remain supine with the leg elevated and placed in the CPM continuously during the first week after surgery.

Throughout the first week after surgery the patient is placed on bed rest with bathroom privileges in order to minimize swelling and maximize ROM. The avoidance of activity is an important, but a misunderstood concept developed after the initial “Accelerated Rehabilitation after ACL Reconstruction” article in 1990.8 The authors believe that bed rest during the first week post-operatively allows the patient to more readily achieve the post-operative goals for each knee. More specifically, bed rest decreases swelling in the patient’s ACL-reconstructed knee allowing for a much quicker return of ROM. Patients are instructed to have a caregiver in place to reduce their overall activity level and permit the patient to focus on their rehabilitation during the first week post-operatively. This plan, when strictly adhered to, greatly diminishes the amount of inflammation and swelling in either knee, which facilitates an earlier restoration of knee symmetry.

**Range of Motion**

Immediately after surgery and while in the hospital, the patient is asked to initiate ROM activities for hyperextension and flexion four times per day. Knee hyperextension is obtained via heel prop exercises (Figure 4), towel stretch exercises (Figure 5), and active hyperextension (Figure 6) while knee flexion activities during this period include active and active-assisted heel slide exercises (Figure 7).

Goals for discharge from the hospital include symmetrical knee hyperextension and 125 degrees of knee flexion. It is important to emphasize that ROM is unlimited during the initial phase of rehabilitation post-operatively. The only limit on obtaining symmetric ROM is patient tolerance. Most patients lose some of their initial ROM after they are

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**Figure 4. Heel props**

**Figure 5. Towel stretches**

**Figure 6. Active hyperextension**

**Figure 7. Heel slides**
discharged. However, the psychological effect of knowing near full ROM has been achieved immediately post-operatively is helpful in obtaining full ROM.

Strength
Following surgery, strength training for the ACL-reconstructed knee is not formally emphasized. Too frequently, an aggressive strengthening program for the patient's ACL-reconstructed knee leads to increased inflammation and loss of ROM, which is counter productive. However, proper quadriceps muscle activation is emphasized in order to have good leg control for ambulation. This quadriceps muscle activation is achieved through quad set exercises and active hyperextension. The same program is followed for both the CBPTB and IBPTB surgical procedures.

Graft-Donor Knee (Contralateral Knee)
Range of Motion
When a CBPTB procedure is performed, both of the patient's knees must be rehabilitated. During the initial post-operative period ROM in the graft-donor knee is addressed by the same methods utilized on the patient's ACL-reconstructed knee. Knee hyperextension activities (heel prop, towel stretch, active hyperextension) are performed along with heel slide exercises for knee flexion several times per day.

Strength
The patient's graft-donor knee easily achieves normal ROM. Due to the nature of the graft harvest procedure, no effusion occurs in the graft-donor knee which allows for an easier restoration of ROM. Once normal ROM has been achieved on the graft-donor knee, focus is placed on tendon regeneration during the immediate post-operative period. Beginning on the day after surgery each patient performs resisted leg press activities on the graft-donor knee. A unilateral leg press machine (SHUTTLE, Contemporary Design Company, Glacier, WA) adapted for in-bed resisted activity is utilized for the first two weeks post-op (Figure 8). Patients are taught to perform up to 100 repetitions with 7 pounds before increasing resistance on the leg press machine. Leg press activities are performed four times per day during this period. Patellar tendon discomfort is expected due to the active work performed by the patellar tendon. However, patients are cautioned to avoid ROM loss at the expense of patellar tendon strengthening. Early patellar tendon hypertrophy can be observed and is encouraged with these patients.

Both Knees – Function
Patients are instructed to remain supine with the ACL reconstructed leg elevated in order to minimize swelling. The patient may shower and have restroom privileges. Gait is evaluated on the second day and patients are instructed to ambulate full weight bearing with proper weight shift and heel strike. It is rare for a patient to be unable to perform this, however, if the patient is having difficulty with quadriceps activation and is unable to safely bear his/her weight, he/she is given an appropriate assistive device. However, most all patients are able to begin ambulating without an assistive device day two post-operatively. Bathroom privileges are available to the patient for the first week after surgery, but ambulation or standing for long period is strongly discouraged.

INTERMEDIATE POST-OPERATIVE REHABILITATION
Following the immediate post-operative phase of rehabilitation, an intermediate phase is implemented. During this phase the goals are to rehabilitate both knees of the patient symmetrically to their pre-operative values. No time lines are used for achievement of these goals. Each patient is progressed according to his or her own healing progression. Once inflammation and swelling have been eliminated and full symmetrical ROM is achieved, strength training is increased to tolerance, and functional training for returning to sports can occur. Single-leg strengthening is emphasized during this period secondary to the strength differences between limbs. Double leg activities are discouraged because they reinforce the stronger limb. It must be emphasized that no time constraints exist on rehabilitation. When a patient
has achieved symmetrical knee ROM and leg strength, and is ready to resume a given activity, he or she is encouraged to participate. Initial participation includes drills and skill development. As the patient progresses, a complete functional progression adapted for the patient's sport is incorporated into the rehabilitation program. No pre-set time frame is used for return to any activity. Typically, patients can return to sport anywhere from 2 – 6 months post-operatively depending on their functional progression.

**Specifics of the Intermediate Phase**

After the first week post surgery, patients are allowed to resume normal activities of daily living. If a CBPTB procedure is performed, patients are instructed to continue with an exercise program that focuses on ROM in the ACL-reconstructed knee and strengthening (or graft stimulation) in the graft-donor knee. Patients who undergo IBPTB procedures must maintain full knee ROM while emphasizing strength training on the surgical knee.

**ACL-Reconstructed Knee**

Patients are instructed to continue with exercises that focus on increasing both passive and active ROM. These include towel stretches, heel props, heels slides, and wall slides. All exercises are performed approximately three times per day. Patients are asked to monitor knee ROM during the second week post-operatively. As long as his/her knee ROM continues to improve, no limitations or restrictions in activities of daily living (ADL) are implemented. By restoring early ROM and encouraging normal use of the patient's ACL reconstructed knee, proprioceptive and neuromuscular control is quickly restored and obtained through normal ADLs. Obtaining symmetrical knee ROM (including hyperextension and flexion equal to the opposite knee) is the primary goal for the patient's ACL-reconstructed knee during the remainder of the rehabilitation process.

When an IBPTB procedure is utilized, the patient must also focus on strength training as outlined in the next paragraph. However, it must be emphasized that strength development is secondary to gaining and maintaining symmetrical knee ROM. If decreases in ROM or increases in pain or swelling are observed in the patient's knee, he or she is instructed to decrease the strength training portion of rehabilitation until ROM and swelling are normalized.

**Graft-Donor Knee**

The graft-donor knee should have full ROM after the first week. This allows the patient and clinician to focus on graft stimulation and strengthening until normal strength has returned. Strengthening is accomplished with low load, high repetition exercises including step down exercises, single leg press, and unilateral knee extension exercises. During this phase, it is common and normal for the patient to experience tendon soreness and discomfort until the tendon has regenerated. Continued stretching and cryotherapy help control the soreness until the tendon is regenerated and knee strength is restored.

Beginning at one month after surgery, patients will continue to undergo strength and functional testing every month until their goals are achieved. Both isokinetic testing (strength testing) and hop testing (functional testing) are performed during this time frame. When patients achieve appropriate knee ROM, they are encouraged to participate in low impact activities such as the bike or elliptical trainer. Both of these exercises assist in increasing strength and cardiovascular endurance. Patients are also allowed to begin light agility activities (shooting baskets, dribbling the soccer ball, foot work, etc.). As long as ROM continues to improve and minimal knee swelling occurs, patients can continue to participate in drills and agilities. Regardless of what time after surgery the patient achieves knee symmetry (symmetrical ROM and strength), he or she is released to begin participating in practice drills and competition. During this time period, it is normal for patients to experience soreness and swelling. Patients need to be educated on how to manage the soreness and swelling without losing ROM because ROM is an important factor in providing the best short- and long-term outcome. Activity modification or days of rest when first returning to full practice or competition may be required if ROM shows signs of decreasing.

**OUTCOME MEASURES**

Each patient is evaluated in several ways. Objective measures for ROM, strength, and stability, and subjective questionnaires are utilized. Range of motion is measured and recorded at each physical therapy visit. Beginning at one month after surgery, isokinetic testing of quadriceps and hamstring muscle strength at 60 degrees and 180 degrees per second is performed bilaterally through a full ROM (0 degrees to 95 degrees). The single leg press test and single leg hop test are also used as outcomes measures.
during the intermediate phase of rehabilitation. The KT-2000 is utilized to measure the amount of anterior excursion of the tibia with 68N, 89N, 133N, and manual maximum force. Each of these measures (ROM, strength, KT-2000) is recorded at the month 1, 2, 4, and 6 evaluation, and at 1, 2, 5, 10, and 20 years post-operatively, when possible. Not all patients are able to return for each of these long-term follow up visits. However, even when patients are not able to return for a clinic visit, they are asked to fill out the subjective questionnaires in an online or paper format.

Tables 1 to 4 outline the objective measures and outcome instruments for a recent group of patients. These tables represent the one year or more post-operative outcomes for patients who underwent a contralateral bone-patellar tendon-bone autograft ACL reconstruction from 2003 to 2006. The mean subjective scores on the IKDC outcome measure are within the established age-specific norms for this instrument.

Table 1 represents the passive ROM measurements. The outcome instrument used is the IKDC objective survey. This outcome instrument defines normal ROM as a side to side difference of less than 2 degrees of knee extension and less than 5 degrees of knee flexion when compared to the uninvolved knee. The results indicate that equal side to side measurements provide the best long term outcome. In Table 1 the authors have outlined that the vast majority of patients achieve “normal” ROM as defined by the IKDC criteria.

Table 2 reports that the subjective and objective knee scores from two outcome instruments (IKDC and modified Noyes). Although a cohort group does not exist to compare the results, the scores reported are within the age-adjusted “normal” scores.

Strength is reported in Tables 3 and 4 for each knee separately. Secondary to the type of surgery performed (CBPTB and IBPTB) both knees were compared to the pre-operative values of the uninjured knee. The patient’s ACL reconstructed knee was compared to the patient’s graft-donor knee. Additionally, information was reported as a frequency distribution to allow the reader to observe the percentage of scores within a given range. This table further outlines the principle of specific rehabilitation for the ACL reconstructed knee and graft-donor knee discussed earlier. A majority of the ACL reconstructed knees were able to achieve 80-100% strength when compared to the graft knee and when compared to the pre-operative value at both 60 degrees and 180 degrees/sec.

**DISCUSSION**

Rehabilitation of the patient following ACL reconstruction has continued to change over the last decade from the “Accelerated Rehabilitation after ACL Reconstruction” program outlined in 1990 to the more current Knee Symmetry Model. The Knee Symmetry Model, which was developed in response to outcome research, emphasizes the return of two normal knees. When compared to the 1990 paper, specific differences that should be emphasized include the symmetric knee concept, the elimination of time frames as post-operative guidelines, unrestricted knee ROM immediately, strict bed rest for the first five days post-operatively, and specialized rehabilitation for the graft-donor knee and the ACL-reconstructed knee.

The Knee Symmetry Model has evolved after observing long-term outcomes. Patients who achieved symmetrical knee ROM had better subjective and objective outcomes as compared to those patients who did not achieve symmetrical ROM. With further analysis, the complication rate for patients with ACL reconstructions was less frequent and less severe in patients who...
obtained knee symmetry sooner post-operatively. The CBPTB surgery further assisted in this process by identifying the different emphases needed for the ACL knee and the graft-donor knee. Understanding the necessary goals for each knee helped in establishing a rehabilitation program directed in restoring knee symmetry as quickly and as safely as possible.

Speculation exists in the literature that ACL reconstruction may lead to a long-term outcome of knee osteoarthritis. Through 26 years of research, patients who achieve symmetrical knee ROM have less chance of developing arthritic changes. (Shelbourne KD, unpublished data 2007) Therefore, the Knee Symmetry Model along with the use of the contralateral graft provides the patient with the best opportunity to restore normal knee ROM with predictable stability. Given that many patients who undergo ACL reconstruction are in their teens and early 20’s, it remains an important factor to provide these patients with not only the return to their current sport but to also provide them with a good outcome 20 years after surgery.

Although other authors present and discuss ROM deficits in their papers, the interpretation of their results in a comparison with this paper is difficult secondary to a lack of specific methods of measurement provided by other authors. Additionally, the authors are not aware of other articles citing reliability of the extension (hyperextension) and flexion measures in their studies. Given that ROM measurements are a central issue in the rehabilitation of a patient after ACL surgery described in this report, the authors have attempted to address both of these issues in order to capture their ROM measures in a repeatable fashion. Other investigators may use the same or similar methods of measurement for extension (hyperextension) and flexion, but their methods are not described and verified with a reliability study. Secondary to a lack of uniformity within ROM measurement following knee surgery, it is difficult to compare ROM results of one study with another.

The IKDC information (Table 2) presented in this paper is in keeping with published age-specific normative data. Although the results of this paper are early (1-3 years), the

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<th>Percentile</th>
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<td>00-59%</td>
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<td>3</td>
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*Percentile = Side to Side Difference
*ACLR = ACL-reconstructed knee
*Graft = Graft-donor knee
*Pre-op = Pre-operative value for the uninjured knee
results are quite promising, and intermediate and long-term results will be published as they become available. Early results also show that ROM (Table 1) is very acceptable. When using the IKDC format for reporting ROM, patients do not have difficulty maintaining their ROM in either knee. While the strength results reported in Table 3 and 4 shows a decrease in strength at the 60 degrees/second testing speed with the graft-donor knee, the 180 degrees/second speed is very acceptable for both knees. We believe that the 60 degrees/second strength deficit in the graft-donor knee further outlines the belief that the primary goal for the graft-donor knee is to improve strength. Interestingly the patient’s ACL reconstructed knee did not have any problems maintaining their strength long-term. This result further outlines that the primary goal for the patient’s ACL reconstructed knee is to achieve full ROM.

Some clinicians appear to be fearful of gaining knee symmetry following knee surgery, but, to restore any joint to equilibrium, the clinician should strive for normal ROM and strength. Previous data from this center demonstrated that patients who failed to achieve symmetrical ROM were unable to achieve symmetrical strength. Additionally, those patients who did achieve symmetrical ROM had better strength scores. Therefore, obtaining symmetrical ROM allows the patient to restore normal strength and ultimately normal function. A stiff knee can be strengthened but never achieves symmetrical and normal strength, leaving the patient with a less than optimal outcome. Knee stability and symmetric ROM can be restored post-operatively without compromising either of these goals. The vast majority of patients who have had ACL reconstructions, contralateral and ipsilateral grafts, have symmetric ROM and a stable knee. In the patient sample of 228 patients (mean age 22.8 years), 221 (97%) obtained full knee ROM and had a mean manual maximum KT-2000 value of 1.8 mm. Therefore, the goals of symmetric ROM and knee stability are not conflicting, and represent what the goal should be for patients following ACL reconstructive surgery.

The understanding of rehabilitation following ACL reconstruction has been enhanced by the large number of patients who receive a contralateral graft. The observation of patients following an ACL reconstruction with a contralateral graft has allowed the analysis of the two elements of surgery individually. Instead of the patient’s ACL reconstruction and the graft-donor being on the same knee, these components of the surgical procedure are on different knees. Thus, each knee has one component of the procedure. The problem-solving gained from observing the patient’s graft-donor knee and the ACL-reconstructed knee in large volumes of patients has led to the understanding of varying goals for each surgical component.

CONCLUSIONS

This clinical commentary outlines a philosophy of care and a new rehabilitation program following ACL reconstructive surgery. Data collected shows that patients who achieve symmetrical knee ROM have better subjective and objective outcomes. The knee symmetry model provides a means and description to achieve these results. Specific principles of the program that facilitate achieving knee symmetry include the following: elimination of time frames as post-operative guidelines, unrestricted ROM immediately, bed rest for the first week post-operatively, and specialized rehabilitation for the patient’s graft-donor knee and the ACL-reconstructed knee. The knee symmetry model produces results that provide patients with the best short- and long-term outcomes while minimizing post-operative complications following ACL reconstruction.

REFERENCES


ABSTRACT

**Background.** Optimal athletic performance may be dependent upon an athlete maintaining adequate iron levels through the consumption of dietary forms of iron and subsequent metabolism. Endurance athletes, especially female distance runners, have been identified as being at risk for developing iron deficiency. While iron deficiency is treatable, early diagnosis may be delayed if an adequate medical history and evaluation is not conducted.

**Objective.** To describe the evaluation, diagnosis, and comprehensive sports medicine treatment of a collegiate cross-country athlete with a medical diagnosis of iron deficiency with anemia and sports-related musculoskeletal pain.

**Case Description.** A 21-year-old female collegiate cross-country athlete experienced a decline in her running performance beginning her freshman year of school. She continued to experience degradation in sports performance despite medical intervention. Two-and-a-half years after initially seeking medical attention she was diagnosed with iron deficiency with anemia by a primary care medical doctor. Additionally, the subject required rehabilitation due to the onset of sports-related musculoskeletal symptoms.

**Outcomes.** Comprehensive treatment for this patient consisted of iron supplementation, therapeutic exercises, manual therapy, and modalities. The athlete was able to compete during her entire cross-country season and earn All-American status at the Division-III level.

**Discussion.** Sports medicine professionals must consider iron deficiency as a possible differential diagnosis when evaluating endurance athletes. Subtle signs of iron deficiency may, unfortunately, be overlooked ultimately delaying treatment.

**Key Words:** iron deficiency with anemia, cross-country, iron supplementation

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INTRODUCTION
Consumption of dietary iron is necessary for optimal human cellular metabolism and growth. An individual who consumes a diet that is deficient of iron rich foods or who experiences depletion of iron stores may experience symptoms ranging from fatigue to degradation in physical performance. Iron deficiency is the number one nutritional deficiency affecting billions worldwide. Iron deficiency with anemia affects between 1% to 2% of all adults in the United States and is estimated to globally affect 0.5 to 0.6 billion people. In addition, up to 20% of Americans may suffer from iron deficiency without anemia with an estimated 1 to 1.8 billion suffering this condition worldwide.

Optimal athletic performance is also dependent upon maintaining iron levels through the consumption of dietary forms of iron and subsequent metabolism. The formation of hemoglobin and the body's subsequent ability to transport oxygen from the lungs to the tissues will be impaired in the athlete who is iron deficient. Additionally, athletes who are iron deficient may experience the following symptoms: nausea, frequent infections, shortness of breath during exercise, respiratory illness, fatigue, weakness, pale appearance, lack of energy, and exhaustion.

Endurance athletes, especially female distance runners, have been identified as being at risk for developing iron deficiency. One epidemiological study of endurance runners identified 82% of the female athletes as iron deficient. While iron deficiency is treatable, early diagnosis may be delayed if an adequate medical history and evaluation is not conducted.

The purpose of this report is to highlight a unique case of a collegiate female cross-country athlete who experienced a chronic degradation in her performance due to becoming iron deficient and anemic. Initial medical and allied healthcare evaluations and interventions failed to identify and appropriately treat her iron deficiency with anemia. The athlete continued to train and compete in distance running for both her collegiate cross-country and track teams, despite suffering fatigue and exhaustion. She considered quitting competitive running due to her inability to compete at a high level. Two-and-a-half years after initially seeking medical attention she was diagnosed with iron deficiency anemia by a primary care medical doctor. This case is unique as it details the medical intervention and sports rehabilitation management in the comprehensive treatment of a female collegiate cross-country athlete with a diagnosis of iron deficiency with anemia.

CASE DESCRIPTION
A 21-year-old female cross-country athlete presented at the start of the cross-country season to the athletic training team with a sports-related injury to the left hip and left knee. Her primary musculoskeletal complaint was her inability to complete her training runs without experiencing either left hip or left knee pain. The patient was concurrently receiving medical management for iron deficiency anemia by her primary care physician.

Previous History
The patient ran competitively on both her high school cross-country and track teams. She denied any history of sports-related running injuries during her high school career. Her best recorded time in high school for the 5,000-meter run was 19:36 (minutes:seconds). During her freshman collegiate cross-country season she experienced a decline in her running performance that she initially attributed to the intensity of the collegiate training program (Division I) and a “slow” acclimation to her new training environment (school situated at an elevation of 6910 feet or 2106 meters). The subject had previously attended a high school that was situated at sea level.

She described “feeling sluggish throughout the day” and that she required long naps during the day despite sleeping for 8 to 10 hours each night. When running she felt that she was racing “flat,” that she lacked energy during workouts, and that she experienced an increase (a slowing) of her race-pace. Her 5000-meter race time had slowed to 19:58.

In fall of 2006, she sought medical attention to identify a cause for her fatigue related symptoms after the completion of her freshman cross-country season. She also sought medical attention at this time for a new onset of allergies. During the course of several medical consults she was diagnosed by her medical doctor with asthma and hypoglycemia. Initial treatments failed to provide symptom relief and did not affect her athletic performance. She continued to seek medical attention for her sports-related symptoms. She reported that she was tested over the next year-and-a-half three times for mononucleosis and one time for anemia. According to the patient each test was negative. A “nutritionist” offered an unsolicited recom-
...mendation to her to increase her protein consumption, but the athlete was not provided any dietary guidance (note: the patient was unaware as to the educational or professional background of the “nutritionist”).

The patient transferred from the Division-I school after two years to a Division-III university in Oregon. Despite the change in training environments (school situated at an elevation of 210 ft or 64 m), she continued to experience her fatigue related symptoms and poor athletic performance. Not long after transferring schools, she began to experience back and left hip musculoskeletal pain. The patient sought chiropractic treatment in order to address her new musculoskeletal complaints. She received several treatments including manipulation of the spine, deep tissue massage, ultrasound, moist heat, and cryotherapy. She continued chiropractic treatment for 6 months despite a lack of improvement.

**Differential Diagnosis**

*Medical Management*

Previous medical evaluations and interventions by allopathic and chiropractic physicians failed to successfully decrease the subject’s symptoms. The subject again sought medical attention in Spring of 2007 after terminating chiropractic treatment. A complete blood count demonstrated low levels of hemoglobin (HGB), hematocrit (HCT), mean corpuscular volume (MCV), and mean corpuscular hemoglobin (MCH) (*Table 1, column 1*). Based upon these values, additional labs were performed 10 days later in order to assess serum iron levels, total iron binding capacity (TIBC), transferrin saturation, and serum ferritin levels (*Table 1, column 2*). Only one lab value, the TIBC, was within the standard reference values. Based upon these results, she was diagnosed with iron deficiency with anemia. The patient was instructed by her medical doctor to begin immediate iron supplementation (see treatment section).

**Musculoskeletal Differential Diagnosis**

At the start of the cross-country season the patient was referred by her coach to the university's athletic training department for treatment of her sports-related musculoskeletal injuries. Despite receiving the medical diagnosis of iron deficiency with anemia (and the initiation of iron supplementation), the patient continued to experience

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**Table 1. Complete Blood Count Lab Values for the Athlete Running Cross-Country. Standard Reference Values are presented in the Far Right Column.**

<table>
<thead>
<tr>
<th></th>
<th>03/24/07</th>
<th>04/03/07</th>
<th>05/17/07</th>
<th>07/11/2007</th>
<th>09/13/07</th>
<th>10/23/07</th>
<th>12/10/07</th>
<th>Reference Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemoglobin (HGB) (g/dL)</td>
<td>10.4</td>
<td>n/a</td>
<td>14.2</td>
<td>n/a</td>
<td>14.7</td>
<td>14.9</td>
<td>n/a</td>
<td>(12.0 – 16.0)</td>
</tr>
<tr>
<td>Hematocrit (HCT) (%)</td>
<td>32.5</td>
<td>n/a</td>
<td>43.7</td>
<td>n/a</td>
<td>42.3</td>
<td>43.0</td>
<td>n/a</td>
<td>(37.0 – 47.0)</td>
</tr>
<tr>
<td>Mean Corpuscular Volume (MCV) (fL)</td>
<td>75.4</td>
<td>n/a</td>
<td>80.9</td>
<td>n/a</td>
<td>92.8</td>
<td>94.1</td>
<td>n/a</td>
<td>(80.0 – 100.0)</td>
</tr>
<tr>
<td>Mean Corpuscular Hemoglobin (MCH) (pg)</td>
<td>24.2</td>
<td>n/a</td>
<td>26.3</td>
<td>n/a</td>
<td>32.2</td>
<td>32.5</td>
<td>n/a</td>
<td>(27.0 – 34.0)</td>
</tr>
<tr>
<td>Iron (ug/dL)</td>
<td>n/a</td>
<td>19</td>
<td>70</td>
<td>127</td>
<td>63</td>
<td>n/a</td>
<td>153</td>
<td>(26 – 170)</td>
</tr>
<tr>
<td>Total Iron Binding Capacity (TIBC) (ug/dL)</td>
<td>n/a</td>
<td>393</td>
<td>424</td>
<td>307</td>
<td>333</td>
<td>n/a</td>
<td>310</td>
<td>(262 – 474)</td>
</tr>
<tr>
<td>% Saturation</td>
<td>n/a</td>
<td>5</td>
<td>17</td>
<td>41</td>
<td>19</td>
<td>n/a</td>
<td>49</td>
<td>(10 – 40)</td>
</tr>
<tr>
<td>Ferritin (ng/mL)</td>
<td>n/a</td>
<td>2</td>
<td>8</td>
<td>18</td>
<td>14</td>
<td>n/a</td>
<td>22</td>
<td>(10 – 200)</td>
</tr>
</tbody>
</table>

n/a: values not available or not tested
recurrent left hip pain as well as an acute episode of left knee pain (onset 1-2 weeks prior to physical examination in the athletic training department). The patient’s primary musculoskeletal complaints were chronic left hip pain and the new onset of non-traumatic anterior-lateral left knee pain both which were affecting her ability to complete her training runs pain free.

**Musculoskeletal Assessment of the Injured Runner**

**Standing Examination**

Static and dynamic posture and alignment were first assessed in standing. Static posture and alignment appeared unremarkable when viewed anteriorly, laterally, and posteriorly. Active lumbar spine range of motion was also assessed to be within normal limits. Gait observation was unremarkable.

Several functional tests were conducted to assess the subject for dysfunctional biomechanical movement patterns. Functional tests may be useful in providing qualitative information relating to an individual’s ability to perform basic and complex movement patterns. When performing a lunge, the patient demonstrated contralateral hip drop, femoral adduction, and knee valgum with each lead leg. When performing a squat, the patient was unable to maintain proper trunk alignment (demonstrating excessive lumbar flexion) during the descent phase. She also was unable to eccentrically control the descent with her hip musculature, instead relying on her quadriceps (as demonstrated by her knees flexing over her feet). The single-legged squat test (SLST) further highlighted her inability to maintain core stability and lower extremity alignment. A Trendelenburg sign, femoral adduction and internal rotation, and knee valgum were demonstrated bilaterally during each SLST with the left lower extremity malalignment qualitatively assessed to be worse than that on the right.

**Seated Examination**

The patient assumed a sitting posture on the evaluation table. In this position dermatomes, reflexes, and selected muscle tests were conducted (Table 2). Dermatomes and reflexes (L3 and S1) were determined to be intact bilaterally. Manual muscle tests for hip internal rotation, hip external rotation, hip flexion, and knee extension were conducted bilaterally revealing gross hip weakness bilaterally (Table 2). A hand held dynamometer (MicroFet 2, Hoggan Health Industries, West Jordan, Utah) was utilized to quantify hip strength. Hip flexion, hip internal rotation, and hip external rotation strength were measured in sitting as recommended by the manufacturer (Table 2).

**Supine Examination**

Active range of motion (AROM) was assessed in supine. Hip, knee, and ankle AROM was deemed symmetrical and within normal limits bilaterally. Provocation tests (special tests) failed to reproduce hip or knee symptoms. Hamstring flexibility was measured bilaterally using the 90-90 test. To quantitate hamstring flexibility, the knee was passively extended from the 90-90 position until resistance prevented further extension of the joint. Hamstring flexibility was measured to be 70º bilaterally. Additional manual muscle tests and dynamometry was conducted (Table 2). Palpation revealed tenderness on the left side at the posterior superior iliac spine, piriformis, gluteus maximus and medius, and hamstring muscles (common origin), as well as the greater tubercle of the hip, distal iliotibial tract, and the antero-lateral knee.

| Table 2. Selected Hip Strength Measures Recorded during the Initial Evaluation and after the End of the Subject’s Cross-Country Season |
|-----------------------------------------------|--|--|--|--|--|
| | Initial Evaluation | Initial Evaluation | Post-Rehabilitation |
| | Dynamometry (foot/pounds) | Traditional Manual Muscle Test (scale 1 – 5) | Measures | Dynamometry (foot/pounds) |
| Flexion | Right | 28.8 | 3+ | 44 | 19.3 |
| | Left | 29.6 | 3+ | 41 | 19.5 |
| Abduction | Right | 32 | 3+ | 40 | 19.3 |
| | Left | 30 | 3+ | 42 | 19.5 |
| Extension | Right | 28 | 4- | 33 | 41 |
| | Left | 29 | 4- | 35 | 42 |
| External Rotation | Right | 19 | 3+ | 23 | 35 |
| | Left | 19 | 3+ | 22 | 41 |
| Internal Rotation | Right | 16 | 4 | 23 | 19.3 |
| | Left | 20 | 4 | 22 | 19.5 |
**Exam Summary**

To summarize, the primary physical examination findings were poor hip and core strength. Based upon these findings, the primary author hypothesized that the patient likely experienced pain while running as a result of her weak hip and core musculature failing to maintain optimal lower extremity biomechanics, especially as she fatigued at or near the end of a run. Altered running mechanics in response to dysfunctional core strength may increase the stress on various tissues in response to repetitive submaximal loads. It was also hypothesized that due to the fact that she was running in an iron deficient (with anemia) state, she was unable to adequately recover between each bout of running. Despite her deficient physiological status, she attempted to train and compete at her perceived optimal level. Continuing to train in this state set the stage for developing a running related overuse injury. Her previous unsuccessful attempt to rehabilitate her injured hip was likely impaired by her iron deficient state and the particular treatments utilized. For example, throughout her course of chiropractic treatment, she was not prescribed any form of stretching or strengthening therapeutic exercises.

**Treatment**

**Medical Treatment**

Once a diagnosis of iron deficiency with anemia was established, the patient was instructed to begin iron supplementation. She reported purchasing an over the counter ferrous sulfate supplement with each 134 mg pill containing 27 mg of elemental iron. She would consume between 2 to 6 pills per day. Her supplementation schedule would change in response to recommendations she would receive from medical providers. One provider recommended she consume as few as 2 pills 3 times a week whereas at a different point in time she was consuming 4 to 6 pills daily. The patient reported that the variability of the supplementation schedule "was a challenge to follow" and concerned her as to the effectiveness of the treatment program. Supplementation did improve the athlete's lab values (Table 1). Her iron, % saturation, and ferritin levels had all increased by the start of the cross-country season (Table 1, column 4).

