CDM Sport develops and distributes rehabilitation and fitness products to the health care, wellness and sports medicine markets. You can find us in the training rooms of most professional sports organizations, Division I athletic programs and the trailers that support professional golf tours. We’re in over 2500 spine and physical therapy clinics in the US and Canada.

Change your body. Change your game.

LightForce™ by LiteCure®
- OTIS
- DS2 Platform
- MR Cube
- MR Squat
- RNT Tubing
- Instant Replay
- Back System 3

LightForce Lasers

get in the game
with Deep Tissue Laser Therapy™

Class IV Laser Therapy
at a value
from the leaders in Deep Tissue Laser Therapy.

Make an impact on your patients AND your practice. Call today to learn more and get the tools you need!
302.709.0408

Request More Information // LightForceLasers.com

#LightForceEducation | LiteCure® Medical | 302.709.0408

CDM SPORT | 817.448.8908 | WWW.CDMSPORT.COM
EDITORIAL STAFF & BOARD

Phil Page, PT, PhD, ATC, CSCS
The Hygenic Corporation
Akron, Ohio – USA

Mark Paterno, PT, PhD, MBA, SCS, ATC
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio – USA

Michael P. Reiman, PT, DPT, OCS, SCS, ATC,
FAAOMPT, CSCS
Duke University School of Medicine
Durham, North Carolina – USA

Mark F. Reinking, PT, PhD, SCS, ATC
Saint Louis University
St. Louis, Missouri – USA

Jill Robertson, PT, MSc (PT), Dip Manip PT
Beaverbank Orthopaedic and Sport Physiotherapy
Halifax, Nova Scotia – Canada

Kevin Robinson, PT, DSc, OCS
Belmont University
Nashville, Tennessee – USA

Barbara Sanders, PT, PhD, SCS, FAPTA
Texas State University-San Marcos
San Marcos, Texas – USA

Teresa L. Schuemann, PT, DPT, SCS, ATC, CSCS
Colorado Physical Therapy Specialists
Fort Collins, Colorado – USA

Patrick Sells, DA, ES
Belmont University
Nashville, Tennessee – USA

Laurie Stickler, MSPT, OCS
Grand Valley State University
Grand Rapids, Michigan – USA

Steven R. Tippett, PT, PhD, SCS, ATC
Bradley University
Peoria, Illinois – USA

Timothy F. Tyler, PT, ATC
NISMA T Lenox Hill Hospital
New York, New York – USA

Timothy Uhl, PT, PhD, ATC
University of Kentucky
Lexington, Kentucky – USA

Mark D. Weber, PT, PhD, SCS, ATC
University of Mississippi Medical Center
Jackson, Mississippi – USA

Kevin Wilk, PT, DPT
Champion Sports Medicine
Birmingham, Alabama – USA

Erik Witvrouw, PT, PhD
Ghent University
Ghent – Belgium
IJSPT is a bimonthly publication, with release dates in February, April, June, August, October and December.

ISSN 2159-2896
TABLE OF CONTENTS
VOLUME 10, NUMBER 1

Original Research
1  Regional Interdependence of the Hip and Lumbo-Pelvic Region in Division II Collegiate Level Baseball Pitchers: A Preliminary Study.
   Authors: Shimamura KK, Cheatham S, Chung W, Farwell D, De la Cruz F, Goetz J, Lindblom K, Powers D

13  Passive Hip Range of Motion is Reduced in Active Subjects with Chronic Low Back Pain Compared to Controls.
   Authors: Roach SM, San Juan JG, Suprak DN, Lyda M, Bies AJ, Boyelston CR

21  Association Between the Functional Movement Screen and Injury Development in College Athletes.
   Authors: Garrison M, Westrick R, Johnson MR, Benenson J

29  Normative Values for the Functional Movement Screen in Adolescent School Aged Children.
   Authors: Abraham A, Sannasi R, Nair R

   Authors: Krause DA, Boyd MS, Hager AN, Smoyer EC, Thompson AT, Hollman JH

45  Temporal Efficacy of Kinesiology Tape vs. Traditional Stretching Methods on Hamstring Extensibility.
   Authors: Farquharson C, Greig M

52  The Reliability and Diagnostic Accuracy of Assessing the Translation Endpoint during the Lachman Test.
   Authors: Mulligan EP, McGuffie DQ, Coyner K, Khazzam M

62  Hand-held Dynamometer Positioning Impacts Discomfort During Quadriceps Strength Testing: A Validity and Reliability Study.
   Authors: Hansen EH, McCartney CN, Sweeney RS, Palimenio MR, Grindstaff TL

69  Effects of Wearing Athletic Shoes, Five-Toed Shoes, and Standing Barefoot on Balance Performance in Young Adults.
   Authors: Smith BS, Burton B, Johnson D, Kendrick S, Meyer E, Yuan W

75  Ultimate Frisbee Injuries in a Collegiate Setting.
   Authors: Akinbola M, Logerstedt D, Hunter-Giordano A, Snyder-Mackler L

Case Report
85  Gait Re-training to Alleviate the Symptoms of Anterior Exertional Lower Leg Pain: A Case Series.
   Author: Breen D, Foster J, Falvey E, Frandlyn-Miller A

95  Return to Sport Following Surgery for a Complicated Tibia and Fibula Fracture in a Collegiate Women's Soccer Player with a Low Level of Kinesiophobia.
   Authors: Freigenbaum LA, Baraga M, Roach KE, Calpino KM, Dorsey K, Martorelli C, Sagarduy B, King L, Scavo VA

104  The Use of Dry Needling for a Subject with Acute Onset of Neck Pain: A Case Report.
   Authors: Pavkovich R

Clinical Commentary
114  An Interval Kicking Progression for Return to Soccer Following Lower Extremity Injury.
   Authors: Arundale A, Silvers H, Logerstedt D, Rojas J, Snyder-Mackler L
ABSTRACT

Background: Pitchers may be at greater risk of injury in comparison to other overhead throwing athletes due to the repetition of the pitching motion. It has been reported that approximately 30% of all baseball injuries occur in the lower body. This may be related to limited hip mobility, which can compromise pitching biomechanics while placing excessive stress on the trunk and upper quarter. Hip motion and strength measurements have been reported in professional baseball pitchers but have not been reported in collegiate pitchers.

Purpose: The purpose of this study was to report preliminary findings for passive hip motion and isometric hip muscle strength in collegiate pitchers and compare them to previously published values for professional level pitchers.

Study Design: Cross sectional study

Methods: Twenty-nine collegiate baseball pitchers (age = 20.0 ± 1.4 years, height = 1.88 ± 0.06 m; weight = 89.3 ± 10.7 kg; body mass index = 25.3 ± 2.5 kg/m²) were recruited. Subjects were assessed for hip internal rotation (IR) and external rotation (ER) passive motion, hip anteverision or retroversion, gluteus maximus, gluteus medius, hip internal rotator, hip external rotator strength, and lumbo-pelvic control with the prone active hip rotation test as described by Sahrmann. Statistical analysis included calculation of subject demographics (means and SD) and use of a two-tailed t-test (p > 0.05).

Results: Fifty-two percent of the right-handed and 50% of the left-handed pitchers demonstrated poor lumbo-pelvic motor control with an inability to stabilize during active hip IR and ER even though isolated strength deficits were not detected at a significant level. There were no significant differences in hip passive motion or gluteus medius strength between right and left-handed pitchers. Differences did exist between collegiate data and previously published values for professional pitchers for IR motion measured in prone and gluteus maximus strength. Hip retroversion was present in 55% of the pitchers primarily in both limbs with four of the pitchers presenting with retroversion singularly in either the stride or trail limb where the ER rotation motion was greater than the IR.

Conclusion: Assessing mobility and muscle strength of the lower quarter in isolation can be misleading and may not be adequate to ensure the potential for optimal pitching performance. These findings suggest that lumbo-pelvic control in relation to the lower extremities should be assessed as one functional unit. This is the first study to explore hip motion, strength, and lumbo-pelvic control during active hip rotation in collegiate baseball pitchers.

Evidence Level: 2

Keywords: Baseball, collegiate, hip, lumbo-pelvic motion

CORRESPONDING AUTHOR
Scott Cheatham PT, DPT, PhD(c), OCS, ATC, CSCS
Assistant Professor
Director Pre-Physical Therapy Program
Division of Kinesiology and Recreation, SAC 1138
California State University Dominguez Hills
1000 E. Victoria St. Carson, CA 90747
office # (310) 243-3794
E-mail: Scheatham@csudh.edu
INTRODUCTION

The repetition of the pitching motion combined with strenuous training schedules place baseball pitchers at a greater risk of injury in comparison to other overhead throwing athletes. Although the majority of injuries occur in the upper extremity, Posner et al found that approximately 30% of all injuries in baseball pitchers occur in the lower body. Increasing evidence indicates that baseball pitchers are susceptible to femoroacetabular impingement, sports hernias, and groin injuries. The development of these conditions are often related to limited hip mobility as proposed by Verrall et al who suggest that hip stiffness is associated with later development of chronic groin injury and may be a risk factor for development of future pathology. Abnormal hip mobility can also predispose other body regions by compromising normal pitching biomechanics which may induce excessive forces through the glenohumeral joint. This can affect the velocity of the pitch as well as increase the potential risk for injury in the upper quarter. Specifically, altered hip rotational range of motion has a direct effect on the amount of external rotation torque and horizontal adduction range of motion of the shoulder that occurs during the throwing motion.

In addition to rotational mobility, it is critical for the pitcher to have adequate strength of both the trailing limb (leg on same side as throwing arm) and stride limb (leg opposite side of throwing arm) in order to effectively transfer power through the lower quarter and trunk into the pitching arm. Adequate strength of the hip abductor muscles demonstrated by good peak hip abductor muscle activity in the trail limb is necessary during the wind-up and early cocking phases in order to stabilize the pelvis and enable optimal stride length for optimal acceleration from the lower quarter.

Over time, the loading patterns specific to individual pitchers that lead to asymmetric patterns can contribute to the development of sport-specific and extremity specific adaptations in hip range of motion. McCulloch et al found that hip rotation in pitchers at the professional level can be asymmetrical, showing significantly greater internal rotation in the trailing hip compared to the stride hip and significantly greater external rotation in the stride hip compared to the trailing limb. Biomechanical changes that result from mal-alignment of the lower extremities can have an influence on joint loading, mechanical efficiency of muscles, and proprioceptive orientation and feedback from the hip and knee. These adaptations ultimately result in altered neuromuscular function and control of the lower extremities. The resulting faulty movement patterns can further perpetuate irritation to the surrounding tissues of the hip and low back which can occur with increased frequency of accessory and physiologic movements seen with poor lumbo-pelvic control.

To date, it is unknown whether collegiate level players display the same hip asymmetries as professional level players. The presence of a retroversion deformity places the femoral neck in a position of posterior rotation in the frontal plane with the end result of increased external rotation ROM of the hip and associated decrease in hip internal rotation. It is often assumed that adequate strength and ROM automatically ensures efficient performance. Although movement patterns are partially dictated by anatomical and biomechanical variables, the neurological control necessary to coordinate smooth movement is often overlooked. During a baseball pitch, it is essential to control the trunk from a position of greatest rotation at arm cocking through the position when the ball is released. The greatest demand for stability of the trunk occurs at stride limb foot contact before ball release. The amount of posterior lumbo-pelvic rotation that exists over the stride limb at foot contact is important since excessive motion can reduce the maximum kinetic values of the pitch. It is therefore necessary to assess trunk stability relative to the rotation in the hip in order to ensure that a pitcher can maintain adequate trunk control as the trunk rotates over the stride limb at ball release.

In a previous study by Sung et al, the increase in axial rotation of the trunk relative to the hip was identified as a significant risk factor for development of low back pain and can occur in conjunction with stiffness in the hip. Van Dillen et al also found that individuals with low back pain often have limited and asymmetrical passive hip rotation. Although this has not been assessed in baseball pitchers, the
assessment of hip rotation in relation to the trunk has been a useful screening tool for other rotational sports such as golf.20

Currently there are no studies exploring range of motion (ROM), strength and motor control of the lumbo-pelvic region during active hip rotation in Division II collegiate level baseball pitchers. Clinical assessment of the hip for passive ROM and strength performed in this study has been used previously in similar populations of young healthy adults.21 Hand held dynamometry and digital goniometry have been determined to be efficient and reliable assessments for muscle strength and range of motion.21,22 Although there are no previous studies validating the use of this test, stability of the lumbo-pelvic area in relation to the hip has also been previously explored in rotational athletes by Harris-Hayes.27

The purpose of this study was to report preliminary findings for passive hip motion and isometric hip muscle strength in collegiate pitchers and compare them to previously published values for professional level pitchers. Additionally, this study explores the relationship between lumbo-pelvic motor control and active hip rotation by assessing movement of the lumbar spine and pelvis during prone active hip rotation.

METHODS
This study was approved by the university Internal Review Board. Eligible participants read and signed an informed consent prior to enrollment in this study. This cross sectional study involved the assessment of pelvic girdle and hip function of Division II baseball pitchers. Each pitcher was assessed for hip passive ROM, isometric strength, Craig’s test, and lumbo-pelvic motor control during active hip rotation during one data collection session. Comparisons were made between right and left handed pitchers and previously established normative values from professional pitchers.

Subjects
Instrumented hip examinations were performed with a digital goniometer and digital dynamometer on a total of 29 collegiate baseball pitchers during the onset of spring training (Table 1). Participants included 15 from the active pitching roster of Azusa Pacific University, and 14 participants were from the pitching roster at California State University San Bernardino. Subjects were between the ages of 18 and 30 years with a mean age of 20.0 ± 1.4 years. The average height of the participants was 1.9 ± 0.06 m, average weight was 89.3 ± 10.7 kg, average body mass index was 25.3 ± 2.5 kg/m². Both right and left-handed pitchers were accepted into the study including 23 right-handed pitchers and six left-handed pitchers. Subjects had to be asymptomatic in both hips at the time of testing and clear of any known hip pathology. Exclusion criteria included previous hip surgery or any other medical problem that would have limited their ability to participate in full activity during the regularly scheduled 2013-2014 baseball season.

Instruments
For range of motion measurements, a hand held digital goniometer (MicroFet 3, Hoggan Health Industries, West Jordan, UT) was used to measure the subjects hip range of motion. Hand held digital goniometers have shown good reliability when compared to a standard goniometer and inclinometer.23 For manual muscle testing (MMT), a digital dynamometer (MicroFet 3, Hoggan Health Industries, West Jordan, UT) was used on each subject. The digital hand dynamometer has shown good intra-rater reliability with intraclass correlation coefficient (ICC) ranging from 0.81 to 0.96.24

Pilot Testing
Prior to data collection, a three session pilot training test was conducted using the two examiners involved in the data collection process. One examiner recorded all results and one examiner performed all of the tests and was blinded to the recording of the data outcomes. The tests were performed on 29 subjects. The intrarater reliability for hip range of motion, strength, and Craig’s test was good with a range of ICC(3,3) = 0.90 to 0.92 and the lumbo-pelvic motor control tests also showed good reliability ICC(3,1) = 0.93. These values met or exceeded the recommended minimal reliability of 0.90 for clinical measurements.25

<table>
<thead>
<tr>
<th>Table 1. Subject Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Mean ± SD</td>
</tr>
</tbody>
</table>
Assessment Procedures

**Sitting:** Passive Hip IR and ER Passive ROM and Manual Muscle Testing (MMT)

For all of the assessments, the subjects were examined in their home team training facility and all procedures were explained in detail and demonstrated by the examiners.

**Hip IR ROM:** For measurement of the hip ROM tests, the subjects were sitting with their legs hanging off the edge of the plinth. The examiner placed one hand at the lateral aspect of the distal thigh and the other on the medial malleoli. The subject was passively moved into hip internal rotation by moving the foot laterally to the end of the available range. The examiner then stabilized the subject's thigh at the point where the hip could no longer be passively moved without inducing movement at the lumbo-pelvic region and measured with a hand held digital goniometer placed at the lateral malleolus.

**Hip ER ROM:** The measurement for external rotation was then performed. The examiner placed one hand at the medial aspect of the distal thigh and the other on the lateral malleoli. The subject was passively moved into hip external rotation by moving the foot medially to the end of the available range. The examiner then stabilized the subject's leg and measured with a hand held goniometer placed at the medial malleolus (Figure 1).

**MMT for Hip Internal Rotators:** While seated, the subject's leg was placed in a neutral position of hip rotation and abduction and adduction by the examiner. The examiner placed a stabilizing belt around the hand held digital dynamometer which was placed at the lateral malleolus. The subject was asked to move their foot outward, internally rotating against the resistance of the stabilizing belt attached to the leg of the plinth and digital dynamometer. The force generated by the subject was recorded as the internal rotator muscle force in kilograms (Figure 2). Two trials were recorded and averaged for each extremity.

**MMT for Hip External Rotators:** While seated, the subject's leg was placed in a neutral position of hip rotation and abduction and adduction by the examiner.

**Prone:** Passive HIP IR, ER, lumbopelvic control and Gluteus maximus MMT

**Passive Hip IR and ER:** Passive hip ROM testing was also conducted using the methods defined by Sahrmann. To assess hip passive rotation, the subject was placed in the prone position on the plinth, with the femur placed in neutral position by the examiner. The subject flexed the knee to 90 degrees. The subject's thigh was abducted 15 degrees to place the Tensor Fascia Lata (TFL) on slack. The examiner placed one hand on the pelvis of the test leg. The examiner's opposite hand was used to move the subject's leg into an internally rotated position by moving the subject's foot laterally. Once the examiner felt the anatomic block or movement of the
pelvis, maximal passive internal rotation mobility of the hip was measured using a digital goniometer placed parallel to the tibia. The measurement was recorded and averaged between two trials. The same position was used for the measurement of external rotation. The examiner kept one hand on the pelvis and the other hand was used to move the foot medially while maintaining the 90 degree flexed position of the knee. The examiner continued to move the foot until the examiner felt the pelvis move. Once the examiner felt the anatomic block or movement of the pelvis, maximal passive external rotation mobility of the hip was measured with a digital goniometer placed parallel to the tibia. The measurement was recorded, with two trials performed, and the average of the two trials was used for data analysis.

Craig's Test
Further testing for femoral anteversion and retroversion was conducted using the Craig’s test. The subject was in the prone position with the knee flexed to 90 degrees. The examiner palpated the same side greater trochanter. The femur was passively rotated through hip internal rotation and external rotation until the position at which the trochanter was parallel to the plinth placing it in the most prominent lateral position, confirmed with manual palpation. The amount of femoral internal rotation was measured by placing a digital goniometer along the tibia. Two trials were performed and recorded. An angle less than 8 degrees was determined to be a position of retroversion and an angle greater than 15 degrees was determined to be a position of anteversion. Intra-tester reliability is high for the Craig’s test and is reported in the literature to range from 0.80–0.90.

Prone lumbopelvic control test: Testing was conducted using the methods defined by Sahrmann. To assess prone active rotation, the subject was placed in a prone position on the plinth with the femur placed in neutral position in regards to IR/ER or abduction or adduction by the examiner. The subject flexed the knee to 90 degrees. The examiner palpated the pelvis at the level of the anterior superior iliac spine (ASIS) and the posterior superior iliac spine (PSIS) bilaterally to assess whether the pelvis and lumbar spine maintained a neutral position throughout the test. The subject was asked to maintain the 90-degree position of the knee and to actively perform femoral IR through their full available ROM (which was visually compared to the passive measurements taken earlier) while maintaining the knee at 90 degrees of knee flexion. As the subject actively rotated the femur the examiner assessed the pelvis for any superior or inferior movement or the ASIS or PSIS. The subject then performed active femoral ER through their full available ROM while the examiner assessed for movement in the pelvis exactly as was performed for IR. This was performed on both lower extremities. A negative test was defined as the subject independently performing active femoral IR and ER throughout their full available ROM without simultaneous movement in the pelvis or trunk (Figure. 3). Criteria for a positive test included early or excessive pelvic or low back rotation with active rotation of either hip (Figure 4).