**Rehabilitation Intervention**

The athlete's primary goal was to be able to compete in each scheduled conference cross-country meet. Her secondary goals included decreasing her musculoskeletal pain while running and increasing her overall hip and core strength. The subject was treated by the primary author in the university's athletic training room facility two days a week throughout the span of the cross-country season (Table 3). Evidence based therapeutic interventions were selected based upon the physical examination findings and patient preferences. Table 3 details the therapeutic exercise, manual therapy, and modality interventions utilized with this athlete. During the initial session, the subject received instruction in exercises designed to increase core strength. Four stretching exercises were added to the home exercise program during the

<table>
<thead>
<tr>
<th>Session</th>
<th>Modalities</th>
<th>Manual Therapy</th>
<th>Therapeutic Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>None</td>
<td>1. Instruct for daily HEP, clamshells, straight leg raise hip abduction, side plank, front plank</td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>1. Effluerage and petrissage massage techniques: left posterior hip and gluteals in sidelying. 2. Grade V sacro-iliac region manipulation performed two times to each side. 1. Review and technique correction of previous HEP. 2. Instruct for daily HEP: hamstring stretch (supine), piriformis stretch (supine), prayer stretch, supine trunk rotations</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>None</td>
<td>1. Effluerage and petrissage massage: left posterior-lateral hip, gluteals. 2. Grade V sacro-iliac manipulation performed two times to each side. 1. HEP review 2. Review/educate proper spine posture 3. Add to HEP: squats and lunges (1-3 sets x10 reps)</td>
<td></td>
</tr>
<tr>
<td>5-17</td>
<td>1. Interferential electrical stimulation 15 min to left hip and left gluteal region 2. Moist heat 15° left hip and left gluteal region</td>
<td>1. Effluerage and petrissage massage: left gluteal, left hip, lumbar spine (side-lying or prone). 2. Grade III-V mobilization as indicated to thoracic spine, lumbar spine, and sacro-iliac joint.</td>
<td></td>
</tr>
</tbody>
</table>
second visit. Manual therapy techniques were also initiated during the second session. Massage techniques (effleurage and petrissage strokes) were performed based upon subject request. She felt that previous massage treatments had helped to “manage her symptoms.” She was also complaining of lower back pain during this session. Utilizing the clinical prediction rule developed by Flynn et al.\(^{18}\) (she had four predictive factors: acute symptoms less than 16 days, hip internal rotation greater than 35 degrees, lumbar hypomobility, and no symptoms distal to the knee), it was determined that the patient might benefit from a general sacroiliac manipulative technique.\(^{18,19}\) The patient experienced cavitations on each side during the manipulation and reported a reduction in low back pain.

After the end of the second week of treatment the patient competed in her first conference run of the season (Table 4). She ran a personal best in the 5,000 meter run dropping 15 seconds off of her all-time best performance.

Manual therapy techniques, as previously discussed, were continued to address soft tissue symptoms (massage) and pain in the lumbar region (manipulation) during sessions 3 and 4. The patient was also instructed to add squats and lunges to her home exercise program. The patient was instructed to perform the squats and lunges facing a mirror in order to reduce the medial collapse of the lower extremities that was observed during the initial evaluation.

She continued to run personal bests and experience improvements from her 2006 race times during each subsequent race (Table 4). To highlight this fact, at the end of week 3 she improved over 3 minutes during a 6,000 meter race.

Despite her improved race times, she continued to experience sport related hip pain. Additional modalities (moist hot packs, interferential electrical stimulation) were utilized in combination with the other manual treatments (Table 3). As the season progressed it became apparent that she would probably continue to experience sports-related pain throughout the remainder of the season. The sports medicine team held the belief that for the athlete to experience a significant reduction in pain, she would need to abstain from running. The treatment focus at the end of the season was to address her musculoskeletal pain with manual therapy, therapeutic exercises, and modalities.

**DISCUSSION**

This case highlights the comprehensive management of a female cross-country athlete who had been diagnosed with iron deficiency with anemia. Successful medical intervention and rehabilitation strategies helped the athlete to achieve her primary goal to compete in each race. The subject was able to achieve personal bests (her time during the 5th race of the season ranks as the 2nd fastest time recorded in school history for the 6000-meter run) (Table 4). She qualified for the NCAA Division III National Championships finishing 34th overall earning her an All-American status.

**Failure to Identify the Iron Deficient State**

The failure to identify the iron deficient state in this endurance athlete affected her ability to compete for both her cross-country and track teams during previous seasons. Despite the successful outcome of this case, additional measures may have helped the sports medicine team recognize her iron deficient state sooner.

It is plausible that the subject had been experiencing symptoms related to iron deficiency, with or without anemia, dating back to her freshman cross-country season. Iron deficiency progresses over three stages.\(^5^{,}20\) The first stage is marked by a decrease in serum ferritin levels, but no change in HGB levels.\(^5\) Physicians who evaluate only the HGB and HCT levels, failing to evaluate other markers such as serum ferritin,

| Table 4. Change in Times between 2006 and 2007 Cross-Country Season |
|-------------------------|-------------------------|-------------------------|
| Event | Distance (m) | 2006 Time (min/sec) | 2007 Time (min/sec) |
| 1 | 5,000 m | 20:59.85 | 18:13.65 |
| 2 | 6,000 m | 26:53.00 | 22.27 |
| 3 | 6,000 m | 24:44.60 | 21.52.40 |
| 4 | 6,000 m | did not compete | 22.03.80 |
| 5 | 6,000 m | did not compete | 22.09 |
may misdiagnose an athlete as iron sufficient.\textsuperscript{9,21} The second stage of iron deficiency is marked by decreasing iron stores, decreasing serum iron, decreasing transferrin saturation, and an increase in TIBC.\textsuperscript{5} In the final stage of iron deficiency, the individual becomes anemic.\textsuperscript{5} Sports medicine physicians recommend conducting a complete blood count to evaluate HGB, HCT, serum iron, TIBC, serum ferritin, and transferrin saturation with athletes who are suspected of iron deficiency (with or without anemia).\textsuperscript{2,5}

The gold standard measure for identifying iron deficiency is a bone marrow biopsy with Prussian blue staining.\textsuperscript{5} In lieu of a bone marrow biopsy, serum ferritin levels are considered to be an appropriate clinical measure for iron deficiency.\textsuperscript{5,21,22} An athlete is considered iron deficient with serum ferritin levels less than 10-12 ng/mL.\textsuperscript{1,5,7,22} When the subject received her diagnosis of iron deficiency with anemia, her serum ferritin levels were 2 ng/mL (Table 1). According to the subject, her ferritin levels had not been tested until April 2007 (Table 1, column 2).

**Diet and Iron Supplementation**

Iron deficiency in athletes may be the result of one or more of the following factors: gastrointestinal blood loss,\textsuperscript{5,13,23-26} hemolysis,\textsuperscript{27,28} hematuria,\textsuperscript{29} sweat loss,\textsuperscript{30} intense activity or exercise,\textsuperscript{5,11,12,23,31,32} and a lack of intake or absorption of dietary iron.\textsuperscript{3,5,33} Consumption of drinks containing caffeine may also inhibit absorption of iron.\textsuperscript{5} The subject in this case possessed several of the risk factors, including a diet poor in dietary iron consumption. When interviewing the subject, the primary author found that the athlete avoided certain foods (red meats, eggs) that may have provided a source of dietary iron. The primary author also referred the athlete to a registered dietician in order to develop an appropriate diet for sport and to rule out the presence of an eating disorder.\textsuperscript{34}

Once a diagnosis of iron deficiency with anemia was established, the subject initiated iron supplementation. According to the patient, she was not provided clear instruction as to the recommended daily dosage. Supplementation, as expected, did positively influence her lab values (Table 1), but it can be argued that her ferritin levels were sub-optimal throughout the majority of the season.\textsuperscript{35} Shaskey and Green\textsuperscript{2} suggest that once an athlete begins iron supplementation, 12 months may be needed for iron stores to be completely restored.

**Rehabilitation Interventions**

The subject did present with weakness in her core musculature as demonstrated by biomechanical faults with functional movement patterns. A growing body of evidence exists suggesting a relationship between core weakness in endurance runners and the onset of injury.\textsuperscript{36-38} The subject did experience improvements in hip strength (Table 2), but these gains did not appear to correlate with a decrease in pain. At the end of the season, the primary author reviewed the home exercise program with the athlete, encouraging her to continue the strengthening exercises. Continued strength gains may ultimately decrease the subject’s pain experience or help to reduce the risk of future lower extremity injuries.

**CONCLUSION**

Iron deficiency (with or without anemia) may severely affect an athlete’s ability to perform at an optimal level. Sports medicine professionals must consider iron deficiency as a possible differential diagnosis when evaluating endurance athletes. Subtle signs of iron deficiency may be overlooked delaying treatment. In this case, proper treatment allowed the athlete to compete at a high level throughout her cross-country season.

**REFERENCES**


CASE REPORT

TREATMENT OF LATERAL KNEE PAIN BY ADDRESSING TIBIOFIBULAR HYPOMOBILITY IN A RECREATIONAL RUNNER

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Terry L. Grindstaff, PT, DPT, ATC, SCS, CSCS2
Eric M. Magrum, PT, OCS, FAAOMPT1
Robert Wilder, MD, FACSM2

ABSTRACT

Background. Altered joint arthrokinematics can affect structures distal and proximal to the site of dysfunction. Hypomobility of the proximal tibiofibular joint may limit ankle dorsiflexion and indirectly alter stresses about the knee.

Objectives. To examine the effect of addressing hypomobility of the proximal tibiofibular joint in an individual with lateral knee pain.

Case Description. A 24 year old female recreational runner presented with a three month history of right lateral knee pain. Limited right ankle dorsiflexion was noted and determined to be related to decreased mobility of the proximal tibiofibular joint, as well as, the talocrural and distal tibiofibular joints. Functional movement deficits were noted during the squat test and step down test. Treatment was performed three times over the course of two weeks which included proximal tibiofibular joint manipulation and an exercise program consisting of hip strengthening, balance, and gastrocnemius/soleus muscle complex stretching.

Outcomes. Immediately following intervention, improvements were noted for ankle dorsiflexion, squat test, and step down test. One week following the initial intervention the patient reported she was able to run pain free.

Discussion. Addressing impairments distant to the site of dysfunction, such as the proximal tibiofibular joint, may be indicated in individuals with lateral knee pain.

Key Words: ankle sprain, arthrokinematics, manipulation

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This is an original manuscript and portions of the findings for this research were presented this past fall at the American Academy of Orthopaedic Manual Physical Therapists Annual Conference in St. Louis, Missouri. The associated abstract was published in the Journal of Manual and Manipulative Therapy earlier this year.

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INTRODUCTION
The knee joint is the most commonly injured joint for runners and typical injuries include patellofemoral pain, iliotibial band syndrome, meniscus lesions, and patellar tendinopathy.1 Knee pain about the lateral aspect of the knee is less commonly described and primarily thought to be related to iliotibial band syndrome2 or a lateral meniscus lesion.3 In the absence of these two conditions, other less common presentations could be lateral plica, fabella syndrome, biceps tendinosis, or popliteus tendinosis. A thorough examination of the local structures as well as distant sites may be helpful in the differential diagnosis of lateral knee pain.

An adjacent structure which may contribute to lateral knee pain is the proximal tibiofibular joint. The proximal tibiofibular joint may be a source of lateral knee pain. During ankle dorsiflexion, torsional stress is placed through the proximal tibiofibular joint, via external rotation and anterior glide of the fibula. Decreased mobility of the proximal tibiofibular joint may subsequently limit ankle dorsiflexion range of motion (ROM). Ankle dorsiflexion restrictions have been previously associated with anterior knee pain and are thought to be due to gastrocnemius/soleus tightness or talocrural joint hypomobility. No study has discussed the potential for hypomobility of the proximal tibiofibular joint and the contribution to lower extremity dysfunction. The purpose of this case report was to examine the effect of addressing hypomobility of the proximal tibiofibular joint in an individual with lateral knee pain.

CASE DESCRIPTION
The patient was a 24 year old recreational runner and reported an onset of right knee pain three months prior to initial examination. At that time she had been running 3-4 miles, 5-6 times a week, for the previous six months. After the onset of knee pain she reduced both distance and frequency to 2-3 miles, 2-3 times per week. She recalled no specific trauma or incident that precipitated the pain and reported symptoms only occurred during running and not other activities such as prolonged sitting or stair climbing. Although she was not experiencing pain (0/10) at rest, she rated her worst pain during running as 5/10. She described pain on the lateral aspect of knee which extended into the region of the proximal tibiofibular joint.

Her past medical history included a right lateral ankle sprain, which occurred six years previous. The patient did not seek medical consultation for this injury. She indicated that she had difficulty with walking for 2 to 3 days following the injury and severe ecchymosis resolved within one month. Based on her recall of the injury, the injury was likely be a grade II ankle sprain. This injury was not disclosed until assessment of ankle mobility during the physical examination. The rest of her medical and orthopedic history was unremarkable.

Previous intervention for lateral knee pain had included the use of a patellar tendon strap, based on physician initial recommendations, but provided minimal relief of symptoms. Prior to examination the patient completed the Activity Measure for Post-Acute Care (AM-PAC) outcomes measure and scored 76 out of a possible 81.5 Clinical outcomes collected during the initial examination and follow up sessions are presented in Table 1. The initial examination consisted of observation of static posture, dynamic movement including balance, strength, range of motion (ROM), joint mobility, and special tests.

<table>
<thead>
<tr>
<th>TABLE 1. Clinical Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Visual Analog Scale</strong></td>
</tr>
<tr>
<td>Current/Best/Worst</td>
</tr>
<tr>
<td><strong>Dorsiflexion (degree)</strong></td>
</tr>
<tr>
<td>(knee extended)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Dorsiflexion (degree)</strong></td>
</tr>
<tr>
<td>(knee flexed 90°)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Step Down Test</strong></td>
</tr>
<tr>
<td>Right 5/6</td>
</tr>
<tr>
<td>Left 1/6</td>
</tr>
<tr>
<td><strong>AM-PAC Score</strong></td>
</tr>
<tr>
<td>Right = involved</td>
</tr>
</tbody>
</table>
**Static Posture and Functional Movement**

Static posture was assessed visually in standing, and the right knee was held in slightly more knee flexion than the left knee. Functional movement examination included the squat test, single limb stance, and step down test. All tests were performed using visual observation. The squat test was used to qualitatively examine the movement pattern and functional ROM of the lower extremity. During the descent phase of the squat, the patient's involved (right) lower extremity demonstrated dynamic knee valgus, which has been defined as a combination of femoral adduction, knee abduction, and ankle eversion, compared to the uninvolved (left) lower extremity. A left weight shift was also noted and squat depth was limited on the right side relative to the left. This limitation was thought to be associated with a decrease in right ankle dorsiflexion motion, as compared to the left, which occurred without report of associated ankle pain. After discussion of this impairment, the patient recalled a history of right ankle sprain which had occurred six years previous.

Next, single limb stance was performed with eyes open while standing on a stable surface. The patient was able to balance 10 seconds on the right and 30 seconds on the left before losing balance. The last functional test was the step down test which provided a quantitative assessment of lower extremity functional movement. This test was scored using established criteria (Table 2) with lower scores (0 or 1) indicating good quality of movement and higher scores (5 or 6) indicating poor quality of movement. The patient scored 5 points on right (involved) and 1 point on the left (uninvolved) side.

**Strength, Range of Motion, and Joint Mobility**

Examination of lower extremity strength, ROM, and joint mobility occurred with the patient lying on a treatment table. Manual muscle testing indicated weakness of the right hip abductors (4/5) and hip external rotators (4/5) with all other major muscle groups determined to have full strength (5/5) with no re-creation of pain. The patient's lower extremity ROM was within a functional range and equal bilaterally with the exception of limited right ankle dorsiflexion. Active ankle dorsiflexion was assessed with both the knee extended (right, 5 degrees; left 15 degrees) and flexed to 90 degrees (right, 8 degrees; left 15 degrees).

Mobility of the patella was assessed with the patient in supine with the knee in full extension and determined to be normal and equal bilaterally. To determine if limited right ankle dorsiflexion was due to contractile or non-contractile tissues, further assessment of joint mobility was performed at the talocrural joint as well as the distal and proximal tibiofibular joints. Talocrural joint mobility (Figure 1) was assessed with the patient in a supine position with the ankle over the edge of the treatment table. The therapist stabilized the tibia and fibula with one hand while the other hand was placed over the talus. The webspace of the movement hand made contact with the neck of the talus while the fingers and thumb grasped the medial and lateral talus. Next, an anterior to posterior directed force was applied to determine the excursion and end feel of talar glide in the ankle mortise. The right talocrural joint was noted to be hypomobile with posterior glide of the talus on the tibia/fibula relative to the left.

Joint mobility of the proximal tibiofibular joint (Figure 2) was assessed with the patient in a hook-lying position. The proximal tibia was stabilized with one hand while the thumb and index finger grasped the proximal fibular head. The fibular head was translated posterior to anterior in the plane of the articulation with the tibia. Compared to the left, the right proximal tibiofibular joint was determined to be hypomobile with limited anterior glide of the fibula on the tibia.

Next, mobility of the distal tibiofibular joint (Figure 3) was assessed with the patient in supine. The therapist stabilized the distal tibia by making contact with the anterior aspect of the tibia with the thenar emi-

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**Table 2. Step Down Test (20 cm/8 in box) Scoring Criteria**

<table>
<thead>
<tr>
<th>Arm Strategy</th>
<th>1 point</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>If subject used an arm strategy in an attempt to recover balance</td>
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<table>
<thead>
<tr>
<th>Trunk Movement:</th>
<th>1 point</th>
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<tr>
<td></td>
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<tr>
<td>Trunk lean to side</td>
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<table>
<thead>
<tr>
<th>Pelvis Plane:</th>
<th>1 point</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td>If pelvis rotated or elevated one side compared with the other</td>
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<table>
<thead>
<tr>
<th>Knee Position:</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Knee deviates medially and tibial tuberosity crossed an imaginary vertical line over either:</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>the 2nd toe</td>
<td>1 point</td>
</tr>
<tr>
<td>medial border of the foot</td>
<td>2 points</td>
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<table>
<thead>
<tr>
<th>Maintain steady unilateral stance:</th>
<th>1 point</th>
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<tr>
<td></td>
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<tr>
<td>Stepped down on the non-tested side, or if test limb became unsteady (i.e. wavered from side to side on the tested side)</td>
<td></td>
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<table>
<thead>
<tr>
<th>Movement Quality:</th>
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<tbody>
<tr>
<td>Good: 0-1 points</td>
<td></td>
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<tr>
<td>Medium: 2-3 points</td>
<td></td>
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<tr>
<td>Poor: 4-6 points</td>
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nence and the posterior aspect of the tibia with a lumbrical grip. The other hand grasped the distal fibula with the anterior aspect in contact with the thenar eminence and the posterior aspect of the fibula in contact with the index finger. The distal fibula was translated in an anterior to posterior direction on the stable tibia and was determined to be hypomobile on the right relative to the left.

Based on the assessment of these three joints, the greatest restriction was determined to occur at the right proximal tibiofibular joint, which also reproduced familiar knee pain experienced by the patient. A second physical therapist, blinded to the initial examination findings, was asked to perform mobility assessment of the right proximal tibiofibular joint and pain provocation to confirm findings. The second physical therapist also noted hypomobility in the right proximal tibiofibular joint. Thus, clinical agreement with examination findings existed, but no statistical measures of intertester reliability were performed.

**Palpation and Special Tests**

The medial and lateral knee joint line and soft tissue structures including the patella tendon, medial and lateral retinacula, biceps tendon, and popliteus tendon were palpated without any complaint bilaterally. Palpable tenderness was reported on the right side along the distal aspect of the iliotibial band lateral to the patella and the fibular head.

Varus stress tests, McMurray's, and Apley's compression were all negative bilaterally. Isometric quadriceps contraction and patellar compression did not reproduce symptoms. Ober's Test and Thomas Test were equally limited bilaterally, per visual observation, but did not reproduce familiar pain. Noble compression test also did not reproduce pain with passive flexion and extension of the knee. Although these special tests are commonly performed in the assessment of lower extremity dysfunction, the sensitivity and specificity for iliotibial band syndrome has not been determined.

**Evaluation and Differential Diagnosis**

Based on evaluation of examination findings, the patellofemoral joint and iliotibial band were ruled out as sources of dysfunction. During the examination, the patient did not have pain with prolonged sitting, stairs (step down test), squatting, and palpation of the medial retinaculum. These findings indicated something other than patellofemoral joint pain was a cause of the dysfunction. Iliotibial band syndrome was also ruled out as a cause due to the inability to provoke symptoms during Ober's or Thomas Tests.

Pertinent examination findings included limited right ankle dorsiflexion ROM, proximal tibiofibular joint hypomobility, provocation of familiar pain with proximal tibiofibular joint mobility testing, and abnormal lower extremity biomechanics during the squat and step down tests. Hypomobility of the patient's right tibiofibular joint was most likely the underlying cause of pain and dysfunction. At this point the decision was made to direct treatment to the patient's right proximal tibiofibular joint.

**INTERVENTION**

Initial intervention utilized a high velocity, end range, posterior to anterior thrust, applied to the proximal tibiofibular joint (Figure 4) in a manner consistent with previously published methods. Briefly, the subject was in a supine position while the physical therapist aligned his index finger with the proximal fibular head and uti-
lized the other hand to produce passive knee flexion and external rotation of the tibia. The associated soft tissue of the popliteal region was pulled in a lateral direction until the metacarpophalangeal joint was firmly stabilized behind the fibular head. The opposite hand grasped the anterior aspect of the ankle while the knee was passively flexed and the tibia was externally rotated. When the restrictive barrier was engaged, indicating the end of physiological motion, a high velocity, low amplitude thrust was applied through the tibia with the force directed towards the subject’s heel toward the ipsilateral buttoc.k. An audible joint cavitation (pop) was felt and heard by the patient and heard by both physical therapists (treatment and observing) that were in the room.

OUTCOME

Initial Visit

Following initial intervention, joint mobility of the proximal tibiofibular, distal tibiofibular, and talocrural joints of the involved extremity was re-assessed, using the same methods as previously described, and noted to have improved mobility, but still hypomobile relative to the uninvolved joints. Ankle dorsiflexion was re-assessed using the same methods as the initial assessment. A 5 degree increase in ankle dorsiflexion occurred with the knee extended (right, 10 degrees; left 15 degrees) and a 2 degree increase with the knee flexed to 90 degrees (right, 10 degrees; left 15 degrees). Functional movements were also re-assessed with an improvement, per visual observation, in active ankle dorsiflexion during the squat test. The step down test was repeated and the score improved to three points which indicated improvement to medium quality of movement.

Additional treatment during the first clinical visit consisted of therapeutic exercises which included hip abduction in side-lying (Figure 5) and hip abduction/external rotation (clam shell) in crook lying (Figure 6). Both exercises were performed for three sets of 30 repetitions each, to target hip abductor and external rotator muscles. The patient was instructed to maintain the trunk in neutral and isolate the hip abductor and external rotator muscles. These exercises were also incorporated into a home exercise program. The patient was also allowed to continue her current running program (2-3 miles, 2-3 times per week) with the stipulation that lateral knee pain did not increase during the activity.

Second Visit-One Week Following Initial Visit

One week following the initial visit, the patient reported improvement in symptoms and the ability to run without reproducing knee pain. The AM-PAC was repeated and a maximum score of 81.53 was obtained. The step down test was performed and a score of one point was obtained bilaterally. Joint mobility of the proximal and distal tibiofibular joints and posterior glide of the talus were re-assessed and determined to be improved compared to first visit but still hypomobile relative to the left side. The patient's right proximal tibiofibular joint once again demonstrated the greatest amount of hypomobility, thus the treatment was directed at this joint. A proximal tibiofibular joint manipulation was performed using the...
same technique as the first visit. Additionally, small amplitude, end of ROM (Grade IV), anterior to posterior joint mobilization\(^{14}\) was performed at the talocrural joint with the subject lying in supine to improve posterior glide of the talus on the tibia/fibula. Therapeutic exercise program during the second clinical visit included the hip exercises performed during the initial visit as well as the addition of single limb stance exercises with repetitive rhythmic oscillations of the opposite limb performed with an elastic band attached to the opposite limb. This exercise was intended to increase strength and neuromuscular control of the lower extremity in a functional standing position. All exercises performed during the second clinical visit were also continued as part of the home exercise program.

**Third Visit- Two Weeks Following Initial Visit**

The patient returned for a third visit one week later and reported she was pain free, and still able to run without symptom exacerbation (0/10). The step down test was reassessed and the patient scored one bilaterally. Ankle ROM was also reassessed on the right side using the same methods as previously described. Compared to measurements during the initial examination, ankle dorsiflexion had improved 10 degrees with the knee extended (15 degrees) and 10 degrees with the knee flexed to 90 degrees (20 degrees). The AM-PAC score remained at a maximal obtainable score of 81.53.

Joint mobility of the proximal and distal tibiofibular joints and the talocrural joint was performed in a similar manner as previous examinations and was noted to be normal and equal bilaterally. Since the patient had no reports of pain, functional deficits, nor joint mobility restrictions the decision was made, with the consent of the patient, to discontinue physical therapy services and discharge her to her established home exercise program.

**Follow-up**

Ten months following discharge, the patient was contacted by phone for follow up evaluation of function. She reported that her knee and ankle had remained symptom free, and she was able to run 4-5 miles, 4-5 times per week. Another telephone follow up was conducted sixteen months following discharge, and the patient indicated she continued to remain symptom free and had increased running distance to 4-8 miles 4-5 times per week.

**DISCUSSION**

In this case report, restricted mobility of the joints associated with the tibia, fibula, and talus may have been a contributing factor to lateral knee pain.\(^{7}\) Decreased ankle dorsiflexion ROM\(^{7,8}\) and altered mobility of the tibiofibular joints\(^{14}\) have been shown to be associated with knee pain. It is unknown if limited ankle dorsiflexion was a precipitating, or compensatory mechanism, but stresses may have been increased about the knee joint during gait.\(^{19}\)

A plausible explanation for proximal tibiofibular joint dysfunction may be indirectly related to the history of a previous ankle sprain.\(^3\) Changes in the positional alignment of the talus, tibia, and fibula have been implicated in a subpopulation of individuals with a history of ankle sprain.\(^{3,20-23}\) Two positional faults have been described to occur at either the talocrural joint\(^21\) or the distal tibiofibular joint.\(^3,20,22,23\) At the talocrural joint, the talus is thought to migrate anteriorly following lateral ankle sprains due to the disruption of the ligaments restraining anterior talus translation.\(^21\) At the distal tibiofibular joint, a slight anterior or displacement of the fibula relative to the tibia is thought to occur.\(^3,20,22,23\) Based on the arthrokinematics associated with the tibiofibular joints, anterior translation of the distal fibula is associated with a concomitant posterior translation (external rotation) of the proximal fibula.\(^{24}\) Clinically the positional faults are recognized as decreased posterior glide of the talus (Figure 1) or distal fibula (Figure 3) or decreased anterior glide of the proximal fibula (Figure 2), all of which manifest as decreased ankle dorsiflexion ROM.\(^3,20,23\) If altered arthrokinematics and compensatory movement patterns are not appropriately addressed following injury, an opportunity exists for future local and distant joint pathology.\(^{25-27}\) Although the ankle sprain reported by the patient had occurred approximately six years previously, only within the past year had her activity level increased to the point where this dysfunction may have become symptomatic. It is possible that her level of function prior to the initiation of her running program nine months previous may have not been enough to create symptomatic dysfunction. Repetitive stresses through the lower quarter associated with running may have provided enough stress to the joints creating a painful response.

Manual therapeutic interventions\(^{14,20-30}\) are reported clinically to offer the ability to restore normal joint arthrokinematics. By addressing hypomobility of the proximal
tibiofibular joints, lower extremity arthrokinematics may be restored, ultimately altering stresses placed at the local joint. It is possible that this restoration of arthrokinematics may have contributed to the patient’s decreased lateral knee pain symptoms. Due to the nature of the case report and the use of a multifaceted home exercise program, a cause and effect relationship can not be determined.

Results of this case report should be approached with caution due to the nature the single subject design and limited reliability and validity of examination methods. Examiner bias may have also been present during analysis of functional movements and joint mobility following intervention. Additional study is required to examine the contribution of the proximal tibiofibular joint in individuals with lateral knee pain and better develop examination and treatment for lateral knee pain.

**SUMMARY**
Consideration of the potential for ankle joint hypomobility contradicts common clinical thoughts associated with a history of lateral ankle sprain. Although the lateral ligaments of the ankle may have laxity associated with ligament disruption, recent evidence suggests that hypomobility of the adjacent talocrural and tibiofibular joints may contribute to chronic dysfunction. Dysfunction may be asymptomatic unless tissues are stressed with activities such as running. This case presentation documents that proximal tibiofibular hypomobility may serve as a contributor to lateral knee pain. A thorough history and examination of surrounding structures will help identify underlying impairments which contribute to dysfunction. The treating clinician should be aware of specific biomechanical deficits that may contribute to lateral knee pain, as well as additional treatment options such as manual interventions for this type of condition.

**REFERENCES**


APPLICATION OF ANKLE PLASTY IN TOTAL ANKLE ARTHROPLASTY

ABSTRACT

Athletes with persistent anterolateral ankle discomfort may have developed sinus tarsi syndrome (STS). Sinus tarsi syndrome develops from excessive motions of the subtalar joint that results in subtalar joint synovitis and infiltration of fibrotic tissue into the sinus tarsi space. Physical therapists treating athletes with ankle conditions should examine the talocrural and subtalar joints for signs of hypermobility as injuries can affect both of these important articulations of the lower extremity. Localized ankle discomfort to the sinus tarsi space and feelings of instability with pronation and supination movements of the subtalar joint will help identify STS. Intervention for this condition will focus on enhancing subtalar joint stability and function of the lower extremities. The purpose of this clinical commentary is to discuss the etiologies and signs of STS and describe the components of an intervention plan appropriate for athletes with STS.

Key Words: ankle injuries, subtalar joint, joint instability

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INTRODUCTION
Sinus tarsi syndrome (STS) is a clinical entity characterized by persistent anterolateral ankle pain secondary to traumatic injuries to the ankle. Historically, the etiology of this condition has not been well understood. Recent discussions of STS now describe this entity as primarily an instability of the subtalar joint due to ligamentous injuries that results in a synovitis and infiltration of fibrotic tissue into the sinus tarsi space. This clinical commentary will describe the possible etiologies and examination findings of athletes with STS and treatment options for this condition for the sports physical therapist.

ANATOMICAL AND KINESIOLOGICAL CONSIDERATIONS
The subtalar joint is comprised of the articulation of the talus and calcaneus across an anterior, middle, and posterior facet. These facets may have variations in their structure and alignments that will affect the movement and stability of the subtalar joint. Extrinsic and intrinsic ligaments provide static stability for the subtalar joint. Extrinsic ligaments include the calcaneofibular ligament and the deltoid ligament, which also provide stability for the talocrural joint. The talocalcaneal, interosseous, and cervical ligaments are the intrinsic ligaments that provide a strong connection for the calcaneal and talar joint surfaces. Ruptures of the intrinsic ligaments allow increased movement of the subtalar joint that may result in instability.

The motions of the subtalar joint and the entire rearfoot are complex and have been the subject of extensive study and controversy. The osteokinematics of the subtalar joint occur about a triplanar axis to create pronation and supination movements. Supination motions of the subtalar joint create a bony stability through the rearfoot and midfoot that is important for propulsive movements through the foot. Pronation motions create increased mobility of the rearfoot and midfoot joints allowing the foot to accommodate to uneven surfaces. During running activities, athletes may weight bear entirely onto the forefoot, with ground reaction forces creating supination and pronation motions that occur from the midfoot into the rearfoot. Ground reaction forces during running create movements through the subtalar joint at a higher rate of acceleration and forces than during walking activities.

The sinus tarsi space is filled with many connective tissues that contribute to the stability and the overall proprioception of the ankle. The space is filled with adipose tissue that serves as a bedding for numerous mechanoreceptors and free nerve endings, which along with the ligaments and muscles provide proprioceptive information on the movement of the foot and ankle. The vascular supply of the sinus tarsi is provided by an anastomosis of the sinus tarsi and tarsal canal arteries. The extensor digitorum brevis muscle attaches to the medial and distal aspect of the sinus tarsi, running over the calcaneocuboid joint towards the toes. The inferior extensor retinaculum lies over the lateral aspect of this space and serves as a covering over the sinus tarsi.

ETIOLOGY
Sinus tarsi syndrome is believed to occur following a single traumatic event or a series of ankle sprains that result in significant injuries to the talocrural interosseous and cervical ligaments. These injuries cause instability of the subtalar joint resulting in excessive supination and pronation movements. The excessive movement of the subtalar joint imparts increased forces onto the synovium of the subtalar joint and across the sinus tarsi tissues. The excessive forces result in subtalar joint synovitis with chronic inflammation and infiltration of fibrotic tissues in the sinus tarsi that are responsible for the characteristic anterolateral ankle pain of STS. These traumatic injuries may also injure ligaments of the tibiotalar and talocalcaneal joints resulting in increased mobility and instability of the rearfoot and midfoot. Athletes with increased mobility of the talocrural and subtalar joints may be at a greater risk for developing instability after an ankle injury.

The incidence of STS is unknown, but has been associated with ankle sprains that may also result in talocrural joint instability. Keefe and Haddad estimated that 10-25% of patients with chronic talocrural joint instability will also have subtalar joint instability. Hubbard et al found that 9 out of 12 patients with recurrent ankle sprains had signs of increased talocrural and subtalar joint motions upon a radiographic examination. Hubbard and Hertel have advocated that a large percentage of injuries classified as an ankle sprain will include an injury to the subtalar joint ligaments.

EXAMINATION
Athletes with STS usually describe a history of a traumatic ankle injury, typically with a supination/inversion
mechanism of injury. Athletes involved with jumping sports may incur an injury to the subtalar joint after coming to an abrupt stop after a jump or a fall. This mechanism is thought to create a “whiplash injury” to the rearfoot with the talus moving anteriorly over the calcaneus. This mechanism may result in a sprain to the ligaments of the talocrural joint as well. Physical therapists should also be cautious with athletes who have an extended history of talocrural joint instability even after undergoing reconstruction of the lateral ankle ligaments, as these procedures are intended to improve stability of the talocrural joint and may not improve stability at the subtalar joint.

An acute ankle injury will typically present with pain accompanied by swelling, ecchymosis, and tenderness in the anterolateral ankle. Because the synovitis and fibrotic tissues associated with STS will take time to develop, athletes with injuries to the subtalar joint may not initially have symptoms that can be localized to the sinus tarsi (Figure 1). Athletes with STS will typically describe a feeling of instability of the foot and ankle that is provoked upon walking over uneven ground, stepping off a curb, or running or sprinting activities. Athletes involved with cutting and jumping activities on firm surfaces will have the greatest difficulty with subtalar instability as these activities will cause excessive movements of the subtalar joint to the end ranges of pronation and supination.

Assessment of standing posture in athletes with STS may demonstrate a pes planus posture or an asymmetry of the rearfoot angle with the leg, but these are not typical findings. Passive range of motion of the ankle and subtalar joint may not reveal excessive motion, but pain over the sinus tarsi at the end range of ankle plantarflexion with foot supination is typical of STS. Muscles that cross the ankle joint should be assessed for any loss of strength, especially the plantarflexor muscles.

Before examining the subtalar joint, a careful assessment of the talocrural joint should be performed. Anterior and posterior glides of the talus on the tibia and a talar tilt test that produces movement of the talus in the frontal plane are recommended for assessing talocrural joint stability. Mobility of the contralateral ankle and foot joints should be assessed to determine if the athlete has increased joint mobility that will make them susceptible to developing an instability.

Stability of the subtalar joint is assessed with medial and lateral subtalar joint glides performed by moving the calcaneus over a stabilized talus in the transverse plane and with subtalar joint distraction. Therman et al described a stability test that is thought to recreate instability of the subtalar joint (Figure 2). The test is performed with the athlete in supine with the ankle in 10 degrees of dorsiflexion to keep the talocrural joint in a stable position. The forefoot is first stabilized by the examiner’s hand, while an inversion and internal rotational force is applied to the calcaneus. Then an inversion force is applied to the forefoot. The examiner assesses for an excessive medial shift of the calcaneus and a reproduction of the athlete’s complaint of instability and symptoms.

Figure 1. Symptoms associated with STS are usually described as deep in the ankle and can be localized by athlete pointing to the sinus tarsi space.

Figure 2. Clinical test for reproduction of subtalar instability. The forefoot is first stabilized by the examiners hand, while an inversion and internal rotational force is applied to the calcaneus.
Reproduction of the athletes' feeling of instability or giving way may be reproduced by having the athlete single leg stand on the affected side and perform rotating motions of the leg and foot that may reproduce their symptoms. Therapists may also want to assess the athlete during functional activities of walking, running, stepping down from a step, and hopping on the affected extremity. Activities that produce feelings of instability should be assessed for the relative position of the rearfoot and leg for any compensation through the lower extremity the athlete makes when the instability is produced. The activity levels of athletes with STS can be assessed using the Ankle Disability Index, which includes the athlete's rankings of sports related activities.

DIFFERENTIAL DIAGNOSIS
Athletes with recurrent ankle sprains or symptoms of ankle instability should be suspected of having instability of the talocrural and subtalar joints. Localization of pain to the sinus tarsi with the presence of ankle instability is a good indication that the athlete has developed STS. Conditions that may also produce lateral ankle discomfort include a cuboid subluxation and peroneal tendon subluxation. The diagnosis of STS has typically been confirmed by the cessation of symptoms upon injection of lidocaine into the sinus tarsi.

IMAGING
Athletes suspected of having subtalar joint instability and STS may be referred for diagnostic imaging. Although imaging studies have been proposed to assess the stability of the subtalar joint, most of these methods have been proven to be inconsistent in their findings with low levels of specificity for subtalar joint instability. Radiographs of the subtalar joint are usually performed with Broden stress views which are a series of oblique-lateral views performed with the ankle and foot placed in inverted and supinated positions. Stress fluoroscopy is a method of visualizing the motions of the subtalar joint in real time using low level radiation. The advantage of fluoroscopy over radiographs is that the examiner can attempt to replicate the movements that are causing the athlete's sensation of instability or discomfort from the sinus tarsi.

Magnetic resonance imaging (MRI) is the best method to visualize the structure within the sinus tarsi, especially the interosseous and cervical ligaments. The most distinct finding for individuals with STS is a bright signal seen on T2 weighted images found in the area for sinus tarsal adipose tissue as this represents an infiltration or replacement of this tissue with inflammatory cells and fibrotic tissue. The MRI findings may also include alterations in the structure of the interosseous and cervical ligaments and degenerative changes in the subtalar joint.

INTERVENTION
Recommendations for rehabilitation of STS include balance and proprioceptive training, muscle strengthening exercises, bracing, taping, and foot orthosis. No random control trials for the efficacy of a rehabilitation program for STS are available. Instability of the talocrural joint or chronic ankle instability (CAI) is a similar and associated entity to subtalar joint instability and STS. Numerous studies of the effects of balance and proprioceptive training for CAI have been conducted, with improvements found in athletes' balance, joint position sense, and functional abilities.

Athletes with STS have developed a chronic inflammatory process that results in a synovitis and inflammation of connective tissues and may benefit from a trial of nonsteroidal anti-inflammatory medication to help control their symptoms and inflammation. Cryotherapies, especially the use of ice massage over the lateral ankle, may also be useful for diminishing local inflammation and pain associated with this condition. Athletes with STS may have limited joint mobility at the talocrural and mid tarsal joints that can be addressed with specific joint mobilization techniques. Precautions should be made not to place excessive stress across the subtalar joint with these techniques. Muscular stiffness of the gastrocnemius, posterior tibialis, or peroneal muscles may also be found in athletes with STS, but stretching activities for these muscles should be carefully provided or avoided as excessive forces across the subtalar joint may be detrimental.

Orthoses
Stability of the subtalar joint may be initially improved with the use of an orthosis. Ankle braces intended for CAI may be useful for some athletes with STS, but the overall design of these braces may not significantly improve the stability of the subtalar joint during athletic activities. Foot orthosis have also been recommended as a method for limiting motion at the subtalar joint and reducing symptoms associated with STS. The types of shoes the athlete is using for training, practices, and competition should also be considered, as well constructed shoes can restrict excessive rearfoot movements.
General recommendations for shoes include those with a straight last, a firm heel counter, and rigid material through the midsole. A shoe should also be assessed for wear, as materials within a shoe will begin to break down before the external material shows signs of deterioration. The use of a foot orthosis with an athletic shoe should be considered together, as the effect of an orthosis can be inconsistent. An ongoing assessment of shoe and orthosis use is needed to provide adequate support of the foot and ankle throughout an athlete's cycle of training and competition.

Taping or strapping has also been used to specifically limit movements of the subtalar joint and the midfoot. Wilkerson et al have described a taping procedure that combines a closed basket weave with a subtalar sling to control movements at the talocrural and subtalar joints. Viczenzio et al have described a modified Low-Dye taping method that uses a calcaneal sling intended to provide support to the medial longitudinal arch of the foot (Figure 3). This method could be used to control or reduce the amount of pronation through the subtalar joint during walking and running activities. Taping techniques have been used as a precursor for the use and selection of specific types of shoes and foot orthotics.

**Stability Training**

Training programs to improve the stability of the subtalar joint and lower extremity function will be the hallmark of treatment plans for STS. Joint stability relies on passive joint structures, dynamic muscular responses, and neurological control. Because tears or ruptures of the interosseous and cervical ligaments of the subtalar joint are believed to be the essential lesions that lead to STS, the dynamic muscular responses and neurological control of the rearfoot will need to be emphasized to compensate for the loss of passive stability. The muscles that cross the subtalar joint are important for maintaining stability, as they act as force transducers to guide and control the pronation and supination motions of the subtalar joint. The relative strength of these muscles is important, but their reaction time to joint perturbations and the ability to work in a coordinated fashion is even more important for the rehabilitation of STS. Dynamic stability will also rely on the proprioceptive information from the muscle spindles and Golgi tendon organs of these muscles to compensate for the lack of proprioceptive information from the stabilizing ligaments of the joint. The endurance of the muscles will also be important to maintain stability during long bouts of exercise or sports activities.

Training programs to improve joint stability have been described as multi-phase processes that start the athlete at an appropriate level of activity and progresses to higher levels of activities while maintaining joint stability. To help the athlete understand this process the progression of three phases are called: Attain, Maintain, and Sustain. The Attain phase will determine postures or positions the athlete is able to attain in a stable fashion. The Maintain phase will develop coordinated isometric and eccentric muscle contractions of the muscles crossing the joint. The Sustain phase will involve integrating all of the neuromuscular subsystems needed for stability during...
The Attain phase for subtalar joint instability is usually started with the athlete in standing positions. Single leg standing, with the contralateral limb held in approximately 30 degrees of hip flexion and 90 degrees of knee flexion, will emphasize ankle balance strategies. The clinician should closely observe the arch of the foot and rearfoot to assess the athlete’s ability to attain a stable position for the subtalar joint while avoiding excessive pronation movements (Figure 4). The Attain phase begins with the eyes open and attempting to hold the single leg position for 30 to 60 seconds with minimal alterations in body position. Once the athlete is able to hold a single leg standing position consistently, a progression to eyes closed conditions can be made.

The second phase, Maintain, is performed with perturbations to the single leg positions. Perturbation forces are imparted near the level of the athlete’s center of gravity to replicate the type of forces that produce subtalar joint instability during athletic activities. The perturbating forces are intended to facilitate rapid isometric and eccentric contractions of the stabilizer muscles of the ankle. Perturbations to standing balance are begun with movements from the contralateral hip starting in the sagittal and coronal planes of motion, progressing to transverse plane motions. Observations of the athlete’s rearfoot and hip stability will indicate his/her ability to maintain this position. The clinician needs to insure that the athlete is not using excessive compensatory motions at the rearfoot or hip to maintain a single leg standing position.

The star excursion balance test activities can also be used in this phase, with the athlete in the single leg standing position and touching different lines drawn on the floor in a star pattern. Standing heel raises and lowering exercises can be performed at a slow speed in double leg and single leg standing. Emphasis is placed on promoting controlled concentric and eccentric muscle contraction of the ankle plantarflexors and subtalar joint pronator muscles. External perturbations can be imparted with the athlete holding a two-foot length of theraband. With both hands in front of the umbilicus, the therapist can then pull on the theraband with oscillating motions. Catching and throwing a small ball or medicine ball while in single leg standing can also be used for perturbations in multiple directions and different timing.

The Sustain phase will begin with the athlete learning to “close the chain” meaning moving from an open kinematic chain to a stable closed kinematic chain position. The emphasis is on developing the feedforward motor control of the lower extremities. This activity can be started by having the athlete perform lunging steps and then stepping down from a 4 or 8 inch step onto the involved extremity into a single leg standing position. Progression can be to lateral lunge steps and lateral step downs. Observations of the athlete’s overall control of motion through the lower extremities with an emphasis on alignment of the knee and foot will insure that excessive subtalar joint motion is not occurring.

Table 1: Progression through three stages of stability training.

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<td>Athlete demonstrates ability to maintain stability and good alignment through the lower extremities.</td>
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<td>Sustain</td>
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Figure 4. Foot held in an excessive pronated position.
Progressions of the Sustain phase can be performed with the athlete jumping or hopping in place and then into hopping in different directions. Running activities can begin by acceleration and deceleration with forward and backward motions. Athletes needing to perform pivoting or cutting maneuvers can begin these activities at a slow speed maintaining good alignment of the foot and leg and avoiding excessive motions through the rearfoot.

Return to play criteria is based on the athlete's ability to move in all directions and at appropriate speeds. Athletes performing cutting and jumping maneuvers on firm surfaces, such as basketball and volleyball players, should be returned to full activities over a period of days to insure their tolerance to these stressful maneuvers. A progression of the athletic activities should be assessed with the athlete in his or her normal practice or competitive environment. The athlete's anterolateral ankle symptoms will need to be well controlled to insure that the return to competition will not create chronic inflammation of the sinus tarsi tissues.

Surgery
Athletes who fail a course of rehabilitation may need an arthroscopic exploration and reconstruction of the subtalar joint in order to return to their athletic pursuits. Arthroscopy of the subtalar joint has allowed for a more precise examination of the subtalar joint and the sinus tarsi. A synovectomy of the subtalar joint along with an arthrotomy of the subtalar joint can be used to remove chronic synovitis and arthrofibrosis that is commonly found in STS. Surgical reconstructions of the cervical and interosseous ligaments are made by splitting the tendon of the peroneus brevis and routing the graft through bone tunnels made through the calcaneus and the talus. Patients with instability of the talocrural and subtalar joints may require a tri-ligamentous reconstruction of the anterior talofibular, calcaneofibular, and cervical ligaments. Patients who present with significant joint degeneration or continue to have persistent symptoms even after ligamentous reconstruction may require an arthodesis resulting in an isolated fusion of the subtalar joint.

Athletes who have undergone ligamentous reconstructions will commonly be immobilized for a 6-week period, followed by a rehabilitation program to regain normal ankle mobility, strength, and balance. Return to athletic activities usually begins at 4 to 6 months post-operative-

Common post-operative problems are transient loss of sensation of the lateral ankle and foot and persistent peroneal weakness.

SUMMARY
Sinus tarsi syndrome is a condition of the ankle and foot that results from instability of the subtalar joint. Athletes with this condition typically have complaints of instability with functional activities and persistent anterolateral ankle discomfort. The joints of the ankle should be assessed for mobility and reproduction of feelings of instability and discomfort. Treatments for this condition will need to control the athlete's ankle discomfort and improve the overall stability of the foot and ankle. Therapists should design intervention plans based on the athlete's need for training and competition.

REFERENCES


Athletes with persistent anterolateral ankle discomfort may have developed sinus tarsi syndrome (STS). Sinus tarsi syndrome develops from excessive motions of the subtalar joint that results in subtalar joint synovitis and infiltration of fibrotic tissue into the sinus tarsi space. Physical therapists treating athletes with ankle conditions should examine the talocrural and subtalar joints for signs of hypermobility as injuries can affect both of these important articulations of the lower extremity. Localized ankle discomfort to the sinus tarsi space and feelings of instability with pronation and supination movements of the subtalar joint will help identify STS. Intervention for this condition will focus on enhancing subtalar joint stability and function of the lower extremities. The purpose of this clinical commentary is to discuss the etiologies and signs of STS and describe the components of an intervention plan appropriate for athletes with STS.

Key Words: ankle injuries, subtalar joint, joint instability
INTRODUCTION
Sinus tarsi syndrome (STS) is a clinical entity characterized by persistent anterolateral ankle pain secondary to traumatic injuries to the ankle. Historically, the etiology of this condition has not been well understood. Recent discussions of STS now describe this entity as primarily an instability of the subtalar joint due to ligamentous injuries that results in a synovitis and infiltration of fibrotic tissue into the sinus tarsi space. This clinical commentary will describe the possible etiologies and examination findings of athletes with STS and treatment options for this condition for the sports physical therapist.

ANATOMICAL AND KINESIOLOGICAL CONSIDERATIONS
The subtalar joint is comprised of the articulation of the talus and calcaneus across an anterior, middle, and posterior facet. These facets may have variations in their structure and alignments that will affect the movement and stability of the subtalar joint. Extrinsic and intrinsic ligaments provide static stability for the subtalar joint. Extrinsic ligaments include the calcaneofibular ligament and the deltoid ligament, which also provide stability for the talocrural joint. The talocalcaneal, interosseous, and cervical ligaments are the intrinsic ligaments that provide a strong connection for the calcaneal and talar joint surfaces. Ruptures of the intrinsic ligaments allow increased movement of the subtalar joint that may result in instability.

The motions of the subtalar joint and the entire rearfoot are complex and have been the subject of extensive study and controversy. The osteokinematics of the subtalar joint occur about a triplanar axis to create pronation and supination movements. Supination motions of the subtalar joint create a bony stability through the rearfoot and midfoot that is important for propulsive movements through the foot. Pronation motions create increased mobility of the rearfoot and midfoot joints allowing the foot to accommodate to uneven surfaces. During running activities, athletes may weight bear entirely onto the forefoot, with ground reaction forces creating supination and pronation motions that occur from the midfoot into the rearfoot. Ground reaction forces during running create movements through the subtalar joint at a higher rate of acceleration and forces than during walking activities.

The sinus tarsi space is filled with many connective tissues that contribute to the stability and the overall proprioception of the ankle. The space is filled with adipose tissue that serves as a bedding for numerous mechanoreceptors and free nerve endings, which along with the ligaments and muscles provide proprioceptive information on the movement of the foot and ankle. The vascular supply of the sinus tarsi is provided by an anastomosis of the sinus tarsi and tarsal canal arteries. The extensor digitorum brevis muscle attaches to the medial and distal aspect of the sinus tarsi, running over the calcaneocuboid joint towards the toes. The inferior extensor retinaculum lies over the lateral aspect of this space and serves as a covering over the sinus tarsi.

ETIOLOGY
Sinus tarsi syndrome is believed to occur following a single traumatic event or a series of ankle sprains that result in significant injuries to the talocrural interosseous and cervical ligaments. These injuries cause instability of the subtalar joint resulting in excessive supination and pronation movements. The excessive movement of the subtalar joint imparts increased forces onto the synovium of the subtalar joint and across the sinus tarsi tissues. The excessive forces result in subtalar joint synovitis with chronic inflammation and infiltration of fibrotic tissues in the sinus tarsi that are responsible for the characteristic anterolateral ankle pain of STS. These traumatic injuries may also injure ligaments of the tibiotalar and talocalcaneal joints resulting in increased mobility and instability of the rearfoot and midfoot. Athletes with increased mobility of the talocrural and subtalar joints may be at a greater risk for developing instability after an ankle injury.

The incidence of STS is unknown, but has been associated with ankle sprains that may also result in talocrural joint instability. Keefe and Haddad estimated that 10-25% of patients with chronic talocrural joint instability will also have subtalar joint instability. Hertel et al found that 9 out of 12 patients with recurrent ankle sprains had signs of increased talocrural and subtalar joint motions upon a radiographic examination. Hubbard and Hertel have advocated that a large percentage of injuries classified as an ankle sprain will include an injury to the subtalar joint ligaments.

EXAMINATION
Athletes with STS usually describe a history of a traumatic ankle injury, typically with a supination/inversion
mechanism of injury. Athletes involved with jumping sports may incur an injury to the subtalar joint after coming to an abrupt stop after a jump or a fall. This mechanism is thought to create a “whiplash injury” to the rearfoot with the talus moving anteriorly over the calcaneus. This mechanism may result in a sprain to the ligaments of the talocrural joint as well. Physical therapists should also be cautious with athletes who have an extended history of talocrural joint instability even after undergoing reconstruction of the lateral ankle ligaments, as these procedures are intended to improve stability of the talocrural joint and may not improve stability at the subtalar joint.

An acute ankle injury will typically present with pain accompanied by swelling, ecchymosis, and tenderness in the anterolateral ankle. Because the synovitis and fibrotic tissues associated with STS will take time to develop, athletes with injuries to the subtalar joint may not initially have symptoms that can be localized to the sinus tarsi (Figure 1). Athletes with STS will typically describe a feeling of instability of the foot and ankle that is provoked upon walking over uneven ground, stepping off a curb, or running or sprinting activities. Athletes involved with cutting and jumping activities on firm surfaces will have the greatest difficulty with subtalar instability as these activities will cause excessive movements of the subtalar joint to the end ranges of pronation and supination.

Assessment of standing posture in athletes with STS may demonstrate a pes planus posture or an asymmetry of the rearfoot angle with the leg, but these are not typical findings. Passive range of motion of the ankle and subtalar joint may not reveal excessive motion, but pain over the sinus tarsi at the end range of ankle plantarflexion with foot supination is typical of STS. Muscles that cross the ankle joint should be assessed for any loss of strength, especially the plantarflexor muscles.

Before examining the subtalar joint, a careful assessment of the talocrural joint should be performed. Anterior and posterior glides of the talus on the tibia and a talar tilt test that produces movement of the talus in the frontal plane are recommended for assessing talocrural joint stability. Mobility of the contralateral ankle and foot joints should be assessed to determine if the athlete has increased joint mobility that will make them susceptible to developing an instability.

Stability of the subtalar joint is assessed with medial and lateral subtalar joint glides performed by moving the calcaneus over a stabilized talus in the transverse plane and with subtalar joint distraction. Therman et al. described a stability test that is thought to recreate instability of the subtalar joint (Figure 2). The test is performed with the athlete in supine with the ankle in 10 degrees of dorsiflexion to keep the talocrural joint in a stable position. The forefoot is first stabilized by the examiner’s hand, while an inversion and internal rotational force is applied to the calcaneus. Then an inversion force is applied to the forefoot. The examiner assesses for an excessive medial shift of the calcaneus and a reproduction of the athlete’s complaint of instability and symptoms.

Figure 1. Symptoms associated with STS are usually described as deep in the ankle and can be localized by athlete pointing to the sinus tarsi space.

Figure 2. Clinical test for reproduction of subtalar instability. The forefoot is first stabilized by the examiner’s hand, while an inversion and internal rotational force is applied to the calcaneus.
Reproduction of the athletes' feeling of instability or giving way may be reproduced by having the athlete single leg stand on the affected side and perform rotating motions of the leg and foot that may reproduce their symptoms. Therapists may also want to assess the athlete during functional activities of walking, running, stepping down from a step, and hopping on the affected extremity. Activities that produce feelings of instability should be assessed for the relative position of the rearfoot and leg for any compensation through the lower extremity the athletes make when the instability is produced. The activity levels of athletes with STS can be assessed using the Ankle Disability Index, which includes the athlete's rankings of sports related activities.23

DIFFERENTIAL DIAGNOSIS
Athletes with recurrent ankle sprains or symptoms of ankle instability should be suspected of having instability of the talocrural and subtalar joints. Localization of pain to the sinus tarsi with the presence of ankle instability is a good indication that the athlete has developed STS. Conditions that may also produce lateral ankle discomfort include a cuboid subluxation and peroneal tendon subluxation.24 The diagnosis of STS has typically been confirmed by the cessation of symptoms upon injection of lidocaine into the sinus tarsi.1

IMAGING
Athletes suspected of having subtalar joint instability and STS may be referred for diagnostic imaging. Although imaging studies have been proposed to assess the stability of the subtalar joint, most of these methods have been proven to be inconsistent in their findings with low levels of specificity for subtalar joint instability.15,16 Radiographs of the subtalar joint are usually performed with Broden stress views which are a series of oblique-lateral views performed with the ankle and foot placed in inverted and supinated positions.1 Stress fluoroscopy is a method of visualizing the motions of the subtalar joint in real time using low level radiation. The advantage of fluoroscopy over radiographs is that the examiner can attempt to replicate the movements that are causing the athlete's sensation of instability or discomfort from the sinus tarsi.16 Magnetic resonance imaging (MRI) is the best method to visualize the structure within the sinus tarsi, especially the interosseous and cervical ligaments.2 The most distinct finding for individuals with STS is a bright signal seen on T2 weighted images found in the area for sinus tarsal adi-

pose tissue as this represents an infiltration or replacement of this tissue with inflammatory cells and fibrotic tissue.25,26 The MRI findings may also include alterations in the structure of the interosseous and cervical ligaments and degenerative changes in the subtalar joint.2,25

INTERVENTION
Recommendations for rehabilitation of STS include balance and proprioceptive training, muscle strengthening exercises, bracing, taping, and foot orthosis.21,24 No random control trials for the efficacy of a rehabilitation program for STS are available. Instability of the talocrural joint or chronic ankle instability (CAI) is a similar and associated entity to subtalar joint instability and STS. Numerous studies of the effects of balance and proprioceptive training for CAI have been conducted, with improvements found in athletes' balance, joint position sense, and functional abilities.27,28

Athletes with STS have developed a chronic inflammatory process that results in a synovitis and inflammation of connective tissues and may benefit from a trial of nonsteroidal anti-inflammatory medication to help control their symptoms and inflammation.30 Cryotherapies, especially the use of ice massage over the lateral ankle, may also be useful for diminishing local inflammation and pain associated with this condition. Athletes with STS may have limited joint mobility at the talocrural and mid tarsal joints that can be addressed with specific joint mobilization techniques. Precautions should be made not to place excessive stress across the subtalar joint with these techniques. Muscular stiffness of the gastrocnemius, posterior tibialis, or peroneal muscles may also be found in athletes with STS, but stretching activities for these muscles should be carefully provided or avoided as excessive forces across the subtalar joint may be detrimental.31

ORTHOS
Stability of the subtalar joint may be initially improved with the use of an orthosis.32 Ankle braces intended for CAI may be useful for some athletes with STS, but the overall design of these braces may not significantly improve the stability of the subtalar joint during athletic activities. Foot orthosis have also been recommended as a method for limiting motion at the subtalar joint and reducing symptoms associated with STS.33 The types of shoes the athlete is using for training, practices, and competition should also be considered, as well constructed shoes can restrict excessive rearfoot movements.34
General recommendations for shoes include those with a straight last, a firm heel counter, and rigid material through the midsole. Shoes should also be assessed for wear, as materials within a shoe will begin to break down before the external material shows signs of deterioration. The use of a foot orthosis with an athletic shoe should be considered together, as the effect of an orthosis can be inconsistent. An ongoing assessment of shoe and orthosis use is needed to provide adequate support of the foot and ankle throughout an athlete's cycle of training and competition.

Taping or strapping has also been used to specifically limit movements of the subtalar joint and the midfoot. Wilkerson et al have described a taping procedure that combines a closed basket weave with a subtalar sling to control movements at the talocrural and subtalar joints. Viczenzio et al have described a modified Low-Dye taping method that uses a calcaneal sling intended to provide support to the medial longitudinal arch of the foot (Figure 3). This method could be used to control or reduce the amount of pronation through the subtalar joint during walking and running activities. Taping techniques have been used as a precursor for the use and selection of specific types of shoes and foot orthotics.

**Stability Training**

Training programs to improve the stability of the subtalar joint and lower extremity function will be the hallmark of treatment plans for STS. Joint stability relies on passive joint structures, dynamic muscular responses, and neurological control. Because tears or ruptures of the interosseous and cervical ligaments of the subtalar joint are believed to be the essential lesions that lead to STS, the dynamic muscular responses and neurological control of the rearfoot will need to be emphasized to compensate for the loss of passive stability. The muscles that cross the subtalar joint are important for maintaining stability, as they act as force transducers to guide and control the pronation and supination motions of the subtalar joint. The relative strength of these muscles is important, but their reaction time to joint perturbations and the ability to work in a coordinated fashion is even more important for the rehabilitation of STS. Dynamic stability will also rely on the proprioceptive information from the muscle spindles and Golgi tendon organs of these muscles to compensate for the lack of proprioceptive information from the stabilizing ligaments of the joint. The endurance of the muscles will also be important to maintain stability during long bouts of exercise or sports activities.

Training programs to improve joint stability have been described as multi-phase processes that start the athlete at an appropriate level of activity and progress to higher levels of activities while maintaining joint stability. To help the athlete understand this process the progression of three phases are called: Attain, Maintain, and Sustain. The Attain phase will determine postures or positions the athlete is able to attain in a stable fashion. The Maintain phase will develop coordinated isometric and eccentric muscle contractions of the muscles crossing the joint. The Sustain phase will involve integrating all of the neuromuscular subsystems needed for stability during

![Figure 3. Taping for stabilizing the rearfoot. These taping methods can be used in addition to an closed ankle basket weave or a foot Low-Dye method. Figure on the top shows a calcaneal sling with a long strip to control rearfoot pronation, figure on the bottom shows heel lock strips to control rearfoot supination.](image-url)
sports specific activities (Table 1).

The Attain phase for subtalar joint instability is usually started with the athlete in standing positions. Single leg standing, with the contralateral limb held in approximately 30 degrees of hip flexion and 90 degrees of knee flexion, will emphasize ankle balance strategies. The clinician should closely observe the arch of the foot and rearfoot to assess the athlete’s ability to attain a stable position for the subtalar joint while avoiding excessive pronation movements (Figure 4). The Attain phase begins with the eyes open and attempting to hold the single leg position for 30 to 60 seconds with minimal alterations in body position. Once the athlete is able to hold a single leg standing position consistently, a progression to eyes closed conditions can be made.

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Table 1: Progression through three stages of stability training.

Figure 4. Foot held in an excessive pronated position.
Progressions of the Sustain phase can be performed with the athlete jumping or hopping in place and then into hopping in different directions. Running activities can begin by acceleration and deceleration with forward and backward motions. Athletes needing to perform pivoting or cutting maneuvers can begin these activities at a slow speed maintaining good alignment of the foot and leg and avoiding excessive motions through the rearfoot.

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**SUMMARY**

Sinus tarsi syndrome is a condition of the ankle and foot that results from instability of the subtalar joint. Athletes with this condition typically have complaints of instability with functional activities and persistent anterolateral ankle discomfort. The joints of the ankle should be assessed for mobility and reproduction of feelings of instability and discomfort. Treatments for this condition will need to control the athlete's ankle discomfort and improve the overall stability of the foot and ankle. Therapists should design intervention plans based on the athlete's need for training and competition.

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ABSTRACT

Background. Previous studies have shown military physical therapists (PT) to have comparable clinical diagnostic accuracy (CDA) and interobserver agreement to orthopaedic surgeons (OS). However, no studies have examined hip pathology or used intraoperative findings as the reference standard for diagnosis.

Objective. To compare the CDA of physical examination findings among a PT, an OS, and two surgical orthopaedic residents (ORs) for hip labral tears.

Methods. Thirty-six patients (15 males, 21 females) aged 18-47 (mean + SD, 31.4 + 8.1 years) with 37 symptomatic hips were enrolled in a prospective study and underwent a standardized clinical examination followed by hip arthroscopy. A PT, an OS, and two ORs independently performed history and examinations with the emphasis of diagnosis on the results of six special tests.

Results. Thirty-two of 37 individuals (86%) had labral tears to the hip at arthroscopy. Analysis of agreement between clinical diagnosis and intra-operative findings of a labral tear produced a CDA of 85.3% (29/34 correct) for the PT, 84.4% (27/32 correct) for the OS, and 80.0% (24/30 correct) for ORs. No significant difference in CDA occurred in comparing the PT, OS, and ORs.

Conclusions. Using arthroscopy as the reference standard, hip labral tears were clinically suspected with 80-85% accuracy. The clinical diagnostic accuracy of the PT, OS, and ORs was high with no significant difference between examiners. In this study, an experienced PT, an OS, and two ORs demonstrated similarly high diagnostic skills.