Reliability of the MSI exam has been substantiated by Harris-Hayes and Van Dillen where inter-tester reliability of classification of patients with LBP when therapists used the MSI classification system was substantial. The Movement System Impairment (MSI) exam, which encompasses the prone rotation test, has demonstrated good reliability with a kappa...
coefficient of 0.81 for classification using entire MSI exam. The prone hip rotation test has been used by Scholtes et al to identify early lumbo-pelvic motion in athletes with low back pain who played rotation related sports. The presence of greater lumbo-pelvic rotation is frequently associated with low back pain, indicating that clinical assessment of early lumbo-pelvic movement in relation to the hip can be of great importance in individuals who play rotational sports.

**Gluteus Maximus MMT:** The subject was positioned prone with bilateral ASIS on the end of the plinth, leaning over the edge of the plinth, while feet maintained contact with the ground. The knee of the test leg was flexed to 90 degrees. The examiner lifted the test leg with one hand and stabilized the pelvis with the other hand to assess the amount of available ROM the subject had in hip extension. The stabilizing belt attached to the leg of the plinth was placed around the hand held digital dynamometer on the distal posterior surface of the subject’s femur above the knee. The examiner instructed the subject to hold the position of the leg lifted off the table with the knee flexed as maximal resistance was applied by the stabilizing belt attached to the leg of the plinth. The maximal force measured by the hand held digital dynamometer was recorded. Two trials were recorded for each extremity.

**Sidelying Gluteus Medius Manual Muscle Test**

**Gluteus Medius MMT:** The subject was positioned sidelying with the test leg on top. The examiner placed one hand on the pelvis and placed the other hand under the test leg. The examiner lifted the test leg into hip abduction to assess the amount of available ROM that the subject had in hip abduction. The examiner's other hand stabilized the pelvis to avoid the subject from rolling forward or backward during the test. The subject's leg was returned to neutral (hip flexion 90 degrees with 90 degrees knee flexion). The stabilizing belt attached to the leg of the plinth was placed around the hand held digital dynamometer on the distal posterior surface of the subject’s femur above the knee. The examiner instructed the subject to hold the position of the leg lifted off the table with the knee flexed as maximal resistance was applied by the stabilizing belt attached to the leg of the plinth. The maximal force measured by the hand held digital dynamometer was recorded. Two trials were recorded for each extremity.
of hip abduction without rotating the pelvis forward or backward. In this position, the examiner placed the stabilizing belt around the hand held digital dynamometer on the lateral mid femur above the knee. The examiner instructed the subject to hold the position against the resistance of the stabilizing belt secured on the underside of the plinth. The maximal force measured by the hand held digital dynamometer was recorded. Two trials were recorded for each extremity.

**STATISTICAL ANALYSIS**

Statistical analysis was performed using SPSS version 22.0 for Windows® (IBM SPSS, Chicago, IL). Participant descriptive data was calculated and reported as the mean and standard deviation (SD). During the pilot test, rater reliability was determined by the ICC model (3, k). The T-Test was used with a Bonferroni correction to measure mean differences between variables. Statistical significance was consider to be p < 0.05.

**RESULTS**

**Right Handers**

For right-handed pitchers, the mean sitting IR ROM for the trail limb (right) was 33.6° ± 9.4° versus the forward limb of 35.6° ± 8.1°. There was no significant difference in seated IR ROM between the trailing and forward limb (p = 0.22). For prone IR ROM, the trail limb (right) was 24.8° ± 8.6° versus of forward limb (left) of 27.0° ± 8.9°. There was no significant difference in prone IR ROM between the trailing and forward limb (p = 0.19).

For sitting ER ROM, the mean trail limb was 36.9° ± 9.8° versus the forward limb 39.4° ± 10.3°. There was no significant difference in sitting ER ROM between the trailing and forward limb with the seated measurement (p = 0.08). For prone ER ROM, the mean trail limb was 43.2° ± 8.0° versus the forward limb 46.3° ± 12.1°. There was no significant difference in sitting ER ROM between the trailing and forward limb with the prone measurements (p = 0.11).

**Left Handers**

For left handed pitchers, the mean sitting IR ROM for the trail limb (left) was 33.0° ± 9.5° versus of forward limb (right) of 32.1° ± 7.4°. There was no significant difference in seated IR ROM between the trailing and forward limb (p = 0.80). For prone IR ROM, the trail limb (left) was 20.5° ± 8.4° versus of forward limb (right) of 17.3° ± 7.9°. There was no significant difference in prone IR ROM between the trailing and forward limb (p = 0.29).

For sitting ER ROM, the mean trail limb was 43.2° ± 13.6° versus the forward limb 45.2° ± 13.6°. There was no significant difference in seated ER ROM between the trailing and forward limb (p = 0.56). For prone ER ROM, the mean trail limb was 49.4° ± 7.3° versus the forward limb 48.9° ± 13.6°. There was no significant difference in prone ER ROM between the trailing and forward limb (p = 0.84).

**Comparison of Left and Right Handed Pitchers**

When comparing the trailing limb of right and left pitchers there were no significant differences in seated IR and prone IR ROM measurements (p = 0.85 and p = 0.79 respectively) (Table 2). For ER ROM, there were no significant differences in seated ER and prone ER measurement (p = 0.38 and p = 0.87 respectively) (Table 2). When comparing the forward limb of right and left pitchers there was no significant difference in seated IR and prone IR ROM measurements (p = 0.51 and p = 0.72 respectively) (Table 2). For ER ROM of the forward limb, there was no significant difference in seated ER and prone ER measurement (p = 0.31 and p = 0.77 respectively) (Table 3).

**Comparison of Collegiate Pitchers’ data to Previously Established Values for Professional Pitchers**

The trailing limb of the right-handed pitchers sitting IR ROM was 33.6° ± 9.4° as compared to values for professional baseball pitchers of 37.7° ± 5.70°, demonstrating an approximate four degree difference. The trailing limb prone IR ROM was 34.45° ± 8.51° compared to professional values of 34.6° ± 4.0°, demonstrating an approximate 0.2 degree difference. The stride limb of the right-handed pitchers sitting IR ROM was 35.6° ± 8.1° compared to values for professional baseball pitchers of 37.0° ± 5.60°, demonstrating an approximate one degree difference. The stride limb prone IR ROM was 27.0° ± 8.9° compared to professional values of 34.4° ± 6.0°, demonstrating an approximate seven degree difference.
Force measures were combined for right and left-handed pitchers. MMT outcomes for the internal rotators were 55.33 kg ± 13.62 for the stride limb and 49.17 kg ± 13.24 for the trailing limb (Table 4). MMT outcomes for the external rotators were 38.10 kg ± 8.45 for the stride limb and 36.45 kg ± 8.80 for the trailing limb. MMT outcomes for the gluteus maximus were 90.55 kg ± 20.32 for the stride limb and 90.93 kg ± 24.60 for the trailing limb. MMT outcomes for the gluteus medius were 40.58 kg ± 10.85 for the stride limb and 42.90 kg ± 10.23 for the trailing limb. These were the only values that were able to be compared to previously established values for professional baseball players of 41.9 kg ± 7.2 for the stride limb and 41.4 kg ± 6.3 for the trailing limb (Table 4). This represents a difference of 1.32 kg and 1.50 kg respectively.

**Craig's Test**
Sixteen out of 29 (55%) pitchers demonstrated retroversion in both limbs with four of the pitchers pre-
The results of the current study revealed a 7 degree difference in stride limb IR when compared to the previously established normative values for IR in professional players measured in the prone position. The presence of this deficit may prove to be problematic as time progresses for pitchers and other athletes where the demand for hip rotation is high. Limitations of hip ROM may result in changes at the lumbo-pelvic region as a compensation strategy; especially during activities that require hip rotation such as golf, racquetball, and baseball.27

Fifty-five percent of the pitchers in the current study presented with hip retroversion where an angle less than eight degrees of femoral internal rotation in the prone position with the greater trochanter positioned parallel to the plinth was determined to be a position of retroversion. This can be highly problematic as the retroverted orientation of the hip may give rise to problems of impingement between the femoral neck and anterior acetabulum.39 Prolonged and severe impingement resulting from sporting activities can lead to progressive degenerative changes at the hip where loads greater than eight times body weight have been reported during competitive sports.40

The unique part of this investigation that has not been previously explored is the ability of pitchers to maintain lumbo-pelvic motor control during the prone

---

**Table 4. Comparison of strength values between collegiate and professional pitchers.**

<table>
<thead>
<tr>
<th></th>
<th>IR Stride Limb</th>
<th>IR Trail Limb</th>
<th>ER Stride Limb</th>
<th>ER Trail Limb</th>
<th>Gluteus Maximus Stride Limb</th>
<th>Gluteus Maximus Trail Limb</th>
<th>Gluteus Medius Stride Limb</th>
<th>Gluteus Medius Trail Limb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Right and Left Hand Pitchers Mean ± SD</td>
<td>55.33 kg ± 13.62</td>
<td>49.17 kg ± 13.24</td>
<td>38.10 kg ± 8.45</td>
<td>36.45 kg ± 8.80</td>
<td>90.55 kg ± 20.32</td>
<td>90.93 kg ± 24.60</td>
<td>40.58 kg ± 10.85</td>
<td>42.90 kg ± 10.23</td>
</tr>
<tr>
<td>Professional Values38 Mean ± SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41.9 kg ± 7.20</td>
<td></td>
<td>41.40 kg ± 6.3</td>
<td></td>
</tr>
</tbody>
</table>

IR = internal rotators; ER = external rotators

**DISCUSSION**

Currently there are no studies exploring ROM, strength, and motor control of the lumbo-pelvic region during the prone active hip rotation test in collegiate level Division II baseball pitchers. These preliminary findings in collegiate level Division II baseball pitchers were inconsistent with the findings of McCulloch et al comparing rotation measurements between the stride and trailing limb.3 This may be due to the professional level status of the pitchers in McCulloch’s study who would have had increased overall pitching time as compared to the collegiate level pitchers in the current study. Although the results of the current study showed differences between the two limbs IR and ER PROM, they did not reach a statistically significant level.

The results of the current study revealed a 7 degree difference in stride limb IR when compared to the previously established normative values for IR in professional players measured in the prone position. The presence of this deficit may prove to be problematic as time progresses for pitchers and other athletes where the demand for hip rotation is high. Limitations of hip ROM may result in changes at the lumbo-pelvic region as a compensation strategy; especially during activities that require hip rotation such as golf, racquetball, and baseball.27

Fifty-five percent of the pitchers in the current study presented with hip retroversion where an angle less than eight degrees of femoral internal rotation in the prone position with the greater trochanter positioned parallel to the plinth was determined to be a position of retroversion. This can be highly problematic as the retroverted orientation of the hip may give rise to problems of impingement between the femoral neck and anterior acetabulum.39 Prolonged and severe impingement resulting from sporting activities can lead to progressive degenerative changes at the hip where loads greater than eight times body weight have been reported during competitive sports.40

The unique part of this investigation that has not been previously explored is the ability of pitchers to maintain lumbo-pelvic motor control during the prone
The close proximity of the hip to the lumbo-pelvic region may predispose the low back to excessive rotational forces when more proximal regions need to compensate for limited rotation at the hips. The regional interdependence of the low back and hips was assessed using the MSI prone active IR and ER test. Results of the current study indicate that 52% of the right-handed pitchers were positive for excessive lumbo-pelvic rotation with active hip rotation in their trailing limb and 42% in the stride limb indicating that the pitchers had early or excessive lumbo-pelvic movement with active hip rotation. This was characterized by dysfunctional coupled movement of the pelvis and the hip where the pelvis rotated prior to the hip reaching the limits of available active ROM in the prone position. Fifty percent of left-handed pitchers were positive in the stride limb while none of the left-handed pitchers had excessive lumbo-pelvic movement with active hip rotation in the trailing limb. Previous research has linked early lumbo-pelvic motion with an increased incidence of low back pain.

Although the strength findings of the gluteus maximus in the collegiate population were similar to the professional players, adequate strength and ROM alone may not be sufficient to ensure optimal pitching performance. The regional interdependence of the lumbo-pelvic region and hip should be assessed to determine if excessive motion occurs in the lumbo-pelvic region with active hip rotation. Improving lumbo-pelvic movement patterns by reducing lumbo-pelvic motion during hip rotation could be an important component of improving efficiency of the baseball pitch as well as preventing injury to the low back and shoulder.

The limitations of the current study include a small sample size of 29 pitchers from two Division II baseball teams in Southern California. The years of pitching experience, pitch count, or training methods of each team were not considered in this study. Future research should include a comparison of the incidence of low back pain with larger samples sizes. There were no cited values for active control of hip rotation in professional athletes. Data on neuromuscular control of hip IR and ER in the prone position should be collected for pitchers at the other levels of baseball including professional, collegiate, and high school.

CONCLUSION

Strength findings of the gluteus maximus in the collegiate population were similar to the previously reported values of professional players. Simple range of motion comparisons performed between outcomes recorded herein for collegiate players revealed a 7-degree difference in stride limb IR when compared to the previously established values for IR in the prone position recorded for professional pitchers. Although strength and ROM are often assessed in the lower quarter, they may not be sufficient to optimize potential pitching performance. The results of the current study indicate that lumbo-pelvic motor control deficits were present during testing of both the stride and trailing limb in greater than 50% of the pitchers tested. The early lumbo-pelvic motion with prone active hip rotation may represent an abnormal pattern of movement that may predispose the low back to excessive rotational forces as the low back compensates for limited rotation at the hips during rotational sports. Further research should focus on the assessment of prone lumbo-pelvic control with active hip rotation in baseball pitchers and all athletes that participate in high demand rotational sports.

REFERENCES

6. Laudner K, Wong R, Onuki T, et al. The relationship between clinically measured hip rotational motion and shoulder biomechanics during the pitching...


ABSTRACT

Background: Non-specific low back pain is a common condition often without a clear mechanism for its presentation. Recently more attention has been placed on the hip and its potential contributions to non-specific chronic low back pain (NSCLBP). Emphasis in research has mainly been placed on motor control, strength and endurance factors in relation to NSCLBP. Limited focus has been placed on hip mobility and its potential contribution in subjects with NSCLBP.

Purpose/Aim: The aim of this study was to compare passive ROM in hip extension, hip internal rotation, hip external rotation and total hip rotation in active subjects with NSCLBP to healthy control subjects. The hypothesis was that active subjects with NSCLBP would present with decreased total hip ROM and greater asymmetry when compared to controls.

Design: Two group case controlled

Setting: Clinical research laboratory

Participants: 30 healthy subjects without NSCLBP and 30 active subjects with NSCLBP. Subjects categorized as NSCLBP were experiencing pain in the low back area with or without radicular symptoms of greater than three months duration.

Main Outcome Measure: Passive hip extension (EXT), hip internal rotation (IR), hip external rotation (ER) and total hip rotation ROM. A digital inclinometer was used for measurements.

Results: There was a statistically significant difference (p<0.001) in hip passive extension ROM between the control group and the NSCLBP group bilaterally. Mean hip extension for the control group was 6.8° bilaterally. For the NSCLBP group, the mean hip extension was -4.2° bilaterally. This corresponds to a difference of means between groups of 10.8°. There was no statistically significant differences (p>0.05) in hip IR, ER, or total rotation ROM between groups.

Conclusions: The results of this study indicate that a significant difference in hip extension exists in active subjects with NSCLBP compared to controls. It may be important to consider hip mobility restrictions and their potential impact on assessment of strength in NSCLBP subjects. Future studies may be needed to investigate the relationship between measurements and intervention strategies.

Level of Evidence: 2b

Keywords: Hip extension, hip mobility, hip rotation, inclinometer, non-specific low back pain
INTRODUCTION

Low back pain is a common condition with a lifetime prevalence in the general population ranging up to 84%, with prevalence of chronic low back pain noted at approximately 23%.\(^1\) The condition is also common amongst both adolescent and adult athletes.\(^2\) In spite of the significant resources that have been utilized to treat this condition, it appears that current approaches have resulted in less than satisfactory outcomes for pain and function.\(^5\) One reason for such poor outcomes may be a limited understanding of a clear causative mechanism for this condition. Secondary to this limited knowledge regarding the mechanism of injury, this condition is generally referred to as non-specific chronic low back pain (NSCLBP).\(^6\)

The majority of the literature on low back pain continues to focus on anatomical and biomechanical/motor control abnormalities or dysfunction in the trunk and or spine regions without regard to other potential contributors to the condition.\(^7\)\(^-\)\(^9\) There has recently been an increased interest in the possibility of hip involvement contributing to clinical conditions involving NSCLBP.\(^10\)\(^-\)\(^12\) This attention on the hip is often focused upon motor control, strength and endurance deficits of the gluteus maximus and medius muscles.\(^13\)\(^-\)\(^15\) Less emphasis appears to be placed on mobility or range of motion (ROM) of the hip joint itself. Of the studies examining hip ROM in relation to low back pain, many have focused primarily upon transverse and not sagittal or frontal plane motion.\(^16\)\(^-\)\(^18\) Findings from these studies have noted significant asymmetry in hip internal rotation (IR) or external rotation (ER) and total rotation (TR) in subjects with low back pain as opposed to subjects without low back pain. The subjects in these reports participated in rotation dependent sports, that included golf, tennis and racquetball.\(^19\)\(^,\)\(^20\)

Hip extension is another essential motion for proper loading and function of the lumbar spine and hip. It has been noted that normal hip extension mobility is imperative for normal mechanical load distribution in the hip and for efficient metabolic demands in standing.\(^21\) A decrease in hip extension, for example occurring due to shortening of the hip flexors, may result in an external flexor torque at the hip. This could result in an increased metabolic cost as a result of extensor muscles of the hip attempting to prevent collapse of hip and knee into full flexion.\(^21\) Theoretically it is possible that hip flexor shortening may result in an increased activation of low back musculature, with resultant increased internal moment, to keep the trunk in an upright position during standing and walking. Excessive activation of lumbar spine extensors may lead to early onset fatigue and decreased protection from shearing and torsional loads to lumbar spine, as well as impaired postural control strategies.\(^22\) Additionally, it has been demonstrated that in subjects with longstanding hip fusions that an excessive anterior pelvic tilt occurs during gait to compensate for lack of hip extension.\(^23\) This provides further evidence to suggest that lack of normal hip extension may alter the timing mechanism and motor activation of the lumbar spine. The role that mobility of hip abduction, adduction and flexion plays in the condition of NSCLBP appears to be limited based on current understandings of the condition and lack of significant investigation of issue.

A great number of musculoskeletal changes occur during the aging process. This includes decreased hip extension ROM during gait and with clinical testing as observed with instrumented gait analysis.\(^24\) Currently, a dearth of normative data exists for what constitutes normal ROM of the hip within differing subsets of the human population. Existing information consists of an assortment of different testing positions, genders, active versus passive testing and use of different numbers of examiners during testing.\(^25\)\(^-\)\(^27\) Some studies are limited to young healthy athletic subjects who may not be reflective of the general or the aging athletic population.\(^28\)\(^,\)\(^29\)

The purpose of this study was to compare passive ROM in hip extension, hip internal rotation and external rotation and total hip rotation in healthy subjects to active subjects with non-specific chronic low back pain. Further, the current study will contribute additional data for what constitutes normal passive hip ROM. This will assist in clinical decision making and to help determine if significant differences exist between the groups examined. The authors hypothesized that active subjects with NSCLBP would have less total hip ROM and greater asymmetry than healthy subjects.

METHODS

The study utilized a sample of convenience of 30 volunteer subjects without NSCLBP (13 males and 17
females; mean ± SD age 34.0 ± 13.1 years; height, 171.5 ± 11.9 cm; mass, 71.9 ± 13.9 kg) and 30 subjects with a diagnosis of NSCLBP (14 males and 16 females; age 45.0 ± 12.0 years; height, 170.5 ± 8.3 cm; mass, 71.1 ± 12.8 kg). Subjects were recruited through local medical and recreational facilities. All subjects were included if they reported no history of surgery to spine, hips, knees, or history of neurological insult to the musculoskeletal system and had not experienced acute pain (defined as within previous two weeks) of the hips, low back or knees. Subjects categorized as active with NSCLBP met the criteria above in addition to experiencing pain in the low back area with or without radicular symptoms of greater than three months duration. Subjects were considered active if they participated in some form of recreational sport or regular exercise routine a minimum of three days a week. All subjects were informed of the purpose of the study and signed an informed consent document prior to data collection. The human subject's review board at Western Washington University approved the protocol for the study.