Key Words: diagnosis, physical exam, hip joint, labral tear, direct access.

DISCLAIMER
The views expressed in this manuscript are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or U.S. Government. All authors are employees of the United States government. This work was prepared as part of their official duties and as such, there is no copyright to be transferred.
INTRODUCTION
United States Army physical therapists (PTs) have been practicing in orthopaedic management roles since the Vietnam War and their primary role is to provide evaluation and treatment to alleviate or prevent physical impairments stemming from injury, pre-existing problems, or disease. In their role as physician extenders, Army PTs can also gain privileges to evaluate patients without physician referral; order radiographs, bone scans, magnetic resonance imaging (MRI), and computed tomography scans; order certain lab tests; refer patients to medical specialty clinics; perform electromyographic and nerve conduction studies; restrict service members to their living quarters for up to 72 hours; restrict work and training for up to 30 days; and prescribe certain medications. It is well documented that Army PTs have performed successfully as physician extenders in the evaluation and treatment of patients with neuromusculoskeletal dysfunction. Further, evidence points towards minimal risk for negligent care when patients are evaluated and managed by PTs, through direct access or by referral.

Diagnostic accuracy is fundamental to direct access providers. Previous studies in the military health care system have shown that PTs have comparable clinical diagnostic accuracy and interobserver agreement to orthopaedic surgeons (OSs) comparing MRI findings for multiple conditions or radiographs following patients with acute ankle sprains. However, no research currently exists which prospectively compares the accuracy of diagnosis between PTs and OSs from a battery of clinical examination tests and compares it to the gold standard for orthopaedic diagnosis-intraoperative findings.

One condition for which limited evidence exists in the accuracy of the clinical examination is hip labral pathology. The acetabular labrum functions to both enhance joint stability and decrease contact stresses between the acetabular and femoral cartilage. A patient with a labrum tear can be symptomatic and may require open or arthroscopic debridement, or possibly repair.

Table 1 describes the clinical signs and symptoms of acetabular labral tears. An examiner would not rely on the finding of just one clinical item in isolation, but should use information gathered from the history, site of pain, mechanical symptoms, and physical examination to determine a diagnosis. Mechanisms of injury and risk factors noted in the literature include hip hyperabduction, twisting, falling, motor vehicle accidents, sports (especially those that require hip external rotation or hyperextension such as soccer, karate or ballet), a direct blow, or hip dislocation. The anterior inguinal area is the most common site of pain in patients with labral pathology; this sign is highly sensitive and pain is typically rated as moderate to severe. For mechanical symptoms, some patients with labral pathology report clicking, catching, or locking of the hip with motion, though the significance of these signs is questionable. Currently, research has not demonstrated sufficient specificity of individual or clusters of clinical tests to confidently rule in a diagnosis of hip labral lesion; but high sensitivity of many tests allows a negative finding to increase confidence that a hip labral lesion is absent. The decision, therefore, to perform hip arthroscopy on a patient suspected of having labral pathology is typically based on a number of factors to include patient history, conservative treatment results, clinical examination, magnetic resonance arthrography (MRA), and response to intra-articular injection of anesthetic. While the value of MRA and intra-articular injections in diagnosis has been shown, the accuracy of clinical examination tests in detecting labral tears is less well defined.
Physical therapists in orthopaedic and sports medicine practices manage patients with suspected hip labral tears and are trained to perform physical examinations using clinical tests shared by orthopaedics and physical therapy practice. It is important for a PT to determine how his or her clinical diagnostic accuracy (CDA) compares with an OS and ORs working in the same facility in order to diagnose, treat, or refer patients most appropriately during the conservative treatment phase. Therefore, the purpose of this study was to prospectively assess the CDA of physical examination findings for hip labral pathology among a PT, an OS, and ORs using arthroscopy as the definitive diagnosis. The hypothesis to be tested was that all providers would have similar CDAs.

METHODS

Subjects

Thirty-six consecutive military health care beneficiaries presenting to the orthopaedic sports medicine clinic at a tertiary military medical center with hip pain were recruited by ORs. All subjects provided informed consent to their participation and the rights of the subjects were protected as governed by the Clinical Investigation and Human Use Committees of the Department of Clinical Investigation at Walter Reed Army Medical Center. Subjects included active-duty military members or Department of Defense beneficiaries who were between 18-47 years of age and who were seeking treatment for hip pain refractory to conservative treatment. Subjects who were pregnant or with previous hip surgery were excluded. Subjects with a primary diagnosis of hip osteoarthritis, congenital hip pathology (i.e. dysplasia), avascular necrosis, or femoral neck stress fracture were also excluded.

Procedures

Before initiation of the study, a PT with 19 years of experience, two ORs (one with 4 years, one with 5 years surgery experience) and an OS (with 7 years experience as a fellowship-trained sports surgeon) who performed all hip arthroscopies participated in a 30 minute practice session to standardize the following clinical examination techniques: Thomas hip flexion-to-extension maneuver (aka McCarthy Sign), internal rotation load/grind, Fitzgerald Test, eccentric hip flexion, resisted straight leg raise (SLR), and resisted SLR in external rotation.

Patients were examined independently by the PT, one of two ORs, and the OS in varied order based on provider availability. Physical examinations were performed first and the results recorded prior to gathering clinical histories and radiographic findings. Each examiner was blinded to the results of the other providers. For the purposes of this study, the test was considered positive if the patient had one or more of these symptoms during the test: click, clunk, or pain in the groin region which reproduced their chief complaint. The final diagnosis was not algorithmically derived, instead the diagnosis was driven by clinical reasoning based on meaningful interpretation of all the factors (pain, location, mechanical symptoms) integrated across all six tests. A description of physical examination tests follows.

Thomas hip flexion-to-extension maneuver (aka McCarthy Sign)17,20,21

In supine, the subject fully flexed both hips (Figure 1), then the examiner slowly and passively extended the subject’s lower extremities with hips going into external rotation (ER) (Figure 2A). This test was repeated, but with the subject’s hip going into internal rotation (IR) (Figure 2B).
Sensitivity and specificity of this test has yet to be published.\textsuperscript{22,27}

**Internal rotation load/grind test**
In supine, the examiner flexed the subject’s hip passively to approximately 100 degrees and then rotated the subject’s hip from IR to ER while pushing along the long axis of the femur through the knee to cause “grind” (axial compression of the femoral head in the acetabulum through knee) (Figure 3). This movement mimics, and is very similar to, the flexion-internal rotation-axial compression test, which has a reported specificity of 0.43 and a sensitivity of 0.75.\textsuperscript{28}

**Fitzgerald Test\textsuperscript{18}**
To test the anterior labrum, the examiner started with the subject’s hip in maximum flexion, ER, and full abduction (Figure 4A); then extended the subject’s hip while placing it into full IR, and adduction (Figure 4B). To test the subject’s posterior labrum, the examiner started with the subject’s hip in maximum flexion, IR, and adduction (Figure 5A); then extended the subject’s hip while placing it into full ER and abduction (Figure 5B). Sensitivity is reported to be 1.00.\textsuperscript{18} For inter-rater reliability of the flexion-internal rotation-adduction-impingement test, which is described like the Fitzgerald test for anterior labral tears, Kappa was 0.58 with a 95% confidence interval of (0.29-0.87).\textsuperscript{29}

**Eccentric hip flexion (patient-controlled lowering)**
While supine, the subject lifted the lower extremity into full hip flexion with knee extended, then slowly lowered the leg to the table, reporting any clicks, clunks, or pain. This test was used to identify possible iliopsoas tendon snapping.

**Resisted SLR\textsuperscript{21}**
While supine, the subject actively raised the lower extremity to 30 degrees of hip flexion with the knee fully extended. The subject held the lower extremity while the examiner applied resistance to the ankle. The resisted SLR is thought to load the joint antero-superiorly and to cause anterior groin pain if an intra-articular lesion is present.\textsuperscript{30} Sensitivity and specificity of this test has yet to be published.\textsuperscript{22,27}
Resisted SLR in ER
The test was repeated, but subject's hip was in ER (Figure 6). This test is thought to “wind up” the iliopsoas and place more tension at the labrum. Sensitivity and specificity of this test has yet to be published.22,27

Statistical Analysis
Descriptive statistics, frequency tables, and Cochran’s Q test31-32 (repeated measures test for dichotomous data with three or more independent variables- examiners in this case) were used to determine whether a PT could demonstrate a comparable degree of CDA with an OS and one of two ORs when conducting hip examination tests targeting labral pathology (alpha level set at p<.05). Clinical diagnostic accuracy has been used in a previous study11 and is a ratio represented by the number of correct diagnoses as the numerator and the total number of diagnoses made as the denominator (number correct diagnoses/total number diagnoses).33 The number of false negatives (condition in which the examiner diagnosed a subject without a tear but a tear existed) and false positives (condition in which the examiner diagnosed a subject with a tear but no tear existed) were also determined for each examiner. All statistics were performed with SPSS 9.0 for Windows (SPSS Inc., Chicago, IL).

RESULTS
Over an 18 month period, 36 patients (15 male and 21 females) aged 18-47 (mean 31.4 + SD 8.1 years) with 37 symptomatic hips were enrolled in this study. All 36 enrolled subjects completed the study. The PT, OS and ORs independently examined the patients, documented results of their clinical tests, and then made a diagnosis based on their findings. Table 2 shows the frequency of positive clinical findings among the examiners. Only one test (Fitzgerald test going into external rotation and abduction) showed a large variability between providers.

In this cohort, 34 patients had complete examination and diagnosis data by the PT, 32 patients by the OS, and 30 patients by the ORs. The ORs examined approximately 15 patients each. All 36 patients underwent hip arthroscopy, one bilaterally. Results from the hip arthroscopy provided the definitive diagnosis. Thirty-two of 37 subjects (86%) had acetabular labral tears at the hip confirmed at the hip during hip arthroscopy. Some subjects had multiple tears at the hip and the locations noted were: 11 tears located anterior, 21 anterior-superior, six superior, and one tear posterior-superior.

Analysis of agreement between clinical diagnosis and intra-operative findings of a labral tear produced a CDA of 85.3% (29/34) for the PT (five false positives), 84.4% (27/32) for the OS (five false positives), and 80.0% (24/30) for ORs (four false positives, two false negatives). No significant difference in CDA existed among all three examiners (Q= 2.00, p = .999). A remarkable observation was that the PT and OS each had five false positives which were on the same five patients.

DISCUSSION
The findings from this study support the hypothesis regarding CDA by demonstrating that the PT, OS, and ORs practicing at a tertiary military medical center during the period of this study demonstrated a high degree of CDA on hip labral pathology diagnosis, confirmed with arthroscopy, for patients referred with hip pain. Though

<table>
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<th>TABLE 2. Percentage of positive clinical findings for the physical therapist (PT), orthopaedic surgeon (OS) and orthopaedic residents (ORs).</th>
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<td>PT</td>
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<tr>
<td><strong>n = 34</strong></td>
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<tr>
<td>Thomas maneuver (McCarthy Sign) in external rotation</td>
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<td>Thomas maneuver (McCarthy Sign) in internal rotation</td>
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<td>Eccentric hip flexion (controlled lowering)</td>
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responses of individual tests during the clinical exam showed some variability between providers (i.e. Fitzgerald test), the overall interpretation of all clinical exam tests combined yielded very similar diagnoses. As a result, no significant difference occurred in diagnostic accuracy between the PT, OS and ORs.

The results of this study are comparable to previously published literature. Other studies which have addressed PT clinical accuracy have found similar interobserver or CDA agreements. Moore et al conducted a retrospective review of 560 patients with musculoskeletal injuries referred for magnetic resonance imaging and compared CDA of PTs to OSs and non-orthopaedic providers. The authors reported no significant difference in CDA between PTs (74.5%; 108/145) and OSs (80.8%; 139/172) across a variety of orthopaedic conditions, though hip labral tears were not assessed. Physical therapists and OSs both showed significantly higher CDAs than non-orthopaedic providers (35.4%; 86/243). Therefore, the current study reinforces the diagnostic accuracy of PTs. Further, the present study design improves on the validity of these findings by overcoming two limitations Moore et al describe: 1) the need for a prospective analysis of CDA, and 2) a reference standard based on surgical confirmation of the diagnosis.

The results are in agreement with previous literature on the diagnostic accuracy of Army PTs and their orthopaedic colleagues. The high agreement in exam findings and diagnosis translates into better consistency in management of orthopaedic-related conditions and ultimately benefits the patient and the medical system. The strength of the accuracy may be explained by several factors, some intrinsic to the Army physical therapy education, training, and credentialing model, and others related to the nature of the Army medical system.

The Army medical system further strengthens the evaluation skill sets of PTs by the close relationship in most facilities where PTs and OSs routinely see patients together in combined clinics to manage nonsurgical or perioperative conditions. Combined training is critical and greatly emphasized in a deployed theater, where the PT’s role in managing the large volume of nonsurgical orthopaedic conditions frees the OS to concentrate on individuals with complicated trauma and surgical cases.

Limitations

The subjects enrolled in this study were all selected from a tertiary-level orthopaedic sports medicine clinic. Since this clinic is completely referral based, all patients presenting for evaluation would have been previously evaluated by a PT or physician. Further, the OS has developed a specialization in hip arthroscopy for the treatment of patients with labral pathology, which is known to the referring providers. As a result, this sample is biased towards hip labral pathology, as other etiologies for hip pain, which may indeed be more common, were typically excluded prior to final referral to the clinic. Therefore, it is not known how many people might have similar hip symptoms or complaints who were never referred to the clinic. A limitation known as “spectrum bias” could have occurred which could have improved the overall diagnostic accuracy by eliminating patients with conditions in which the physical examination tests assessed in this study are less discriminate. Results of this study may be different if the PT, OS, and ORs had evaluated the subjects in a general practice setting prior to any other evaluations and interventions.

Additionally, the use of arthroscopy as the gold standard reference in this study significantly improves validity, but at the consequence of furthering spectrum bias. Spectrum bias can cause an overestimation when diagnostic accuracy is studied in samples in which the vast majority of subjects have the disease in question. These studies tend to overstate the accuracy when applied to the general population. Regardless, this population bias effect would be expected to equally impact each of the examiners. Thus, spectrum bias may have artificially elevated the CDA; however, it should not have impacted the finding of equivalent CDA for PT, OS and ORs conducting physical exams of the subject’s hip to detect labral tears.

Lastly, the use of a single PT, OS, and two ORs limits the generalizability of the findings. This limitation could have
been overcome by having more than one of each type of provider perform examinations. While the external validity of our results may have improved, such a study was not practical in the present clinic setting.

**Clinical Relevance**
Army PTs frequently perform initial evaluations for a myriad of orthopaedic and sports injuries while serving in a physician extender role. Recent studies have shown the effectiveness of using Army PTs as primary neuromusculoskeletal screeners during peace and war, including during deployments to Operations Desert Shield and Storm, Bosnia, and Operation Iraqi Freedom. This study provides further evidence that military PTs demonstrate competency in making sound, independent clinical judgments regarding the evaluation and management of patients with hip labral pathology.

**Future Research**
These findings warrant further studies to evaluate CDA between PTs and other health care providers in a variety of settings for the patients with the most common musculoskeletal conditions across the full spectrum of a disease or injury process. In addition, prospective studies involving PTs with varying levels of clinical experience, board certification, and fellowship training will provide important data to further conclusions regarding the abilities of PTs to manage patients in a direct access environment.

**CONCLUSION**
Using arthroscopy as the reference standard, hip labral tears in the subjects were clinically suspected with 80-85% accuracy among the examining clinicians. Clinical diagnostic accuracy of an experienced physical therapist, orthopaedic surgeon, and orthopaedic residents on patients with hip labral pathology was excellent with no significant difference among examiners. This study further strengthens the evidence that the use of Army PTs in the role of managing, evaluating, and treating patients with neuromusculoskeletal dysfunction is a successful model.

**REFERENCES**


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 prognoses. 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 ($r = -0.26$ to $0.27$). 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

Figure 1. The sliding incline apparatus with subject in full extension.

Figure 2. The sliding incline apparatus with subject at full allowable flexion of the knee.
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. 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.

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, 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 rxx 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:

\[
\text{MDC95} = z_{0.975} \times \sqrt{2 \times \text{SEM}^2}
\]

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.

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<td><strong>Session</strong></td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Initial</td>
</tr>
<tr>
<td>Follow-up</td>
</tr>
<tr>
<td>Reliability</td>
</tr>
</tbody>
</table>

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.
Table 2: Distribution of diagnoses, by self-report, at initial test of study and at follow-up.

<table>
<thead>
<tr>
<th>Self-Report Diagnosis</th>
<th>Initial (n)</th>
<th>Follow-up (n)</th>
</tr>
</thead>
<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>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Iliotibial band syndrome</td>
<td>2</td>
<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>Total</td>
<td>37</td>
<td>23</td>
</tr>
</tbody>
</table>

Reliability Study

The ICCs 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. 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
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 uninvolved 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 change scores 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.2 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 4. Correlation matrix for all measures. (n = 37)

<table>
<thead>
<tr>
<th></th>
<th>PWB20</th>
<th>PWB30</th>
<th>Stairs UP</th>
<th>Stairs DOWN</th>
<th>Walk</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWB20</td>
<td>-</td>
<td>-0.78</td>
<td>-0.60</td>
<td>-0.61</td>
<td>-0.72</td>
</tr>
<tr>
<td>PWB30</td>
<td>0.49</td>
<td>0.50</td>
<td>0.56</td>
<td>-</td>
<td>0.81</td>
</tr>
<tr>
<td>Stairs UP</td>
<td>0.96</td>
<td>0.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stairs DOWN</td>
<td></td>
<td>0.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 5. Mean measures for the partial weight bearing performance tests and the measures of function (sd).

<table>
<thead>
<tr>
<th>Test</th>
<th>Initial</th>
<th>Follow-up</th>
<th>Absolute Change</th>
<th>Relative Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWB20 Uninvolved</td>
<td>22.1 (5.5)</td>
<td>23.0 (6.2)</td>
<td>1.1 (1.6)</td>
<td>4.1</td>
</tr>
<tr>
<td>PWB20 Involved</td>
<td>17.1 (6.7)*</td>
<td>19.1 (6.7)*</td>
<td>4.8 (2.7)</td>
<td>28.1</td>
</tr>
<tr>
<td>PWB30 Uninvolved</td>
<td>30.4 (9.1)</td>
<td>29.3 (9.3)</td>
<td>1.1 (1.4)</td>
<td>3.7</td>
</tr>
<tr>
<td>PWB30 Involved</td>
<td>43.2 (24.3)</td>
<td>33.9 (12.9)*</td>
<td>9.2 (6.3)</td>
<td>27.4</td>
</tr>
<tr>
<td>Stair UP</td>
<td>13.3 (5.9)</td>
<td>10.7 (4.2)*</td>
<td>2.7 (3.0)</td>
<td>24.3</td>
</tr>
<tr>
<td>Stair DOWN</td>
<td>14.0 (7.3)</td>
<td>11.5 (6.5)*</td>
<td>2.6 (2.5)</td>
<td>21.7</td>
</tr>
<tr>
<td>Walk</td>
<td>10.2 (2.7)</td>
<td>8.6 (2.8)*</td>
<td>1.8 (1.2)</td>
<td>19.0</td>
</tr>
<tr>
<td>LSI PWB20</td>
<td>77.3 (9.7)</td>
<td>95.2 (7.9)*</td>
<td>17.9 (8.9)</td>
<td>23.0</td>
</tr>
<tr>
<td>LSI PWB30</td>
<td>70.3 (21.1)</td>
<td>86.4 (17.4)*</td>
<td>16.1 (7.7)</td>
<td>23.0</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-
hance 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

Chana Frommer, PT, DPT, OCS, SCS
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 decreased 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 non-operatively. 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. 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 1), which is also described by Giannotti et al when discussing classification of MCL sprains.

### Table 1: Indelicato’s classification of MCL injuries

<table>
<thead>
<tr>
<th>Grade</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade I sprain</td>
<td>Tenderness on palpation and pain with valgus stress testing with no detectable laxity</td>
</tr>
<tr>
<td>Grade II sprain</td>
<td>Joint line gapping of less than 5mm with a clinical subjective end-feel as well as pain and tenderness with palpation</td>
</tr>
<tr>
<td>Grade III sprain</td>
<td>Joint line gapping greater than 5mm with no subjective clinical end-feel as well as pain and tenderness with palpation</td>
</tr>
</tbody>
</table>

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 LEFS20 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 5º-0º-136º, and on the left was 4º-110º (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 rotatory 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 Scening**
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.

<table>
<thead>
<tr>
<th>Table 2: Manual Muscle Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Hip flexion</td>
</tr>
<tr>
<td>Hip abduction</td>
</tr>
<tr>
<td>Hip adduction</td>
</tr>
<tr>
<td>Knee flexion</td>
</tr>
<tr>
<td>Knee extension</td>
</tr>
<tr>
<td>Dorsiflexion</td>
</tr>
<tr>
<td>Plantarflexion</td>
</tr>
</tbody>
</table>
Diagnosis
Based on the grading system of Indelicato, 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 McConnell 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 0°-135° with minimal discomfort, and 0°-138° 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 8°-0°-138°; 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 30° 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 6°-0°-133°. 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 30° 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.
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.

**Treatement 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...
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.22 The consensus seems to be a minimum of 6-8 weeks for sports, such as soccer, that place more stress on the MCL.22 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.13,22 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.4,28 This difference may be due in part to differences of opinion regarding the biomechanics of the MCL. Slocum and Larsen,13 as well as Last,12 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.25,22 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.2,22

Several therapeutic exercises were included in the program for this patient (Table 3). Retro-treadmill walking was utilized to improve concentric quadriceps muscle strength.21 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.29 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.22

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.21 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.23 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.

**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. 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.

The recent study by Herrington 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. 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. 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. In the past few years, studies utilizing electromyography (EMG) have demonstrated that taping improves the timing of the firing of the VMO. 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. 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. 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. 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. 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. 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.

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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. 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. 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. Rolling is defined as “moving from supine to prone or from prone to supine position” 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. 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 motions 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. 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.

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. 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 colleagues 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. were similar to the original patterns of rolling movement described by Voss et al. 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.
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 quadruped 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 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.

**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.

**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.
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”

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”

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.
- 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 facilitatory 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. 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, sacroiliac 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-

Figure 8. Quadruped with tubing to facilitate scapular control/stability.

Figure 9. Quadruped with tubing to facilitate core/scapular/pelvic stability.

Figure 10. Assisted rolling supine to prone, left upper extremity led. Note the use of a half foam roll behind the trunk for assistance.
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 mnemonic 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.12,24 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.14,15 The 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 literature11,14,15 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 risk2,24 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). 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 angles 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

**CORRESPONDENCE**

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Financial Disclosure: The primary author of this study is the inventor of the Y Balance Test Kit™ used in this study.
Unilateral balance and dynamic neuromuscular control are required for sport. Dysfunctional unilateral stance has been prospectively identified as a risk for injury in sport.1-6 Recent discussion in the literature has occurred regarding the importance of assessing dynamic neuromuscular control for injury prediction using body relative movement testing.7 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.8, 9 The SEBT has been used to measure physical performance, compare balance ability among different sports, and identify individuals who have chronic ankle instability.10-13 Recently, the test has been used to identify athletes at greater risk for lower extremity injury.1 Researchers have suggested using the SEBT as a screening tool for sport participation and as a post-rehabilitation test to ensure dynamic functional symmetry.11 Further, researchers have shown that SEBT performance improves after training.10,14

The test originally incorporated reaching in eight directions while standing on each foot,9 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.15 Further, Plisky et al1 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 in high school basketball players. Hubbard et al12 reported that the anterior and posteromedial reach directions identified persons with chronic ankle instability. In a second study, these same authors found that hip abduction strength was correlated with the posteromedial reach distance, and hip extension strength correlated with posterolateral reach distance on the SEBT.16

For clinical use and screening purposes, the test needs to capture the greatest amount of information in the shortest amount of time. Thus, the anterior, posteromedial, and posterolateral directions appear to be important to identify individuals with chronic ankle instability and those at greater risk of lower extremity injury.

The intrarater reliability of the SEBT has been reported as moderate to good (ICC 0.67- 0.97),8,10,17 and interrater reliability has been reported as poor to good (0.35-0.93).17

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 touch-down 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,18-21 most distal aspect of the toes,22 center of the foot,11,18,23-32 and varied according to reach direction.9,33

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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**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.1-6 Recent discussion in the literature has occurred regarding the importance of assessing dynamic neuromuscular control for injury prediction using body relative movement testing.7 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.8, 9 The SEBT has been used to measure physical performance, compare balance ability among different sports, and identify individuals who have chronic ankle instability.10-13 Recently, the test has been used to identify athletes at greater risk for lower extremity injury.1 Researchers have suggested using the SEBT as a screening tool for sport participation and as a post-rehabilitation test to ensure dynamic functional symmetry.11 Further, researchers have shown that SEBT performance improves after training.10,14

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**METHODS**

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<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Reach Foot Touch Down</th>
<th>Stance Foot Alignment</th>
<th>Stance Foot Movement Allowed</th>
<th>Average or Greatest Reach</th>
<th>Testing Directions*</th>
<th>Limb Length Measured</th>
<th>Attempts allowed / trials</th>
<th>Shoes on / off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray^</td>
<td>NA†</td>
<td>No, within 3 inches of test vector</td>
<td>Varied to direction of reach</td>
<td>No</td>
<td>Greatest (unit of measure unspecified)</td>
<td>AL, AM, P, PM, P, L, PL, L</td>
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<td>20</td>
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<td>AM, PM</td>
<td>No</td>
<td>5</td>
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<tr>
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<td>16</td>
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<td>Center of grid</td>
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<td>Avg of 1: 3:4:5:7, 9:10:12 (cm)</td>
<td>AM, A, AM, M, PM, P, PL, L</td>
<td>No</td>
<td>1practice followed by 3 trials</td>
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</tr>
<tr>
<td>Earl and Hettel^10</td>
<td>10</td>
<td>Yes</td>
<td>Varied to direction of reach</td>
<td>Not specified</td>
<td>Within 1 min of precision</td>
<td>AM, PM</td>
<td>No</td>
<td>6 practices / 5 trials / lost 3 marked</td>
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<tr>
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<td>40</td>
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<td>Center of grid</td>
<td>No</td>
<td>Avg of 3 greatest (cm)</td>
<td>A, AM, M, PM, P, PL, L, AL</td>
<td>No</td>
<td>6practices / then till 3 good reaches met</td>
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<tr>
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<td>Mean of 3 trials (cm)</td>
<td>A, AM, M, PM, P, PL, L, AL</td>
<td>Yes / ASIS to mid ipsilateral medial malleolus</td>
<td>6 trials / 3 trials</td>
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</tr>
<tr>
<td>Griddle et al^26</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 trials / 3 trials</td>
<td>Pictured with shoes off</td>
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<tr>
<td>Cate et al^27</td>
<td>48</td>
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<td>Center of grid</td>
<td>No</td>
<td>Mean of 3 trials (cm)</td>
<td>A, AM, M, PM, P, PL, L, AL</td>
<td>Not normalized to height</td>
<td>1 practice / 3 trials</td>
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<tr>
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<td>Center of Box</td>
<td>No</td>
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<td>Yes / ASIS to mid medial malleolus bilateral</td>
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</tr>
<tr>
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<td>235</td>
<td>No</td>
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<td>No</td>
<td>Greatest of 3 trials (cm), &amp; sum of each direction greatest (composite)</td>
<td>A, PM, PL</td>
<td>Yes / ASIS to distal lateral malleolus, after clearing of the hip</td>
<td>6 trials / 3 trials</td>
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</tr>
<tr>
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<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>A, AM, M, PM, P, PL, L, AL</td>
<td>Yes / ASIS to distal tip medial malleolus</td>
<td>6 trials / 3 trials</td>
<td>Geometric center of foot / pictured with shoes off</td>
</tr>
<tr>
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<td>Yes</td>
<td>Foot bisected equally in all planes</td>
<td>No</td>
<td>Hands on iliac crest</td>
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<td>A</td>
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<td>6 trials / 3 trials</td>
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<tr>
<td>Sawkins et al^12</td>
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<td>Varied to direction of reach</td>
<td>No</td>
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<td>A, P, PM</td>
<td>Not specified</td>
<td>6practice (center to tapng) / 3 trials</td>
<td>Shoes off</td>
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<tr>
<td>Bressel et al^11</td>
<td>34</td>
<td>Yes</td>
<td>Middle of grid with center of foot on small dot</td>
<td>Cited as Griddle^26</td>
<td>Avg of 3trials (cm &amp; mm used)</td>
<td>A, AM, M, PM, P, PL, L, AL</td>
<td>Yes / ASIS to medial malleolus (nearest mm) Both lower extremities</td>
<td>138 seconds of practice prior to testing, 3 trials</td>
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<tr>
<td>Hubbard et al^11</td>
<td>60</td>
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<td>Not specified</td>
<td>Not specified</td>
<td>Avg of 3 (cm)</td>
<td>A, PM, PL</td>
<td>Yes / Griddle^26</td>
<td>6 trials / 3 trials</td>
<td>Not specified</td>
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<tr>
<td>Hubbard et al^11</td>
<td>30</td>
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<td>Not specified</td>
<td>Not specified</td>
<td>Avg of 3 (cm)</td>
<td>A, PM, PL</td>
<td>Yes / Griddle^26</td>
<td>6 trials / 3 trials</td>
<td>Not specified</td>
</tr>
<tr>
<td>Griddle et al^26</td>
<td>30</td>
<td>Yes</td>
<td>Middle of grid</td>
<td>No</td>
<td>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 trials / 3 trials</td>
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<tr>
<td>English and Haines^13</td>
<td>3</td>
<td>Methods cited as Kinney et al^14, with touchdown</td>
<td>Center of box</td>
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<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 trials / 3 trials</td>
<td>Pictured with shoes on</td>
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<tr>
<td>Hail et al^13</td>
<td>67</td>
<td>Yes</td>
<td>Not specified</td>
<td>Not specified; hands on hips</td>
<td>Mean of 3 trials (unit not specified)</td>
<td>A, AM, M, PM, P, PL, L, AL</td>
<td>Not specified</td>
<td>6 trials / 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 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 subjects 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 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
pre-participation physicals and rehabilitation sessions with a large variety of footwear, often not appropriate for sport. Future studies should utilize a similar, standardized testing protocol so that results may be compared across studies. In addition, only one limb (right) was measured twice by the first rater.