**Study Design**

All data collection took place in a research institution and all testing was completed in a single session by the primary investigator. The investigator is a licensed physical therapist with 20 years of experience in the musculoskeletal practice environment. During evaluation, the investigator measured EXT, IR and ER of both left and right hip. A digital inclinometer (Digital Protractor Pro 3600, Miutoyo America, Aurora, Illinois) with an accuracy of 0.1° was used to measure hip ROM of all subjects in this study. This digital inclinometer has been found to possess good reliability and concurrent validity with the universal goniometer which is the standard tool in clinical practice. The reliability of the device in previous work on hip ROM was noted to be 0.90. No practice or warm up was performed prior to measurements.

During EXT measurement, the subjects were positioned supine and a modified Thomas test was performed. The modified Thomas test, typically a test for length of hip flexors to measure hip extension PROM, has been found to possess good reliability. The hip being measured was positioned at the end of the treatment table and the tested leg was then cantilevered over the edge of table with the end feel resulting from the effects of gravity. No manual contact was made with the tested leg. The opposite leg was held actively by the subjects with the hip and knee in a flexed position against the chest. Instructions were provided for subjects to pull their knee straight toward their head to avoid any abduction. In addition, subjects were provided both verbal and tactile feedback to maintain a neutral lumbar spine and pelvis throughout the evaluation, which was accomplished with consistency in keeping knee firmly against the chest. The inclinometer measurement was taken from the anterior mid femur position with midpoint between the greater trochanter and lateral femoral condyle. Measurements were recorded as a negative number if they were above the horizontal position (more flexed than neutral position) and a positive number if they fell below the horizontal position (more extended than neutral position).

For IR and ER measurements, the subjects were positioned in the prone position on the treatment table and the following standard protocol was used. The investigator passively flexed both the knees to 90 degrees while both hips were positioned in neutral for measuring hip internal rotation. Next, the investigator instructed the subjects to relax, allowing the shank of both legs to rotate outward for IR until reaching passive end feel of joint motion under the effects of gravity. For ER, the investigator passively flexed one knee to 90 degrees and then instructed the subject to relax, allowing the shank to rotate towards the midline and leg crossed over midline until reaching passive end feel as per effects of gravity. The non-measured leg was positioned in extension on the table. The subject's pelvis was stabilized by the investigator's assistant during hip ER measures in order to prevent pelvic rotation. Additionally, the subjects that displayed with greater ER (motion blocked by presence of opposite leg) had their non-tested leg abducted slightly to allow for full measurement. Measurements with the inclinometer were taken with device placed at midline of medial shaft of tibia between the medial malleoli and medial tibial condyle.

Each measurement was performed three times and the mean of the three measurements was calculated.
and recorded. Total hip range of motion was calculated as the sum of internal and external hip rotation. The order of the hip ROM measurements was randomized for each subject. In addition, the inclinometer measurements were verbally given by the investigator and recorded by an assistant.

**Statistical Analyses**

Statistics were run for all data using SPSS 22. For each direction of motion (extension, external rotation, and internal rotation), a two-way mixed analysis of variance (ANOVA) was conducted to determine the effects of side (left vs. right) and group (control vs. NSCLBP) on hip ROM. In addition, a two-way mixed ANOVA was run to determine the effects of side and group on total hip ROM. Simple effects analyses were conducted for significant interaction effects. Alpha level was set to $p < 0.05$.

**RESULTS**

**Hip Extension**

Hip extension ROM was significantly greater in the control group ($6.78 \pm 7.18^\circ$) compared to the NSCLBP group ($-4.16 \pm 8.81^\circ$) ($F[1, 58] = 29.19, p < .001, \eta^2 = .335$) (Figure 1). There was no significant main effect of side on hip extension ROM ($F[1, 58] = .191, p = .664$), and no significant side by group interaction effect on hip extension ROM ($F[1, 58] = .122, p = .728$).

**Hip External Rotation**

Hip external rotation showed no difference between groups ($F[1, 58] = .850, p = .360$). External rotation was significantly greater in both groups on the left side ($55.97 \pm 11.84^\circ$) than the right ($50.08 \pm 12.37^\circ$), $F[1, 58] = 21.79, p < .001$ (Figure 1). There was no side by group interaction effect on hip external rotation mediating the effect of side ($F[1, 58] = 1.23, p = .272$).

**Hip Internal Rotation**

There was no significant effect of group on hip internal rotation ($F[1, 58] = 2.55, p = .116$). Internal rotation ROM was significantly greater in the right ($31.84 \pm 10.41^\circ$) than the left hip ($30.25 \pm 11.00^\circ$) ($F[1, 58] = 4.51, p = .038$) (Figure 1). There was no side by group interaction effect on hip internal rotation ROM ($F[1, 58] = 1.11, p = .297$).

**Total Hip Rotation ROM**

There was nearly a significant effect of group on total hip ROM, with the NSCLBP group having insignificantly lower ranges of motion ($80.61 \pm 14.89^\circ$) than controls ($87.54 \pm 14.81^\circ$) ($F[1, 58] = 3.55, p = .065$). Total ROM was significantly lower on the right side ($81.92 \pm 15.53^\circ$) than the left ($86.22 \pm 14.17^\circ$) ($F[1, 58] = 15.59, p < .001$). These were not mediated by a side by group interaction ($F[1, 58] = .312, p = .579$).

**DISCUSSION**

The primary purpose of this study was to compare passive hip ROM in controls and active subjects with NSCLBP. The current data demonstrated a significant difference in hip extension only. The control group on average demonstrated $10^\circ$ greater hip extension than the NSCLBP population. These findings suggest that hip extension should be evaluated in active subjects with NSCLBP during clinical assessment.

Hip extension measurements in the clinical setting tend to raise concerns in terms of validity of true hip measurements. The concerns are generally centered on the ability to separate out contributions of the hip from the lumbo-pelvic region. Additional concerns may be in the validity of measurement devices utilized in the clinical setting. Measurements are often taken with a universal goniometer in the clinical setting as compared to a biomechanics lab that may use three dimensional (3D) analysis. This has recently been addressed by Moreside and McGill who examined 77 healthy young males and assisted in the establishment of normative data for hip extension, external and internal rotation ROM. Importantly, they compared 3D video based measurements with standard goniometer for hip extension and found a high correlation between the measurements ($r^2 = .88$).35 This provides increased validity for use of common clinical tools in assessing hip ROM. The inclinometer used in this study has been found to be a valid and reliable tool for assessing hip ROM.32

Several studies have noted a relationship between low back pain and tightness of the anterior hip region. Pattelma et al noted that subjects with both sub-acute low back pain and chronic low back pain had significantly shortened hip flexors than those
without low back pain. Others have also noted a correlation between low back pain and short hip flexors in subjects ranging from young elite golfers to people who were employed in fields involving at least moderate physical effort and experienced chronic or recurrent low back pain. These findings are consistent with the current results where we noted on average a difference of 10° between those with NSCLBP and controls. When individuals lack appropriate hip extension during gait they may compensate through mechanisms such as excessive anterior pelvic tilt with resultant increased lumbar lordosis. This compensation could potentially lead to overuse, fatigue and altered motor activation patterns in the lumbar spine and hip region. A decrease in normal lumbo-pelvic motion may result in other structures compensating for the lack of potential and elastic strain energy that normally occurs with stretching of the anterior hip region during terminal stance phase of gait. The lack of passive stretching may result in the need to excessively recruit contractile agents in a manner that may not be energy efficient. Interestingly, the authors of a recent study demonstrated that increases in passive hip ROM in extension and rotation through selected interventions did not result in a carryover into functional movement patterns in normal healthy males. The possibility is raised that additional interventions in conjunction with stretching may be necessary to create functional changes in individuals.

The current study's findings were not in agreement with other literature in regards to total hip ROM. Van Dillen et al noted in a study of 48 subjects with low back pain (LBP) a significant decrease in total hip ROM and asymmetry in rotation as compared to controls. The results of the current study showed no differences in total ROM. The VanDillen et al LBP group consisted of young athletes and may not be comparable to this study's sampled population which differed in mean age by approximately 20 years. What is particularly noteworthy is the large difference in total ROM and hip ER data collected in the present study. This study measured a total hip ROM of 89.7° on left and 85.7° on right in the control group. Three other studies that specifically recorded this data had values ranging between 60.26° and 77.1° in controls. Total mean ROM measurements for subjects in the

---

Figure 1. Left Hip Extension (LHE), Left Hip Internal Rotation (LHIR), Left Hip External Rotation (LHER), Right Hip Extension (RHE), Right Hip Internal Rotation (RHIR), Right Hip External Rotation. *p < 0.05
current study with LBP were 83.1° for left hip and 78.2° for right hip. This contrasted with Barbee-Ellison et al and Van Dillen et al that recorded values ranging between a low of 51.55° and a high of 69.66° in subjects with LBP. These noted differences may be the result of the present study utilizing a digital inclinometer as compared to photographic method (use of digital camera to capture measures for objective analysis), or a universal goniometer and fluid filled goniometer used in above studies. It may also have been the result of differing criteria in what constitutes pelvic stabilization. As noted previously, all efforts were made to prevent compensatory movement of the pelvis during this study.

Given the fact that clear agreement on the diagnosis of NSCLBP remains elusive at this point, it is important to consider all potential anatomical structures in the region as a potential contributor to the condition. This would include the sacroiliac joint (SIJ) which is intricately linked to the lumbar spine through a vast network of both contractile and non-contractile elements. Cibulka noted that subjects with LBP and evidence of sacroiliac joint (SIJ) dysfunction had significantly greater hip ER than hip IR ROM unilaterally. This was in opposition to those without SIJ dysfunction who demonstrated with bilaterally greater hip ER than hip IR ROM. Additionally, Cibulka noted that asymmetries in hip rotation may result in significant differences in muscle strength of hip rotator muscles. Both of these studies indicate that asymmetry in hip ER between groups could result in changes in motor control and increased loading of lumbo-pelvic structures. Flynn et al found that a difference in hip rotation was one of five predictive variables that relates to successful short-term improvement with spinal manipulation in patients with nonradicular low back pain. It was observed that manipulation was more likely to contribute to a successful outcome if hip IR was greater than 35°. The data in the current study demonstrated no difference in IR/ER ROM between or within groups.

**Study Limitations**

The main limitation during data collection was potential for alterations of stabilization of the pelvis during measurements. As other authors have noted, stabilizing the pelvis during the modified Thomas test, and for passive hip ROM in general, is very important in order to achieve consistency during hip measurement and limit lumbar spine involvement. All efforts were made to limit this involvement and it was felt that verbal and tactile cues given to subjects was sufficient to achieve this goal. Additionally, the main investigator was not blinded to the subjects’ condition, which had the potential to bias measurements. Another potential limitation may be in the average age difference of 11 years between the NSCLBP group vs control group (mean age of 34 versus mean age of 45 respectively). Future studies may consider age matching subjects. Lastly, the subjects were not required to complete a low back disability score questionnaire or pain scale to quantify their low back pain. This may have helped to determine if significant differences existed between individuals before the study was conducted. The authors believe that the criteria utilized in the study were sufficient in assessing what is examined in the common clinical practice.

**CONCLUSION**

The results of this study indicate that active subjects presenting with NSCLBP had significantly less passive hip extension than controls, when measured using the Thomas test. There were no significant differences noted in total hip rotation ROM nor hip IR/ER between groups. These findings suggest that passive hip extension may be an important variable that should be included within the clinical examination of active subjects with NSCLBP. It may be important to consider hip mobility restrictions and their potential impact on assessment of strength and possible SIJ involvement. Future studies may be needed to investigate the relationship between measurements and intervention strategies.

**REFERENCES**

3. Van Hilst J, Hilgersom NF, Kuilman MC, Kuijjer PP, Frings-Dresen MH. Low back pain in young elite field hockey players, football players and speed


ABSTRACT

Background: As the number of sports participants continues to rise, so does the number of sports injuries. Establishing a valid method of identifying athletes at elevated risk for injury could lead to intervention programs that lower injury rates and improve overall athlete performance. The Functional Movement Screen (FMS)™ is an efficient and reliable method to screen movement patterns during the performance of specific tasks. The purpose of this study is to explore the association between pre-season FMS TM scores and the development of injury in a population of collegiate athletes.

Study Design: Descriptive epidemiology study

Methods: FMS™ scores were obtained for 160 collegiate athletes and injury development was tracked throughout the season. These athletes were both male and female and participated in contact and non-contact sports. Redundancies were utilized with injury data collection, including medical record reviews and interviews with team athletic trainers, to ensure that all injuries requiring medical attention were captured. At the conclusion of the season, a logistic regression analysis was performed to determine which combination of factors best predicted injury.

Results: Athletes with an FMS™ composite score at 14 or below combined with a self-reported past history of injury were at 15 times increased risk of injury. A positive likelihood ratio of 5.8 was calculated which improved the probability of predicting injury from 33% pretest to 74% posttest.

Conclusions: This study adds to the growing body of evidence demonstrating a predictive relationship between FMS™ composite scores and past history of injury with the development of future injury.

Level of Evidence: 3, Non-random prospective cohort design

Keywords: Functional Movement Screen™, Injury prediction, Sports Injury
ABSTRACT

Background: International sports programs have established pre-participation athletic screening procedures as an essential component to identify athletes that are at a high risk of becoming injured. The Functional Movement Screen (FMS™) is a screening instrument intended to evaluate deficiencies in the mobility and stability of an athlete that might be linked to injury. To date, there are no published normative values for the FMS™ in adolescent school aged children. The purpose of this study was to establish normative values for the FMS™ in adolescent school aged children (10 to 17 years). Secondary aims were to investigate whether the performance differed between boys and girls and between those with or without previous history of injury.

Methods: 1005 adolescent school students, including both males and females between the ages of 10 and 17 years who fulfilled the inclusion and exclusion criteria, were selected for the study. The test administration procedures, instructions and scoring process associated with the standardized version of the test were followed in order to ensure accuracy in scoring. The components of the FMS™ include the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push up, and rotary stability.

Results: The mean composite FMS™ score was 14.59 (CI 14.43 - 14.74) out of a possible total of 21. There was a statistically significant difference in scores between females and males (p = .000). But no statistically significant difference in scores existed between those who reported a previous injury and those who did not report previous injury (p = .300). The variables like age (r = -.038, p = .225), height(r = .065, p = .040), weight (r = .103, p = .001) did not show a strong correlations with the mean composite score.

Conclusion: This study provides normative values for the FMS™ in adolescent school aged children, which could assist in evaluation of functional mobility and stability in this population.

Level of evidence: 2c

Keywords: Adolescent aged school children, Functional Movement Screen™, normative values.
INTRODUCTION
The past decade has seen an explosion in the number of children participating in team and solo sports. At a young age, sport is for enjoyment, health and personal development. This balance changes as a competitive element intervenes. Subsequently, young athletes train harder and longer and participate in sports throughout the year. As an undesired but inevitable consequence, sports-related injuries have increased significantly. A report of the 1995 to 1997 high school sport seasons indicates that more than two million injuries were sustained, requiring 500,000 doctor visits and 30,000 hospitalizations in United States (US). The volume of injuries reported in this setting, along with the fact that many of the more significant sports-related injuries may lead to long-term physical impairment, warrants research into the possibility of utilizing pre-participation screening methods that are able to identify young athletes that are at a high risk of becoming injured.

In an attempt to create a pre-participation functional evaluation, Gray Cook and Lee Burton developed the Functional Movement Screen (FMS)™. This screening tool is comprised of a battery of tests to simultaneously evaluate joint mobility and stability through a series of seven movements. Although none of the tests specific are to any individual sport, these FMS™ tests challenge both upper and lower extremities and trunk in functional tasks, unlike some types of athletic performance testing, which fails to test these aspects. As designed, the evaluation is practical, as the desired movements can be tested within five to ten minutes, allowing the clinician to quickly screen for deficiencies that may require more in-depth evaluation and possible rehabilitation in order to reduce the risk of injury. The tests of the FMS™ include the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability accompanied by three clearing tests. Each test is scored on a three-point scale, with three indicating perfect performance, two; minor deficits or perfect performance with modifications, and one, the inability to perform the movement. A score of 0 indicates that pain was reported during the movement. Three attempts were allowed for each test (deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability) with the highest score recorded. For the tests that are conducted on the right and the left, the lower of the two net scores was used for the final score. Three of the tests (shoulder mobility, trunk stability push-up and rotary stability) also have associated clearing tests (spinal flexion, spinal extension, shoulder internal rotation with flexion). They are scored as either positive or negative with a positive response indicating that pain was reproduced during the examination movement. The maximum score is 21.

Asymmetry and weak links in one’s basic functional movement can be identified by Functional movement screen. Asymmetries heightened the risk of injuries 2.3 times during a professional season which was found during FMS assessment. Influence of limb dominance on asymmetry has been addressed by various studies. Vanden Abeele might be amongst the first to suggest a relationship between laterality and functional gait symmetry. A theory proposed by Previc indicated that asymmetry in the lower limb should correlate positively with the measure that reflects unilateral dominance. Sadegi et al stated that functional asymmetry might be related to limb dominance.

The FMS™ has been used with sports teams as a pre-season screen to detect injury risk and to develop specific intervention programs in order to prevent injuries. It is also has been utilized to evaluate and reduce injury risk in specific occupational groups (e.g. fire-fighters). The FMS™ has been used to determine injury risks in various groups including military personnel and female collegiate athletes. Onate et al conducted a study on real-time intersession and inter-rater reliability of the FMS when used with healthy active adults. They found that all the tasks displayed moderate to high intersession reliability and good to high inter rater reliability. Another study was conducted to establish normative values for the FMS™ in a population of active, healthy individuals. Secondary aims were to investigate whether performance differed between males and females, between those with and without a previous history of injury, and to establish real-time inter-rater reliability of the FMS™. Schneiders et al established normative values for FMS™ for young active individuals. They also found that there...
was no statistically significant difference in scores between females and males, or those who reported a previous injury and those who did not. Inter-rater reliability for the composite FMS score demonstrated excellent reliability.16

To date, there are no published normative values for score on the FMS™ on the adolescent population. The use of FMS™ in the adolescent school-aged population can be enhanced by the availability of reference values, as well permitting evaluation of functional mobility and stability in this group. Young athletes’ scores can be compared to the normative reference values. The purpose of this study was to establish normative values for the FMS™ in adolescent school aged children (10 to 17 years). Secondary aims were to investigate whether the performance differed between boys and girls and between those with or without previous history of injury.

**METHODS**

**Subjects**

This study utilized a prospective cross sectional design. A total of 1005 subjects were selected for the study by convenience sampling. The sample consisted of male and female adolescent school aged children between the ages of 10 to 17 years. The subjects were selected from various schools across cities like Mumbai, Aurangabad, and Mangalore, India. The data was collected by a primary investigator, an experienced sports physical therapist, who underwent in house training for the scoring and administration of FMS™, by studying training video and relevant literature. The purpose of the study was explained to all the subjects and informed consent was obtained from the guardians. Subjects were included in the study if they participated regularly in physical activity at a competitive or recreational level (According ACSM guidelines for Physical Activity 2008) and if they were between the ages of 10 and 17 years. Exclusion criteria were use of mobility aid or a prophylactic device, history of recent (less than 6 weeks) musculoskeletal or head injury (using Cantu grading system 2001) which could have affected their performance at FMS™. The study had been approved by Srinivas College of Physiotherapy and Research Centre Ethical Committee and written informed consent was obtained from all the parents or guardians of the subjects prior to data collection.

**Data collection procedures**

Each subject completed a short form regarding their injury history and demographic information along with information about the primary sports they played and primary position in them. Each participant’s weight was measured in kilograms and height in centimeters. Descriptive information about the subjects including limb dominance, was collected to describe any asymmetry that may have been found during testing. Four short tests, which have been shown to provide a valid measure of footedness, were conducted.17 Handedness was determined by observing the hand with which the subject filled the questionnaire. Despite observing the hand used by the subjects to fill the form, the primary investigator also checked for ambidextrous individuals by inquiring the participants, notably, the investigator failed to come across any. Each participant was instructed in the performance of all test movements by the primary investigator to ensure a standardized explanation. The scoring was recorded done on a FMS™ scoring sheet.