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


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 prognoses. 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 ($r = -0.26$ to $0.27$). 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 intra-tester 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\textsuperscript{21} 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\textsuperscript{21} 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. 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. 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, 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:

\[ MDC_{95} = z \times sx \times \sqrt{2} \]

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 2: Distribution of diagnoses, by self-report, at initial test of study and at follow-up. |
|---------------------------------|-------|-------|
| **Self-Report Diagnosis**       | **Initial (n)** | **Follow-up (n)** |
| Knee joint pain                 | 10     | 5     |
| Patella-femoral dysfunction with/without lateral release | 8     | 4     |
| Anterior cruciate ligament reconstruction | 7     | 6     |
| Total knee arthroplasty         | 6      | 4     |
| Achilles tendon rupture and repair | 2      | 2     |
| Iliotibial band syndrome        | 2      | 0     |
| Tibial plateau fracture         | 1      | 1     |
| Hamstring tear                  | 1      | 1     |
| **Total**                      | **37** | **23** |

| Table 3: Intraclass correlation coefficients (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) for select measures. (n = 15) |
|---------------------------------|-------|-------|-------|
| **Measure**                     | **ICC (lower 95% CI)** | **SEM (upper 95% CI)** | **MDC** |
| PWB20                           | 0.95 (0.83) | 1.35 (1.86) | 3.74 |
| PWB30                           | 0.98 (0.88) | 1.23 (1.78) | 3.41 |
| Walk Time                       | 0.99 (0.97) | ---        | ---   |
| Stairs UP                       | 0.98 (0.96) | ---        | ---   |
| Stairs DOWN                     | 0.96 (0.92) | ---        | ---   |
| Hop Distance                    | 0.97 (0.78) | ---        | ---   |
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 uninvolved 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 change scores 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 intrater 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-

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<th>Table 4. Correlation matrix for all measures. (n = 37)</th>
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<th>Table 5. Mean measures for the partial weight bearing performance tests and the measures of function (sd).</th>
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<td>LSI PWB30</td>
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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


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 decreased 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.1,2 Injuries to the MCL are classified into grades I, II, and III based mostly on clinical examination.3 Currently, treatment of isolated MCL injuries, especially grades I and II, are managed non-operatively.4 Injuries to the MCL are especially common in young athletes involved in sports which place valgus loads on the knee.5 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 Marshall6 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.7

Based on the work by Warren and Marshall,6 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.8,9 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.7 Other authors10 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.7 Brantigan et al8 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 al8 and Mains et al11 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.12,13 Still other authors, such as Horowitz4 and Warren et al,15 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.7,16 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.3,5,17,18 For this case report the authors used the clinical classification system developed by Indelicato17 (Table 1), which is also described by Giannotti et al3 when discussing classification of MCL sprains.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade I sprain</td>
<td>Tenderness on palpation and pain with valgus stress testing with no detectable laxity</td>
</tr>
<tr>
<td>Grade II sprain</td>
<td>Joint line gaping of less than 5mm with a clinical subjective end-feel as well as pain and tenderness with palpation</td>
</tr>
<tr>
<td>Grade III sprain</td>
<td>Joint line gaping greater than 5mm with no subjective clinical end-feel as well as pain and tenderness with palpation</td>
</tr>
</tbody>
</table>

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 5º-0º-136º, and on the left was 4º-110º (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 rotatory 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,\textsuperscript{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 McConnell\textsuperscript{26} 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 0°-135° with minimal discomfort, and 0°-138° 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 8°-0°-138°; 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 30° 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 6°-0°-143°. 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 30° 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.

\textbf{Figure 1.} Medial patellar glide taping

\textbf{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>Left knee 15 min</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Cold</td>
<td>Left knee 10 min</td>
<td></td>
<td>X</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>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhythmic stabilization</td>
<td></td>
<td></td>
<td></td>
<td>Left lower extremity</td>
<td></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</td>
<td>(90°-45°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall squats</td>
<td>10 x 3</td>
<td></td>
<td>Left unilateral 10 x 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left lateral dips 4° step</td>
<td>5 x 3</td>
<td>with a mirror</td>
<td></td>
<td></td>
<td></td>
</tr>
<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></td>
<td>Independent 10 x 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single limb stance (SLS)</td>
<td></td>
<td>SLS on a balance pad with ball catch (to fatigue)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Home Exercise Program</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BID: Left quad sets and SLR with ER 10 x 3</td>
<td>X</td>
<td></td>
<td>Add 1x/day right hip bilks and left LAQ with ER and ball squeeze 10 x 3</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>with wall slide 10 minutes</td>
<td></td>
<td></td>
<td>Add 1x/day left hip adduction with red theraband 10 x 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Table 4: Outcome Measures

<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>
<tr>
<td>Functional Activities</td>
<td>Ambulation with axillary crutches, sports activities unable to be assessed</td>
<td>Normal gait, figure-8, shuttle run no difficulty, mild decreased dynamic balance with hopping activities</td>
</tr>
</tbody>
</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 recovery process.
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.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.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.31,33,34

The recent study by Herrington32 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 al35 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.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.33,34 In the past few years, studies utilizing electromyography (EMG) have demonstrated that taping improves the timing of the firing of the VMO.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.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.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.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.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.31,33,34 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.

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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.2 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 al7 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 quadruped 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”

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 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 rotation is occurring, in this case the left side. (Figure 5 demonstrates the therapist giving a cue while placed 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 rolling to the right and rolling to the left.

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”

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 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 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 facilitatory 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. 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-

Figure 8. Quadruped with tubing to facilitate scapular control/stability.

Figure 9. Quadruped with tubing to facilitate core/scapular/pelvic stability.

Figure 10. Assisted rolling supine to prone, left upper extremity led. Note the use of a half foam roll behind the trunk for assistance.
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 mnemonic 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.11,14,15 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 literature11,14,15 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 risk24 is decreased. If peak values occur during the initial stages of landing, previous studies would be supported by sug-

gesting that peak values occur at angles of knee flexion that are associated with increased ACL injury risk. However, if peak values do not occur during the initial phase of landing, it would suggest that the methods 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 and strain, namely, degree of knee flexion. Therefore, it is important to determine when peak values of key biomechanical variables that have been linked to injury (knee valgus angle, VGRF) occur relative to knee flexion angles during the landing cycle.

Additionally, although several studies have investigated the effect of sex (male vs female)11-15 and fatigue12,21-25 on the biomechanics of landing, none have described if differences exist in the angle of knee flexion at peak values relative to sex and fatigue. Such differences may influence the interpretation of data to date and future data. For example, if women have a peak value which is significantly higher than men, but the peak value for women occurs much later in the cycle than the peak value for men, direct comparison of these values for injury risk may be not be valid given the influence of knee joint angle on ACL forces and relative function of various muscles about the knee. Therefore, this study will also examine differences in knee flexion at the occurrence of peak biomechanical values relative to sex and fatigue.

Biomechanical variables that have been linked to knee injury by investigators include knee valgus, VGRF, and lower extremity muscle activity (LEMG). In a prospective biomechanical-epidemiological study,26 athletes with higher knee valgus angles during landing were at higher risk of suffering an ACL sprain. High VGRF has been linked to injury risk as the forces are being transferred up the kinetic chain, thereby, increasing the moments and forces in the joints.27 Strong contractions of the quadriceps muscles have been shown to increase anterior translation of the tibia and place increased demands on the ACL9,28 while hamstrings muscle contractions reduce the force within the ACL.9 Most ACL injuries occur during closed kinetic chain activities with the foot planted and the quadriceps muscles eccentrically contracting such as during landing from a jump or cutting.
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.32,33 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 muscle32,34-36 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.31

**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)38,39 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).

**Figure 2.** Occurrence of peak values in the landing cycle: non-fatigued males

**Figure 5.** Occurrence of peak values in the landing cycle: fatigued females

**Figure 3.** Occurrence of peak values in the landing cycle: fatigued males

**Figure 6.** Knee flexion angle at occurrence of peak vertical ground reaction force

**Figure 4.** Occurrence of peak values in the landing cycle: non-fatigued females

**Figure 7.** Knee flexion angle at occurrence of peak lateral hamstring muscles normalized electromyographic amplitude
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 hamstring 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. 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 fatigu ing 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 quadricep 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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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.

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, postero-medial, and postero-lateral 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...
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Reach Foot Touch Down</th>
<th>Stance Foot Alignment</th>
<th>Stance Foot Movement Allowed</th>
<th>Average or Greatest reach</th>
<th>Testing Directions*</th>
<th>Limb Length Measured</th>
<th>Attempts allowed / trials</th>
<th>Shoes on / off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray*</td>
<td>1A†</td>
<td>No, within 3 inches of test vector</td>
<td>Varied to direction of reach</td>
<td>No</td>
<td>Greatest of 3 trials (cm)</td>
<td>A, AM, M, P, PL, L</td>
<td>No</td>
<td>Not specified</td>
<td>Pictured with shoes on</td>
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<tr>
<td>Kinsey and Armstrong*</td>
<td>20</td>
<td>No</td>
<td>Center box</td>
<td>No</td>
<td>Average of 3 greatest reach</td>
<td>AM, PL</td>
<td>No</td>
<td>5</td>
<td>Not controlled</td>
</tr>
<tr>
<td>Hertel et al*</td>
<td>16</td>
<td>Yes</td>
<td>Center of grid</td>
<td>No</td>
<td>Average of 3 greatest reach</td>
<td>AM, M, P, PL, L, AL</td>
<td>No</td>
<td>1 practice followed by 3 trials</td>
<td>Pictured with shoes on</td>
</tr>
<tr>
<td>Earl and Hertel*</td>
<td>10</td>
<td>Yes</td>
<td>Varied to direction of reach</td>
<td>Not specified</td>
<td>Within 1 min of precision</td>
<td>A, AM, P, PL, L, AL</td>
<td>No</td>
<td>6 practice / 5 trials / last 3 marked</td>
<td>Pictured with shoes on</td>
</tr>
<tr>
<td>Cimneci et al*</td>
<td>40</td>
<td>Yes</td>
<td>Center of grid</td>
<td>No</td>
<td>Average of 3 greatest reach</td>
<td>A, M, P</td>
<td>No</td>
<td>6 practices / then till 3 good reaches met</td>
<td>Pictured with shoes on</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, AM, P, PL, L, AL</td>
<td>Yes/ASIS to medial malleolus</td>
<td>6 practice / 3 trials</td>
<td>Pictured with shoes on</td>
</tr>
<tr>
<td>Gribble et al*</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</td>
<td>6 practice / 3 trials</td>
<td>Pictured with shoes on</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, AM, P, PL, L, AL</td>
<td>Not normalized to height</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>A, AM, P, PL, L, AL</td>
<td>Yes / ASIS to mid medial malleolus bilateral</td>
<td>6 practice / 3 trials</td>
<td>With the shoes on</td>
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<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, PL, P</td>
<td>Inferior aspect of ASIS to distal lateral malleolus, after closing of the hips</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>A, AM, M, P, PL, L, AL</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>
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<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, PL, L</td>
<td>Not specified</td>
<td>6 practice (center to tapping) / 3 trials</td>
<td>Shoes off</td>
</tr>
<tr>
<td>Bressel et al*</td>
<td>34</td>
<td>Yes</td>
<td>Middle of grid with center of foot on small dot</td>
<td>Cited &quot;as Gribble&quot;</td>
<td>Avg of 3 trials (cm &amp; mm used)</td>
<td>A, AM, P, PL, L, AL</td>
<td>Yes/ASIS to medial malleolus (nearest mm) Both lower extremities</td>
<td>6 practice / 3 trials</td>
<td>108 seconds of practice prior to testing, 3 trials</td>
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<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, AM, P, PL, L, AL</td>
<td>Yes / Gribble*</td>
<td>6 practice / 3 trials</td>
<td>Not specified</td>
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<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, AM, P, PL, L, AL</td>
<td>Yes / Gribble*</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 malleolus bilateral</td>
<td>6 practice / 3 trials</td>
<td>Not specified (cinematic markers placed)</td>
</tr>
<tr>
<td>English and Happe*</td>
<td>3</td>
<td>Methods cited as Kinsey 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 anterolateral; Left anterolateral; Left posterior; Left anterior (M, PL)</td>
<td>Not specified</td>
<td>6 practice / 3 trials</td>
<td>Pictured with shoes on</td>
</tr>
<tr>
<td>Halle et al*</td>
<td>67</td>
<td>Yes</td>
<td>Not specified</td>
<td>Not specified; hands on hips</td>
<td>Mean of 3 trials (unit not specified)</td>
<td>A, M, AM, P, PL, L, AL</td>
<td>Not specified</td>
<td>6 practice / 3 trials</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

*A= Anterior, AM= Anterior, 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.1 Hertel et al17 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 other’s 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 subjects 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
TABLE 3: Intrarater reliability (one rater) for the right stance limb for the Y Balance Test™

<table>
<thead>
<tr>
<th></th>
<th>ICC* (3,1)</th>
<th>95% CI</th>
<th>SEM (cm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>0.88</td>
<td>0.69-0.96</td>
<td>2.01</td>
</tr>
<tr>
<td>Postero medial</td>
<td>0.85</td>
<td>0.62-0.95</td>
<td>2.83</td>
</tr>
<tr>
<td>Posterolateral</td>
<td>0.86</td>
<td>0.64-0.95</td>
<td>3.11</td>
</tr>
<tr>
<td>Composite</td>
<td>0.89</td>
<td>0.69-0.96</td>
<td>5.84</td>
</tr>
</tbody>
</table>

* Intraclass correlation coefficient
† 95% confidence interval
pre-participation physicals and rehabilitation sessions with a large variety of footwear, often not appropriate for sport. Future studies should utilize a similar, standardized testing protocol so that results may be compared across studies. In addition, only one limb (right) was measured twice by the first rater.

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
ABSTRACT

This clinical commentary outlines a new clinical model for anterior cruciate ligament (ACL) rehabilitation, the Knee Symmetry Model. This model has been developed by clinical observation, patient interaction, and by analyzing outcome measures derived from prospective follow-up of patients. More specifically, the best outcome scores occurred in patients with symmetric range of motion and strength. A thorough discussion of the details involved in the development and implementation of this rehabilitation program for this patient following ACL reconstruction is described. Included in this description is the supporting evidence and clinical rationale behind pre-operative and post-operative ACL rehabilitation. Preliminary results from a recent group of patients are presented. When using the Knee Symmetry Model 100% of patients achieved normal knee extension and 97% of patients achieved normal knee flexion.

Key Words: ACL rehabilitation, pre-operative rehabilitation, post-operative rehabilitation

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INTRODUCTION
Rehabilitation of patients following anterior cruciate ligament (ACL) surgery has evolved dramatically over the last several decades. During this time, clinicians have gradually changed their approach from absolute immobilization and no muscle activity to minimal range of motion (ROM) restrictions with immediate muscle activation following surgery. Although ACL post-operative rehabilitation has continued to evolve, relatively minimal literature is available outlining the precise nature of ACL rehabilitation. The authors of this report have focused their clinical practice entirely on knee injuries and, through this focus, have developed a new model for ACL rehabilitation, the Knee Symmetry Model.

Current articles on ACL rehabilitation are few or lack the proper detail necessary for a practicing clinician to fully implement the rehabilitation program. Even those articles where rehabilitation is the primary focus of the study do not give full descriptions of the details involved with ACL rehabilitation. Therefore, clinicians are left with insufficient detail when attempting to implement a rehabilitation program outlined in the literature. More specifically, most articles in the current literature focus on the details involved with strength training while ROM is not focused upon. Through research and data collection, ROM appears to be the primary issue involved in excellent outcomes following ACL reconstruction. To date, other articles within the literature are infrequent that specifically focus on the ROM part of the rehabilitation process.

The authors have been able to develop the Knee Symmetry Model for ACL rehabilitation in part due to the utilization of the same graft with the same surgical approach and the same graft fixation for the past 25 years. Therefore, because the surgical procedure has been constant, the primary variable observed in patient outcomes is the rehabilitation. The surgical procedure used in this center is an ACL autograft with bone-patellar tendon-bone. While most surgeons have changed their surgical procedure, this center has maintained the same graft source, the same graft fixation, and the same surgical approach, thus, allowing changes in patient outcomes to be observed as a result of changing the rehabilitation program. Given that the graft source, fixation, and surgical approach have not changed, the focus has been on refining the rehabilitation program.

Outcomes have helped identify that patients who achieve symmetrical ROM and strength have better subjective and objective outcomes, regardless of meniscal or articular cartilage damage found at the time of surgery. Physical therapists do not have control over the surgeon or patient's choice of graft selection, but do play an important role in the patient's ability to achieve symmetrical ROM. Understanding the importance of symmetrical ROM makes it the most important factor in the rehabilitation process, regardless of graft choice or the surgical procedure. The Knee Symmetry Model provides an outline to achieve this goal of full ROM. The goal of the rehabilitation program should be symmetrical ROM and the surgical procedure performed should allow the physical therapist the best opportunity to restore the patient’s knee to symmetrical ROM and strength. Although the basic principles of rehabilitation outlined in this report apply to all grafts, the specific details of rehabilitation along with the outcomes reported are based on the knee symmetry model following an ACL reconstruction performed with a patellar tendon graft.

SURGICAL APPROACH
Both contralateral (CBPTB) and ipsilateral (IBPTB) bone patellar bone ACL autografts are utilized in this center. The CBPTB and IBPTB surgical procedures have been described in depth elsewhere. The CBPTB can be used as a primary procedure or to revise a previous ipsilateral reconstruction. Critical elements of the CBPTB and IBPTB surgical procedures include proper graft placement in the tibial and femoral tunnels, full knee ROM (hyperextension and flexion) after the graft has been placed and tensioned in the tibial and femoral tunnels, and accommodative fixation (sutures tied over buttons) of the graft in the tibial and femoral bone tunnels. The graft needs to be tight enough to provide stability but loose enough to allow for full knee ROM in the operating room. If the knee is not able to go through a full ROM once the graft is tensioned, post-operative rehabilitation programs designed to restore symmetric ROM may result in decreased knee stability or leave the patient with the inability to achieve symmetrical ROM. Therefore, the authors recommend a thorough discussion with the referring surgeon when implementing this program.

REHABILITATION PHILOSOPHY
As our knowledge of the patient’s response to this surgery has grown, an increased emphasis has been placed on restoring the surgical knee to the pre-injury status. To fully accomplish this goal, the clinician is asked to restore
bilateral knee symmetry. Most clinicians believe that early elimination of pain and inflammation in the injured knee is critical to achievement of knee symmetry in patients. However, the rehabilitation approach should also include bilateral knee symmetry in terms of ROM, strength, stability, and function as soon as symptoms allow. Principles of treatment begin pre-operatively and continue until complete knee symmetry is achieved post-operatively. Once knee symmetry is achieved post-operatively, the patient is discharged from formal rehabilitation; however, each patient is followed closely after discharge from formal rehabilitation. It is only through patient follow-up that the long-term results of surgery and rehabilitation have been observed and rated. Failure to perform follow-up evaluations on patients leads to an inaccurate understanding or a misinterpretation of results.

Therefore, our rehabilitation philosophy has been shaped by frequently analyzing the patient's post-operative status. Each and every patient is strongly advised to follow up on regular intervals including 1, 2, 4, and 6 months and at the first, second, fifth, tenth, and twentieth year post-operatively. This information is entered into the center's database so that all patient outcomes can be analyzed together. The understanding gained from the long-term follow up of patients has guided the establishing principles of rehabilitation within this program. This program has developed based on long-term research and data collection that recognizes the importance of obtaining knee symmetry, most importantly symmetrical ROM, as a means to provide the patient with optimal short and long-term outcomes.

**PRE-OPERATIVE REHABILITATION**

Patients are evaluated by the physician and physical therapist at the time of their initial appointment. The physician makes the medical diagnosis, and the physical therapist performs an initial examination by observing and measuring all elements of knee symmetry. Patients are taught a home rehabilitation program for each component of the knee symmetry model. Although an emphasis on a home program requires fewer visits to physical therapy, each visit is quite comprehensive. Emphasis is placed on educating patients and their families about the goals of rehabilitation. The primary goal, knee symmetry, is stressed repeatedly during the pre-operative period. Once the patient has achieved the specified goals and is able to demonstrate the ability to perform the exercises, they are approved for surgery.

Patients are required to reduce the inflammation and swelling in the involved limb prior to surgery. They are instructed to utilize ice, compression, and elevation 3-4 times per day until the inflammation and swelling are eliminated. During the pre-operative period patients are instructed to refrain from competitive sports; however, they are not specifically restricted from their normal daily activities.

Restoring complete passive ROM pre-operatively is a key to the entire rehabilitation program. Included in the knee ROM is bilaterally symmetric motion, which, in most patients, includes a component of hyperextension and knee flexion. Passive knee extension is measured with the patient lying supine with the heel propped on a bolster to allow the knee to fall into hyperextension (Figure 1). Passive knee flexion is also measured in supine (Figure 2). Both a quantitative (measurement) and qualitative (end

**Figure 1. Knee hyperextension measurement**

**Figure 2. Knee flexion measurement**
feel) approach is utilized for assessment of motion. Measurement is performed and recorded in a hyperextension/extension/flexion format. If a patient has 5 degrees of hyperextension and 135 degrees of flexion their measurement is recorded as 5/0/135. If a patient has lost 5 degrees of extension from 0 degrees neutral, the measurement is recorded as 0/5/135. Likewise, the end feel for hyperextension is observed quite meticulously by the physical therapist (Figure 3). It is not until both the end feel and the measurement of hyperextension are symmetrical that surgery is an option. Each physical therapist has performed a reliability test for both knee extension (hyperextension) and knee flexion. Previously the authors reported interrater intra-class correlation (ICC) values for knee extension (.88) and flexion (.99) and intrarater reliability for knee extension (.95) and flexion (.99).12

As the inflammation, swelling, and knee ROM are improved, neuromuscular re-training is initiated pre-operatively. Patients are taught leg control activities like quad sets and leg raises, and instructed how to walk with a normal gait pattern. Patients may resume low impact activities and weight training if they desire, but these activities are not required pre-operatively. Before surgery, each patient is tested for quadriceps and hamstring muscle strength isokinetically at 60° and 180° per second. Both single leg hop and unilateral leg press are measured pre-operatively and used as post-operative strength goals as well. The strength measures obtained on the uninjured knee are utilized as a post-operative goal for both knees.

Knee function is measured with both the modified Noyes and International Knee Documentation Committee (IKDC) subjective outcome instruments.13 Each patient is given these instruments pre-operatively and at regular intervals post-operatively.

**IMMEDIATE POST-OPERATIVE REHABILITATION**

When CBPTB surgery is performed, both knees of the patient must be addressed in the rehabilitation process. Although a rehabilitation program must be applied to each patient’s knee, the goals for each knee are somewhat different. On the graft-donor knee (contralateral knee), ROM is easily achieved and allows the clinician to focus on strength within the first 1-2 days post-operative. While on the ACL-reconstructed knee (ACL injured knee) the focus is on ROM, not strength. By performing surgery in this manner, the rehabilitation clinician is able to concentrate on the most important goals for each knee and minimize the post-operative complications. It is only through the process of performing surgery and rehabilitation on BOTH knees that the importance of goals and expectations for the two types of surgery (the ACL reconstruction and the graft-donor site) have been more completely understood. The rehabilitation program for each knee will now be outlined in detail.

**ACL-Reconstructed Knee (ACL Injured Knee) – CBPTB or IBPTB**

*General Guidelines*

During the immediate post-operative period, patients are hospitalized overnight to assure proper pain and swelling control is obtained. Patients are given ketoralac intravenously, placed on a continuous passive motion (CPM) machine, and provided with a cold/compression device (Cryocuff™, DJ Orthopaedics, Vista, CA).

Ketoralac, a prostaglandin inhibitor, is used both pre-operatively and post-operatively. Patients are given 30mg intravenously pre-operatively and started on a continuous drip post-operatively. The continuous drip consists of 90 mg of ketoralac in 1L of normal saline solution over a 23-hour period. Ketoralac is combined with a local injection of .25% Marcaine and, when combined with the ketoralac, provides patients with excellent post-operative pain relief.14 A thin waterproof dressing is applied over the incision sites and drains are placed in bilateral knees for the first 23 hours to help minimize a hemarthrosis. Thromboembolic compression stocking are placed on both legs and worn during the first week of bedrest. A cold/compression device is also immediately initiated in the operating room and utilized continually for the first week post-operatively.
The patient’s ACL-reconstructed knee is placed in a CPM machine immediately after surgery. The primary purpose of the CPM machine is to elevate the knee above the level of the heart to help minimize post-operative swelling. Secondarily, the CPM machine provides gentle passive ROM to the ACL-reconstructed knee and is set to move from 0-30 degrees of knee flexion continuously throughout the first week after surgery. The patient is instructed to remain supine with the leg elevated and placed in the CPM continuously during the first week after surgery.

Throughout the first week after surgery the patient is placed on bed rest with bathroom privileges in order to minimize swelling and maximize ROM. The avoidance of activity is an important, but a misunderstood concept developed after the initial “Accelerated Rehabilitation after ACL Reconstruction” article in 1990. The authors believe that bed rest during the first week post-operatively allows the patient to more readily achieve the post-operative goals for each knee. More specifically, bed rest decreases swelling in the patient’s ACL-reconstructed knee allowing for a much quicker return of ROM. Patients are instructed to have a caregiver in place to reduce their overall activity level and permit the patient to focus on their rehabilitation during the first week post-operatively. This plan, when strictly adhered to, greatly diminishes the amount of inflammation and swelling in either knee, which facilitates an earlier restoration of knee symmetry.

**Range of Motion**

Immediately after surgery and while in the hospital, the patient is asked to initiate ROM activities for hyperextension and flexion four times per day. Knee hyperextension is obtained via heel prop exercises (Figure 4), towel stretch exercises (Figure 5), and active hyperextension (Figure 6) while knee flexion activities during this period include active and active-assisted heel slide exercises (Figure 7). Goals for discharge from the hospital include symmetrical knee hyperextension and 125 degrees of knee flexion. It is important to emphasize that ROM is unlimited during the initial phase of rehabilitation post-operatively. The only limit on obtaining symmetric ROM is patient tolerance. Most patients lose some of their initial ROM after they are

**Figure 4.** Heel props

**Figure 5.** Towel stretches

**Figure 6.** Active hyperextension

**Figure 7.** Heel slides
discharged. However, the psychological effect of knowing near full ROM has been achieved immediately post-operatively is helpful in obtaining full ROM.

Strength
Following surgery, strength training for the ACL-reconstructed knee is not formally emphasized. Too frequently, an aggressive strengthening program for the patient's ACL-reconstructed knee leads to increased inflammation and loss of ROM, which is counter productive. However, proper quadricep muscle activation is emphasized in order to have good leg control for ambulation. This quadriceps muscle activation is achieved through quad set exercises and active hyperextension. The same program is followed for both the CBPTB and IBPTB surgical procedures.

Graft-Donor Knee (Contralateral Knee)
Range of Motion
When a CBPTB procedure is performed, both of the patient's knees must be rehabilitated. During the initial post-operative period ROM in the graft-donor knee is addressed by the same methods utilized on the patient's ACL-reconstructed knee. Knee hyperextension activities (heel prop, towel stretch, active hyperextension) are performed along with heel slide exercises for knee flexion several times per day.

Strength
The patient's graft-donor knee easily achieves normal ROM. Due to the nature of the graft harvest procedure, no effusion occurs in the graft-donor knee which allows for an easier restoration of ROM. Once normal ROM has been achieved on the graft-donor knee, focus is placed on tendon regeneration during the immediate post-operative period. Beginning on the day after surgery each patient performs resisted leg press activities on the graft-donor knee. A unilateral leg press machine (SHUTTLE, Contemporary Design Company, Glacier, WA) adapted for in-bed resisted activity is utilized for the first two weeks post-op (Figure 8). Patients are taught to perform up to 100 repetitions with 7 pounds before increasing resistance on the leg press machine. Leg press activities are performed four times per day during this period. Patellar tendon discomfort is expected due to the active work performed by the patellar tendon. However, patients are cautioned to avoid ROM loss at the expense of patellar tendon strengthening. Early patellar tendon hypertrophy can be observed and is encouraged with these patients.

Both Knees – Function
Patients are instructed to remain supine with the ACL reconstructed leg elevated in order to minimize swelling. The patient may shower and have restroom privileges. Gait is evaluated on the second day and patients are instructed to ambulate full weight bearing with proper weight shift and heel strike. It is rare for a patient to be unable to perform this, however, if the patient is having difficulty with quadriceps activation and is unable to safely bear his/her weight, he/she is given an appropriate assistive device. However, most all patients are able to begin ambulating without an assistive device day two post-operatively. Bathroom privileges are available to the patient for the first week after surgery, but ambulation or standing for long periods is strongly discouraged.

INTERMEDIATE POST-OPERATIVE REHABILITATION
Following the immediate post-operative phase of rehabilitation, an intermediate phase is implemented. During this phase the goals are to rehabilitate both knees of the patient symmetrically to their pre-operative values. No time lines are used for achievement of these goals. Each patient is progressed according to his or her own healing progression. Once inflammation and swelling have been eliminated and full symmetrical ROM is achieved, strength training is increased to tolerance, and functional training for returning to sports can occur. Single-leg strengthening is emphasized during this period secondary to the strength differences between limbs. Double leg activities are discouraged because they reinforce the stronger limb. It must be emphasized that no time constraints exist on rehabilitation. When a patient
has achieved symmetrical knee ROM and leg strength, and is ready to resume a given activity, he or she is encouraged to participate. Initial participation includes drills and skill development. As the patient progresses, a complete functional progression adapted for the patient's sport is incorporated into the rehabilitation program. No pre-set time frame is used for return to any activity. Typically, patients can return to sport anywhere from 2 – 6 months post-operatively depending on their functional progression.

Specifics of the Intermediate Phase
After the first week post surgery, patients are allowed to resume normal activities of daily living. If a CBPTB procedure is performed, patients are instructed to continue with an exercise program that focuses on ROM in the ACL-reconstructed knee and strengthening (or graft stimulation) in the graft-donor knee. Patients who undergo IBPTB procedures must maintain full knee ROM while emphasizing strength training on the surgical knee.

ACL-Reconstructed Knee
Patients are instructed to continue with exercises that focus on increasing both passive and active ROM. These include towel stretches, heel props, heels slides, and wall slides. All exercises are performed approximately three times per day. Patients are asked to monitor knee ROM during the second week post-operatively. As long as his/her knee ROM continues to improve, no limitations or restrictions in activities of daily living (ADL) are implemented. By restoring early ROM and encouraging normal use of the patient's ACL reconstructed knee, proprioceptive and neuromuscular control is quickly restored and obtained through normal ADLs. Obtaining symmetrical knee ROM (including hyperextension and flexion equal to the opposite knee) is the primary goal for the patient's ACL-reconstructed knee during the remainder of the rehabilitation process.

When an IBPTB procedure is utilized, the patient must also focus on strength training as outlined in the next paragraph. However, it must be emphasized that strength development is secondary to gaining and maintaining symmetrical knee ROM. If decreases in ROM or increases in pain or swelling are observed in the patient's knee, he or she is instructed to decrease the strength training portion of rehabilitation until ROM and swelling are normalized.

Graft-Donor Knee
The graft-donor knee should have full ROM after the first week. This allows the patient and clinician to focus on graft stimulation and strengthening until normal strength has returned. Strengthening is accomplished with low load, high repetition exercises including step down exercises, single leg press, and unilateral knee extension exercises. During this phase, it is common and normal for the patient to experience tendon soreness and discomfort until the tendon has regenerated. Continued stretching and cryotherapy help control the soreness until the tendon is regenerated and knee strength is restored.

Beginning at one month after surgery, patients will continue to undergo strength and functional testing every month until their goals are achieved. Both isokinetic testing (strength testing) and hop testing (functional testing) are performed during this time frame. When patients achieve appropriate knee ROM, they are encouraged to participate in low impact activities such as the bike or elliptical trainer. Both of these exercises assist in increasing strength and cardiovascular endurance. Patients are also allowed to begin light agility activities (shooting baskets, dribbling the soccer ball, foot work, etc.). As long as ROM continues to improve and minimal knee swelling occurs, patients can continue to participate in drills and agilities. Regardless of what time after surgery the patient achieves knee symmetry (symmetrical ROM and strength), he or she is released to begin participating in practice drills and competition. During this time period, it is normal for patients to experience soreness and swelling. Patients need to be educated on how to manage the soreness and swelling without losing ROM because ROM is an important factor in providing the best short- and long-term outcome. Activity modification or days of rest when first returning to full practice or competition may be required if ROM shows signs of decreasing.

OUTCOME MEASURES
Each patient is evaluated in several ways. Objective measures for ROM, strength, and stability, and subjective questionnaires are utilized. Range of motion is measured and recorded at each physical therapy visit. Beginning at one month after surgery, isokinetic testing of quadriceps and hamstring muscle strength at 60 degrees and 180 degrees per second is performed bilaterally through a full ROM (0 degrees to 95 degrees). The single leg press test and single leg hop test are also used as outcomes measures.
during the intermediate phase of rehabilitation. The KT-2000 is utilized to measure the amount of anterior excursion of the tibia with 68N, 89N, 133N, and manual maximum force. Each of these measures (ROM, strength, KT-2000) is recorded at the month 1, 2, 4, and 6 evaluation, and at 1, 2, 5, 10, and 20 years post-operatively, when possible. Not all patients are able to return for each of these long-term follow up visits. However, even when patients are not able to return for a clinic visit, they are asked to fill out the subjective questionnaires in an online or paper format.

Tables 1 to 4 outline the objective measures and outcome instruments for a recent group of patients. These tables represent the one year or more post-operative outcomes for patients who underwent a contralateral bone-patellar tendon-bone autograft ACL reconstruction from 2003 to 2006. The mean subjective scores on the IKDC outcome measure are within the established age-specific norms for this instrument.

Table 1 represents the passive ROM measurements. The outcome instrument used is the IKDC objective survey. This outcome instrument defines normal ROM as a side to side difference of less than 2 degrees of knee extension and less than 5 degrees of knee flexion when compared to the uninvolved knee. The results indicate that equal side to side measurements provide the best long term outcome. In Table 1 the authors have outlined that the vast majority of patients achieve “normal” ROM as defined by the IKDC criteria.

Table 2 reports that the subjective and objective knee scores from two outcome instruments (IKDC and modified Noyes). Although a cohort group does not exist to compare the results, the scores reported are within the age-adjusted “normal” scores.

Strength is reported in Tables 3 and 4 for each knee separately.

Secondary to the type of surgery performed (CBPTB and IBPTB) both knees were compared to the pre-operative values of the uninjured knee. The patient’s ACL reconstructed knee was compared to the patient’s graft-donor knee. Additionally, information was reported as a frequency distribution to allow the reader to observe the percentage of scores within a given range. This table further outlines the principle of specific rehabilitation for the ACL reconstructed knee and graft-donor knee discussed earlier. A majority of the ACL reconstructed knees were able to achieve 80-100% strength when compared to the graft knee and when compared to the pre-operative value at both 60 degrees and 180 degrees/sec.

DISCUSSION
Rehabilitation of the patient following ACL reconstruction has continued to change over the last decade from the “Accelerated Rehabilitation after ACL Reconstruction” program outlined in 1990 to the more current Knee Symmetry Model. The Knee Symmetry Model, which was developed in response to outcome research, emphasizes the return of two normal knees. When compared to the 1990 paper, specific differences that should be emphasized include the symmetric knee concept, the elimination of time frames as post-operative guidelines, unrestricted knee ROM immediately, strict bed rest for the first five days post-operatively, and specialized rehabilitation for the graft-donor knee and the ACL-reconstructed knee.

The Knee Symmetry Model has evolved after observing long-term outcomes. Patients who achieved symmetrical knee ROM had better subjective and objective outcomes as compared to those patients who did not achieve symmetrical ROM. With further analysis, the complication rate for patients with ACL reconstructions was less frequent and less severe in patients who
obtained knee symmetry sooner post-operatively. The CBPTB surgery further assisted in this process by identifying the different emphases needed for the ACL knee and the graft-donor knee. Understanding the necessary goals for each knee helped in establishing a rehabilitation program directed in restoring knee symmetry as quickly and as safely as possible.

Speculation exists in the literature that ACL reconstruction may lead to a long-term outcome of knee osteoarthritis. Through 26 years of research, patients who achieve symmetrical knee ROM have less chance of developing arthritic changes. (Shelbourne KD, unpublished data 2007) Therefore, the Knee Symmetry Model along with the use of the contralateral graft provides the patient with the best opportunity to restore normal knee ROM with predictable stability. Given that many patients who undergo ACL reconstruction are in their teens and early 20’s, it remains an important factor to provide these patients with not only the return to their current sport but to also provide them with a good outcome 20 years after surgery.

Although other authors present and discuss ROM deficits in their papers, the interpretation of their results in a comparison with this paper is difficult secondary to a lack of specific methods of measurement provided by other authors. Additionally, the authors are not aware of other articles citing reliability of the extension (hyperextension) and flexion measures in their studies. Given that ROM measurements are a central issue in the rehabilitation of a patient after ACL surgery described in this report, the authors have attempted to address both of these issues in order to capture their ROM measures in a repeatable fashion. Other investigators may use the same or similar methods of measurement for extension (hyperextension) and flexion, but their methods are not described and verified with a reliability study. Secondary to a lack of uniformity within ROM measurement following knee surgery, it is difficult to compare ROM results of one study with another.

The IKDC information (Table 2) presented in this paper is in keeping with published age-specific normative data. Although the results of this paper are early (1-3 years), the

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**Table 3. Frequency Distribution for Quadriceps Muscle Strength at 60°/second (n=228)**

<table>
<thead>
<tr>
<th>Percentile</th>
<th>ACLR vs. Graft</th>
<th>ACLR vs. Pre-op</th>
<th>Graft vs. Pre-op</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-59%</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>60-79%</td>
<td>5</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>80-100%</td>
<td>95</td>
<td>88</td>
<td>79</td>
</tr>
</tbody>
</table>

*Percentile = Side to Side Difference  
*ACLR = ACL-reconstructed knee  
*Graft = Graft-donor knee  
*Pre-op = Pre-operative value for the uninjured knee

---

**Table 4. Frequency Distribution for Quadriceps Muscle Strength at 180°/second (n=228)**

<table>
<thead>
<tr>
<th>Percentile</th>
<th>ACLR vs. Graft</th>
<th>ACLR vs. Pre-op</th>
<th>Graft vs. Pre-op</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-59%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>60-79%</td>
<td>4</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>80-100%</td>
<td>96</td>
<td>93</td>
<td>91</td>
</tr>
</tbody>
</table>

*Percentile = Side to Side Difference  
*ACLR = ACL-reconstructed knee  
*Graft = Graft-donor knee  
*Pre-op = Pre-operative value for the uninjured knee
results are quite promising, and intermediate and long-term results will be published as they become available. Early results also show that ROM (Table 1) is very acceptable. When using the IKDC format for reporting ROM, patients do not have difficulty maintaining their ROM in either knee. While the strength results reported in Table 3 and 4 shows a decrease in strength at the 60 degrees/second testing speed with the graft-donor knee, the 180 degrees/second speed is very acceptable for both knees. We believe that the 60 degrees/second strength deficit in the graft-donor knee further outlines the belief that the primary goal for the graft-donor knee is to improve strength. Interestingly the patient's ACL reconstructed knee did not have any problems maintaining their strength long-term. This result further outlines that the primary goal for the patient's ACL reconstructed knee is to achieve full ROM.

Some clinicians appear to be fearful of gaining knee symmetry following knee surgery, but, to restore any joint to equilibrium, the clinician should strive for normal ROM and strength. Previous data from this center demonstrated that patients who failed to achieve symmetrical ROM were unable to achieve symmetrical strength. Additionally, those patients who did achieve symmetrical ROM had better strength scores. Therefore, obtaining symmetrical ROM allows the patient to restore normal strength and ultimately normal function. A stiff knee can be strengthened but never achieves symmetrical and normal strength, leaving the patient with a less than optimal outcome. Knee stability and symmetric ROM can be restored post-operatively without compromising either of these goals. The vast majority of patients who have had ACL reconstructions, contralateral and ipsilateral grafts, have symmetric ROM and a stable knee. In the patient sample of 228 patients (mean age 22.8 years), 221 (97%) obtained full knee ROM and had a mean manual maximum KT-2000 value of 1.8 mm. Therefore, the goals of symmetric ROM and knee stability are not conflicting, and represent what the goal should be for patients following ACL reconstructive surgery.

The understanding of rehabilitation following ACL reconstruction has been enhanced by the large number of patients who receive a contralateral graft. The observation of patients following an ACL reconstruction with a contralateral graft has allowed the analysis of the two elements of surgery individually. Instead of the patient's ACL reconstruction and the graft-donor being on the same knee, these components of the surgical procedure are on different knees. Thus, each knee has one component of the procedure. The problem-solving gained from observing the patient's graft-donor knee and the ACL-reconstructed knee in large volumes of patients has led to the understanding of varying goals for each surgical component.

CONCLUSIONS

This clinical commentary outlines a philosophy of care and a new rehabilitation program following ACL reconstructive surgery. Data collected shows that patients who achieve symmetrical knee ROM have better subjective and objective outcomes. The knee symmetry model provides a means and description to achieve these results. Specific principles of the program that facilitate achieving knee symmetry include the following: elimination of time frames as post-operative guidelines, unrestricted ROM immediately, bed rest for the first week post-operatively, and specialized rehabilitation for the patient's graft-donor knee and the ACL-reconstructed knee. The knee symmetry model produces results that provide patients with the best short- and long-term outcomes while minimizing post-operative complications following ACL reconstruction.

REFERENCES


ABSTRACT

Background. Optimal athletic performance may be dependent upon an athlete maintaining adequate iron levels through the consumption of dietary forms of iron and subsequent metabolism. Endurance athletes, especially female distance runners, have been identified as being at risk for developing iron deficiency. While iron deficiency is treatable, early diagnosis may be delayed if an adequate medical history and evaluation is not conducted.

Objective. To describe the evaluation, diagnosis, and comprehensive sports medicine treatment of a collegiate cross-country athlete with a medical diagnosis of iron deficiency with anemia and sports-related musculoskeletal pain.

Case Description. A 21-year-old female collegiate cross-country athlete experienced a decline in her running performance beginning her freshman year of school. She continued to experience degradation in sports performance despite medical intervention. Two-and-a-half years after initially seeking medical attention she was diagnosed with iron deficiency with anemia by a primary care medical doctor. Additionally, the subject required rehabilitation due to the onset of sports-related musculoskeletal symptoms.

Outcomes. Comprehensive treatment for this patient consisted of iron supplementation, therapeutic exercises, manual therapy, and modalities. The athlete was able to compete during her entire cross-country season and earn All-American status at the Division-III level.

Discussion. Sports medicine professionals must consider iron deficiency as a possible differential diagnosis when evaluating endurance athletes. Subtle signs of iron deficiency may, unfortunately, be overlooked ultimately delaying treatment.

Key Words: iron deficiency with anemia, cross-country, iron supplementation

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INTRODUCTION
Consumption of dietary iron is necessary for optimal human cellular metabolism and growth. An individual who consumes a diet that is deficient of iron rich foods or who experiences depletion of iron stores may experience symptoms ranging from fatigue to degradation in physical performance. Iron deficiency is the number one nutritional deficiency affecting billions worldwide. Iron deficiency with anemia affects between 1% to 2% of all adults in the United States and is estimated to globally affect 0.5 to 0.6 billion people. In addition, up to 20% of Americans may suffer from iron deficiency without anemia with an estimated 1 to 1.8 billion suffering this condition worldwide.

Optimal athletic performance is also dependent upon maintaining iron levels through the consumption of dietary forms of iron and subsequent metabolism. The formation of hemoglobin and the body's subsequent ability to transport oxygen from the lungs to the tissues will be impaired in the athlete who is iron deficient. Additionally, athletes who are iron deficient may experience the following symptoms: nausea, frequent infections, shortness of breath during exercise, respiratory illness, fatigue, weakness, pale appearance, lack of energy, and exhaustion.

Endurance athletes, especially female distance runners, have been identified as being at risk for developing iron deficiency. One epidemiological study of endurance runners identified 82% of the female athletes as iron deficient. While iron deficiency is treatable, early diagnosis may be delayed if an adequate medical history and evaluation is not conducted.

The purpose of this report is to highlight a unique case of a collegiate female cross-country athlete who experienced a chronic degradation in her performance due to becoming iron deficient and anemic. Initial medical and allied healthcare evaluations and interventions failed to identify and appropriately treat her iron deficiency with anemia. The athlete continued to train and compete in distance running for both her collegiate cross-country and track teams, despite suffering fatigue and exhaustion. She considered quitting competitive running due to her inability to compete at a high level. Two-and-a-half years after initially seeking medical attention she was diagnosed with iron deficiency anemia by a primary care medical doctor. This case is unique as it details the medical intervention and sports rehabilitation management in the comprehensive treatment of a female collegiate cross-country athlete with a diagnosis of iron deficiency with anemia.

CASE DESCRIPTION
A 21-year-old female cross-country athlete presented at the start of the cross-country season to the athletic training team with a sports-related injury to the left hip and left knee. Her primary musculoskeletal complaint was her inability to complete her training runs without experiencing either left hip or left knee pain. Her primary musculoskeletal complaint was her inability to complete her training runs without experiencing either left hip or left knee pain. The patient was concurrently receiving medical management for iron deficiency anemia by her primary care physician.

Previous History
The patient ran competitively on both her high school cross-country and track teams. She denied any history of sports-related running injuries during her high school career. Her best recorded time in high school for the 5,000-meter run was 19:36 (minutes:seconds). During her freshman collegiate cross-country season she experienced a decline in her running performance that she initially attributed to the intensity of the collegiate training program (Division I) and a “slow” acclimation to her new training environment (school situated at an elevation of 6910 feet or 2106 meters). The subject had previously attended a high school that was situated at sea level.

She described “feeling sluggish throughout the day” and that she required long naps during the day despite sleeping for 8 to 10 hours each night. When running she felt that she was racing “flat,” that she lacked energy during workouts, and that she experienced an increase (a slowing) of her race-pace. Her 5000-meter race time had slowed to 19:58.

In fall of 2006, she sought medical attention to identify a cause for her fatigue related symptoms after the completion of her freshman cross-country season. She also sought medical attention at this time for a new onset of allergies. During the course of several medical consults she was diagnosed by her medical doctor with asthma and hypoglycemia. Initial treatments failed to provide symptom relief and did not affect her athletic performance. She continued to seek medical attention for her sports-related symptoms. She reported that she was tested over the next year-and-a-half three times for mononucleosis and one time for anemia. According to the patient each test was negative. A “nutritionist” offered an unsolicited recom-
mendation to her to increase her protein consumption, but the athlete was not provided any dietary guidance (note: the patient was unaware as to the educational or professional background of the “nutritionist”).

The patient transferred from the Division-I school after two years to a Division-III university in Oregon. Despite the change in training environments (school situated at an elevation of 210 ft or 64 m), she continued to experience her fatigue related symptoms and poor athletic performance. Not long after transferring schools, she began to experience back and left hip musculoskeletal pain. The patient sought chiropractic treatment in order to address her new musculoskeletal complaints. She received several treatments including manipulation of the spine, deep tissue massage, ultrasound, moist heat, and cryotherapy. She continued chiropractic treatment for 6 months despite a lack of improvement.

**Differential Diagnosis**

**Medical Management**

Previous medical evaluations and interventions by allopathic and chiropractic physicians failed to successfully decrease the subject’s symptoms. The subject again sought medical attention in Spring of 2007 after terminating chiropractic treatment. A complete blood count demonstrated low levels of hemoglobin (HGB), hematocrit (HCT), mean corpuscular volume (MCV), and mean corpuscular hemoglobin (MCH) (*Table 1, column 1*). Based upon these values, additional labs were performed 10 days later in order to assess serum iron levels, total iron binding capacity (TIBC), transferrin saturation, and serum ferritin levels (*Table 1, column 2*). Only one lab value, the TIBC, was within the standard reference values. Based upon these results, she was diagnosed with iron deficiency with anemia. The patient was instructed by her medical doctor to begin immediate iron supplementation (see treatment section).

**Musculoskeletal Differential Diagnosis**

At the start of the cross-country season the patient was referred by her coach to the university's athletic training department for treatment of her sports-related musculoskeletal injuries. Despite receiving the medical diagnosis of iron deficiency with anemia (and the initiation of iron supplementation), the patient continued to experience

<table>
<thead>
<tr>
<th>Date</th>
<th>Hemoglobin (HGB) (g/dL)</th>
<th>Hematocrit (HCT) (%)</th>
<th>Mean Corpuscular Volume (MCV) (fL)</th>
<th>Mean Corpuscular Hemoglobin (MCH) (pg)</th>
<th>Iron (ug/dL)</th>
<th>Total Iron Binding Capacity (TIBC) (ug/dL)</th>
<th>% Saturation</th>
<th>Ferritin (ng/mL)</th>
</tr>
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<tr>
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<td>42.3</td>
<td>92.8</td>
<td>32.2</td>
<td>63</td>
<td>333</td>
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</tr>
<tr>
<td>10/23/07</td>
<td>14.9</td>
<td>43.0</td>
<td>94.1</td>
<td>32.5</td>
<td>n/a</td>
<td>n/a</td>
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</tr>
<tr>
<td>12/10/07</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>153</td>
<td>310</td>
<td>49</td>
<td>22</td>
</tr>
</tbody>
</table>

n/a: values not available or not tested
recurrent left hip pain as well as an acute episode of left knee pain (onset 1-2 weeks prior to physical examination in the athletic training department). The patient’s primary musculoskeletal complaints were chronic left hip pain and the new onset of non-traumatic anterior-lateral left knee pain both which were affecting her ability to complete her training runs pain free.

**Musculoskeletal Assessment of the Injured Runner**

**Standing Examination**

Static and dynamic posture and alignment were first assessed in standing. Static posture and alignment appeared unremarkable when viewed anteriorly, laterally, and posteriorly. Active lumbar spine range of motion was also assessed to be within normal limits. Gait observation was unremarkable.

Several functional tests were conducted to assess the subject for dysfunctional biomechanical movement patterns. Functional tests may be useful in providing qualitative information relating to an individual’s ability to perform basic and complex movement patterns. When performing a lunge, the patient demonstrated contralateral hip drop, femoral adduction, and knee valgum with each lead leg. When performing a squat, the patient was unable to maintain proper trunk alignment (demonstrating excessive lumbar flexion) during the descent phase. She also was unable to eccentrically control the descent with her hip musculature, instead relying on her quadriceps (as demonstrated by her knees flexing over her feet). The single-legged squat test (SLST) further highlighted her inability to maintain core stability and lower extremity alignment. A Trendelenburg sign, femoral adduction and internal rotation, and knee valgum were demonstrated bilaterally during each SLST with the left lower extremity malalignment qualitatively assessed to be worse than that on the right.

**Seated Examination**

The patient assumed a sitting posture on the evaluation table. In this position dermatomes, reflexes, and selected muscle tests were conducted (Table 2). Dermatomes and reflexes (L3 and S1) were determined to be intact bilaterally. Manual muscle tests for hip internal rotation, hip external rotation, hip flexion, and knee extension were conducted bilaterally revealing gross hip weakness bilaterally (Table 2). A hand held dynamometer (MicroFet 2, Hoggan Health Industries, West Jordan, Utah) was utilized to quantify hip strength. Hip flexion, hip internal rotation, and hip external rotation strength were measured in sitting as recommended by the manufacturer (Table 2).

**Supine Examination**

Active range of motion (AROM) was assessed in supine. Hip, knee, and ankle AROM was deemed symmetrical and within normal limits bilaterally. Provocation tests (special tests) failed to reproduce hip or knee symptoms. Hamstring flexibility was measured bilaterally using the 90-90 test. To quantify hamstring flexibility, the knee was passively extended from the 90-90 position until resistance prevented further extension of the joint. Hamstring flexibility was measured to be 70° bilaterally. Additional manual muscle tests and dynamometry was conducted (Table 2). Palpation revealed tenderness on the left side at the posterior superior iliac spine, piriformis, gluteus maximus and medius, and hamstring muscles (common origin), as well as the greater tubercle of the hip, distal iliotibial tract, and the antero-lateral knee.

<table>
<thead>
<tr>
<th>Table 2. Selected Hip Strength Measures Recorded during the Initial Evaluation and after the End of the Subject’s Cross-Country Season</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Evaluation</strong></td>
</tr>
<tr>
<td><strong>Flexion</strong></td>
</tr>
<tr>
<td><strong>Abduction</strong></td>
</tr>
<tr>
<td><strong>Extension</strong></td>
</tr>
<tr>
<td><strong>External Rotation</strong></td>
</tr>
<tr>
<td><strong>Internal Rotation</strong></td>
</tr>
</tbody>
</table>
Exam Summary
To summarize, the primary physical examination findings were poor hip and core strength. Based upon these findings, the primary author hypothesized that the patient likely experienced pain while running as a result of her weak hip and core musculature failing to maintain optimal lower extremity biomechanics, especially as she fatigued at or near the end of a run. Altered running mechanics in response to dysfunctional core strength may increase the stress on various tissues in response to repetitive submaximal loads. It was also hypothesized that due to the fact that she was running in an iron deficient (with anemia) state, she was unable to adequately recover between each bout of running. Despite her deficient physiological status, she attempted to train and compete at her perceived optimal level. Continuing to train in this state set the stage for developing a running related overuse injury. Her previous unsuccessful attempt to rehabilitate her injured hip was likely impaired by her iron deficient state and the particular treatments utilized. For example, throughout her course of chiropractic treatment, she was not prescribed any form of stretching or strengthening therapeutic exercises.

Treatment
Medical Treatment
Once a diagnosis of iron deficiency with anemia was established, the patient was instructed to begin iron supplementation. She reported purchasing an over the counter ferrous sulfate supplement with each 134 mg pill containing 27 mg of elemental iron. She would consume between 2 to 6 pills per day. Her supplementation schedule would change in response to recommendations she would receive from medical providers. One provider recommended she consume as few as 2 pills 3 times a week whereas at a different point in time she was consuming 4 to 6 pills daily. The patient reported that the variability of the supplementation schedule "was a challenge to follow" and concerned her as to the effectiveness of the treatment program. Supplementation did improve the athlete’s lab values (Table 1). Her iron, % saturation, and ferritin levels had all increased by the start of the cross-country season (Table 1, column 4).

Rehabilitation Intervention
The athlete’s primary goal was to be able to compete in each scheduled conference cross-country meet. Her secondary goals included decreasing her musculoskeletal pain while running and increasing her overall hip and core strength. The subject was treated by the primary author in the university's athletic training room facility two days a week throughout the span of the cross-country season (Table 3). Evidence based therapeutic interventions were selected based upon the physical examination findings and patient preferences. Table 3 details the therapeutic exercise, manual therapy, and modality interventions utilized with this athlete. During the initial session, the subject received instruction in exercises designed to increase core strength. Four stretching exercises were added to the home exercise program during the

<table>
<thead>
<tr>
<th>Session</th>
<th>Modalities</th>
<th>Manual Therapy</th>
<th>Therapeutic Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>None</td>
<td>1. Instruct for daily HEP: clamshells, straight leg raise hip abduction, side plank, front plank</td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>1. Effluerage and petrissage massage techniques: left posterior hip and gluteals in sidelying. 2. Grade V sacro-iliac region manipulation performed two times to each side.</td>
<td>1. Review and technique correction of previous HEP. 2. Instruct for daily HEP: hamstring stretch (supine), piriformis stretch (supine), prayer stretch, supine trunk rotations</td>
</tr>
<tr>
<td>3-4</td>
<td>None</td>
<td>1. Effluerage and petrissage massage: left posterior-lateral hip, gluteals. 2. Grade V sacro-iliac manipulation performed two times to each side.</td>
<td>1. HEP review 2. Review/educate proper spine posture 3. Add to HEP: squats and lunges (1-3 sets x10 reps)</td>
</tr>
<tr>
<td>5-17</td>
<td>1. Interferential electrical stimulation 15 min to left hip and left gluteal region 2. Moist heat 15° left hip and left gluteal region</td>
<td>1. Effluerage and petrissage massage: left gluteal, left hip, lumbar spine (side-lying or prone). 2. Grade III-V mobilization as indicated to thoracic spine, lumbar spine, and sacro-iliac joint.</td>
<td></td>
</tr>
</tbody>
</table>
The season progressed it became apparent that she would probably continue to experience sports-related pain throughout the remainder of the season. The sports medicine team held the belief that for the athlete to experience a significant reduction in pain, she would need to abstain from running. The treatment focus at the end of the season was to address her musculoskeletal pain with manual therapy, therapeutic exercises, and modalities.

**DISCUSSION**

This case highlights the comprehensive management of a female cross-country athlete who had been diagnosed with iron deficiency anemia. Successful medical intervention and rehabilitation strategies helped the athlete to achieve her primary goal to compete in each race. The subject was able to achieve personal bests (her time during the 5th race of the season ranks as the 2nd fastest time recorded in school history for the 6000-meter run) (Table 4). She qualified for the NCAA Division III National Championships finishing 34th overall earning her an All-American status.

**Failure to Identify the Iron Deficient State**

The failure to identify the iron deficient state in this endurance athlete affected her ability to compete for both her cross-country and track teams during previous seasons. Despite the successful outcome of this case, additional measures may have helped the sports medicine team recognize her iron deficient state sooner.

It is plausible that the subject had been experiencing symptoms related to iron deficiency, with or without anemia, dating back to her freshman cross-country season. Iron deficiency progresses over three stages.5,20 The first stage is marked by a decrease in serum ferritin levels, but no change in HGB levels.5 Physicians who evaluate only the HGB and HCT levels, failing to evaluate other markers such as serum ferritin,
may misdiagnose an athlete as iron sufficient.\textsuperscript{9, 21} The second stage of iron deficiency is marked by decreasing iron stores, decreasing serum iron, decreasing transferrin saturation, and an increase in TIBC.\textsuperscript{5} In the final stage of iron deficiency, the individual becomes anemic.\textsuperscript{5} Sports medicine physicians recommend conducting a complete blood count to evaluate HGB, HCT, serum iron, TIBC, serum ferritin, and transferrin saturation with athletes who are suspected of iron deficiency (with or without anemia).\textsuperscript{2, 5}

The gold standard measure for identifying iron deficiency is a bone marrow biopsy with Prussian blue staining.\textsuperscript{5} In lieu of a bone marrow biopsy, serum ferritin levels are considered to be an appropriate clinical measure for iron deficiency.\textsuperscript{2, 3, 22} An athlete is considered iron deficient with serum ferritin levels less than 10-12 ng/mL.\textsuperscript{1, 5, 7, 22} When the subject received her diagnosis of iron deficiency with anemia, her serum ferritin levels were 2 ng/mL (Table 1). According to the subject, her ferritin levels had not been tested until April 2007 (Table 1, column 2).

### Diet and Iron Supplementation

Iron deficiency in athletes may be the result of one or more of the following factors: gastrointestinal blood loss,\textsuperscript{5, 13, 23-26} hemolysis,\textsuperscript{27, 28} hematuria,\textsuperscript{29} sweat loss,\textsuperscript{30} intense activity or exercise,\textsuperscript{5, 11, 12, 23, 31, 32} and a lack of intake or absorption of dietary iron.\textsuperscript{3, 5, 33} Consumption of drinks containing caffeine may also inhibit absorption of iron.\textsuperscript{3} The subject in this case possessed several of the risk factors, including a diet poor in dietary iron consumption. When interviewing the subject, the primary author found that the athlete avoided certain foods (red meats, eggs) that may have provided a source of dietary iron. The primary author also referred the athlete to a registered dietician in order to develop an appropriate diet for sport and to rule out the presence of an eating disorder.\textsuperscript{34}

Once a diagnosis of iron deficiency with anemia was established, the subject initiated iron supplementation. According to the patient, she was not provided clear instruction as to the recommended daily dosage. Supplementation, as expected, did positively influence her lab values (Table 1), but it can be argued that her ferritin levels were sub-optimal throughout the majority of the season.\textsuperscript{35} Shaskey and Green\textsuperscript{2} suggest that once an athlete begins iron supplementation, 12 months may be needed for iron stores to be completely restored.

### Rehabilitation Interventions

The subject did present with weakness in her core musculature as demonstrated by biomechanical faults with functional movement patterns. A growing body of evidence exists suggesting a relationship between core weakness in endurance runners and the onset of injury.\textsuperscript{36-38} The subject did experience improvements in hip strength (Table 2), but these gains did not appear to correlate with a decrease in pain. At the end of the season, the primary author reviewed the home exercise program with the athlete, encouraging her to continue the strengthening exercises. Continued strength gains may ultimately decrease the subject's pain experience or help to reduce the risk of future lower extremity injuries.

### CONCLUSION

Iron deficiency (with or without anemia) may severely affect an athlete's ability to perform at an optimal level. Sports medicine professionals must consider iron deficiency as a possible differential diagnosis when evaluating endurance athletes. Subtle signs of iron deficiency may be overlooked delaying treatment. In this case, proper treatment allowed the athlete to compete at a high level throughout her cross-country season.

### REFERENCES


ABSTRACT

Background. Altered joint arthrokinematics can affect structures distal and proximal to the site of dysfunction. Hypomobility of the proximal tibiofibular joint may limit ankle dorsiflexion and indirectly alter stresses about the knee.

Objectives. To examine the effect of addressing hypomobility of the proximal tibiofibular joint in an individual with lateral knee pain.

Case Description. A 24 year old female recreational runner presented with a three month history of right lateral knee pain. Limited right ankle dorsiflexion was noted and determined to be related to decreased mobility of the proximal tibiofibular joint, as well as, the talocrural and distal tibiofibular joints. Functional movement deficits were noted during the squat test and step down test. Treatment was performed three times over the course of two weeks which included proximal tibiofibular joint manipulation and an exercise program consisting of hip strengthening, balance, and gastrocnemius/soleus muscle complex stretching.

Outcomes. Immediately following intervention, improvements were noted for ankle dorsiflexion, squat test, and step down test. One week following the initial intervention the patient reported she was able to run pain free.

Discussion. Addressing impairments distant to the site of dysfunction, such as the proximal tibiofibular joint, may be indicated in individuals with lateral knee pain.

Key Words: ankle sprain, arthrokinematics, manipulation

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This is an original manuscript and portions of the findings for this research were presented this past fall at the American Academy of Orthopaedic Manual Physical Therapists Annual Conference in St. Louis, Missouri. The associated abstract was published in the Journal of Manual and Manipulative Therapy earlier this year.

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INTRODUCTION
The knee joint is the most commonly injured joint for runners and typical injuries include patellofemoral pain, iliotibial band syndrome, meniscus lesions, and patellar tendinopathy. Knee pain about the lateral aspect of the knee is less commonly described and primarily thought to be related to iliotibial band syndrome or a lateral meniscus lesion. In the absence of these two conditions, other less common presentations could be lateral plica, fabella syndrome, biceps tendinosis, or popliteus tendinosis. A thorough examination of the local structures as well as distant sites may be helpful in the differential diagnosis of lateral knee pain.

An adjacent structure which may contribute to lateral knee pain is the proximal tibiofibular joint. Previous authors have suggested that hypermobility of the proximal tibiofibular joint may be a source of lateral knee pain. During ankle dorsiflexion, torsional stress is placed through the proximal tibiofibular joint, via external rotation and anterior glide of the fibula. Decreased mobility of the proximal tibiofibular joint may subsequently limit ankle dorsiflexion range of motion (ROM). Ankle dorsiflexion restrictions have been previously associated with anterior knee pain and are thought to be due to gastrocnemius/soleus tightness or talar/crural joint hypomobility. No study has discussed the potential for hypomobility of the proximal tibiofibular joint and the contribution to lower extremity dysfunction. The purpose of this case report was to examine the effect of addressing hypomobility of the proximal tibiofibular joint in an individual with lateral knee pain.

CASE DESCRIPTION
The patient was a 24 year old recreational runner and reported an onset of right knee pain three months prior to initial examination. At that time she had been running 3-4 miles, 5-6 times a week, for the previous six months. After the onset of knee pain she reduced both distance and frequency to 2-3 miles, 2-3 times per week. She recalled no specific trauma or incident that precipitated the pain and reported symptoms only occurred during running and not other activities such as prolonged sitting or stair climbing. Although she was not experiencing pain (0/10) at rest, she rated her worst pain during running as 5/10. She described pain on the lateral aspect of knee which extended into the region of the proximal tibiofibular joint.

Her past medical history included a right lateral ankle sprain, which occurred six years previous. The patient did not seek medical consultation for this injury. She indicated that she had difficulty with walking for 2 to 3 days following the injury and severe ecchymosis resolved within one month. Based on her recall of the injury, the injury was likely be a grade II ankle sprain. This injury was not disclosed until assessment of ankle mobility during the physical examination. The rest of her medical and orthopedic history was unremarkable.