**Statistical Methods**

Comprehensive description of the participants and FMS™ data were provided by computing frequencies, means, standard deviation, 95% confidence intervals (CI) for males and females separately and for all participants combined. Frequencies and percentages of the total scores were also computed and number of participants who scored at or below the cut-off value of 14 was tabulated. Using the FMS™ to assess the injury risk in athletes requires a defined failure, or cut-off score. The most widely accepted failure or cut-off score referenced in the literature, when using the 21-point FMS™, is a composite FMS™ score of 14. This referenced value comes from a study by Kiesel et al conducted in 2007, using a cohort of professional football players.11 The cut-off score of 14 is supported by an O’Connor et al study of a large number of marine officer candidates, a study by Chorba et al with female collegiate athletes, and in a Lisman et al study also using marine officers.13,14,21 Independent t-tests were used to examine for potential between those who had reported and had not sustained an injury in the previous six months, with the exact probability values presented. Score distributions of individual FMS™ scores were also tabulated. Chi-square tests were used to evaluate if there were
any significant differences between males and females in the distribution of scores for the different FMS™ tests. Correlation of FMS™ scores with various variables including age, weight and height were computed using Karl Pearson correlation. All calculations were performed using SPSS (version 22.0) and the prior level of significance was set at p ≤ 0.05.

Results
The subjects for this study (N = 1005) included 548 males and 457 females between the ages of 10 to 17 years. Handedness distributions of the subjects studied were 87.9% right handed and rest were left handed. Footedness distribution of the subjects studied 86.9% right footed and the rest were left footed. Fifteen point one percent of the subjects had reported of having sustained an injury in the previous six months, from which they had recovered.

The subjects completed the entire FMS™. The descriptive data for the FMS™ and its composite items are presented in Table 1. Individual FMS™ tests showing difference between males and females are presented in Table 2. There was significant difference in composite scores between male and female subjects (t = 4.89, p = .000). In this study 46.5% (465/1005) of the participants had a score of 14 or less which might indicate a potentially higher risk of injury according to results of the study performed by Kiesel et al on professional football players.11

The score distributions for individual FMS™ tests are presented in Table 3. Seventeen point three percent recorded a score of 3 in the rotary stability test out of the total population which was high compared to the previous study that reported normative values for the FMS™ on young active adults between the ages of 18 to 40 years, in which 88.0% (184/209) of all the participants were scored as a ’2´, 11.0% (23/209) a ’1´ and only 1.0% (2/209) ’3´. 16 The score for this test in the current study was high, as compared to the previous study but the scores cannot be statistically compared, as sample size and the age of the target population in the both studies are different.

There was no statistically significant difference in scores between those who reported a previous injury during last six months and those who did not (t = 1.04, p = .300)

It is important to note that there exists a very weak correlation of the mean composite score with age (r= -.038, p =.225). With respect to other variables like height(r= .065, p =.040) and weight (r=.103, p =.001), only weak correlations exist with the mean composite score.

DISCUSSION
The focus of this study was to describe normative values in adolescents for FMS™, which consists of a battery of tests developed in 1997 that relies upon common, basic movements to identify athletes that may be at an elevated risk of injury. The FMS™ was constructed around seven basic movement patterns that were deemed to represent foundational actions of many sport maneuvers. No evidence has yet been published to establish the normative values for functional movement screen in high school children. The availability of a normative reference data could increase the clinical utility of FMS™ in younger populations, to screen for movements that could provide risk for injury in children and adolescents.

The mean composite score reported in this study is 14.59 which is slightly lower than that reported for a group of average athletes between the ages of 18

### Table 1. Descriptive data for the FMS™ and its composite items

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>95% Confidence Interval for Mean</th>
<th>SD</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td></td>
</tr>
<tr>
<td>Combined scores</td>
<td>14.59</td>
<td>14.43</td>
<td>14.74</td>
<td>2.48</td>
</tr>
<tr>
<td>Males</td>
<td>14.93*</td>
<td>14.71</td>
<td>15.15</td>
<td>2.61</td>
</tr>
<tr>
<td>Females</td>
<td>14.17†</td>
<td>13.97</td>
<td>14.38</td>
<td>2.24</td>
</tr>
</tbody>
</table>

*†‡ difference in the mean composite scores for males and females (t = 4.89, p = .000)
Table 2. Individual FMS™ tests showing difference between Males and Females

<table>
<thead>
<tr>
<th>FMS TESTS</th>
<th>GENDER</th>
<th>Mean</th>
<th>95% Confidence Interval for Mean</th>
<th>t value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep squat</td>
<td>Male</td>
<td>2.38</td>
<td>2.33 - 2.42</td>
<td>.09</td>
<td>.931</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>2.38</td>
<td>2.33 - 2.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.38</td>
<td>2.35 - 2.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hurdle step</td>
<td>Male</td>
<td>2.03</td>
<td>1.98 - 2.07</td>
<td>.92</td>
<td>.359</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>2.06</td>
<td>2.01 - 2.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.04</td>
<td>2.01 - 2.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inline lunge</td>
<td>Male</td>
<td>2.10</td>
<td>2.05 - 2.16</td>
<td>4.38</td>
<td>.000*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.92</td>
<td>1.85 - 1.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.02</td>
<td>1.98 - 2.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder mobility</td>
<td>Male</td>
<td>2.57</td>
<td>2.53 - 2.62</td>
<td>.44</td>
<td>.659</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>2.59</td>
<td>2.54 - 2.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.58</td>
<td>2.54 - 2.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active SLR</td>
<td>Male</td>
<td>2.00</td>
<td>1.95 - 2.05</td>
<td>1.14</td>
<td>.256</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.96</td>
<td>1.91 - 2.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.98</td>
<td>1.95 - 2.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk stability</td>
<td>Male</td>
<td>1.91</td>
<td>1.85 - 1.97</td>
<td>8.29</td>
<td>.000†</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.58</td>
<td>1.53 - 1.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.76</td>
<td>1.72 - 1.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotary stability</td>
<td>Male</td>
<td>2.01</td>
<td>1.95 - 2.06</td>
<td>4.70</td>
<td>.000‡</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.82</td>
<td>1.76 - 1.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.92</td>
<td>1.88 - 1.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Male</td>
<td>14.93</td>
<td>14.71 - 15.15</td>
<td>4.89</td>
<td>.000§</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>14.17</td>
<td>13.97 - 14.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combine</td>
<td></td>
<td>14.59</td>
<td>14.43 - 14.74</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. The score distributions for individual FMS™ scores

<table>
<thead>
<tr>
<th>FMS TESTS</th>
<th>1.00</th>
<th>2.00</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq</td>
<td>%</td>
<td>Freq</td>
<td>%</td>
</tr>
<tr>
<td>Deep Squat</td>
<td>32</td>
<td>3.2%</td>
<td>560</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td>147</td>
<td>14.6%</td>
<td>670</td>
</tr>
<tr>
<td>Inline Lunge</td>
<td>219</td>
<td>21.8%</td>
<td>549</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>27</td>
<td>2.7%</td>
<td>370</td>
</tr>
<tr>
<td>Active SLR</td>
<td>163</td>
<td>16.2%</td>
<td>699</td>
</tr>
<tr>
<td>Trunk Stability Push Up</td>
<td>362</td>
<td>36.0%</td>
<td>512</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td>254</td>
<td>25.3%</td>
<td>577</td>
</tr>
</tbody>
</table>
to 40 years (mean score 15.7),16 professional male football players (mean score 16.9)11 and male Gaelic field sports players (mean score 15.56).18 The normative value reported in middle aged adults is 14.14,19 which was similar to the mean composite score reported for the children and adolescents in this study. It might be expected that professional football players and average athletes between the age group of 18 and 40 years would score better due to their physical maturity, conditioning, fitness, age, and body composition, compared to the status of general adolescent aged school subjects.

It is important to note that there was no strong correlation of FMS™ composite scores with any of the variables studied. A very weak negative correlation exists between the mean composite score and age (r = -.038, p = .225). With respect to other variables like height (r = .065, p = .040) and weight (r = .103, p = .001), only weak correlations exist with the mean composite score. Since the variables like age, height, weight do not show a strong correlation with the mean composite score, it can be proposed that the mean composite score can be used as the normative value for the adolescent aged school children and adolescents between the ages of 10 and 17 years.

According to the study done on normative values reported in middle aged adults, age was significantly related to FMS™ scores.19 Duncan and colleagues that reported both BMI and physical activity were predictors of FMS™ scores in elementary aged children;20 however, BMI was the more dominant of the factors. Hence further research is warranted, wherein FMS™ scores can be compared to various age groups and other variables like BMI and physical activity level, especially in adolescent aged school populations.

There was a significant difference in scores between male and female subjects (t = 4.89, p = .000). But the difference in the mean composite scores was less than a point. Hence it can be proposed that the mean composite score can be used as the normative value for FMS™ for both male and female adolescent aged school children between the ages of 10 to 17 years. Significant differences were apparent between females and males on four individual FMS™ tests. Males were on average better on the in line lunge, active straight leg raise, trunk stability push-up and the rotary stability tests than females.

The validity of FMS™ as a screening tool to predict injury has been established through the use of an evidence based cut off score. Three studies have utilized screening statistics to establish the cut off score of <= 14 as being appropriate to identify individuals who have greater odds for sustaining an injury.11,21,22 In the current study 46.5%(465/1005) of the participants had a score of 14 or less which might indicate potentially higher risk for injury. This is in comparison to the 22% of the professional football players in the Kiesel et al study11 and 89% in the subsequent study by Kiesel et al.12 The study by Peate et al conducted on firefighters suggested that a cut off score of <= 16 was strongly associated with an injury.23 The finding of a significant difference in FMS™ scores in those with a prior injury was not observed in active adults.16 The difference

**Figure 1. Distribution of mean scores on different FMS™ tests.**

**Figure Legend:** There is significant difference in scores between Male and Female (t = 4.89, p = .000). The difference was found in individual FMS tests like Inline lunge (t value = 4.38, p value = .000), Shoulder mobility (t value = 2.49, p value = .013), Active SLR(t value = 6.44, p value = .000), Trunk stability push up (t value = 8.29, p value = .000), Rotary stability(t value = 4.70 , p value = .000)
between these studies is likely associated with the difference in the common magnitude of injuries in fire-fighters or professional athletes as opposed to a general population. Moreover, the absence of any study, to establish cut off scores in the adolescent aged school population, has limited the clinical utility of FMS™ to understand what individual characteristics may be related to FMS™ composite scores in this population.

There are several strengths of this study. This study is the first of its kind to provide comprehensive descriptive profile of the participants and large sample size on a primarily adolescent aged school population. This will allow for both meaningful comparisons between females and males and the potential to make useful future comparisons with similar studies. The provision of a normative dataset with narrow confidence intervals could enhance the use of FMS™ to detect biomechanical deficits in fundamental movement that may limit human performance. The clinical utility of FMS™ is currently limited by its lack of normative reference values the said population. This study aimed to fill this void by providing normative reference values for the adolescent aged school population. Future research should target at specific sporting population in adolescent aged school children and should look for improvement in FMS™ scores following intervention in these sporting groups. Future studies should try to validate the use of FMS™ in adolescent aged school population by establishing a cut-off score to predict injury rate and performance in the said population.

CONCLUSION
With the advent of increased injuries in adolescent aged school population, it is essential to introduce a pre screening procedure prior to any sporting event that would be helpful to determine any potential risks for injury. The FMS™ is a robust, practical, easy to administer screening tool which can be used in athletic as well as general population. The normative value provided for the FMS™ in this study may be helpful to identify abnormal overall scores in adolescent aged school population.

REFERENCES
9. Cowen VS. Functional fitness improvements after a worksite-based yoga initiative Bodilv Nyv Ther. 2010;14:50-54
15. Onate, James A; Dewey, Thomas; Kollock, Roger O; Thomas, Kathleen S; Van Lunen, Bonnie L; DeMaio, Marlene; Ringleb, Stacie I. Real-Time Intersession and Interrater Reliability of the Functional


ABSTRACT

Background/Purpose: The squat is a fundamental movement of many athletic and daily activities. Methods to clinically assess the squat maneuver range from simple observation to the use of sophisticated equipment. The purpose of this study was to examine the reliability of Coach’s Eye (TechSmith Corp), a 2-dimensional (2D) motion analysis mobile device application (app), for assessing maximal sagittal plane hip, knee, and ankle motion during a functional movement screen deep squat, and to compare range of motion values generated by it to those from a Vicon (Vicon Motion Systems Ltd) 3-dimensional (3D) motion analysis system.

Methods: Twenty-six healthy subjects performed three functional movement screen deep squats recorded simultaneously by both the app (on an iPad [Apple Inc]) and the 3D motion analysis system. Joint angle data were calculated with Vicon Nexus software (Vicon Motion Systems Ltd). The app video was analyzed frame by frame to determine, and freeze on the screen, the deepest position of the squat. With a capacitive stylus reference lines were then drawn on the iPad screen to determine joint angles. Procedures were repeated with approximately 48 hours between sessions.

Results: Test-retest intrarater reliability (ICC3,1) for the app at the hip, knee, and ankle was 0.98, 0.98, and 0.79, respectively. Minimum detectable change was hip 6°, knee 6°, and ankle 7°. Hip joint angles measured with the 2D app exceeded measurements obtained with the 3D motion analysis system by approximately 40°. Differences at the knee and ankle were of lower magnitude, with mean differences of 5° and 3°, respectively. Bland-Altman analysis demonstrated a systematic bias in the hip range-of-motion measurement. No such bias was demonstrated at the knee or ankle.

Conclusions: The 2D app demonstrated excellent reliability and appeared to be a responsive means to assess for clinical change, with minimum detectable change values ranging from 6° to 7°. These results also suggest that the 2D app may be used as an alternative to a sophisticated 3D motion analysis system for assessing sagittal plane knee and ankle motion; however, it does not appear to be a comparable alternative for assessing hip motion.

Level of Evidence: 3

Keywords: Functional movement; range of motion; reliability; squat
INTRODUCTION
The squat is a fundamental movement at the basis of many athletic and physical activities. Performing an efficient squat requires mobility and stability of the ankle, knee, hip, and spine. Abnormal lower extremity kinematics while performing a deep squat may be due to restricted mobility. Abnormal lower extremity movement patterns during a squat may also be associated with an increased risk for injury. Hence, assessing squat mechanics may provide insight on functional capabilities as well as risk for injury.

The Functional Movement Screen (FMS™) is a battery of seven fundamental movement tests, including the deep squat, that is used to evaluate and categorize functional movement patterns. Cook et al developed a 4-point scoring system to classify movement patterns observed during performance of FMS tests. A score of (3) is given if the movement is performed correctly, a (2) if compensation occurs, a (1) if the subject is unable to perform the movement, and a (0) if pain occurs with testing. These scores are used to guide interventions and may predict risk for injury. The scoring system has been shown to be reliable and can be used by examiners with varying levels of experience. Minick et al has reported that examiner experience does not affect the reliability of scoring the FMS™ deep squat test. Although reliable, the scoring system has a degree of subjectivity, with broad movement pattern classifications not reflecting specific joint mobility. Motion analysis allows greater objectivity in the assessment of joint mobility observed during the squat maneuver. Using a Vicon motion analysis system (Vicon Motion Systems Ltd, Oxford, UK) to record specific joint motion in comparison to FMS™ scoring categories, Butler et al reported those who scored higher on the FMS™ squat had greater peak range of motion (ROM) values at the hip and knee and greater ankle dorsiflexion excursion than those who scored low. While the FMS™ scoring assesses the quality of motion, precise measurement of specific joint performance can provide additional information on which to base interventions.

Three-dimensional (3D) motion analysis has been cited as the gold standard for kinematic joint analysis, however, these systems are expensive, require time-consuming procedures, and are not readily available to all clinics. Conversely, 2-dimensional (2D) motion analysis is now widely available, ranging from camera systems to mobile device applications (apps). Researchers have previously compared 2D to 3D motion analysis systems, and report varying levels of agreement between the two types of systems. To the authors’ knowledge, the analysis of the FMS™ deep squat maneuver with the simultaneous use of 2D and 3D motion analysis has not been reported.

The primary objective of this study was to examine the reliability of the Coach's Eye (TechSmith Corporation, Okemos, MI), a 2D motion analysis tablet computer app, for goniometric assessment of maximal sagittal plane hip, knee, and ankle motion during the FMS™ deep squat. A secondary objective was to compare ROM values obtained with the app to ROM values obtained with the 3D Vicon motion analysis system.

METHODS
Subjects
Healthy subjects were recruited through flyers and word-of-mouth publicity to participate in the study. Inclusion criteria included being able to perform a pain free squat as described per the FMS™ procedure. Exclusion criteria, which were assessed via questioning by an examiner, included any injury, surgery, or self-reported musculoskeletal abnormality of a lower or upper extremity that would prevent the subject from performing a deep squat. The methods and procedures used in this study were approved by the Mayo Clinic institutional review board. Each subject was informed of procedures and risks and signed an informed consent form prior to participation.

Instrumentation
2D Analysis
The 2D analysis was performed using a second-generation tablet computer (iPad by Apple Inc., Cupertino, CA) running the iOS 7 operating system with the Coach's Eye app version 4.0. The app utilized video recording of the subject's performance, which was captured and analyzed at 30 frames per second.

3D Analysis
The 3D analysis of the lower extremity was recorded by a Vicon motion analysis system (Vicon Motion
Systems Ltd, Oxford, UK) consisting of five Vicon MX20+ infrared motion capture cameras running at 100 Hz, a Vicon MX control unit, and a Vicon MX Ultranet unit. The five wall mounted cameras were at a height of 300 cm and spaced around the periphery of the room, thereby providing the necessary coverage to ensure that each reflective marker placed on the subject was viewable from at least two cameras at all times. Data were captured and analyzed on a desktop computer using Vicon Nexus software version 1.8.5.

**Procedures**

Subjects were briefed on the procedures prior to participating. To allow adequate skin exposure for placement of the reflective markers, the male subjects wore compression shorts and the female subjects wore compression shorts and a support top. Using a measurement caliper, each subject's inter-anterior superior iliac spine (ASIS) distance, knee width at the medial and lateral femoral condyles, and ankle width at the medial and lateral malleoli were measured. Leg length was measured from the ASIS to the medial malleoli using a standard retractable measuring tape. These measurements were taken to facilitate kinematic calculations, as described below. Height and weight were also recorded. All anthropometric measurements were taken by the same tester for each trial.

The Vicon motion analysis system was configured and calibrated by the same tester before each data collection, according to the manufacturer's instructions (Vicon Plug-in-Gait Product Guide for use with Plug-in-Gait Version 1.9 in Vicon Nexus). Sixteen 10-mm reflective markers were placed on the subject's lower extremities using the Vicon Plug-In Gait template. A single examiner, trained in procedures by an individual with over 20 years of experience with motion analysis systems, placed markers on the subjects. Markers were located at the head of the second metatarsal, the posterior calcaneus, the lateral malleolus, the lateral fibula, one cm proximal to the knee joint axis laterally, and the lateral femur. Four markers were also placed on the pelvis at each anterior and posterior superior iliac spine bony landmark. The ASIS markers were adjusted 2.5 cm laterally to the ASIS proper to prevent loss of view of the markers between the torso and the thigh when the subject performed the deep squat. The inter-ASIS measurement recorded for the Plug-in marker set reflected this adjustment. Markers were placed by the same tester for each trial.

The tablet was placed at a standard height (floor to camera) of 43 cm and distance (camera to center of the subject's stance) of 280 cm in the sagittal plane to the right of the subject. For consistent subject positioning, the subject was positioned on a non-reflective dark surface marked with a nonreflective line. The subject stood with arms crossed over the chest and a static image was recorded using the 3D motion analysis system software. These data were reconstructed, each reflective marker was labeled, and the Vicon Static Plug-In Gait process was performed to create a Vicon skeleton of the subject. As the static trial was being calibrated and saved, standardized instructions describing how to perform the deep squat maneuver of the FMS™ were given at each trial by the same tester, who read a prepared script. Subjects were instructed to start with their feet shoulder-width apart, with feet pointed forward (in line with the sagittal plane). The subject was given a dowel to hold in both hands. The dowel was raised such that the subject's elbows were extended and the shoulders maximally flexed. The subject was instructed to keep both feet flat on the floor and keep the chest forward while slowly squatting as far as possible. While the authors used standardized FMS™ instructions, the squat was not modified by placing a board under the subject's heels based on performance as would be done with a formal FMS™ screen as the primary objective was to compare the 2D and 3D measurement systems. Once the subject received instructions and verbally reported an understanding of them, the subject performed three practice deep squats. After the three practice squats, the subject was allowed a rest period of one minute. The tester then instructed the subject to perform three squats, of which only the third was subsequently analyzed. Specifically, the tester said “ready,” thus prompting the 2D app and the 3D motion analysis system to begin recording, and then said “go,” thus prompting the subject to perform three squats to the best of his or her ability. When the subject returned to an erect stance after completing the third squat, both recordings were stopped, checked for any recording errors, and saved. The procedures were repeated...
with approximately 48 hours between sessions for each subject.