Previous intervention for lateral knee pain had included the use of a patellar tendon strap, based on physician initial recommendations, but provided minimal relief of symptoms. Prior to examination the patient completed the Activity Measure for Post-Acute Care (AM-PAC) outcomes measure and scored 76 out of a possible 81. Clinical outcomes collected during the initial examination and follow up sessions are presented in Table 1. The initial examination consisted of observation of static posture, dynamic movement including balance, strength, range of motion (ROM), joint mobility, and special tests.

<table>
<thead>
<tr>
<th>TABLE 1. Clinical Outcomes</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Visual Analog Scale Current/Best/Worst</td>
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<tr>
<td>Dorsiflexion (degree) (knee extended)</td>
</tr>
<tr>
<td>Right</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Dorsiflexion (degree) (knee flexed 90°)</td>
</tr>
<tr>
<td>Right</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Step Down Test</td>
</tr>
<tr>
<td>Right</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>AM-PAC Score</td>
</tr>
<tr>
<td>Right = involved</td>
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</tbody>
</table>
Static Posture and Functional Movement

Static posture was assessed visually in standing, and the right knee was held in slightly more knee flexion than the left knee. Functional movement examination included the squat test, single limb stance, and step down test. All tests were performed using visual observation. The squat test was used to qualitatively examine the movement pattern and functional ROM of the lower extremity. During the descent phase of the squat, the patient’s involved (right) lower extremity demonstrated dynamic knee valgus, which has been defined as a combination of femoral adduction, knee abduction, and ankle eversion, compared to the uninvolved (left) lower extremity. A left weight shift was also noted and squat depth was limited on the right side relative to the left. This limitation was thought to be associated with a decrease in right ankle dorsiflexion motion, as compared to the left, which occurred without report of associated ankle pain. After discussion of this impairment, the patient recalled a history of right ankle sprain which had occurred six years previous.

Next, single limb stance was performed with eyes open while standing on a stable surface. The patient was able to balance 10 seconds on the right and 30 seconds on the left before losing balance. The last functional test was the step down test which provided a quantitative assessment of lower extremity functional movement. This test was scored using established criteria with lower scores (0 or 1) indicating good quality of movement and higher scores (5 or 6) indicating poor quality of movement. The patient scored 5 points on right (involved) and 1 point on the left (uninvolved) side.

Table 2. Step Down Test (20 cm/8 in box) Scoring Criteria

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm Str</td>
<td>1 point</td>
</tr>
<tr>
<td>Trunk Movement:</td>
<td>1 point</td>
</tr>
<tr>
<td>Pelvis Plane:</td>
<td>1 point</td>
</tr>
<tr>
<td>Knee Position:</td>
<td>1 point</td>
</tr>
<tr>
<td>Maintain steady unilateral stance:</td>
<td>1 point</td>
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</tbody>
</table>

Joint mobility of the proximal tibiofibular joint (Figure 2) was assessed with the patient in a hook-lying position. The proximal tibia was stabilized with one hand while the other hand grasped the proximal fibular head. The fibular head was translated posterior to anterior in the plane of the articulation with the tibia. Compared to the left, the right proximal tibiofibular joint was determined to be hypomobile with limited anterior glide of the fibula on the tibia.

Next, mobility of the distal tibiofibular joint (Figure 3) was assessed with the patient in supine. The therapist stabilized the distal tibia by making contact with the anterior aspect of the tibia with the thenar emi-
nence and the posterior aspect of the tibia with a lumbral
grip. The other hand grasped the distal fibula with the
anterior aspect in contact with the thenar eminence and
the posterior aspect of the fibula in contact with the index
finger. The distal fibula was translated in an anterior to
posterior direction on the stable tibia and was determined
to be hypomobile on the right relative to the left.

Based on the assessment of these three joints, the greatest
restriction was determined to occur at the right proximal
tibiofibular joint, which also reproduced familiar knee
pain experienced by the patient. A second physical ther-
apist, blinded to the initial examination findings, was
asked to perform mobility assessment of the right prox-
imal tibiofibular joint and pain provocation to confirm
findings. The second physical therapist also noted hypo-
mobility in the right proximal tibiofibular joint. Thus, clin-
cal agreement with examination findings existed, but no
statistical measures of intertester reliability were per-
formed.

**Palpation and Special Tests**

The medial and lateral knee joint line and soft tissue
structures including the patella tendon, medial and later-
al retinacula, biceps tendon, and popliteus tendon were
palpated without any complaint bilaterally. Palpable ten-
derness was reported on the right side along the distal
aspect of the iliotibial band lateral to the patella and the
fibular head.

Varus stress tests, McMurray’s, and Apley’s compression
were all negative bilaterally. Isometric quadriceps con-
traction and patellar compression did not reproduce
symptoms. Ober’s Test and Thomas Test were equally
limited bilaterally, per visual observation, but did not
reproduce familiar pain. Noble compression test also did
not reproduce pain with passive flexion and extension of
the knee. Although these special tests are commonly per-
formed in the assessment of lower extremity dysfunction,
the sensitivity and specificity for iliotibial band syndrome
has not been determined.

**Evaluation and Differential Diagnosis**

Based on evaluation of examination findings, the
patellofemoral joint and iliotibial band were ruled out as
sources of dysfunction. During the examination, the
patient did not have pain with prolonged sitting, stairs
(step down test), squatting, and palpation of the medial
retinaculum. These findings indicated something other
than patellofemoral joint pain was a cause of the dysfunc-
tion. Iliotibial band syndrome was also ruled out as a
cause due to the inability to provoke symptoms during
Ober’s or Thomas Tests.

Pertinent examination findings included limited right
ankle dorsiflexion ROM, proximal tibiofibular joint hypo-
mobility, provocation of familiar pain with proximal
tibiofibular joint mobility testing, and abnormal lower
extremity biomechanics during the squat and step down
tests. Hypomobility of the patient’s right tibiofibular joint
was most likely the underlying cause of pain and dysfunc-
tion. At this point the decision was made to direct treat-
ment to the patient’s right proximal tibiofibular joint.

**INTERVENTION**

Initial intervention utilized a high velocity, end range,
posterior to anterior thrust, applied to the proximal
tibiofibular joint (Figure 4) in a manner consistent with
previously published methods.7,13 Briefly, the subject was
in a supine position while the physical therapist aligned
his index finger with the proximal fibular head and uti-
lized the other hand to produce passive knee flexion and external rotation of the tibia. The associated soft tissue of the popliteal region was pulled in a lateral direction until the metacarpophalangeal joint was firmly stabilized behind the fibular head. The opposite hand grasped the anterior aspect of the ankle while the knee was passively flexed and the tibia was externally rotated. When the restrictive barrier was engaged, indicating the end of physiological motion, a high velocity, low amplitude thrust was applied through the tibia with the force directed towards the subject's heel toward the ipsilateral buttock. An audible joint cavitation (pop) was felt and heard by the patient and heard by both physical therapists (treating and observing) that were in the room.

OUTCOME
Initial Visit
Following initial intervention, joint mobility of the proximal tibiofibular, distal tibiofibular, and talocrural joints of the involved extremity was re-assessed, using the same methods as previously described, and noted to have improved mobility, but still hypomobile relative to the uninvolved joints. Ankle dorsiflexion was reassessed using the same methods as the initial assessment. A 5 degree increase in ankle dorsiflexion occurred with the knee extended (right, 10 degrees; left 15 degrees) and a 2 degree increase with the knee flexed to 90 degrees (right, 10 degrees; left 15 degrees). Functional movements were also re-assessed with an improvement, per visual observation, in active ankle dorsiflexion during the squat test. The step down test was repeated and the score improved to three points which indicated improvement to medium quality of movement.

Additional treatment during the first clinical visit consisted of therapeutic exercises which included hip abduction in side-lying (Figure 5) and hip abduction/external rotation (clam shell) in crook lying (Figure 6). Both exercises were performed for three sets of 30 repetitions each, to target hip abductor and external rotator muscles. The patient was instructed to maintain the trunk in neutral and isolate the hip abductor and external rotator muscles. These exercises were also incorporated into a home exercise program. The patient was also allowed to continue her current running program (2-3 miles, 2-3 times per week) with the stipulation that lateral knee pain did not increase during the activity.

Second Visit-One Week Following Initial Visit
One week following the initial visit, the patient reported improvement in symptoms and the ability to run without reproducing knee pain. The AM-PAC was repeated and a maximum score of 81.53 was obtained. The step down test was performed and a score of one point was obtained bilaterally. Joint mobility of the proximal and distal tibiofibular joints and posterior glide of the talus were re-assessed and determined to be improved compared to first visit but still hypomobile relative to the left side.

The patient's right proximal tibiofibular joint once again demonstrated the greatest amount of hypomobility, thus the treatment was directed at this joint. A proximal tibiofibular joint manipulation was performed using the
same technique as the first visit. Additionally, small amplitude, end of ROM (Grade IV), anterior to posterior joint mobilization\textsuperscript{14} was performed at the talocrural joint with the subject lying in supine to improve posterior glide of the talus on the tibia/fibula. Therapeutic exercise program during the second clinical visit included the hip exercises performed during the initial visit as well as the addition of single limb stance exercises with repetitive rhythmic oscillations of the opposite limb performed with an elastic band attached to the opposite limb. This exercise was intended to increase strength and neuromuscular control of the lower extremity in a functional standing position. All exercises performed during the second clinical visit were also continued as part of the home exercise program.

**Third Visit- Two Weeks Following Initial Visit**

The patient returned for a third visit one week later and reported she was pain free, and still able to run without symptom exacerbation (0/10). The step down test was re-assessed and the patient scored one bilaterally. Ankle ROM was also reassessed on the right side using the same methods as previously described. Compared to measurements during the initial examination, ankle dorsiflexion had improved 10 degrees with the knee extended (15 degrees) and 10 degrees with the knee flexed to 90 degrees (20 degrees). The AM-PAC score remained at a maximal obtainable score of 81.53.

Joint mobility of the proximal and distal tibiofibular joints and the talocrural joint was performed in a similar manner as previous examinations and was noted to be normal and equal bilaterally. Since the patient had no reports of pain, functional deficits, nor joint mobility restrictions the decision was made, with the consent of the patient, to discontinue physical therapy services and discharge her to her established home exercise program.

**Follow-up**

Ten months following discharge, the patient was contacted by phone for follow up evaluation of function. She reported that her knee and ankle had remained symptom free, and she was able to run 4-5 miles, 4-5 times per week. Another telephone follow up was conducted sixteen months following discharge, and the patient indicated she continued to remain symptom free and had increased running distance to 4-8 miles 4-5 times per week.

**DISCUSSION**

In this case report, restricted mobility of the joints associated with the tibia, fibula, and talus may have been a contributing factor to lateral knee pain.\textsuperscript{7} Decreased ankle dorsiflexion ROM,\textsuperscript{7, 8} and altered mobility of the tibiofibular joints\textsuperscript{4-6} have been shown to be associated with knee pain. It is unknown if limited ankle dorsiflexion was a precipitating, or compensatory mechanism, but stresses may have been increased about the knee joint during gait.\textsuperscript{19}

A plausible explanation for proximal tibiofibular joint dysfunction may be indirectly related to the history of a previous ankle sprain.\textsuperscript{3} Changes in the positional alignment of the talus, tibia, and fibula have been implicated in a subpopulation of individuals with a history of ankle sprain.\textsuperscript{3,20-23} Two positional faults have been described to occur at either the talocrural joint\textsuperscript{21} or the distal tibiofibular joint.\textsuperscript{3,20,22,23} At the talocrural joint, the talus is thought to migrate anteriorly following lateral ankle sprains due to the disruption of the ligaments restraining anterior talus translation.\textsuperscript{21} At the distal tibiofibular joint, a slight anterior displacement of the fibula relative to the tibia is thought to occur.\textsuperscript{3,20,22,23} Based on the arthrokinematics associated with the tibiofibular joints, anterior translation of the distal fibula is associated with a concomitant posterior translation (external rotation) of the proximal fibula.\textsuperscript{24} Clinically the positional faults are recognized as decreased posterior glide of the talus (Figure 1) or distal fibula (Figure 3) or decreased anterior glide of the proximal fibula (Figure 2), all of which manifest as decreased ankle dorsiflexion ROM.\textsuperscript{3,20-23} If altered arthrokinematics and compensatory movement patterns are not appropriately addressed following injury, an opportunity exists for future local and distant joint pathology.\textsuperscript{25-27} Although the ankle sprain reported by the patient had occurred approximately six years previously, only within the past year had her activity level increased to the point where this dysfunction may have become symptomatic. It is possible that her level of function prior to the initiation of her running program nine months previous may have not been enough to create symptomatic dysfunction. Repetitive stresses through the lower quarter associated with running may have provided enough stress to the joints creating a painful response.

Manual therapeutic interventions\textsuperscript{14, 20-30} are reported clinically to offer the ability to restore normal joint arthrokinematics. By addressing hypomobility of the proximal
tibiofibular joints, lower extremity arthrokine
tics may be restored, ultimately altering stresses placed at the local joint. It is possible that this restoration of arthrokine
matics may have contributed to the patient's decreased lateral knee pain symptoms. Due to the nature of the case report and the use of a multifaceted home exercise program, a cause and effect relationship can not be determined.

Results of this case report should be approached with caution due to the nature the single subject design and limited reliability and validity of examination methods. Examiner bias may have also been present during analysis of functional movements and joint mobility following intervention. Additional study is required to examine the contribution of the proximal tibiofibular joint in individuals with lateral knee pain and better develop examination and treatment for lateral knee pain.

SUMMARY
Consideration of the potential for ankle joint hypomobili
ty contradicts common clinical thoughts associated with a history of lateral ankle sprain. Although the lateral ligaments of the ankle may have laxity associated with ligament disruption, recent evidence suggests that hypomobility of the adjacent talocrural and tibiofibular joints may contribute to chronic dysfunction. Dysfunction may be asymptomatic unless tissues are stressed with activities such as running. This case presentation documents that proximal tibiofibular hypomobility may serve as a contributor to lateral knee pain. A thorough history and examination of surrounding structures will help identify underlying impairments which contribute to dysfunction. The treating clinician should be aware of specific biomechanical deficits that may contribute to lateral knee pain, as well as additional treatment options such as manual interventions for this type of condition.

REFERENCES


Athletes with persistent anterolateral ankle discomfort may have developed sinus tarsi syndrome (STS). Sinus tarsi syndrome develops from excessive motions of the subtalar joint that results in subtalar joint synovitis and infiltration of fibrotic tissue into the sinus tarsi space. Physical therapists treating athletes with ankle conditions should examine the talocrural and subtalar joints for signs of hypermobility as injuries can affect both of these important articulations of the lower extremity. Localized ankle discomfort to the sinus tarsi space and feelings of instability with pronation and supination movements of the subtalar joint will help identify STS. Intervention for this condition will focus on enhancing subtalar joint stability and function of the lower extremities. The purpose of this clinical commentary is to discuss the etiologies and signs of STS and describe the components of an intervention plan appropriate for athletes with STS.

Key Words: ankle injuries, subtalar joint, joint instability
INTRODUCTION
Sinus tarsi syndrome (STS) is a clinical entity characterized by persistent anterolateral ankle pain secondary to traumatic injuries to the ankle. Historically, the etiology of this condition has not been well understood. Recent discussions of STS now describe this entity as primarily an instability of the subtalar joint due to ligamentous injuries that results in a synovitis and infiltration of fibrotic tissue into the sinus tarsi space.2,3 This clinical commentary will describe the possible etiologies and examination findings of athletes with STS and treatment options for this condition for the sports physical therapist.

ANATOMICAL AND KINESIOLOGICAL CONSIDERATIONS
The subtalar joint is comprised of the articulation of the talus and calcaneus across an anterior, middle, and posterior facet. These facets may have variations in their structure and alignments that will affect the movement and stability of the subtalar joint.4 Extrinsic and intrinsic ligaments provide static stability for the subtalar joint. Extrinsic ligaments include the calcaneofibular ligament and the deltoid ligament, which also provide stability for the talocrural joint. The talocalcaneal, interosseous, and cervical ligaments are the intrinsic ligaments that provide a strong connection for the calcaneal and talar joint surfaces.5 Ruptures of the intrinsic ligaments allow increased movement of the subtalar joint that may result in instability.6,8

The motions of the subtalar joint and the entire rearfoot are complex and have been the subject of extensive study and controversy.4,9 The osteokinematics of the subtalar joint occur about a triplanar axis to create pronation and supination movements.7 Supination motions of the subtalar joint create a bony stability through the rearfoot and midfoot that is important for propulsive movements through the foot. Pronation motions create increased mobility of the rearfoot and midfoot joints allowing the foot to accommodate to uneven surfaces.8,11 During running activities, athletes may weight bear entirely onto the forefoot, with ground reaction forces creating supination and pronation motions that occur from the midfoot into the rearfoot. Ground reaction forces during running create movements through the subtalar joint at a higher rate of acceleration and forces than during walking activities.12

The sinus tarsi space is filled with many connective tissues that contribute to the stability and the overall proprioception of the ankle. The space is filled with adipose tissue that serves as a bedding for numerous mechanoreceptors and free nerve endings, which along with the ligaments and muscles provide proprioceptive information on the movement of the foot and ankle.5,13 The vascular supply of the sinus tarsi is provided by an anastomosis of the sinus tarsi and tarsal canal arteries.14 The extensor digitorum brevis muscle attaches to the medial and distal aspect of the sinus tarsi, running over the calcaneocuboid joint towards the toes. The inferior extensor retinaculum lies over the lateral aspect of this space and serves as a covering over the sinus tarsi.2

ETIOLOGY
Sinus tarsi syndrome is believed to occur following a single traumatic event or a series of ankle sprains that result in significant injuries to the talocrural interosseous and cervical ligaments.2,5 These injuries cause instability of the subtalar joint resulting in excessive supination and pronation movements. The excessive movement of the subtalar joint imparts increased forces onto the synovium of the subtalar joint and across the sinus tarsi tissues. The excessive forces result in subtalar joint synovitis with chronic inflammation and infiltration of fibrotic tissues in the sinus tarsi that are responsible for the characteristic anterolateral ankle pain of STS.2 These traumatic injuries may also injure ligaments of the tibiotalar and talocalcaneal joints resulting in increased mobility and instability of the rearfoot and midfoot. Athletes with increased mobility of the talocrural and subtalar joints may be at a greater risk for developing instability after an ankle injury.1

The incidence of STS is unknown, but has been associated with ankle sprains that may also result in talocrural joint instability. Keefe and Haddad15 estimated that 10-25% of patients with chronic talocrural joint instability will also have subtalar joint instability. Hertel et al16 found that 9 out of 12 patients with recurrent ankle sprains had signs of increased talocrural and subtalar joint motions upon a radiographic examination. Hubbard and Hertel17 have advocated that a large percentage of injuries classified as an ankle sprain will include an injury to the subtalar joint ligaments.

EXAMINATION
Athletes with STS usually describe a history of a traumatic ankle injury, typically with a supination/inversion...
mechanism of injury. Athletes involved with jumping sports may incur an injury to the subtalar joint after coming to an abrupt stop after a jump or a fall. This mechanism is thought to create a “whiplash injury” to the rearfoot with the talus moving anteriorly over the calcaneus. This mechanism may result in a sprain to the ligaments of the talocrural joint as well. Physical therapists should also be cautious with athletes who have an extended history of talocrural joint instability even after undergoing reconstruction of the lateral ankle ligaments, as these procedures are intended to improve stability of the talocrural joint and may not improve stability at the subtalar joint.18

An acute ankle injury will typically present with pain accompanied by swelling, ecchymosis, and tenderness in the anterolateral ankle. Because the synovitis and fibrotic tissues associated with STS will take time to develop, athletes with injuries to the subtalar joint may not initially have symptoms that can be localized to the sinus tarsi (Figure 1). Athletes with STS will typically describe a feeling of instability of the foot and ankle that is provoked upon walking over uneven ground, stepping off a curb, or running or sprinting activities.5,15,19 Athletes involved with cutting and jumping activities on firm surfaces will have the greatest difficulty with subtalar instability as these activities will cause excessive movements of the subtalar joint to the end ranges of pronation and supination.15,20

Assessment of standing posture in athletes with STS may demonstrate a pes planus posture or an asymmetry of the rearfoot angle with the leg, but these are not typical findings.19 Passive range of motion of the ankle and subtalar joint may not reveal excessive motion, but pain over the sinus tarsi at the end range of ankle plantarflexion with foot supination is typical of STS. Muscles that cross the ankle joint should be assessed for any loss of strength, especially the plantarflexor muscles.

Before examining the subtalar joint, a careful assessment of the talocrural joint should be performed. Anterior and posterior glides of the talus on the tibia and a talar tilt test that produces movement of the talus in the frontal plane are recommended for assessing talocrural joint stability.21,22 Mobility of the contralateral ankle and foot joints should be assessed to determine if the athlete has increased joint mobility that will make them susceptible to developing an instability.

Stability of the subtalar joint is assessed with medial and lateral subtalar joint glides performed by moving the calcaneus over a stabilized talus in the transverse plane and with subtalar joint distraction.16,17 Therman et al20 described a stability test that is thought to recreate instability of the subtalar joint (Figure 2). The test is performed with the athlete in supine with the ankle in 10 degrees of dorsiflexion to keep the talocrural joint in a stable position. The forefoot is first stabilized by the examiner’s hand, while an inversion and internal rotational force is applied to the calcaneus. Then an inversion force is applied to the forefoot. The examiner assesses for an excessive medial shift of the calcaneus and a reproduction of the athlete’s complaint of instability and symptoms.

Figure 1. Symptoms associated with STS are usually described as deep in the ankle and can be localized by athlete pointing to the sinus tarsi space.

Figure 2. Clinical test for reproduction of subtalar instability. The forefoot is first stabilized by the examiner’s hand, while an inversion and internal rotational force is applied to the calcaneus.
Reproduction of the athletes feeling of instability or giving way may be reproduced by having the athlete single leg stand on the affected side and perform rotating motions of the leg and foot that may reproduce their symptoms. Therapists may also want to assess the athlete during functional activities of walking, running, stepping down from a step, and hopping on the affected extremity. Activities that produce feelings of instability should be assessed for the relative position of the rearfoot and leg for any compensation through the lower extremity the athletes makes when the instability is produced. The activity levels of athletes with STS can be assessed using the Ankle Disability Index, which includes the athlete's rankings of sports related activities.

DIFFERENTIAL DIAGNOSIS
Athletes with recurrent ankle sprains or symptoms of ankle instability should be suspected of having instability of the talocrural and subtalar joints. Localization of pain to the sinus tarsi with the presence of ankle instability is a good indication that the athlete has developed STS. Conditions that may also produce lateral ankle discomfort include a cuboid subluxation and peroneal tendon subluxation. The diagnosis of STS has typically been confirmed by the cessation of symptoms upon injection of lidocaine into the sinus tarsi.

IMAGING
Athletes suspected of having subtalar joint instability and STS may be referred for diagnostic imaging. Although imaging studies have been proposed to assess the stability of the subtalar joint, most of these methods have been proven to be inconsistent in their findings with low levels of specificity for subtalar joint instability. Radiographs of the subtalar joint are usually performed with Broden stress views which are a series of oblique-lateral views performed with the ankle and foot placed in inverted and supinated positions. Stress fluoroscopy is a method of visualizing the motions of the subtalar joint in real time using low level radiation. The advantage of fluoroscopy over radiographs is that the examiner can attempt to replicate the movements that are causing the athlete's sensation of instability or discomfort from the sinus tarsi.

Magnetic resonance imaging (MRI) is the best method to visualize the structure within the sinus tarsi, especially the interosseous and cervical ligaments. The most distinct finding for individuals with STS is a bright signal seen on T2 weighted images found in the area for sinus tarsal adipose tissue as this represents an infiltration or replacement of this tissue with inflammatory cells and fibrotic tissue. The MRI findings may also include alterations in the structure of the interosseous and cervical ligaments and degenerative changes in the subtalar joint.

INTERVENTION
Recommendations for rehabilitation of STS include balance and proprioceptive training, muscle strengthening exercises, bracing, taping, and foot orthosis. No random control trials for the efficacy of a rehabilitation program for STS are available. Instability of the talocrural joint or chronic ankle instability (CAI) is a similar and associated entity to subtalar joint instability and STS. Numerous studies of the effects of balance and proprioceptive training for CAI have been conducted, with improvements found in athletes' balance, joint position sense, and functional abilities.

Athletes with STS have developed a chronic inflammatory process that results in a synovitis and inflammation of connective tissues and may benefit from a trial of nonsteroidal anti-inflammatory medication to help control their symptoms and inflammation. Cryotherapies, especially the use of ice massage over the lateral ankle, may also be useful for diminishing local inflammation and pain associated with this condition. Athletes with STS may have limited joint mobility at the talocrural and mid tarsal joints that can be addressed with specific joint mobilization techniques. Precautions should be made not to place excessive stress across the subtalar joint with these techniques. Muscular stiffness of the gastrocnemius, posterior tibialis, or peroneal muscles may also be found in athletes with STS, but stretching activities for these muscles should be carefully provided or avoided as excessive forces across the subtalar joint may be detrimental.

Orthoses
Stability of the subtalar joint may be initially improved with the use of an orthosis. Ankle braces intended for CAI may be useful for some athletes with STS, but the overall design of these braces may not significantly improve the stability of the subtalar joint during athletic activities. Foot orthosis have also been recommended as a method for limiting motion at the subtalar joint and reducing symptoms associated with STS. The types of shoes the athlete is using for training, practices, and competition should also be considered, as well constructed shoes can restrict excessive rearfoot movements.
General recommendations for shoes include those with a straight last, a firm heel counter, and rigid material through the midsole.33 Shoes should also be assessed for wear, as materials within a shoe will begin to break down before the external material shows signs of deterioration. The use of a foot orthosis with an athletic shoe should be considered together, as the effect of an orthosis can be inconsistent.35 An ongoing assessment of shoe and orthosis use is needed to provide adequate support of the foot and ankle throughout an athlete’s cycle of training and competition.

Taping or strapping has also been used to specifically limit movements of the subtalar joint and the midfoot. Wilkerson et al.36 have described a taping procedure that combines a closed basket weave with a subtalar sling to control movements at the talocrural and subtalar joints. Viczenzio et al.37 have described a modified Low-Dye taping method that uses a calcaneal sling intended to provide support to the medial longitudinal arch of the foot (Figure 3). This method could be used to control or reduce the amount of pronation through the subtalar joint during walking and running activities. Taping techniques have been used as a precursor for the use and selection of specific types of shoes and foot orthotics.37

**Stability Training**

Training programs to improve the stability of the subtalar joint and lower extremity function will be the hallmark of treatment plans for STS. Joint stability relies on passive joint structures, dynamic muscular responses, and neurological control. Because tears or ruptures of the interosseous and cervical ligaments of the subtalar joint are believed to be the essential lesions that lead to STS, the dynamic muscular responses and neurological control of the rearfoot will need to be emphasized to compensate for the loss of passive stability.38,39

The muscles that cross the subtalar joint are important for maintaining stability, as they act as force transducers to guide and control the pronation and supination motions of the subtalar joint. The relative strength of these muscles is important, but their reaction time to joint perturbations and the ability to work in a coordinated fashion is even more important for the rehabilitation of STS.40,41 Dynamic stability will also rely on the proprioceptive information from the muscle spindles and Golgi tendon organs of these muscles to compensate for the lack of proprioceptive information from the stabilizing ligaments of the joint.42 The endurance of the muscles will also be important to maintain stability during long bouts of exercise or sports activities.

Training programs to improve joint stability have been described as multi-phase processes that start the athlete at an appropriate level of activity and progress to higher levels of activities while maintaining joint stability.40,42 To help the athlete understand this process the progression of three phases are called: Attain, Maintain, and Sustain. The Attain phase will determine postures or positions the athlete is able to attain in a stable fashion. The Maintain phase will develop coordinated isometric and eccentric muscle contractions of the muscles crossing the joint. The Sustain phase will involve integrating all of the neuromuscular subsystems needed for stability during...
Table 1: Progression through three stages of stability training.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Activities</th>
<th>Criteria for Progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attain</td>
<td>Single leg standing – Eyes open and closed</td>
<td>Athlete demonstrates ability to attain a stable position through the foot and ankle.</td>
</tr>
<tr>
<td>Maintain</td>
<td>Single leg standing – Hip swings, and Star pattern reaching. Heel raises, oscillation with theraband, and impulse with medicine ball.</td>
<td>Athlete demonstrates ability to maintain stability and good alignment through the lower extremities.</td>
</tr>
<tr>
<td>Sustain</td>
<td>Lunges and step down exercises, Bilateral and single leg hops, Forward and backward acceleration and deceleration, Pivoting and cutting maneuvers</td>
<td>Athlete demonstrates the ability to tolerate loading and pushing-off the involved lower extremity.</td>
</tr>
</tbody>
</table>

Sports specific activities (Table 1).

The Attain phase for subtalar joint instability is usually started with the athlete in standing positions. Single leg standing, with the contralateral limb held in approximately 30 degrees of hip flexion and 90 degrees of knee flexion, will emphasize ankle balance strategies.43 The clinician should closely observe the arch of the foot and rearfoot to assess the athlete’s ability to attain a stable position for the subtalar joint while avoiding excessive pronation movements (Figure 4). The Attain phase begins with the eyes open and attempting to hold the single leg position for 30 to 60 seconds with minimal alterations in body position. Once the athlete is able to hold a single leg standing position consistently, a progression to eyes closed conditions can be made.

The second phase, Maintain, is performed with perturbations to the single leg positions. Perturbation forces are imparted near the level of the athlete’s center of gravity to replicate the type of forces that produce subtalar joint instability during athletic activities. The perturbing forces are intended to facilitate rapid isometric and eccentric contractions of the stabilizer muscles of the ankle.42 Perturbations to standing balance are begun with movements from the contralateral hip starting in the sagittal and coronal planes of motion, progressing to transverse plane motions. Observations of the athlete’s rearfoot and hip stability will indicate his/her ability to maintain this position. The clinician needs to ensure that the athlete is not using excessive compensatory motions at the rearfoot or hip to maintain a single leg standing position.

The star excursion balance test activities can also be used in this phase, with the athlete in the single leg standing position and touching different lines drawn on the floor in a star pattern.27 Standing heel raises and lowering exercises can be performed at a slow speed in double leg and single leg standing. Emphasis is placed on promoting controlled concentric and eccentric muscle contraction of the ankle plantarflexors and subtalar joint pronators.44 External perturbations can be imparted with the athlete holding a two-foot length of theraband. With both hands in front of the umbilicus, the therapist can then pull on the theraband with oscillating motions. Catching and throwing a small ball or medicine ball while in single leg standing can also be used for perturbations in multiple directions and different timing.46

The Sustain phase will begin with the athlete learning to “close the chain” meaning moving from an open kinematic chain to a stable closed kinematic chain position. The emphasis is on developing the feedforward motor control of the lower extremities.45 This activity can be started by having the athlete perform lunging steps and then stepping down from a 4 or 8 inch step onto the involved extremity into a single leg standing position. Progression can be to lateral lunge steps and lateral step downs. Observations of the athlete’s overall control of motion through the lower extremities with an emphasis on alignment of the knee and foot will insure that excessive subtalar joint motion is not occurring.

Figure 4. Foot held in an excessive pronated position.
Progressions of the Sustain phase can be performed with the athlete jumping or hopping in place and then into hopping in different directions. Running activities can begin by acceleration and deceleration with forward and backward motions. Athletes needing to perform pivoting or cutting maneuvers can begin these activities at a slow speed maintaining good alignment of the foot and leg and avoiding excessive motions through the rearfoot.

Return to play criteria is based on the athlete’s ability to move in all directions and at appropriate speeds. Athletes performing cutting and jumping maneuvers on firm surfaces, such as basketball and volleyball players, should be returned to full activities over a period of days to insure their tolerance to these stressful maneuvers.15,20 A progression of the athletic activities should be assessed with the athlete in his or her normal practice or competitive environment. The athlete’s anterolateral ankle symptoms will need to be well controlled to insure that the return to competition will not create chronic inflammation of the sinus tarsi tissues.