A single examiner performed the 2D analysis after data collection using the app. The app allowed the video to be collected and analyzed at a frame rate of 30 frames per second. The built-in angle tool was used to determine joint angle values for the subject as viewed from the subject's right side. Measurements were determined by moving each subject's video frame by frame to the lowest portion of the third squat. On the selected image, the examiner used a capacitive stylus to draw lines to establish specific joint angles. For the hip, a line was used to bisect the trunk and a line was used to bisect the thigh. For the knee angle, a line was drawn to bisect the thigh and a line was drawn to bisect the leg. For the ankle, a line was drawn to bisect the leg, and a line was drawn to bisect the lateral plantar border of the foot (Figure 1).

Motion analysis system data were reconstructed using the Vicon Nexus software, and the Vicon Dynamic Plug-in Gait process was run on the recorded data to output the recorded and calculated joint angles. Marker trajectories were filtered with a Woltring quintic spline filter, at a mean square error of 20 mm. Right lower-extremity joint angle data from the deepest portion of the third squat were recorded.

**Data Analysis**

Test–retest reliability was assessed using model 3 form 1 intraclass correlation coefficients (ICC3,1) as described by Shrout and Fleiss. Minimum detectable change (MDC) was calculated with the following equation from Schmitt and Di Fabio:

\[
MDC = z \times SD \times \sqrt{2(1 - ICC)}
\]

where \( z \) is the z-score associated with a 95% level of confidence (\( z = 1.96 \)) and the SD is from a representative sample of data. Bland–Altman analysis 95% limits of agreement were used to assess agreement between the results from the motion analysis system and the results from the app. Data were analyzed with IBM SPSS 21.0 statistical software (IBM Corp).

**RESULTS**

Twenty-six healthy subjects (age range, 21-26 years) were recruited to participate in the study. There were 11 men and 15 women, with a mean (SD) weight of 72.15 (12.64) kg and a mean height of 175.8 (10.61) cm.

The mean joint angles recorded at the termination of the third squat with the 3D motion analysis system and the 2D app are summarized in Table 1. Angles obtained via the Vicon motion analysis system were 87.3˚ for hip flexion, 109.9˚ for knee flexion and 24.1˚ for ankle dorsiflexion. Measurements derived with the Coaches Eye app were 127.2˚, 114.9˚ and 27.2˚ for the hip, knee and ankle respectively. The reliability of measurement using the motion analysis system to evaluate the deep squat is summarized in Table 2.

![Figure 1. Screen Shot of the Coach’s Eye (TechSmith Corporation, Okemos, MI) Tablet Computer Goniometer Application.](image-url)
and the reliability of measurement using the app is summarized in Table 3. Reliability of measurement ranged from 0.62 to 0.88 for the motion analysis system, and from 0.79 to 0.98 for the app. The MDC using the app was 6° at the hip, 6° at the knee, and 7° at the ankle.

Joint angles measured with the app consistently overestimated joint angles measured with the motion analysis system. Most prominently, hip angle measurements obtained with the app (mean, 127°±16°) exceeded measurements obtained with the motion analysis system (mean, 87°±11°) by approximately 40°. Differences at the knee and ankle were of lower magnitude, with mean differences of 5° and 3°, respectively. A systematic bias was found with the Bland-Altman analysis at the hip, with the 95% coefficient of agreement −10.3° to −69.3° (Figure 2).

### DISCUSSION

The primary objective of this study was to examine the reliability of the 2D Coach’s Eye goniometer app during the performance of the deep squat. According to the values previously described by Shrout and Fleiss14 (ICC >0.75, excellent reliability; ICC 0.40-0.75, fair to good reliability; and ICC <0.40, poor reliability), the current data suggest that sagittal plane hip, knee, and ankle angle measurements with the app demonstrate excellent test-retest reliability. Clinically, the ability to reproduce measurements accurately is valuable in assessing outcomes of joint mobility interventions.16 Test-retest reliability at the hip, knee, and ankle for

---

**Table 2. Test-Retest Reliability of the 3-Dimensional Vicon Motion Analysis System**

<table>
<thead>
<tr>
<th>Joint</th>
<th>Mean (SD) (Degrees)</th>
<th>ICC (3, 1)*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip 1</td>
<td>87.33 (10.52)</td>
<td>.615</td>
<td>306-807</td>
</tr>
<tr>
<td>Hip 2</td>
<td>87.83 (8.33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee 1</td>
<td>109.87 (17.58)</td>
<td>.879</td>
<td>748-944</td>
</tr>
<tr>
<td>Knee 2</td>
<td>108.17 (17.65)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle 1</td>
<td>24.10 (6.60)</td>
<td>.628</td>
<td>324-814</td>
</tr>
<tr>
<td>Ankle 2</td>
<td>21.77 (6.55)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: ICC= intraclass correlation coefficient.

* p<.05.

**Table 3. Test-Retest Reliability of the Coach’s Eye 2-Dimensional Smart Tablet Goniometer Application**

<table>
<thead>
<tr>
<th>Joint</th>
<th>Mean (SD) (Degrees)</th>
<th>ICC (3, 1)*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip 1</td>
<td>127.15 (15.54)</td>
<td>.978</td>
<td>953-990</td>
</tr>
<tr>
<td>Hip 2</td>
<td>127.96 (14.53)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee 1</td>
<td>114.88 (15.91)</td>
<td>.984</td>
<td>964-993</td>
</tr>
<tr>
<td>Knee 2</td>
<td>115.69 (15.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle 1</td>
<td>27.23 (5.29)</td>
<td>.792</td>
<td>589-901</td>
</tr>
<tr>
<td>Ankle 2</td>
<td>27.10 (5.57)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: ICC= intraclass correlation coefficient.

* p<.05.

---

**Figure 2. Bland-Altman 95% Limits of Agreement Between the Coach’s Eye (TechSmith Corp) Tablet Computer Goniometer Application and the Vicon (Vicon Motion Systems Ltd) 3-Dimensional Motion Analysis System for the Hip, Knee, and Ankle.**
this app was 0.978, 0.984, and 0.792, respectively, suggesting that it is a reliable tool for assessment of sagittal lower extremity joint ROM. To the authors’ knowledge, the reliability of measurements obtained with this app has not been described previously. ICC values of comparable goniometer apps have been reported. Werner et al\(^\text{17}\) reported an interrater reliability of 0.65 using five raters with varying degrees of experience to compare the use of a standard goniometer to the Clinometer (Plaincode Software Solutions, Germany), a smartphone app, at the shoulder. Likewise, Ferriero et al\(^\text{11,12}\) reported test-retest reliability of 0.958-0.996 and of 0.998 for the knee and elbow, respectively, when results obtained with a standard goniometer were compared to those obtained with the DrGoniometer (Dr.Goniometer, Milano, Italy smartphone app). In a validation of a photography-based goniometry method to measure elbow ROM, Blonna et al\(^\text{18}\) reported test-retest reliability ranging from 0.930 to 0.990. The current results support the utilization of the Coach’s Eye app as a simple and reliable means to measure sagittal plane hip, knee, and ankle motion.

When compared to the 3D motion analysis system, the 2D app had greater reliability, which may be due to several factors. While the procedures outlining the placement of the reflective markers for the motion analysis system were well defined and a single examiner was used to place the markers, there was most likely some variation in the exact positioning of the markers from subject to subject or from session to session.\(^\text{19}\) In addition, it is possible that there was some movement of the markers during the squat because of skin movement.\(^\text{20}\) In contrast, with the app, there may be less comparative variation in the placement of the reference lines.

MDC represents the smallest change in measurement over time that reflects a true threshold change rather than simple measurement error.\(^\text{15}\) MDC is used to indicate the level of responsiveness of a measurement. It is a function of both the SD of a set of measurements and the reliability coefficient, or ICC, for a given measurement.\(^\text{15}\) The lower the MDC, the more responsive an instrument is to smaller levels of change in measurement over time, which allows the clinician to be confident that noted changes in measurements represent true change. More specifically, if a subsequent measure is greater than the MDC, then the change is likely not due to measurement error.\(^\text{21,22}\) The current study found MDC values for joint ROM measurements using the app of 6°, 6°, and 7° for the hip, knee, and ankle, respectively. In terms of practical use, repeated measurements at the ankle when using the app during a deep squat would have to be greater than 7° to indicate true change. Similarly, when measuring ankle dorsiflexion during a weight bearing lunge using a standard goniometer, Konor et al\(^\text{23}\) reported MDC values of 5° on the left and 7.7° on the right.

The secondary objective of this study was to compare the kinematic data obtained via the 3D motion analysis system with that obtained with the 2D app. The mean average differences between these two systems were small at the knee and ankle joints; however, they were considerable at the hip joint. Using the 95% limit of agreement, calculated as the mean difference between devices ±1.96xSD of the mean difference, one can predict the expected range of measurement error between the 2D and 3D goniometric measurements. On the basis of the Bland-Altman statistic for determining the 95% limit of agreement, the knee had a mean average difference of 5°, with a 95% limit of agreement ranging from −17.6° to 7.6°. The ankle had a mean average difference of 3.1°, with a 95% limit of agreement ranging from −14.6° to 8.3°. These results at the knee and ankle parallel differences found in previous app-based goniometer studies.\(^\text{12,24,25}\)

A systematic bias was noted between the 2D and 3D systems for hip flexion angles, with the app overestimating the motion analysis system measurements by an average of 39.8°. This discrepancy may be due to a difference in the reference points used to calculate or measure the hip joint angle. Nussbaumer et al\(^\text{24}\) suggested that current goniometer measurements of hip flexion measure a combination of “true” hip flexion and pelvic tilt, resulting in a thigh flexion angle on the trunk in contrast to a true Coxafemoral angle. Consequently, when hip ROM is acquired without consideration of normal pelvis motion, as was the case during the 2D measurement, recorded hip flexion values are likely greater than the true coxafemoral angle. According to Norkin and White,\(^\text{26}\) the hip flexion angle (thigh to trunk measurement) specified by the American Academy of Orthopaedic
Surgeons is 120°. This is similar to the measured hip flexion angle of 127˚ in this study using the 2D app. Conversely, Elson and Aspinall27 reported a mean hip flexion angle of 85˚ using a standard goniometer. Included in their methods was monitoring of pelvic motion via palpation. Thus, their values may be a better reflection of true coxafemoral motion. Likewise, Hemmerich et al28 used a six-degree-of-freedom electromagnetic tracking system to measure hip, knee, and ankle ROM during activities of daily living, including squatting, and found a mean coxafemoral angle of 95.4˚. The values of these two studies are similar to our measurement of 87.3˚ found with the 3D motion analysis system in the current study. The results for the app appear to systematically overestimate the hip flexion angle from measurement of a trunk-thigh angle, whereas the motion analysis system more accurately measures true coxafemoral flexion. Thus, although both the 2D and 3D capture systems are reliable, clinicians should be aware that they likely represent two distinctly different measurements that are not interchangeable.

This study has limitations. The frame rate of the mobile app was 30 frames per second, which may have limited the ability of the researchers to capture the exact low point of a subject's squat. Additionally, while the two systems were used simultaneously to record performance, they were not time sequenced with specific time markers, which could compromise the ability to analyze the exact same squat position between the two systems. Given the speed of the squat performance, the authors do not believe that the frame-rate limitation or the lack of sequencing had a meaningful impact on the current findings. Lastly, analysis of human movement using 3D or 2D technology is subject to instrument errors, errors in identifying anatomical landmarks, and soft tissue movement artifact. Although this study analyzed only sagittal-plane lower-extremity motion, future research should investigate other planes of lower-extremity motion, as well as other joints and other movement patterns.

CONCLUSION

This study examined the reliability of a 2D goniometric tablet computer app to assess sagittal plane kinematic data at the hip, knee, and ankle joints during a deep squat and compared the results with those from a 3D motion analysis system. The current findings suggest that this app provides a reliable means of assessing sagittal plane kinematics during a deep squat maneuver. Measurements obtained at the knee and ankle are comparable to those obtained with the more sophisticated 3D motion analysis system. However, hip flexion measurements do not appear to be interchangeable between the two systems. Although each system is reliable, for clinical use, if an individual is assessed over time, consistent use of a single system is recommended for measuring sagittal plane hip motion. If it is important for the clinician to understand the motion occurring between the pelvis and the femur, the Vicon measurement is preferred, whereas if a thigh-to-trunk angle meets the needs of the clinician, the 2D analysis is a reliable tool to acquire this information.

REFERENCES


ABSTRACT

Background: The epidemiology and aetiology of hamstring injuries in sport have been well documented. Kinesiology tape has been advocated as a means of improving muscle flexibility, with potential implications for injury prevention. Purpose: To compare the temporal pattern of efficacy of kinesiology tape and traditional stretching techniques on hamstring extensibility. Study Design: Controlled laboratory study. Methods: Thirty recreationally active male participants (Mean ± SD: age 21.0 ± 0.1 years; height 180 ± 6 cm; mass 79.4 ± 6.9 kg) completed an active knee extension assessment (of the dominant leg) as a measure of hamstring extensibility. Three experimental interventions of equal time duration were applied in randomized order: Kinesiology tape (KT), static stretch (SS), proprioceptive neuromuscular facilitation (PNF). Measures were taken at baseline, +1, +10 and +30 mins after each intervention. The temporal pattern of change in active knee extension (AKE) was modelled as a range of regression polynomials for each intervention, quantified as the regression coefficient. Results: With baseline scores not statistically different between groups, and baseline AKE set at 100%, PNF showed a significant improvement immediately post-intervention (PNF+1 = 107.7 ± 8.2%, p = .01). Thereafter, only KT showed significant improvements in active knee extension (KT+10 = 106.0 ± 7.1%, p = .05; KT+30 = 106.9 ± 5.0%, p = .02). The temporal pattern of changes in active knee extension after intervention was best modelled as a positive quadratic for KT, with a predicted peak of 108.8% baseline score achieved at 24.2 mins. SS was best modelled as a negative linear function, and PNF as a negative logarithmic function, reflecting a rapid decrease in active knee extension after an immediate positive effect. Conclusion: Each intervention displayed a unique temporal pattern of changes in active knee extension. PNF was best suited to affect immediate improvements in hamstring extensibility, whereas kinesiology tape offered advantages over a longer duration. Clinical Relevance: The logistics of the sporting or clinical context will often dictate the delay between intervention and performance. Our findings have implications for the timing and choice of intervention aimed at increasing hamstring extensibility in relation to performance.

Level of Evidence: 2c

Keywords: Flexibility, hamstring, kinesiology tape, stretching

CORRESPONDING AUTHOR

Matt Greig
Sports Injuries Research Group,
Department of Sport & Physical Activity,
Edge Hill University,
St. Helens Road, Ormskirk, Lancashire,
L39 4QP,
United Kingdom
Tel: (+44) 01695 584848
Fax: (+44) 01695 584812
E-mail: matt.greig@edgehill.ac.uk

1 Sports Injuries Research Group, Edge Hill University,
Lancashire, United Kingdom
INTRODUCTION
The incidence and recurrence of hamstring injuries in sport have been well documented, leading to calls for a review of injury prevention strategies. Although many biomechanical and physiological components can influence the occurrence, one “modifiable” risk factor that is commonly discussed is muscle flexibility. Greater hamstring flexibility has been associated with reduced injury incidence in sporting and military populations. Traditionally musculoskeletal stretching protocols adopted a static stretching approach, more recently linked to detrimental effects on strength and power and advocated only as an outcome measure. Alternative methods such as active, isometric contractions, and the use of proprioceptive neuromuscular facilitation (PNF) techniques have subsequently been considered and used to treat a broad range of orthopaedic conditions. The brief isometric contraction creates a reduction in muscle tension and subsequently enables range of movement (ROM).

A more recent development within the clinical setting theorizing similar physiological mechanisms is the application of kinesiology taping (KT), creating a pulling force on the skin in order to attempt to enable and enhance ROM. However there remains little empirical evidence for its support. Only 22% (of 72 studies) reported immediate positive results for the use of KT on muscle extensibility, with methodological variations in application, anatomical regions, recruitment criteria and sample size limiting direct comparisons between studies.

The temporal efficacy of intervention techniques on muscle extensibility has been afforded little consideration, despite the implications for sporting performance and the clinical environment. Immediate change in muscle extensibility post-intervention is likely to be through increased stretch tolerance, pain gate theory, reciprocal or autogenic inhibition. Thus static stretching and PNF would have an acute effect on hamstring extensibility, with PNF expected to show greater gains due to the increased contraction. However over a period of 30 minutes it would be expected that KT would show the greater effect as the properties of the tape are activated. Since tape is applied from the origin to insertion through the muscle stretch it could be hypothesized that through prolonged stress relaxation and visoelastic deformation, applying a constant force over a period of time (creep) will increase tissue extensibility. Although it is suggested that improving hamstring extensibility decreases the injury risk, the efficacy of the improvement over time is vital to ensure the extensibility is maintained through training and performance. The aim of the present study was to compare the immediate, 10-minute and 30-minute post-intervention efficacy of KT to traditional stretching techniques on hamstring extensibility to assist practitioners in choice of intervention. It was hypothesized that the temporal pattern of changes in hamstring extensibility will be unique to each intervention, given their discrete mechanistic influence.

METHODS
30 male participants (Mean ± SD: age 21.0 ± 0.1 years; height 180 ± 6 cm; mass 79.4 ± 6.9 kg) completed the present study, with inclusion criteria requiring that each participant be male between the ages of 18-22 years, participating in recreational sport four times a week, asymptomatic from injury and with no history of previous hamstring injury. Exclusion criteria included history of lumbar or neurological symptoms, history of musculoskeletal disorders or injuries within the previous 12 months, medical conditions that may have altered muscle flexibility and skin allergies or conditions. All participants were further screened and excluded if their straight leg raise was < 70°. The 30 participants were randomly and evenly selected into 3 groups defining the nature of the intervention: static stretch (SS), PNF and KT. Detailed information regarding the nature and purpose of the study was provided, and all participants provided written informed consent in accordance with the departmental and university ethical procedures and following the principles outlined in the Declaration of Helsinki.

Data Collection & Analysis
All participants completed a standardized five minute warm up on the cycle ergometer. Five centimeter (cm) seat belts were placed across ASIS and the non-dominant leg at 20cm above tibial tuberosity to stabilize participants during the standardized Active Knee Extension (AKE) position. The hip was placed at 90° and fixed using a seat belt, proximal to...
the popliteal crease (Figure 1). All belts were marked for remeasurement, and the dominant leg was measured for all participants.

The measurement of AKE was taken once the participant had actively extended the knee to their point of hamstring stretch tolerance (no pain and at initial resistance) and at that point the calcaneus was supported to allow a baseline measurement to be recorded, via a standard goniometer (Myrin, Patterson Medical, North Ryde, Australia) at the tibial tuberosity. The participant was then placed prone on the plinth with a pillow under the ankles to assist in relaxation of hamstrings.

Subsequent to this baseline measure, AKE measurements were completed immediately, 10 minutes and 30 minutes post intervention. In SS the group barrier of resistance was found in AKE and a 30 sec hamstring stretch applied, with a 10 sec rest period between each stretch, repeated three times. The PNF group was placed in AKE position and the initial stretch barrier held for 10 secs, prior to 10 secs PNF contract-relax resistance of 75%. There was a three second release from barrier prior to stretching to new resistance barrier for 10 secs, and this process was repeated three times. For the SS and PNF interventions the time of active implementation was standardised, and this same time (5 minutes total) duration was used in the KT intervention. For KT application the distributor’s guidelines were followed, with the area prepared and a single Y-cut application at 25% stretch, applied from origin at ischial tuberosity to insertion at head of fibula, and medial condyle of tibia to hamstring muscle insertion points (Figure 2). For all participants and for each intervention, all procedures were performed by the same therapist.