**Surgery**

Athletes who fail a course of rehabilitation may need an arthroscopic exploration and reconstruction of the subtalar joint in order to return to their athletic pursuits. Arthroscopy of the subtalar joint has allowed for a more precise examination of the subtalar joint and the sinus tarsi. A synovectomy of the subtalar joint along with an arthrotomy of the subtalar joint can be used to remove chronic synovitis and arthrofibrosis that is commonly found in STS.44 Surgical reconstructions of the cervical and interosseous ligaments are made by splitting the tendon of the peroneus brevis and routing the graft through bone tunnels made through the calcaneus and the talus.2,18 Patients with instability of the talocrural and subtalar joints may require a tri-ligamentous reconstruction of the anterior talofibular, calcaneofibular, and cervical ligaments.18 Patients who present with significant joint degeneration or continue to have persistent symptoms even after ligamentous reconstruction may require an arthodesis resulting in an isolated fusion of the subtalar joint.45

Athletes who have undergone ligamentous reconstructions will commonly be immobilized for a 6-week period, followed by a rehabilitation program to regain normal ankle mobility, strength, and balance. Return to athletic activities usually begins at 4 to 6 months post-operative-

ly.18 Common post-operative problems are transient loss of sensation of the lateral ankle and foot and persistent peroneal weakness.3

**SUMMARY**

Sinus tarsi syndrome is a condition of the ankle and foot that results from instability of the subtalar joint. Athletes with this condition typically have complaints of instability with functional activities and persistent anterolateral ankle discomfort. The joints of the ankle should be assessed for mobility and reproduction of feelings of instability and discomfort. Treatments for this condition will need to control the athlete’s ankle discomfort and improve the overall stability of the foot and ankle. Therapists should design intervention plans based on the athlete’s need for training and competition.

**REFERENCES**


ABSTRACT

Athletes with persistent anterolateral ankle discomfort may have developed sinus tarsi syndrome (STS). Sinus tarsi syndrome develops from excessive motions of the subtalar joint that results in subtalar joint synovitis and infiltration of fibrotic tissue into the sinus tarsi space. Physical therapists treating athletes with ankle conditions should examine the talocrural and subtalar joints for signs of hypermobility as injuries can affect both of these important articulations of the lower extremity. Localized ankle discomfort to the sinus tarsi space and feelings of instability with pronation and supination movements of the subtalar joint will help identify STS. Intervention for this condition will focus on enhancing subtalar joint stability and function of the lower extremities. The purpose of this clinical commentary is to discuss the etiologies and signs of STS and describe the components of an intervention plan appropriate for athletes with STS.

Key Words: ankle injuries, subtalar joint, joint instability

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INTRODUCTION
Sinus tarsi syndrome (STS) is a clinical entity characterized by persistent anterolateral ankle pain secondary to traumatic injuries to the ankle. Historically, the etiology of this condition has not been well understood. Recent discussions of STS now describe this entity as primarily an instability of the subtalar joint due to ligamentous injuries that results in a synovitis and infiltration of fibrotic tissue into the sinus tarsi space. This clinical commentary will describe the possible etiologies and examination findings of athletes with STS and treatment options for this condition for the sports physical therapist.

ANATOMICAL AND KINESIOLOGICAL CONSIDERATIONS
The subtalar joint is comprised of the articulation of the talus and calcaneus across an anterior, middle, and posterior facet. These facets may have variations in their structure and alignments that will affect the movement and stability of the subtalar joint. Extrinsic and intrinsic ligaments provide static stability for the subtalar joint. Extrinsic ligaments include the calcaneofibular ligament and the deltoid ligament, which also provide stability for the talocrural joint. The talocalcaneal, interosseous, and cervical ligaments are the intrinsic ligaments that provide a strong connection for the calcaneal and talar joint surfaces. Ruptures of the intrinsic ligaments allow increased movement of the subtalar joint that may result in instability.

The motions of the subtalar joint and the entire rearfoot are complex and have been the subject of extensive study and controversy. The osteokinematics of the subtalar joint occur about a triplanar axis to create pronation and supination movements. Supination motions of the subtalar joint create a bony stability through the rearfoot and midfoot that is important for propulsive movements through the foot. Pronation motions create increased mobility of the rearfoot and midfoot joints allowing the foot to accommodate to uneven surfaces. During running activities, athletes may weight bear entirely onto the forefoot, with ground reaction forces creating supination and pronation motions that occur from the midfoot into the rearfoot. Ground reaction forces during running create movements through the subtalar joint at a higher rate of acceleration and forces than during walking activities.

The sinus tarsi space is filled with many connective tissues that contribute to the stability and the overall proprioception of the ankle. The space is filled with adipose tissue that serves as a bedding for numerous mechanoreceptors and free nerve endings, which along with the ligaments and muscles provide proprioceptive information on the movement of the foot and ankle. The vascular supply of the sinus tarsi is provided by an anastomosis of the sinus tarsi and tarsal canal arteries. The extensor digitorum brevis muscle attaches to the medial and distal aspect of the sinus tarsi, running over the calcaneocuboid joint towards the toes. The inferior extensor retinaculum lies over the lateral aspect of this space and serves as a covering over the sinus tarsi.

ETIOLOGY
Sinus tarsi syndrome is believed to occur following a single traumatic event or a series of ankle sprains that result in significant injuries to the talocrural interosseous and cervical ligaments. These injuries cause instability of the subtalar joint resulting in excessive supination and pronation movements. The excessive movement of the subtalar joint imparts increased forces onto the synovium of the subtalar joint and across the sinus tarsi tissues. The excessive forces result in subtalar joint synovitis with chronic inflammation and infiltration of fibrotic tissues in the sinus tarsi that are responsible for the characteristic anterolateral ankle pain of STS. These traumatic injuries may also injure ligaments of the tibiotalar and talocalcaneal joints resulting in increased mobility and instability of the rearfoot and midfoot. Athletes with increased mobility of the talocrural and subtalar joints may be at a greater risk for developing instability after an ankle injury.

The incidence of STS is unknown, but has been associated with ankle sprains that may also result in talocrural joint instability. Keefe and Haddad estimated that 10-25% of patients with chronic talocrural joint instability will also have subtalar joint instability. Hertel et al found that 9 out of 12 patients with recurrent ankle sprains had signs of increased talocrural and subtalar joint motions upon a radiographic examination. Hubbard and Hertel have advocated that a large percentage of injuries classified as an ankle sprain will include an injury to the subtalar joint ligaments.

EXAMINATION
Athletes with STS usually describe a history of a traumatic ankle injury, typically with a supination/inversion
mechanism of injury. Athletes involved with jumping sports may incur an injury to the subtalar joint after coming to an abrupt stop after a jump or a fall. This mechanism is thought to create a “whiplash injury” to the rearfoot with the talus moving anteriorly over the calcaneus. This mechanism may result in a sprain to the ligaments of the talocrural joint as well. Physical therapists should also be cautious with athletes who have an extended history of talocrural joint instability even after undergoing reconstruction of the lateral ankle ligaments, as these procedures are intended to improve stability of the talocrural joint and may not improve stability at the subtalar joint.

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Before examining the subtalar joint, a careful assessment of the talocrural joint should be performed. Anterior and posterior glides of the talus on the tibia and a talar tilt test that produces movement of the talus in the frontal plane are recommended for assessing talocrural joint stability. Mobility of the contralateral ankle and foot joints should be assessed to determine if the athlete has increased joint mobility that will make them susceptible to developing an instability.

Stability of the subtalar joint is assessed with medial and lateral subtalar joint glides performed by moving the calcaneus over a stabilized talus in the transverse plane and with subtalar joint distraction. Therman et al described a stability test that is thought to recreate instability of the subtalar joint (Figure 2). The test is performed with the athlete in supine with the ankle in 10 degrees of dorsiflexion to keep the talocrural joint in a stable position. The forefoot is first stabilized by the examiners hand, while an inversion and internal rotational force is applied to the calcaneus. Then an inversion force is applied to the forefoot. The examiner assesses for an excessive medial shift of the calcaneus and a reproduction of the athlete’s complaint of instability and symptoms.

**Figure 1.** Symptoms associated with STS are usually described as deep in the ankle and can be localized by athlete pointing to the sinus tarsi space.

**Figure 2.** Clinical test for reproduction of subtalar instability. The forefoot is first stabilized by the examiners hand, while an inversion and internal rotational force is applied to the calcaneus.
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![Figure 3. Taping for stabilizing the rearfoot. These taping methods can be used in addition to an closed ankle basket weave or a foot Low-Dye method. Figure on the top shows a calcaneal sling with a long strip to control rearfoot pronation, figure on the bottom shows heel lock strips to control rearfoot supination.](image-url)
sports specific activities (Table 1).

The Attain phase for subtalar joint instability is usually started with the athlete in standing positions. Single leg standing, with the contralateral limb held in approximately 30 degrees of hip flexion and 90 degrees of knee flexion, will emphasize ankle balance strategies. The clinician should closely observe the arch of the foot and rearfoot to assess the athlete’s ability to attain a stable position for the subtalar joint while avoiding excessive pronation movements. The Attain phase begins with the eyes open and attempting to hold the single leg position for 30 to 60 seconds with minimal alterations in body position. Once the athlete is able to hold a single leg standing position consistently, a progression to eyes closed conditions can be made.

The second phase, Maintain, is performed with perturbations to the single leg positions. Perturbation forces are imparted near the level of the athlete’s center of gravity to replicate the type of forces that produce subtalar joint instability during athletic activities. The perturbating forces are intended to facilitate rapid isometric and eccentric contractions of the stabilizer muscles of the ankle. Perturbations to standing balance are begun with movements from the contralateral hip starting in the sagittal and coronal planes of motion, progressing to transverse plane motions. Observations of the athlete’s rearfoot and hip stability will indicate his/her ability to maintain this position. The clinician needs to insure that the athlete is not using excessive compensatory motions at the rearfoot or hip to maintain a single leg standing position.

The star excursion balance test activities can also be used in this phase, with the athlete in the single leg standing position and touching different lines drawn on the floor in a star pattern. Standing heel raises and lowering exercises can be performed at a slow speed in double leg and single leg standing. Emphasis is placed on promoting controlled concentric and eccentric muscle contraction of the ankle plantarflexors and subtalar joint pronators.

External perturbations can be imparted with the athlete holding a two-foot length of theraband. With both hands in front of the umbilicus, the therapist can then pull on the theraband with oscillating motions. Catching and throwing a small ball or medicine ball while in single leg standing can also be used for perturbations in multiple directions and different timing.

The Sustain phase will begin with the athlete learning to “close the chain” meaning moving from an open kinematic chain to a stable closed kinematic chain position. The emphasis is on developing the feedforward motor control of the lower extremities. This activity can be started by having the athlete perform lunging steps and then stepping down from a 4 or 8 inch step onto the involved extremity into a single leg standing position. Progression can be to lateral lunge steps and lateral step downs. Observations of the athlete’s overall control of motion through the lower extremities with an emphasis on alignment of the knee and foot will insure that excessive subtalar joint motion is not occurring.

<table>
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<tr>
<th>Stage</th>
<th>Activities</th>
<th>Criteria for Progression</th>
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<tbody>
<tr>
<td>Attain</td>
<td>Single leg standing – Eyes open and closed</td>
<td>Athlete demonstrates ability to attain a stable position through the foot and ankle.</td>
</tr>
<tr>
<td>Maintain</td>
<td>Single leg standing – Hip swings, and Star pattern reaching. Heel raises, oscillation with theraband, and impulse with medicine ball.</td>
<td>Athlete demonstrates ability to maintain stability and good alignment through the lower extremities.</td>
</tr>
<tr>
<td>Sustain</td>
<td>Lunges and step down exercises Bilateral and single leg hops Forward and backward acceleration and deceleration Pivoting and cutting maneuvers</td>
<td>Athlete demonstrates the ability to tolerate loading and pushing-off the involved lower extremity.</td>
</tr>
</tbody>
</table>

Table 1: Progression through three stages of stability training.

![Figure 4. Foot held in an excessive pronated position.](image-url)
Progressions of the Sustain phase can be performed with the athlete jumping or hopping in place and then into hopping in different directions. Running activities can begin by acceleration and deceleration with forward and backward motions. Athletes needing to perform pivoting or cutting maneuvers can begin these activities at a slow speed maintaining good alignment of the foot and leg and avoiding excessive motions through the rearfoot.

Return to play criteria is based on the athlete's ability to move in all directions and at appropriate speeds. Athletes performing cutting and jumping maneuvers on firm surfaces, such as basketball and volleyball players, should be returned to full activities over a period of days to insure their tolerance to these stressful maneuvers. A progression of the athletic activities should be assessed with the athlete in his or her normal practice or competitive environment. The athlete's anterolateral ankle symptoms will need to be well controlled to insure that the return to competition will not create chronic inflammation of the sinus tarsi tissues.

Surgery

Athletes who fail a course of rehabilitation may need an arthroscopic exploration and reconstruction of the subtalar joint in order to return to their athletic pursuits. Arthroscopy of the subtalar joint has allowed for a more precise examination of the subtalar joint and the sinus tarsi. A synovectomy of the subtalar joint along with an arthroscopy of the subtalar joint can be used to remove chronic synovitis and arthrofibrosis that is commonly found in STS. Surgical reconstructions of the cervical and intersosseus ligaments are made by splitting the tendon of the peroneus brevis and routing the graft through bone tunnels made through the calcaneus and the talus. Patients with instability of the talocrural and subtalar joints may require a tri-ligamentous reconstruction of the anterior talofibular, calcaneofibular, and cervical ligaments. Patients who present with significant joint degeneration or continue to have persistent symptoms even after ligamentous reconstruction may require an arthodesis resulting in an isolated fusion of the subtalar joint.

Athletes who have undergone ligamentous reconstructions will commonly be immobilized for a 6-week period, followed by a rehabilitation program to regain normal ankle mobility, strength, and balance. Return to athletic activities usually begins at 4 to 6 months post-operative.

Common post-operative problems are transient loss of sensation of the lateral ankle and foot and persistent peroneal weakness.

SUMMARY

Sinus tarsi syndrome is a condition of the ankle and foot that results from instability of the subtalar joint. Athletes with this condition typically have complaints of instability with functional activities and persistent anterolateral ankle discomfort. The joints of the ankle should be assessed for mobility and reproduction of feelings of instability and discomfort. Treatments for this condition will need to control the athlete's ankle discomfort and improve the overall stability of the foot and ankle. Therapists should design intervention plans based on the athlete's need for training and competition.

REFERENCES


ABSTRACT

**Background.** Previous studies have shown military physical therapists (PT) to have comparable clinical diagnostic accuracy (CDA) and interobserver agreement to orthopaedic surgeons (OS). However, no studies have examined hip pathology or used intraoperative findings as the reference standard for diagnosis.

**Objective.** To compare the CDA of physical examination findings among a PT, an OS, and two surgical orthopaedic residents (ORs) for hip labral tears.

**Methods.** Thirty-six patients (15 males, 21 females) aged 18-47 (mean + SD, 31.4 + 8.1 years) with 37 symptomatic hips were enrolled in a prospective study and underwent a standardized clinical examination followed by hip arthroscopy. A PT, an OS, and two ORs independently performed history and examinations with the emphasis of diagnosis on the results of six special tests.

**Results.** Thirty-two of 37 individuals (86%) had labral tears to the hip at arthroscopy. Analysis of agreement between clinical diagnosis and intra-operative findings of a labral tear produced a CDA of 85.3% (29/34 correct) for the PT, 84.4% (27/32 correct) for the OS, and 80.0% (24/30 correct) for ORs. No significant difference in CDA occurred in comparing the PT, OS, and ORs.

**Conclusions.** Using arthroscopy as the reference standard, hip labral tears were clinically suspected with 80-85% accuracy. The clinical diagnostic accuracy of the PT, OS, and ORs was high with no significant difference between examiners. In this study, an experienced PT, an OS, and two ORs demonstrated similarly high diagnostic skills.

**Key Words:** diagnosis, physical exam, hip joint, labral tear, direct access.
INTRODUCTION
United States Army physical therapists (PTs) have been practicing in orthopaedic management roles since the Vietnam War and their primary role is to provide evaluation and treatment to alleviate or prevent physical impairments stemming from injury, pre-existing problems, or disease. In their role as physician extenders, Army PTs can also gain privileges to evaluate patients without physician referral; order radiographs, bone scans, magnetic resonance imaging (MRI), and computed tomography scans; order certain lab tests; refer patients to medical specialty clinics; perform electromyographic and nerve conduction studies; restrict service members to their living quarters for up to 72 hours; restrict work and training for up to 30 days; and prescribe certain medications. It is well documented that Army PTs have performed successfully as physician extenders in the evaluation and treatment of patients with neuromusculoskeletal dysfunction. Further, evidence points towards minimal risk for negligent care when patients are evaluated and managed by PTs, through direct access or by referral.

Diagnostic accuracy is fundamental to direct access providers. Previous studies in the military health care system have shown that PTs have comparable clinical diagnostic accuracy and interobserver agreement to orthopaedic surgeons (OSs) comparing MRI findings for multiple conditions or radiographs following patients with acute ankle sprains. However, no research currently exists which prospectively compares the accuracy of diagnosis between PTs and OSs from a battery of clinical examination tests and compares it to the gold standard for orthopaedic diagnosis-intraoperative findings.

One condition for which limited evidence exists in the accuracy of the clinical examination is hip labral pathology. The acetabular labrum functions to both enhance joint stability and decrease contact stresses between the acetabular and femoral cartilage. A patient with a labrum tear can be symptomatic and may require open or arthroscopic debridement, or possibly repair.

Table 1 describes the clinical signs and symptoms of acetabular labral tears. An examiner would not rely on the finding of just one clinical item in isolation, but should use information gathered from the history, site of pain, mechanical symptoms, and physical examination to determine a diagnosis. Mechanisms of injury and risk factors noted in the literature include hip hyperabduction, twisting, falling, motor vehicle accidents, sports (especially those that require hip external rotation or hyperextension such as soccer, karate or ballet), a direct blow, or hip dislocation. The anterior inguinal area is the most common site of pain in patients with labral pathology; this sign is highly sensitive and pain is typically rated as moderate to severe. For mechanical symptoms, some patients with labral pathology report clicking, catching, or locking of the hip with motion, though the significance of these signs is questionable. Currently, research has not demonstrated sufficient specificity of individual or clusters of clinical tests to confidently rule in a diagnosis of hip labral lesion; but high sensitivity of many tests allows a negative finding to increase confidence that a hip labral lesion is absent.

The decision, therefore, to perform hip arthroscopy on a patient suspected of having labral pathology is typically based on a number of factors to include patient history, conservative treatment results, clinical examination, magnetic resonance arthrography (MRA), and response to intra-articular injection of anesthetic. While the value of MRA and intra-articular injections in diagnosis has been shown, the accuracy of clinical examination tests in detecting labral tears is less well defined.
Physical therapists in orthopaedic and sports medicine practices manage patients with suspected hip labral tears and are trained to perform physical examinations using clinical tests shared by orthopaedics and physical therapy practice. It is important for a PT to determine how his or her clinical diagnostic accuracy (CDA) compares with an OS and ORs working in the same facility in order to diagnose, treat, or refer patients most appropriately during the conservative treatment phase. Therefore, the purpose of this study was to prospectively assess the CDA of physical examination findings for hip labral pathology among a PT, an OS, and ORs using arthroscopy as the definitive diagnosis. The hypothesis to be tested was that all providers would have similar CDAs.

METHODS

Subjects

Thirty-six consecutive military health care beneficiaries presenting to the orthopaedic sports medicine clinic at a tertiary military medical center with hip pain were recruited by ORs. All subjects provided informed consent to their participation and the rights of the subjects were protected as governed by the Clinical Investigation and Human Use Committees of the Department of Clinical Investigation at Walter Reed Army Medical Center. Subjects included active-duty military members or Department of Defense beneficiaries who were between 18-47 years of age and who were seeking treatment for hip pain refractory to conservative treatment. Subjects who were pregnant or with previous hip surgery were excluded. Subjects with a primary diagnosis of hip osteoarthritis, congenital hip pathology (i.e. dysplasia), avascular necrosis, or femoral neck stress fracture were also excluded.

Procedures

Before initiation of the study, a PT with 19 years of experience, two ORs (one with 4 years, one with 5 years surgery experience) and an OS (with 7 years experience as a fellowship-trained sports surgeon) who performed all hip arthroscopies participated in a 30 minute practice session to standardize the following clinical examination techniques: Thomas hip flexion-to-extension maneuver (aka McCarthy Sign), internal rotation load/grind, Fitzgerald Test, eccentric hip flexion, resisted straight leg raise (SLR), and resisted SLR in external rotation.

Patients were examined independently by the PT, one of two ORs, and the OS in varied order based on provider availability. Physical examinations were performed first and the results recorded prior to gathering clinical histories and radiographic findings. Each examiner was blinded to the results of the other providers. For the purposes of this study, the test was considered positive if the patient had one or more of these symptoms during the test: click, clunk, or pain in the groin region which reproduced their chief complaint. The final diagnosis was not algorithmically derived, instead the diagnosis was driven by clinical reasoning based on meaningful interpretation of all the factors (pain, location, mechanical symptoms) integrated across all six tests. A description of physical examination tests follows.

Thomas hip flexion-to-extension maneuver (aka McCarthy Sign)\textsuperscript{17,20,21}

In supine, the subject fully flexed both hips (Figure 1), then the examiner slowly and passively extended the subject’s lower extremities with hips going into external rotation (ER) (Figure 2A). This test was repeated, but with the subject’s hip going into internal rotation (IR) (Figure 2B).
Sensitivity and specificity of this test has yet to be published.\textsuperscript{22,27}

**Internal rotation load/grind test**

In supine, the examiner flexed the subject's hip passively to approximately 100 degrees and then rotated the subject's hip from IR to ER while pushing along the long axis of the femur through the knee to cause “grind” (axial compression of the femoral head in the acetabulum through knee) (Figure 3). This movement mimics, and is very similar to, the flexion-internal rotation-axial compression test, which has a reported specificity of 0.43 and a sensitivity of 0.75.\textsuperscript{28}

**Fitzgerald Test\textsuperscript{18}**

To test the anterior labrum, the examiner started with the subject's hip in maximum flexion, ER, and full abduction (Figure 4A); then extended the subject's hip while placing it into full IR, and adduction (Figure 4B). To test the subject's posterior labrum, the examiner started with the subject's hip in maximum flexion, IR, and adduction (Figure 5A); then extended the subject's hip while placing it into full ER and abduction (Figure 5B). Sensitivity is reported to be 1.00.\textsuperscript{18} For inter-rater reliability of the flexion-internal rotation-adduction-impingement test, which is described like the Fitzgerald test for anterior labral tears, Kappa was 0.58 with a 95% confidence interval of (0.29-0.87).\textsuperscript{29}

**Eccentric hip flexion (patient-controlled lowering)**

While supine, the subject lifted the lower extremity into full hip flexion with knee extended, then slowly lowered the leg to the table, reporting any clicks, clunks, or pain. This test was used to identify possible iliopsoas tendon snapping.

**Resisted SLR\textsuperscript{21}**

While supine, the subject actively raised the lower extremity to 30 degrees of hip flexion with the knee fully extended. The subject held the lower extremity while the examiner applied resistance to the ankle. The resisted SLR is thought to load the joint antero-superiorly and to cause anterior groin pain if an intra-articular lesion is present.\textsuperscript{30}

Sensitivity and specificity of this test has yet to be published.\textsuperscript{22,27}
Resisted SLR in ER
The test was repeated, but subject's hip was in ER (Figure 6). This test is thought to “wind up” the iliopsoas and place more tension at the labrum. Sensitivity and specificity of this test has yet to be published.22,27

Statistical Analysis
Descriptive statistics, frequency tables, and Cochran's Q test31-32 (repeated measures test for dichotomous data with three or more independent variables- examiners in this case) were used to determine whether a PT could demonstrate a comparable degree of CDA with an OS and one of two ORs when conducting hip examination tests targeting labral pathology (alpha level set at p<.05). Clinical diagnostic accuracy has been used in a previous study1 and is a ratio represented by the number of correct diagnoses as the numerator and the total number of diagnoses made as the denominator (number correct diagnoses/total number diagnoses).33 The number of false negatives (condition in which the examiner diagnosed a subject without a tear but a tear existed) and false positives (condition in which the examiner diagnosed a subject with a tear but no tear existed) were also determined for each examiner. All statistics were performed with SPSS 9.0 for Windows (SPSS Inc., Chicago, IL).

RESULTS
Over an 18 month period, 36 patients (15 male and 21 females) aged 18-47 (mean 31.4 + SD 8.1 years) with 37 symptomatic hips were enrolled in this study. All 36 enrolled subjects completed the study. The PT, OS and ORs independently examined the patients, documented results of their clinical tests, and then made a diagnosis based on their findings. Table 2 shows the frequency of positive clinical findings among the examiners. Only one test (Fitzgerald test going into external rotation and abduction) showed a large variability between providers.

In this cohort, 34 patients had complete examination and diagnosis data by the PT, 32 patients by the OS, and 30 patients by the ORs. The ORs examined approximately 15 patients each. All 36 patients underwent hip arthroscopy, one bilaterally. Results from the hip arthroscopy provided the definitive diagnosis. Thirty-two of 37 subjects (86%) had acetabular labral tears at the hip confirmed at the hip during hip arthroscopy. Some subjects had multiple tears at the hip and the locations noted were: 11 tears located anterior, 21 anterior-superior, six superior, and one tear posterior-superior.

Analysis of agreement between clinical diagnosis and intra-operative findings of a labral tear produced a CDA of 85.3% (29/34) for the PT (five false positives), 84.4% (27/32) for the OS (five false positives), and 80.0% (24/30) for ORs (four false positives, two false negatives). No significant difference in CDA existed among all three examiners (Q= 2.00, p = .999). A remarkable observation was that the PT and OS each had five false positives which were on the same five patients.

DISCUSSION
The findings from this study support the hypothesis regarding CDA by demonstrating that the PT, OS, and ORs practicing at a tertiary military medical center during the period of this study demonstrated a high degree of CDA on hip labral pathology diagnosis, confirmed with arthroscopy, for patients referred with hip pain. Though

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<th></th>
<th>PT</th>
<th>OS</th>
<th>ORs</th>
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<tr>
<td>Thomas maneuver</td>
<td>83.8</td>
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<td>67.6</td>
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<td>rotation</td>
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<tr>
<td>Thomas maneuver</td>
<td>78.4</td>
<td>89.2</td>
<td>83.8</td>
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<td>(McCarthy Sign)</td>
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<td>rotation</td>
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<tr>
<td>Full flexion</td>
<td>89.4</td>
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<td>Fitzgerald</td>
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<td>lowering</td>
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<tr>
<td>Resisted straight</td>
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<td>59.5</td>
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<tr>
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responses of individual tests during the clinical exam showed some variability between providers (i.e. Fitzgerald test), the overall interpretation of all clinical exam tests combined yielded very similar diagnoses. As a result, no significant difference occurred in diagnostic accuracy between the PT, OS and ORs.

The results of this study are comparable to previously published literature. Other studies which have addressed PT clinical accuracy have found similar interobserver or CDA agreements. Moore et al11 conducted a retrospective review of 560 patients with musculoskeletal injuries referred for magnetic resonance imaging and compared CDA of PTs to OSs and non-orthopaedic providers. The authors reported no significant difference in CDA between PTs (74.5%; 108/145) and OSs (80.8%; 139/172) across a variety of orthopaedic conditions, though hip labral tears were not assessed. Physical therapists and OSs both showed significantly higher CDAs than non-orthopaedic providers (35.4%; 86/243). Therefore, the current study reinforces the diagnostic accuracy of PTs. Further, the present study design improves on the validity of these findings by overcoming two limitations Moore et al11 describe: 1) the need for a prospective analysis of CDA, and 2) a reference standard based on surgical confirmation of the diagnosis.

The results are in agreement with previous literature on the diagnostic accuracy of Army PTs and their orthopaedic colleagues. The high agreement in exam findings and diagnosis translates into better consistency in management of orthopaedic-related conditions and ultimately benefits the patient and the medical system. The strength of the accuracy may be explained by several factors, some intrinsic to the Army physical therapy education, training, and credentialing model, and others related to the nature of the Army medical system.

The Army has always emphasized training physical therapists in strong orthopaedic evaluation skills to serve as physician extenders. Almost all Army PTs attend a postgraduate training course in which specialized skills including orthopaedic examination, advanced diagnostic imaging, and pharmacological management are emphasized. Additionally, as part of the process for PTs to become credentialed as neuromusculoskeletal evaluators, PTs will typically shadow physician colleagues in orthopaedics for up to a week at a time, and shadow radiologists and primary care physicians, as well.

The Army medical system further strengthens the evaluation skill sets of PTs by the close relationship in most facilities where PTs and OSs routinely see patients together in combined clinics to manage nonsurgical or perioperative conditions. Combined training is critical and greatly emphasized in a deployed theater, where the PT's role in managing the large volume of nonsurgical orthopaedic conditions frees the OS to concentrate on individuals with complicated trauma and surgical cases.

**Limitations**

The subjects enrolled in this study were all selected from a tertiary-level orthopaedic sports medicine clinic. Since this clinic is completely referral based, all patients presenting for evaluation would have been previously evaluated by a PT or physician. Further, the OS has developed a specialization in hip arthroscopy for the treatment of patients with labral pathology, which is known to the referring providers. As a result, this sample is biased towards hip labral pathology, as other etiologies for hip pain, which may indeed be more common, were typically excluded prior to final referral to the clinic. Therefore, it is not known how many people might have similar hip symptoms or complaints who were never referred to the clinic. A limitation known as “spectrum bias” could have occurred which could have improved the overall diagnostic accuracy by eliminating patients with conditions in which the physical examination tests assessed in this study are less discriminate. Results of this study may be different if the PT, OS, and ORs had evaluated the subjects in a general practice setting prior to any other evaluations and interventions.

Additionally, the use of arthroscopy as the gold standard reference in this study significantly improves validity, but at the consequence of furthering spectrum bias. Spectrum bias can cause an overestimation when diagnostic accuracy is studied in samples in which the vast majority of subjects have the disease in question. These studies tend to overstate the accuracy when applied to the general population. Regardless, this population bias effect would be expected to equally impact each of the examiners. Thus, spectrum bias may have artificially elevated the CDA; however, it should not have impacted the finding of equivalent CDA for PT, OS and ORs conducting physical exams of the subject's hip to detect labral tears.

Lastly, the use of a single PT, OS, and two ORs limits the generalizability of the findings. This limitation could have
been overcome by having more than one of each type of provider perform examinations. While the external validity of our results may have improved, such a study was not practical in the present clinic setting.

Clinical Relevance
Army PTs frequently perform initial evaluations for a myriad of orthopaedic and sports injuries while serving in a physician extender role. Recent studies have shown the effectiveness of using Army PTs as primary neuromusculoskeletal screeners during peace and war, including during deployments to Operations Desert Shield and Storm, Bosnia, and Operation Iraqi Freedom. This study provides further evidence that military PTs demonstrate competency in making sound, independent clinical judgments regarding the evaluation and management of patients with hip labral pathology.

Future Research
These findings warrant further studies to evaluate CDA between PTs and other health care providers in a variety of settings for the patients with the most common musculoskeletal conditions across the full spectrum of a disease or injury process. In addition, prospective studies involving PTs with varying levels of clinical experience, board certification, and fellowship training will provide important data to further conclusions regarding the abilities of PTs to manage patients in a direct access environment.

CONCLUSION
Using arthroscopy as the reference standard, hip labral tears in the subjects were clinically suspected with 80-85% accuracy among the examining clinicians. Clinical diagnostic accuracy of an experienced physical therapist, orthopaedic surgeon, and orthopaedic residents on patients with hip labral pathology was excellent with no significant difference among examiners. This study further strengthens the evidence that the use of Army PTs in the role of managing, evaluating, and treating patients with neuromusculoskeletal dysfunction is a successful model.

REFERENCES