**Statistical Analysis**

The aim was to describe the temporal nature of improvements in hamstring extensibility post-intervention. A range of regression polynomials were applied to each intervention in order to quantify the strength of fit, and determine the optimum model to best describe temporal efficacy. The strength of the regression was determined using the $r^2$ value. All statistical assumptions associated with the statistical methods above were explored. The statistical analyses were calculated using SPSS for Windows, version 18.0 (SPSS, Inc., Chicago, IL, USA). Data are presented as mean ± standard deviation. Time subscripts are used to specify the measurement time as baseline “00”, immediately post-intervention “+1”, 10 minutes post-intervention “+10”, and 30 minutes post-intervention “+30”. Thus an immediate
post-intervention measure following the PNF intervention would be described as PNF+1.

RESULTS

ANOVA confirmed no significant differences in AKE between the three groups at baseline. With the baseline score for each subject is set to 100%, repeated measures ANOVA revealed a significant interaction between time and intervention (Figure 3). Active knee extension scores at PNF+1 (107.7 ± 8.2%, p = .01), KT+10 (106.0 ± 7.1%, p = .05) and KT+30 (106.9 ± 5.0%, p = .02) were significantly higher than pre-intervention measures.

To investigate the temporal pattern of changes in active knee extension with each intervention, a linear regression was initially conducted for each intervention. The regression equations used to predict active knee extension (AKE) from time after intervention (t) are summarized as follows:

KT:  $AKE = 99.14 + 0.80t - 0.02t^2$  \( r^2 = 0.76 \)

SS:  $AKE = 105.06 - 0.40t$  \( r^2 = 0.82 \)

PNF:  $AKE = 115.16 - 4.25\ln(t)$  \( r^2 = 0.77 \)

Subsequent to a forced linear regression, the polynomial was altered for each condition to investigate the optimum model to fit the changes in AKE with time after intervention. The strength of the regression was used as the parameter to select the optimum function. The best fit for each intervention is shown diagrammatically in Figure 4 and the regression equations are summarized as:

KT: Quadratic  $AKE = 99.14 + 0.80t - 0.02t^2$  \( r^2 = 0.76 \)

SS: Linear  $AKE = 105.06 - 0.40t$  \( r^2 = 0.82 \)

PNF: Logarithmic  $AKE = 115.16 - 4.25\ln(t)$  \( r^2 = 0.77 \)

DISCUSSION

The current study investigated the efficacy of traditional stretching techniques and kinesiology tape on hamstring extensibility over a 30-minute period. Contemporary reviews have found only a minimal number of studies, many of low methodological quality, with KT providing no significant difference to other interventions. However, the temporal nature of the benefits afforded by kinesiology tape have not been considered.

Only kinesiology tape demonstrated a positive linear correlation with time post-intervention. Both static stretching and PNF demonstrated a negative relationship with time, such that hamstring extensibility gradually decreased after an initial improvement. This finding has implications for the practitioner, since the choice of intervention might depend on the time constraints of the context. If immediate and short-term improvements in hamstring flexibility are required then these findings suggest that PNF is the preferable application, consistent with previous literature. However, if improvement is required over a greater time period then kinesiology tape offers potential benefits.

Few studies have considered the temporal influence of these interventions, more commonly considering...
The positive influence of KT supports previous literature, but the temporal pattern of changes in hamstring extensibility following the KT application was best modelled with a quadratic function. The predictive quadratic equation yields a maximum active knee extension score of 108.8% of baseline measure at 24.2 min post-application. Further analysis of the predictive quadratic curve shows that AKE is raised to 105% of baseline by 9 min post-intervention. Therefore a window of opportunity of approximately 30 min exists (from +9 to +39 mins post-intervention) where AKE is greater than 105% of baseline.

The proposed explanatory physiological mechanism is complex and incompletely understood, with the majority of studies theorizing four main mechanisms to that lead to the decrease in muscle tension and increased ROM; autogenic inhibition, reciprocal inhibition, stress relaxation, and pain gate control theory. The current findings suggest that the immediate change in muscle extensibility is likely to be through either increased stretch tolerance, pain gate theory, reciprocal or autogenic inhibition. The greatest initial gains attributed to PNF advocate increased co-contraction theory, with beneficial effects on surrounding anatomical structures in addition to the muscle isolated for contraction. Stress relaxation with viscoelastic deformation of tissue or reciprocal inhibition with contraction of the agonist and antagonist may be plausible theories. However the pain gate control theory may be the most plausible, with the muscle stretched forcefully into a new end of range the golgi tendon organs are activated in an attempt to reduce injury. As the tendons are stretched the muscle is contracted in a lengthened position, inhibiting pain, and potentially enabling the golgi tendon organs to adapt to the new force threshold and achieve an increase in length. The current results demonstrating a negative correlation with time for SS and PNF suggest that if viscoelastic change has occurred this is short term and is unable to be maintained. This supports previous observations that post PNF intervention, muscle activity returned to 50% within one second and 90% in 10 seconds.

The current finding that KT was the preferential intervention over 30 minutes supports the proposal that KT must be applied prior to use to allow the glue properties of the tape to activate. As tape is applied to the skin, it could be hypothesized that any increase in tissue extensibility might be due to cutaneous receptor response influencing the effects of stress relaxation and viscoelastic deformation by applying a constant force over a period of time (creep). The adaptive change in tissue might be due to either increased circulation in the taped area or stimulation of the cutaneous mechanoreceptors to assist in tissue deformation. The optimum post-intervention time derived from the regression equation appears to be 24.2 mins, suggesting a combination of initial cutaneous mechanoreceptor stimulation and viscoelastic change that may assist in deformation over time. The mechanisms underpinning stretch tolerance and the influence of sensory neural pathways remain unclear. Changing muscle extensibility can increase the number of sarcomeres and stimulate the rearrangement of collagen through adaptive change and deformation of tissue.
influence changes in the gluteal and core musculature via the posterior chain. The benefits of kinesiology tape are likely to be influenced by a range of extrinsic factors to include the environment, nature of injury, population, sporting demands, physiological, psychological, and biomechanical characteristics, as well as therapist experience. Efficacy will also be directly related to the execution of the techniques; duration, intensity, and reliability of application. Future studies should consider longitudinal studies, assessment of effects on additional muscle groups, functional task assessment, and alternative tape application methods.

CONCLUSION
This study has modelled the temporal changes in active knee extension to contrast the efficacy of kinesiology tape, static stretching, and PNF. The choice of intervention should consider the temporal context of the scenario. For an immediate improvement in hamstring extensibility PNF is preferable, but for advantages over a longer duration (up to 30 minutes in this study) kinesiology tape is advantageous. The optimum timing of kinesiology tape application was 24 minutes prior to assessment of hamstring extensibility.

REFERENCES


ABSTRACT

Background: Interpretation of Lachman testing when evaluating the status of the anterior cruciate ligament (ACL) typically includes a numerical expression classifying the amount of translation (Grade I, II, III) in addition to a categorical modifier (Grade A [firm] or B [absent]) to describe the quality of the passive anterior tibial translation's endpoint. Most clinicians rely heavily on this tactile sensation and place value in this judgment in order to render their diagnostic decision; however, the reliability and accuracy of this endpoint assessment has not been well established in the literature.

Purpose: The purpose of this study was to determine the intertester reliability of endpoint classification during the passive anterior tibial translation of a standard Lachman test and evaluate the classification's ability to accurately predict the presence or absence of an ACL tear.

Study design: Prospective, blinded, diagnostic reliability and accuracy study.

Methods: Forty-five consecutive patients with a complaint of knee pain were independently evaluated for the endpoint classification during a Lachman test by two physical therapists before any other diagnostic assessment. The 21 men and 24 women ranged in age from 20 to 64 years (mean +/- SD age, 40.7 +/- 14) and in acuity of knee injury from 30 to 365 days (mean +/- SD, 238 +/-157).

Results: 17 of the 45 patients had a torn ACL. The agreement between examiners on A versus B endpoint classification was 91% with a kappa coefficient of 0.72. In contrast, classification agreement based on the translational amount had an agreement of 65% with a weighted kappa coefficient of 0.52. The sensitivity of the endpoint grade alone was 0.81 with perfect specificity resulting in a positive likelihood ratio of 6.2 and a negative likelihood ratio of 0.19. The overall accuracy of the Lachman test using the endpoint assessment grade alone was 93% with a number needed to diagnose of 1.2.

Conclusions: Nominal endpoint classification (A or B) from a Lachman test is a reliable and accurate reflection of the status of the ACL. The true dichotomous nature of the test's interpretation (positive vs. negative) is well-served by the quality of the endpoint during passive anterior tibial translation.

Level of Evidence: 2

Key Terms: ACL, anterior cruciate ligament, diagnosis, knee, Lachman test, reliability, sensitivity, specificity
INTRODUCTION
Physical examination of patients with knee injuries frequently involves assessment of ligamentous stability. One of the most common ligamentous injuries of the knee is to the anterior cruciate ligament (ACL) and the early recognition of the pathology is crucial in dictating the course of care in order to optimize outcomes. The Lachman test is characterized as the most direct and definitive evaluative technique used to determine the status of the ACL and is best performed prior to the onset of the patient’s pain, swelling, and guarding.1-4

The Lachman test is the clinical examination gold standard for diagnosing this injury because of its well-established sensitivity, specificity, and likelihood ratios; however, many clinicians also assign a categorical grade (modifier) to describe the endpoint of the passive anterior tibial translation. Traditionally, a grade of A is given when the endpoint is perceived to be “firm” while a grade of B is given if the endpoint is felt to be soft, absent, or ill-defined. In fact, during instrumented arthrometry with a KT-1000™, it has been suggested that the difference in the amount of translation that occurs between a 15 and 20-lb stress (compliance index) is an objective measure of this phenomenon.5 However, the reliability, accuracy, and clinical utility of this assessment has not been subjected to critical investigation in the literature.

Previous authors have generally shown a suspect level of intra- and inter-tester reliability in classifying the endpoint sensation of anterior tibial movement felt by the examiner. Based on the poor kappa values in a study evaluating endpoint agreement between an orthopedic surgeon and athletic trainers, Hurley et al6-7 concluded that that interpretation of manual clinical examination procedures is technique dependent, somewhat subjective, and open to bias and misinterpretation. Similarly, Cooperman et al8 found intertester agreement on judgments of tibial translation endpoint to be between 60 and 71% with kappa coefficients ranging from 0.19-0.42 indicating moderate concurrence. When analyzed by discipline, physical therapists had an intertester kappa coefficient range of 0.02 to 0.69 with 53-84% agreement. In contrast, orthopedic surgeons had kappa values of 0.38 - 0.61 with an agreement range of 68-81%. Limitations to these studies included inconsistent methods of conducting the test and limited expertise of the examiners. While examiners had appropriate qualifications and credentials, the significant improvement in second trials and/or the limited variability in their interpretation of results would hint at their relative inexperience with this specific type of testing.

Peeler et al9 also evaluated the reliability of Lachman testing in patients with arthroscopically confirmed ACL tears. They found therapists rely heavily on the findings of this test but only have moderate ($P_o = 0.55$) agreement with primary care physicians and poor ($P_o = 0.32$) agreement with orthopedic surgeons. The authors of this study did not specifically detail the translational quantity or quality rationale behind assigning a grade of positive or negative to the test's outcome. In a systematic review of the inter-rater reliability for determining the endpoint to physiological knee movements, Currier et al10 and Hayes et al11 reported relatively low kappa values, ranging from -0.01 – 0.31 for knee flexion and 0.25 – 0.43 for knee extension. These studies evaluated intertester agreement for the resistance met at the end-range of physiological, sagittal plane knee motions using a greater number of descriptors (normal, empty, stiff, or loose) as opposed to the dichotomous terms of firm or soft endpoint that is typically assigned to the ligamentous restraint offered at end-range joint translation.

Despite this relatively poor level of agreement many clinicians utilize the tactile quality of the endpoint sensation felt during the passive tibial translation inherent to the traditional Lachman test. Because of the variance in the amount of translation between individuals, the abruptness of the translation's stopping point can be quite useful and may be predictive. In fact, Callaghan et al12 suggest that an absent or soft endpoint indicates the lack of anterior restraint, whereas a firm endpoint signifies a normal ACL. A firm endpoint in the presence of increased translation may represent a partial tear or a tear of the ACL’s posterolateral bundle.13-15

Although both manual and instrumented assessments of tibial translation can provide relevant information, only the manual knee examination allows the examiner to “feel” the endpoint of motion. This
is an important element of the evaluative process particularly in cases where there is significant inherent laxity of the uninvolved extremity. The general “rule of thumb” for interpreting ligamentous stability is to place more value on the quality of motion and endpoint distinctiveness as compared to the amount of laxity present. The characteristic firm endpoint is evidence of the normal check-reign function of the ligamentous stabilizer while the presence of a soft or mushy endpoint indicates that the primary stabilizer has failed and joint stability is now the responsibility of secondary stabilizers. However, this assessment is somewhat subjective and dependent upon the examiner's skill and experience. A summary of the findings from the previous literature can be found in Table 1.

The purpose of this study was to determine the intertester reliability of endpoint classification of passive anterior tibial translation and evaluate the classification's ability to accurately predict the presence or absence of an ACL tear. The hypothesis for this study was that reliance solely on endpoint feel of passive anterior tibial translation may yield reliable results and be accurate in detecting the presence or absence of a torn ACL.

**METHODS**

The reliability and accuracy of detecting the quality of the anterior translation endpoint during the Lachman test was evaluated on a sample of consecutive patients referred from the emergency room of a county teaching hospital to the orthopedic surgery sports medicine service for definitive evaluation of a painful knee. Patients between the ages of 18 and 64 with knee pain complaint rated verbally as under 8/10 on a numerical rating scale and possessing at least 20-120˚ of range of motion were eligible for study inclusion. The study was approved by the institutional review boards at Parkland Health and Hospital System and the University of Texas Southwestern Medical Center in Dallas, TX. All patients agreed via informed consent to participate in the investigation. Study exclusion criteria were the suspicion of a fracture based on the Ottawa knee rule, previous knee joint arthroplasty, suspicion of posterior cruciate ligament (PCL) involvement, knee surgery in the previous six months, the presence of serious underlying non-mechanical pathology, or systemic illness.

The examination was conducted independently by two licensed physical therapists before any other diagnostic evaluation was performed, including injury history interview or review of previously conducted radiographic or magnetic resonance images. Therefore, the examiners had minimal previous knowledge regarding the patient's condition and complaint. The testing was conducted with each examiner blind to the other's findings. One physical therapist (EPM) had 34 years' experience with evaluating knee stability and the other (DQM) was an orthopedic physical therapy resident with 1 year of experience. Two, 1-hour training sessions for both examiners was conducted prior to data collection to enhance consistency in testing and interpretation.

<table>
<thead>
<tr>
<th>Study</th>
<th>Clinician</th>
<th>Agreement</th>
<th>Reliability (k)</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurley, 2002</td>
<td>Athletic Trainers</td>
<td>42-83%</td>
<td>- 0.40 - 0.56</td>
<td>0.67</td>
</tr>
<tr>
<td>Cooperman, 1990</td>
<td>Physical Therapists Orthopedic Surgeons</td>
<td>53-84%</td>
<td>0.02 - 0.69</td>
<td></td>
</tr>
<tr>
<td>Peeler, 2010</td>
<td>Therapists vs. Primary Care Physicians:</td>
<td>$P_o = 0.55$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Therapists vs. Orthopedic Surgeons:</td>
<td>$P_o = 0.32$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currier, 2007</td>
<td>Physical Therapists</td>
<td>0.25 - 0.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hayes, 2001</td>
<td>Physical Therapists</td>
<td>- 0.01 - 0.43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$k = $kappa coefficient; $P_o = $phi coefficient of association

**Table 1. Literature Review Summary of Examiner Reliability and Accuracy of Lachman Testing for ACL status**
After enrollment, each patient was brought to a private examination room where the testing was conducted. Weight-bearing ambulation without an assistive device to the examination room satisfied one of the items of the Ottawa knee rules. Active knee flexion to at least 90 degrees and palpation for reproduction of pain complaint was conducted at the patella and fibular head in order to complete the Ottawa knee rule algorithm. If there were no adverse signs according to the knee rule the examiners proceeded to screen for PCL injury. PCL injury evaluation was conducted via visual and palpatory assessment of a tibial sag sign with knee flexed at 90 degrees. If the tibial plateau did not appear to be at least one centimeter (cm) anterior to the femoral condyle, a quadriceps active drawer test was applied to rule in PCL injury. The palpatory loss of the tibia-femur step-off relationship has been shown to be a sensitive (0.90) and specific (0.99) means by which to detect the presence of a PCL injury. The quadriceps active drawer test is performed by the patient gently contracting the quadriceps with the knee flexed at 90° and foot stabilized on the treatment plinth. The posterior displacement of the tibia will be reduced with this isometric contraction in the presence of a PCL tear. The specificity of this maneuver has been reported to be 96% and the sensitivity 53%. All preliminary exclusion tests were performed by the examiner who first performed the stability assessment and confirmed by the therapist with 34 year’s experience (EPM).

Following PCL screening, each examiner independently assessed the patient for the quality of their anterior translation endpoint, amount of anterior displacement, and response to a pivot shift maneuver. The results of the Lachman test (quality and quantity of anterior translation) were classified by the criteria outlined in Table 2. If the movement of the tibia on the femur came to a sudden stop the result was described as an A, if not, the endpoint was classified as a B. The results of the pivot shift examination were not allowed to alter the previously recorded results of the Lachman test. The order for which of the examiners conducted the patient’s ligamentous evaluation first was randomized. At the conclusion of the manual examination each patient was evaluated with the KT-1000™ arthrometer (MEDmetric, San Diego, CA) to record the millimeters of anterior translation at 15, 20, and 30 pounds (6.8, 9.1, and 13.6 kg) of force by a single examiner (DQM). The KT-1000™ is a mechanical joint arthrometer allowing for stabilization of the femur with concurrent instrumented assessment of the amount of the tibial translation when an anterior displacement force is applied to the proximal end of the lower leg. This device has been shown to be an accurate and appropriate gauge of sagittal plane tibial displacement in a research setting. Previous studies at the authors’ facility have shown that the examiners involved in the study have good test-retest reliability in performing the KT-1000™ examination with an intraclass correlation coefficient (3,1) of .90, .82, .88, and .78 at 15 pounds (6.8 kg), 20 pounds (9.1 kg), 30 pounds (13.6 kg), and at a manually applied maximal force. This reliability data is consistent with values reported in other studies.

### Ligamentous Testing Description

For all patients the uninvolved knee was evaluated first in order to establish a baseline by which the contralateral knee could be judged. The test was performed with the patient lying supine on a firm examination table and the knee flexed to 20-30 degrees. Care was taken to ensure both knees were in the same degree of flexion during the physical examination procedure. The examiner’s upper hand stabilized the unsupported distal thigh, while the lower hand, with the thumb on the anterior joint line, and the fingers feeling to ensure that the hamstrings were relaxed, pulled the tibia forward with approximately 30 lbs of force. Based on palpatory, tactile, and visual sense, the examiner provided a numerical and letter grade based on the operational definitions recommended by Lubowitz et al² and provided in Table 2. This classification was determined prior to testing for a pivot shift so as to not bias the findings of the examiners.

<table>
<thead>
<tr>
<th>Translation Grade</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt; 5 mm translation</td>
</tr>
<tr>
<td>II</td>
<td>5 – 10 mm translation</td>
</tr>
<tr>
<td>III</td>
<td>&gt; 10 mm translation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Endpoint Grade</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Firm, sudden endpoint to passive anterior translation of tibia on a fixed femur</td>
</tr>
<tr>
<td>B</td>
<td>Absent, ill-defined, or softened endpoint to passive anterior translation of tibia on a fixed femur</td>
</tr>
</tbody>
</table>

---

Table 2. Test Grading Criteria for Lachman Testing Classification

<table>
<thead>
<tr>
<th>Translation Grade</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt; 5 mm translation</td>
</tr>
<tr>
<td>II</td>
<td>5 – 10 mm translation</td>
</tr>
<tr>
<td>III</td>
<td>&gt; 10 mm translation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Endpoint Grade</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Firm, sudden endpoint to passive anterior translation of tibia on a fixed femur</td>
</tr>
<tr>
<td>B</td>
<td>Absent, ill-defined, or softened endpoint to passive anterior translation of tibia on a fixed femur</td>
</tr>
</tbody>
</table>

---

After each examiner had rendered their separate decision on the status of the ACL they compared their findings. In four patients, the examiners had different endpoint interpretations of the test. In these instances, it was determined a priori to defer to the judgment of the more experienced examiner for the diagnostic accuracy portion of the study.

The pivot shift test was also conducted with the patient in a supine position in a standard manner. The examiner graded the pivot shift as positive if there was a “jump” or dramatic clunk as the tibiofemoral relationship reduced within the target range. Alternatively, a negative test was recorded if there was a smooth tibiofemoral glide or “guarded” if the patient could not adequately relax their hamstrings to allow a passive assessment.

For 17 patients the gold standard for diagnostic accuracy was direct arthroscopic visualization of the ACL at the time of surgery. For the 28 patients for whom direct visual evidence through the arthroscope was not available, each patient’s ACL status was categorized as intact or torn based on a cluster of clinical findings. To be classified as having a torn ACL, the patient had to have at least 2 of the 3 following findings: 1) a positive MRI; 2) excessive laxity on KT-1000™ examination which was defined as more than 3 mm greater translation on the involved side during the instrumented assessment with the 30 lb (13.6 kg) and/or manual maximum test as compared to the uninvolved side; and 3) a positive finding on a subsequent independent and comprehensive knee ligamentous evaluation conducted by a physician who was blind to the original examiners’ findings and the patient’s condition. If less than two of these findings were positive the patient’s ACL status was classified as normal.

Fellowship trained orthopedic surgery and radiology investigators not involved in conducting the Lachman tests interpreted the MRI images and/or evaluated the ACL under arthroscopic visualization. No adverse events were reported for any of the patients during the index testing or evaluation of the reference standards.

Statistical Analysis
Cohen kappa (k) coefficients and percent agreement between examiners were used as estimates of inter-rater reliability for endpoint classification. A weighted analysis for the k value was used to evaluate the inter-rater reliability for the 3-point ordinal classification on the amount of anterior translation on all subjects. Secondary to an anticipated high agreement rate in the gold standard group and a low prevalence of an intact ACL in patients who went on to surgery to address their knee complaint, a less divergent perspective of agreement, Gwet’s AC1, was also calculated. The k value is a chance-adjusted measure of agreement. A k of 0.00 represents agreement equivalent with random chance alone, whereas a k of 1.00 represents perfect agreement. A negative k represents worse than what would be expected due to chance alone, whereas a k of –1.00 represents complete discordance between observers. Analysis was performed using Agree-Stat 2011 (Advanced Analytics, LLC, Gaithersburg, Maryland). Kappa values were interpreted according to the guidelines proposed by Landis and Koch. Excellent agreement is described for values between 0.81 and 1.00, good for values between 0.61 and 0.80, moderate for values between 0.41 and 0.60, fair for values between 0.21 and 0.40, and poor for values under 0.20.

A 2x2 contingency table protocol was used to evaluate the sensitivity, specificity, positive and negative predicative values, and likelihood ratios based solely on the endpoint translation classification of the Lachman test. Sensitivity represents the % of true positives in all patients with the reference injury and specificity represents the % of true negatives. Consequently, index tests with high sensitivity are thought to be effective at ruling out the presence of the injury while tests with high specificity are effective at ruling in the injury. Positive and negative predictive values reflect the percentage of time that a positive or negative test (respectively) accurately captures the diagnosis. Exact binomial confidence intervals for the positive and negative predictive values were determined by the Clopper-Pearson method through an on-line calculator at http://statpages.org/ctab2x2.html. Positive and negative likelihood ratios reflect changes in the post-test probability when the index test is positive or negative (respectively). The confidence intervals for the sensitivity, specificity, and likelihood ratios were computed via an on-line calculator at http://www.pedro.org.au/english/downloads/confidence-interval-calculator/
using the Wilson score method. The number needed to diagnose was derived from the formula $1 / (\text{sensitivity} - (1 / \text{specificity}))$ and represents the number of tests that need to be performed to gain a positive response for the presence of the injury. There is no clear method for calculating the confidence intervals for this statistical measure.

**RESULTS**

The Lachman test was prospectively evaluated on 47 consecutive patients between September of 2013 and February of 2014; however, only 45 of them were included in the study. Two patients were excluded whose pain level and guarding prevented anterior tibial translation assessment. Demographic information is presented in Table 3. Figure 1 summarizes the flow of the patients through the study. For 17 of the 45 patients the gold standard of arthroscopic direct visualization was used to classify the status of the ACL. In this subset of patients, 16 individuals had a torn ACL and one had an intact ACL. For the remaining 28 patients a clinical consensus of their imaging results, joint arthrometry examination, and clinical evaluation was used as the reference standard in determining which nominal description would be used to classify their actual physical finding. In this subset of patients there was one individual with a torn ACL and 27 with a normal ACL.

The two examiners agreed on the A/B classification of the Lachman test 91% of the time with a Cohen's kappa coefficient value of 0.72 (95% CI 0.50-0.95), indicating good agreement. For the classification on excessive translation (Grades I-III), the two examiners agreed on the Lachman finding 65% of the time with a free margin kappa coefficient of 0.42 and a weighted kappa value of 0.52 indicating moderate agreement (Table 4). For the seventeen patients with the gold standard of direct visual evidence of an ACL tear, the examiners agreed on the endpoint classification 76% of the time (13 of 17) but the Cohen kappa value dropped to -0.09 indicating an agreement worse than expected by chance. However, the more appropriate alternate agreement coefficient,

<table>
<thead>
<tr>
<th>Table 3. Demographic Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>Age (mean years ± SD (range))</td>
</tr>
<tr>
<td>Side of Involvement (frequency)</td>
</tr>
<tr>
<td>Gender (frequency)</td>
</tr>
<tr>
<td>BMI (mean ± SD (range))</td>
</tr>
<tr>
<td>Mean Days since Injury (mean days ± SD (range))</td>
</tr>
<tr>
<td>Thigh circumference (mean cm ± SD (range))</td>
</tr>
</tbody>
</table>

![Figure 2. Flow chart of eligible patients](image)
Gwet’s AC1, rendered a kappa value of 0.70. There was perfect concordance on endpoint (A or B) classification for the patient’s categorized by the clinical cluster in contrast with a 63% agreement and kappa value of 0.16 – 0.25 when using translation grade criteria.

After blinded classification, the examiners met regarding the four patients in which they disagreed on endpoint classification and came to concurrence based on the senior examiner’s expertise and experience. Overall, the examiners agreed on a rating of the Lachman endpoint as an A in 31 patients and B in 14.

Seventeen of the 45 patients in this study had a torn ACL resulting in a prevalence of 38%. Fourteen of the sixteen patients with an ACL tear identified by surgical observation were classified as an abnormal endpoint (B) resulting in a sensitivity of 0.88 (95% CI = 0.82 - 0.88) (Table 5). All 27 of the patients classified as an intact ACL by the clinical cluster rule were classified as having a normal endpoint (A) during Lachman testing (Table 6). In the other two patients there was one true negative confirmed during surgery and one false negative based on the cluster criteria. For all patients’, regardless of means of classification, the sensitivity of endpoint classification was 0.81 (95% CI = 0.63 – 0.81) with perfect specificity yielding a positive likelihood ratio of infinity (95% CI = 6.2 - ∞) and a negative likelihood ratio of 0.19 (95% CI = 0.19 – 0.41) (Table 7). In contrast, likelihood ratios based on the on the amount of translation classification were computed based on the classification of Grade I as an intact ACL and Grade II or III as a torn ACL. Using this dichotomy the sensitivity of the Lachman test was 0.94 (95% CI

### Table 4. Intertester agreement and kappa coefficient values for the Lachman test

<table>
<thead>
<tr>
<th>Diagnostic Parameters</th>
<th>All Patient Values <em>n= 45</em></th>
<th>Gold Standard Values <em>n= 17</em></th>
<th>Clinic Reference Standard Values <em>n= 28</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B Endpoint Classification</td>
<td>% Agreement</td>
<td>Kappa Coefficient (95% CI)</td>
<td>Kappa Coefficient (95% CI)</td>
</tr>
<tr>
<td>A/B Endpoint Classification</td>
<td>91</td>
<td>0.72 (0.59-0.95)</td>
<td>0.81 (0.65-0.98)</td>
</tr>
<tr>
<td>I-II-III Translation Classification</td>
<td>65</td>
<td>0.42 (0.16-0.66)</td>
<td>0.52 (0.25-0.77)</td>
</tr>
</tbody>
</table>

### Table 5. A/B Classification: 2 x 2 contingency table for patients who had direct visualization of anterior cruciate ligament status during surgical intervention

<table>
<thead>
<tr>
<th>Condition according to Gold Standard: Arthroscopic Visualization</th>
<th>Positive</th>
<th>Negative</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition according to A/B Endpoint Classification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>14</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Negative</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Totals</td>
<td>16</td>
<td>1</td>
<td>17</td>
</tr>
</tbody>
</table>

### Table 6. A/B Classification: 2 x 2 contingency table for patients for whom a clinical cluster of tests was used for the reference standard

<table>
<thead>
<tr>
<th>Condition according to Reference Standard: Clinical Cluster*</th>
<th>Positive</th>
<th>Negative</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition according to A/B Endpoint Classification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Negative</td>
<td>1</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Totals</td>
<td>1</td>
<td>27</td>
<td>28</td>
</tr>
</tbody>
</table>

* To be classified as having a torn ACL, the patient had to have at least 2 of the 3 following findings: 1) a positive MRI; 2) excessive laxity (> 3mm) on KT-1000™ examination; and 3) a positive finding on a subsequent independent and comprehensive knee ligamentous evaluation conducted by a
but the specificity dropped to .83 (95% CI = 0.71 – 0.86) yielding a positive likelihood ratio of 5.4 (95% CI = 2.6 – 7.1) and a negative likelihood ratio of 0.08 (95% CI = 0.004 – 0.38) (Table 8). The overall accuracy of a soft endpoint classification was 93% accurate at predicting a torn ACL.

**DISCUSSION**

In a patient presenting with a possible injury to the ACL it is important to know the accuracy of the tests used to establish a diagnosis. Traditionally, the interpretation of the Lachman test reflects on both the quantity and quality of the tibial anterior translation on a fixed femur. The results of this study provide evidence that the quality aspect of the endpoint feel is a reliable finding, even in examiners with significant differences in experience, and can be used as a part of the comprehensive clinical examination to judge the ACL’s ability to resist anterior tibial translation. In fact, it appears that the “soft” or “B” endpoint may be a pathognomonic finding relative to a torn ACL. It appears that the tactile sense of an abrupt halt to the passive anterior translation of the tibia on the femur represents a healthy, intact ACL whereas the soft, elastic sense represents the secondary stabilizers stopping the motion in absence of an intact ACL. This information may be as, if not more, useful than the amount of translation that is detected during the examination technique.

The findings from this study are in contrast to the findings of Hurley et al, Cooperman et al, and Peeler et al. It is unclear as to why these examiners had much less reliable impressions of the knee’s anterior tibial translation. Possible explanations could include inconsistency in technique, unclear operational definitions and distinctions between soft and firm endpoints, and underutilization of the multiple sensory sources inherent to rendering the categorical assignment. While the examiners in the current study were blind to all relevant patient history and physical exam findings they were able to see the patient (age, athletic demeanor, knee morphology) and were allowed to utilize multiple sensory sources such as visual appreciation of the patellar tendon slope and tactile proprioceptive sense to arrive at their conclusion. Additionally, while not controlling for meniscal injury the authors did exclude patients with suspicion of a torn posterior cruciate ligament that may have displayed an exaggerated anterior translation from a posteriorly displaced position. The authors were not able to confirm that scarring of a torn ACL to the PCL presents in a unique manner (increased translation but firm, delayed endpoint) as suggested by Dhillon et al as there were not any subjects with tears with the finding of an abnormally reattached ACL. Finally, while the authors had numerous subjects with osteoarthritic knees, none of the patients had Kellgren
Lawrence scores of greater than 2 or the presence of large or multiple osteophytes which could have confounded the clarity of the endpoint classification. In fact, two of the three false negatives were in patients with more advanced arthritic findings. Other commonalities in the patients with a false negative were bilateral excessive laxity to anterior tibial translation, complex meniscal pathologies, and one patient that had a healed, partial tear of the ACL. The patient with the partial tear may have had the “delayed” firm endpoint but was classified by the examiners as a 2A yet grouped with the “torn” ACL cohort.

There are limitations to this study design. Reflection from only two examiners on 45 consecutive patients with variable levels of injury acuity should only be considered a starting point in the discussion on Lachman grading and interpretation. The authors’ also acknowledge only partial blinding as the examiners could see the patient and their injured knee during the examination. By design, the applications and external validity of this study’s findings should be quite broad. This study population represented a diverse population of knee pain complaints and would generally be considered to represent a chronologically older and more chronic status when compared to the typical population of patients with a primary concern of ACL deficiency. Additionally, this study does not offer significant diagnostic insight for the patient with partial tears of the ACL or in circumstances where ACL tear has scarred into the notch or PCL.

Based on the current findings the authors would propose that the two-tier classification scheme (translation grade and endpoint quality) proposed by the American Medical Association over 40 years ago is unnecessarily complicated and may decrease reliability. Lachman testing can be reliably and accurately interpreted as either positive (“torn”) or negative (“intact”) based on the tibial translation endpoint. The amount of translation is not as reliable an assessment and does not change or add to the decision-making in how to manage the patient's pathology. The vast majority of the patients (>80%) in this study could have been classified as either 1A (intact) or 2B (torn).

**CONCLUSION**

The results of this study indicate that the examiners were able to reliably detect and categorize the quality of endpoint to anterior tibial translation better than the actual magnitude of translation and the nature of the endpoint classification was very accurate in predicting the histological status of the anterior cruciate. In conjunction with the clinical or instrumented judgment of translation, the Lachman examination technique should highly value the identification of an abnormal endpoint in the determination of the status of the ACL. The dichotomous nature of the Lachman test, as was its original intent, is a reliable and reasonably accurate clinical test of the integrity of the ACL.

**REFERENCES**


ABSTRACT

**Purpose/Background:** A belt-stabilized hand-held dynamometer (HHD) offers the ability to quantify quadriceps muscle strength in a clinical environment, but a limitation is participant discomfort at the interface between the HHD and the tibia. The purpose of this study was to quantify the level of discomfort associated with a modified belt-stabilized HHD configuration compared to a standard belt-stabilized configuration and an isokinetic dynamometer. The secondary purpose of this study was to determine the validity and reliability of a modified configuration used to measure quadriceps strength compared to the "gold-standard" isokinetic dynamometer.

**Methods:** Twenty healthy participants (5 males, 15 females; age = 24.7 ± 2.2 years, height = 171.1 ± 8.8 cm, mass = 72.0 ± 18.7 kg) performed maximal knee extension isometric contractions during each of three testing conditions: isokinetic dynamometer, standard configuration with HHD placement on the tibia, and an alternative configuration with the HHD interfaced with the leg of a table. Discomfort was quantified using a Visual Analog Scale (VAS). Differences in discomfort and torque (N•m) associated with the testing positions were determined using Friedman test or repeated measures analysis of variance. Validity was quantified using Pearson correlations and within-session intrarater reliability was determined using an intraclass correlation coefficient (ICC2,1) and associated confidence intervals (95% CI).

**Results:** The isokinetic dynamometer configuration resulted in the least discomfort (p < .01) and the modified configuration was more comfortable than the standard configuration (p = .003). There was a significant correlation between measures from the isokinetic dynamometer and the standard configuration (r = .87) and modified configuration (r = .93). Within-session intrarater reliability was good for both the standard configuration (ICC2,1 = 0.93) and modified configuration (ICC2,1 = 0.93) conditions.

**Conclusions:** The use of the modified belt-stabilized HHD configuration, where the HHD was interfaced with the leg of a table, offers a more comfortable alternative compared to the standard belt-stabilized configuration to obtain isometric quadriceps strength measures in a clinical environment. This configuration is also a valid and reliable alternative to the "gold standard" isokinetic dynamometer when testing isometric quadriceps strength at 90° of knee flexion.

**Level of Evidence:** Diagnostic, Level 3

**Keywords:** knee extension; muscle; quadriceps; torque
INTRODUCTION
Sufficient strength of the quadriceps muscle group is necessary for functional tasks including walking, sit-to-stand transfers, and climbing stairs.1-3 Quadriceps strength is positively associated with physical activity levels and quality of life.4,5 Assessment of quadriceps strength is used to guide rehabilitation progression and return to play decisions following anterior cruciate ligament injury6 and can be used to predict performance on functional tasks, such as jumping.7 Due to the importance of quadriceps strength, objective strength assessment is often sought in clinical and laboratory settings.

Isokinetic dynamometers are considered the “gold standard” of strength testing8 but cost, space requirements, and portability are barriers for use among clinicians. A hand-held dynamometer (HHD) offers a relatively inexpensive, light, and portable option to obtain objective measures of muscle strength. Specific to testing quadriceps strength, a belt-stabilized HHD configuration is considered a valid (r>0.86) and reliable (ICC=0.88) estimate of strength, but this configuration tends to produce measures which are approximately 23% lower measurements compared to an isokinetic dynamometer.9 and an isokinetic dynamometer. Differences in quadriceps strength measures may be due to discomfort of the HHD against the relatively bony tibia and decreased stability of the HHD testing setup. It may be possible to modify previously described methods9 in order to reduce discomfort and to improve stability of the HHD during testing. This could be accomplished by placing the HHD against a rigid surface and allowing a padded belt to interface with the tibia. The primary purpose of this study was to quantify the level of discomfort associated with a modified belt-stabilized HHD configuration compared to a standard belt-stabilized configuration9 and an isokinetic dynamometer. The secondary purpose of this study was to determine the validity and reliability of a modified belt-stabilized HHD configuration to measure quadriceps strength compared to the “gold-standard” isokinetic dynamometer.

METHODS
Participants
Twenty healthy participants (5 males, 15 females; age = 24.7 ± 2.2 years, height = 171.1 ± 8.8 cm, mass = 72.0 ± 18.7 kg) volunteered for the study. The participants were fully informed of the study purpose, procedures, and risks prior to enrollment. Inclusion criteria included age between 19 and 45 years. Exclusion criteria included history of traumatic spine or lower extremity injury within the past six months or inability to give consent or understand the procedures of the experiment. The Creighton University Institutional Review Board approved the study (IRB 14-17059) and informed consent forms.

Procedures
All participants completed an approved informed consent form, standardized health history form, and a self-reported form related to physical activity level (Tegner Activity Scale). Quadriceps strength (N•m) for the right leg was then measured using an isokinetic dynamometer using a refurbished Biodex System 3 Isokinetic Dynamometer (Computer Sports Medicine Inc.; Stoughton, MA). Participants were seated with their hips flexed at 85° and knees flexed at 90° (Figure 1). The chest and pelvis were secured to the chair using Velcro straps and a padded ankle strap was placed approximately five centimeters proximal to the distal aspect of the lateral malleolus. The
isokinetic dynamometer was interfaced with an external data acquisition system (MP150; Biopac Systems, Inc.; Goleta, CA). Participants performed a warm-up consisting of five submaximal and maximal isometric knee extension contractions (50-100% effort). Participants then performed three maximal isometric contractions with one minute of rest between each contraction. All maximal trials were accompanied with verbal encouragement to ensure maximal effort was achieved. Torque signals were low pass filtered at 50 Hz to remove noise. Peak torque was calculated for each maximal isometric contraction by averaging a 100 ms epoch surrounding the identified peak torque value. The highest peak torque average from a single trial was used for data analysis. Following the isokinetic dynamometer testing, patients were asked to rate their level of discomfort during testing by marking a vertical line on a 100 mm Visual Analog Scale (VAS).

Next, participants transitioned to one of two HHD configurations using the microFET2, (Hoggan Scientific, LLC; West Jordan, UT): standard belt-stabilized HHD configuration or a modified standard belt-stabilized HHD (Figure 2A) configuration (Figure 2B). The order of HHD configuration was randomized. Participants were placed in a seated position with legs hanging from the edge of a wooden treatment table, with the knee in approximately 90° of flexion. A small wedge-type bolster was placed at the posterior aspect of the distal thigh to minimize posterior thigh discomfort and a strap (standard gait belt) was used to stabilize the thighs to the table (Figure 2). A gait belt attached to the leg of the table was used to stabilize the HHD during testing and was positioned approximately 5 cm proximal to the distal aspect of the lateral malleolus, consistent with isokinetic dynamometer pad placement. The standard belt-stabilized configuration positioned the HHD on the tibia, using a curved attachment (Figure 2A), which was consistent with previous methods. The modified standard belt-stabilized configuration positioned the HHD against the back of a treatment table leg using a flat attachment (Figure 2B). A foam pad was placed across the anterior aspect of the tibia and the gait belt was looped through the pad and secured the HHD against the leg of the table. When the participant extended his or her knee, the HHD was compressed against the table leg and force could be measured.

For both HHD configurations, participants were asked to extend their knees in a similar manner as the isokinetic dynamometer testing to obtain three separate maximal isometric contractions. One minute of rest was provided between each contraction. All maximal trials with the HHD were also accompanied by verbal encouragement to ensure maximal effort was achieved. Maximal isometric force (N) was recorded for each trial. To calculate torque, a measure was taken, in centimeters, from the lateral knee joint line (estimated knee axis of rotation) to the point five centimeters proximal to the distal aspect of the lateral malleolus. This value was then multiplied by the amount of force (N) recorded by the HHD to obtain torque (N•m). The highest peak torque from a single trial for each HHD configuration was used for data analysis. After each HHD configuration, participants recorded their level of discomfort during testing using a VAS.

Participants were then provided a 10-minute rest break. After the rest break, both HHD configurations were repeated using the same methods. This data was used to estimate within-session intrarater reliability for both HHD configurations.

Statistical Analysis
The independent variable was testing method (isokinetic dynamometer, standard configuration, modified configuration) and the outcome variables were discomfort (VAS) and torque (N•m). Differences in discomfort (VAS) between the testing positions

Figure 2. A) Standard belt-stabilized HHD configuration B) Modified belt-stabilized HHD configuration.
was determined using a Friedman test. Validity was quantified using Pearson correlations and examining differences in torque (N•m) between testing conditions using a repeated measures analysis of variance. Bland-Altman Plots with Limits of Agreement (LOA) calculations were used to graphically display differences between conditions and provide insights into systematic bias between measurement techniques. Within-session intrarater reliability was determined using the repeated measures ANOVA, intraclass correlation coefficient (ICC), and associated confidence intervals (95% CI). To provide better interpretation of reliability estimates, the authors also calculated the standard error of measurement (SEM) (SEM=SD √(1-ICC)) and minimal detectable change (MDC) (MDC=SEM * 1.96 * √2). Within-session intrarater reliability for HHD measures was interpreted as follows: <0.50 poor, 0.50 to 0.75 moderate, and >0.75 good. Alpha level was set a priori at p ≤ 0.05. When significance was achieved relevant post-hoc tests were performed to determine differences between conditions. Statistical analyses were performed with SPSS Version 20.0 (SPSS Inc., Chicago, IL).

RESULTS

Discomfort
There was a significant difference in discomfort between the three configurations (p<.001). The standard belt-stabilized (p<.001) and modified belt-stabilized configurations (p = .01) were significantly more uncomfortable than the isokinetic dynamometer (Table 1). The modified belt-stabilized configuration was significantly (p = .003) more uncomfortable than the standard belt-stabilized configuration.

Torque-Generating Capacity
There was a significant difference in torque-generating capacity between the three configurations (p<.001). The standard belt-stabilized configuration resulted in significantly less torque than the isokinetic dynamometer (p<.001) and the modified belt-stabilized HHD configuration (p<.001) (Table 2). There was no significant difference (p = .46) in torque between the isokinetic dynamometer and the modified belt-stabilized HHD configuration. There was a significant correlation (p<.001) between measures from the isokinetic dynamometer and the standard belt-stabilized (r = .87) and modified belt-stabilized HHD configurations (r = .93). Bland-

<table>
<thead>
<tr>
<th>Table 1. Discomfort measured using a Visual Analog Scale (cm). Values are mean ± standard deviation.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isokinetic Dynamometer</strong></td>
</tr>
<tr>
<td><strong>Standard Belt-Stabilized HHD</strong></td>
</tr>
<tr>
<td><strong>Modified Belt-Stabilized HHD</strong></td>
</tr>
</tbody>
</table>

* significantly greater discomfort than the isokinetic dynamometer (P <.001) and the modified belt-stabilized HHD (P= .003)
† significantly greater discomfort than the isokinetic dynamometer (P = .01) position

<table>
<thead>
<tr>
<th>Table 2. Torque-Generating capacity (N•m) differences between the three HHD configurations. Values are mean ± standard deviation.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isokinetic Dynamometer Torque (N•m)</strong></td>
</tr>
<tr>
<td><strong>Standard Belt-Stabilized HHD Torque (N•m)</strong></td>
</tr>
<tr>
<td><strong>Modified Belt-Stabilized HHD Torque (N•m)</strong></td>
</tr>
</tbody>
</table>

* significantly less torque (p < .001) than isokinetic dynamometer and the modified belt-stabilized configuration.

| Figure 3. Bland-Altman Plot A) isokinetic dynamometer versus standard belt-stabilized configuration (mean difference 52 ± 43 N•m). B) isokinetic dynamometer versus modified belt-stabilized HHD configuration (mean difference 13 ± 32 N•m). |
Altman plot LOA (Figure 3) indicated standard belt-stabilized configuration had an average difference of 52 N•m (SD = 43) and a lower and upper LOA range between -31 to 136 N•m. The modified belt-stabilized HHD configuration had an average difference of 13 N•m (SD = 32) and a lower and upper LOA range between -50 to 77 N•m.

Reliability
There were no significant differences (p > .64) between the first and second trials for the standard belt-stabilized and modified belt-stabilized HHD configurations (Table 3). Furthermore, within-session intrarater reliability (Table 3) was good for both the standard belt-stabilized (ICC2,1 = 0.93; 95% CI 0.83 to 0.97) and modified belt-stabilized (ICC2,1 = 0.93, 95% CI 0.84 to 0.97) HHD configurations. The standard belt-stabilized configuration SEM was 5.1 N•m with a MDC of 14.1 N•m. The modified belt-stabilized configuration SEM was 5.4 N•m with a MDC of 15.1 N•m.

DISCUSSION
The primary purpose of this study was to quantify the level of discomfort associated with a modified belt-stabilized HHD configuration compared to a standard belt-stabilized HHD configuration and an isokinetic dynamometer. The secondary purpose of this study was to determine the validity and reliability of a modified belt-stabilized HHD configuration in order to measure quadriceps strength compared to the “gold-standard” isokinetic dynamometer. The use of the modified belt-stabilized HHD configuration provided a comfortable option to quantify quadriceps strength measures at 90° of knee flexion. This configuration is a valid and reliable option compared to the “gold standard” isokinetic dynamometer.

HHD positioning had an impact on levels of discomfort during testing. Although the modified belt-stabilized HHD configuration (Figure 2B) resulted in a statistically greater level of discomfort compared to the isokinetic dynamometer (Table 1), this difference (mean difference of 0.6 cm on the VAS) is not thought to be clinically relevant since it is below an accepted clinically important difference of 1.3 cm.14 The standard method of testing quadriceps strength with a HHD utilizes a foam padded attachment, either curved or flat, that is in direct contact with the tibia (Figure 2A).9,15,16 This configuration was less comfortable than modified belt-stabilized configuration and the isokinetic dynamometer. These differences were both statistically significant (Table 2) and clinically significant as the difference exceeds an accepted clinically important difference of 1.3/10.14

Quadriceps strength values were also influenced by HHD testing position compared to the isokinetic dynamometer. The modified belt-stabilized HHD configuration did not result in torque-generating capacity that was significantly different than the isokinetic dynamometer, but was greater than the standard belt-stabilized HHD configuration (Table 2). A similar configuration, in which the treatment table is used to stabilize the dynamometer, has been previously described.17 Comparison between studies is limited since Whitley et al17 used a less common push/pull dynamometer, did not quantify discomfort, and obtained isometric measures at 30° of knee flexion without comparison to an isokinetic dynamometer at the same joint angle. Thus the results of this study provide more comprehensive insights than the Whitley et al17 study and comparison to the “gold-standard” isokinetic dynamometer.

The standard belt-stabilized HHD configuration resulted in quadriceps strength values that were significantly lower than both the modified belt-stabilized HHD configuration and the isokinetic dynamometer (Table 2). These results are in agreement with a previous study, which found the belt-stabilized HHD produced reliable but statistically lower torque measurements compared to the isokinetic dynamometer.9 The standard belt-stabilized HHD configuration in the current study was similar to pre-

### Table 3. Within session intrarater reliability for quadriceps strength using a belt-stabilized HHD.

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>ANOVA p-value</th>
<th>ICC2,1 (95% CI)</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Belt-Stabilized HHD Torque (N•m)</td>
<td>208.9 ± 69.2</td>
<td>208.8 ± 66.7</td>
<td>.98</td>
<td>.93 (83-97)</td>
<td>5.1 N•m</td>
<td>14.1 N•m</td>
</tr>
<tr>
<td>Modified Belt-Stabilized HHD Torque (N•m)</td>
<td>248.5 ± 79.2</td>
<td>251.6 ± 77.3</td>
<td>.64</td>
<td>.93 (84-97)</td>
<td>5.4 N•m</td>
<td>15.1 N•m</td>
</tr>
</tbody>
</table>
viously described methods, but with the addition of
the knee bolster and curved tibia attachment in an
attempt to increase participant comfort and testing
stability. In spite of these changes, the authors also
found that the standard belt-stabilized configuration
used in the current study produced significantly
lower torque readings and more discomfort than the
isokinetic dynamometer. While there is some foam
padding on the curved HHD attachment used in
this study, the area of the tibia where the HHD is
placed typically has little soft tissue coverage and is
relatively bony. Thus, the minimal padding offered
by the HHD curved attachment interfaced with the
tibia may produce a significantly greater level of dis-
comfort for some participants, thereby limiting the
ability to produce a maximal isometric contraction.

The significant correlations between measures
from the isokinetic dynamometer and the stand-
ard belt-stabilized (r = .87) and modified belt-stabi-
li zed (r = .93) HHD configurations further reinforce
that the HHD is a valid measure of knee extensor
strength. Both the standard and modified belt-stabi-
li zed HHD configurations had good within-session
intrarater reliability with low SEM (5.1 to 5.4 N•m)
and MDC (14.1 to 15.1 N•m) values. This indicates
both configurations provide reliable estimates of
quadriceps strength and evidence of the ability to
detect changes in torque-generating capacity near 15
N•m. These results are in agreement with previous
studies that have examined within-session reliability
using a belt-stabilized configuration. Bland-Alt-
man plot LOA average differences for standard belt-
stabilized configuration (52 N•m) were greater than
the modified belt-stabilized HHD configuration (13
N•m). Both HHD placement configurations tended
to underestimate torque-generating capacity values
obtained on the “gold standard” isokinetic dynamom-
eter (Figure 3). These results are in agreement with
previous studies. Nearly all values from this study
fell within two standard deviations of the mean (Fig-
ure 3). This indicates that, although there may be
some underestimation of torque-generating capacity
for HHD configurations compared to the “gold stan-
dard” isokinetic dynamometer, either HHD configu-
ration provides similar information.

A limitation of this study is that a relatively young,
healthy population was utilized and that the testing
angle for quadriceps strength only considered at 90°
of knee flexion. Future studies should further exam-
ine individuals with knee joint or lower extremity
pathology, torque-generating capacity at different
knee joint angles, and examine other muscles using
a similar configuration.

CONCLUSION
The use of a modified belt-stabilized HHD configura-
tion offers a more comfortable alternative compared
to the standard belt-stabilized configuration to obtain
isometric quadriceps strength measures in a clinical
environment. This configuration also provides a
valid and reliable alternative to the “gold standard”
isokinetic dynamometer when testing isometric
quadriceps strength at 90° of knee flexion. Placing a
pad at the tibia and interfacing the HHD with a sta-
ble table leg resulted in less discomfort compared to
the standard belt-stabilized HHD configuration and
produced measurements that were not statistically
significantly different from the isokinetic dynamom-
eter. These results have clinical relevance since this
configuration could likely be reproduced in a clini-
ical environment with an HHD, gait belt, and pad.

REFERENCES
1. Hasegawa R, Islam MM, Sung Chul Lee, Koizumi D,
Rogers ME, Takeshima N. Threshold of lower body
muscular strength necessary to perform adl
independently in community-dwelling older adults.
2. Hortobágyi T, Mizelle C, Beam S, DeVita P. Old
adults perform activities of daily living near their
3. Ploutz-Snyder LL, Manini T, Ploutz-Snyder RJ, Wolf
DA. Functionally relevant thresholds of quadriceps
2002;57(4):B144-B152.
4. Pietrosimione BG, Thomas AC, Saliba SA, Ingersoll
CD. Association between quadriceps strength and
self-reported physical activity in people with knee
328.
5. Ericsson YB, Roos EM, Dahlberg L. Muscle strength,
functional performance, and self-reported outcomes
four years after arthroscopic partial meniscectomy
MJ, Snyder-Mackler L. Current concepts for anterior


ABSTRACT

Background/Purpose: Almost all research using participants wearing barefoot-style shoes study elite runners or have participants with a history of barefoot style shoe training run on a treadmill when shod or barefoot. Wearing barefoot-style shoes is suggested as a method of transition between shod and barefoot running. Static and dynamic balance exercises also are recommended. However, little information is available on the effects five-toed barefoot style shoes have on static balance. The purpose of this study was to examine balance of subjects barefoot, wearing Vibram FiveFingers™ barefoot-style shoes, and regular athletic shoes with eyes closed when using the Biodex Balance System-SD™.

Study Design: This was a repeated measures study.

Methods: Forty nine participants aged 18-30 years without lower extremity injury or experience wearing barefoot-style shoes were tested for static balance on the Biodex Stability System™ with their eyes closed while wearing Vibram FiveFingers™, athletic shoes, or barefoot. Three trials of 10 seconds for each footwear type were completed. Repeated measures analysis of variance with Bonferroni’s correction was used to analyze the degrees of sway in the anterior-posterior and medial lateral directions. An overall stability index was also calculated by the Biodex.

Results: For anterior-posterior and overall indices, differences were found between all conditions. Participants wearing athletic shoes demonstrated the smallest anterior-posterior stability index (least sway) and spent the most time in the innermost concentric circular zone. Medial-lateral indices were not different for any condition.

Conclusions: Wearing Vibram FiveFingers™ provided better overall and anterior-posterior static balance than going barefoot. While differences between Vibram FiveFingers™ and barefoot are significant, results may reflect statistical significance rather than any clinical difference in young, uninjured individuals.

Clinical relevance: It would appear that Vibram FiveFingers™ mimic going barefoot and may be a bridge for exercising in preparation for barefoot exercise.

Level of Evidence: 3B

Keywords: static balance, Biodex, postural control, postural index, Vibram FiveFingers

CORRESPONDING AUTHOR

Barbara S. Smith, PhD, PT
Department of Physical Therapy
Wichita State University
358 N. Main Street
Wichita, KS 67202
316.978-5784 (o)
316.978-3005 (f)
E-mail: barb.smith@wichita.edu

1 Wichita State University Wichita, KS USA
2 Students at Wichita State University Department of Physical Therapy at the time this study was performed.
INTRODUCTION

Vibram FiveFingers (VFFs), a type of barefoot footwear, is considered as a bridge from running in shoes to running barefoot.1 Running barefoot is not without its difficulties. Rothschild recommends a preparatory program done barefoot that includes lower extremity proprioception, ankle flexibility, and intrinsic foot strengthening exercises.2 It might be appropriate, as well, for the person wishing to run barefoot to perform these exercises wearing a barefoot shoe, especially if this person is using VFFs as a bridge to barefoot running.

Vibram FiveFingers (Albizzate, Italy) have less structure and cushioning than even minimalist shoes, defined as shoes with heel material equal in thickness slightly thicker than forefoot material with minimal or no support materials in heel or arch area.1 Vibram’s website describes them as a 5-toed lightweight and flexible shoe, without cushioning and arch support. Each toe has a separate slot. This footwear is purported to mimic the barefoot experience while providing protection for the foot.3

If VFFs mimic barefoot conditions, balance test results for users wearing VFFs should be similar to results obtained when they are barefoot (BF). Most studies compare kinematic, joint loading rates and muscle activity patterns in injury-free recreating or competitive adult runners in BF and shod conditions.4 Few studies compare subjects’ static or dynamic balance while barefoot and wearing VFFs. Amateur runners wearing VFFs and BF had similar static and dynamic ankle position sense when asked to estimate the perceived direction and amplitude of a support-slope surface board.5 Dodson et al examined participants of different ages and abilities who wore VFFs for at least one hour daily for eight weeks. Star Excursion Balance and timed balance scores improved after eight weeks.6 Tests of dynamic balance demonstrated that subjects in hard-soled shoes performed better than those who were BF.7,8 Young adults demonstrated that performing the dynamic balance activity of walking on a balance beam and during unexpected gait termination in hard-soled shoes resulted in better test scores than BF.6 In healthy young adults, only the medial-lateral stability index was significantly smaller for BF than wearing VFFs during static balance measured on a force plate immediately after single leg jump landings.9 Perry et al found that as midsole hardness increased, medial-lateral stability decreased as compared to a BF condition.8

No studies have measured static balance in subjects wearing VFFs or going barefoot using a formal testing system. Thus, the aim of this study was to assess static standing balance of subjects barefoot, wearing VFFs, and regular athletic shoes with eyes closed when using the Biodex® Balance System (BSS-SD). It was hypothesized that static balance measurements would be the same when subjects were BF or wore VFFs compared to when subjects wore regular athletic shoes.

METHODS

A single group repeated measures design was used. Each participant had their balance tested under three conditions: (1) while barefoot, (2) wearing VFFs and (3) wearing regular athletic shoes. The order of testing conditions was randomly determined.

Participants

Forty-nine volunteers aged 18-30 (males = 16; females = 33) without lower extremity musculoskeletal or neurological impairment in the last six months and no previous experience wearing BF style shoes participated. All provided informed consent prior to participation per university Institutional Review Board guidelines. Participants brought their own athletic shoes to the lab. Athletic shoes were defined as a lace-up, buckled, or Velcro-fastened shoe or canvas sneaker with a relatively wide rubber sole, fabric upper material, and a low heel height that is used for casual or athletic activities.10 Participants refrained from exercise 24 hours prior to testing to prevent effects of fatigue. All participants wore the same model of Vibram FiveFingers® shoe (KSO). Participants were measured for size using the fit guide on the Vibram web site.3 Participants were only allowed to move their feet within the VFFs to make sure that all the toes were in the correct place.

Balance testing

The Biodex Balance System (BSS-SD) (Biodex Medical Systems, Shirley, New York, USA) circular platform acted as a standard force plate to measure static conditions. Results are reported as the center of gravity’s
angular displacement as defined by the manufacturer. Using these data, the BSS-SD software calculated indices for anterior-posterior (AP), medial-lateral (ML), and overall (OA) stability. Also measured was the percentage of time spent in one of four concentric zones around the platform’s center. Each participant’s feet were placed in a predetermined position (calculated by BSS-SD based on participant’s height) and a familiarization session was completed.11

After donning the initially assigned footwear, participants were repositioned, crossed their arms over the chest and closed their eyes for each ten-second trial. Between each of the three trials for each type of footwear, participants could relax and open their eyes but not move their feet. Participants repeated the protocol with the two other footwear types in the assigned order. Trial results were discarded if the participants moved hands off the chest, moved the feet from the starting position, fell, or opened their eyes.

**Statistical Analysis**
Using all 9 trials for each subject, a repeated measures analysis of variance including post hoc analysis with Bonferroni’s correction was used to compare balance scores wearing VFFs, athletic shoes, and barefoot. The data met the assumption for homogeneity of variance. The alpha level was set at 0.05; SPSS V-19 was used to analyze the data.

**RESULTS**
Sixteen men participated: mean age 27.2 (+/-5.6 years), mean height 179.6 (+/-4.5 cm), mean body mass 75.6 (+/- 9.9 kg). Female participants numbered 33: mean age 26.1 (+/-5.9 years), mean height 167.4 (+/-6.3 cm), mean body mass 64.0 (+/- 7.6 kg). No participant data were excluded. Overall stability indices were smallest when participants wore their regular athletic shoes (overall, 3.4°, shoes; 5.62°, VFF; 6.13°, BF). Table 1 shows that anterior-posterior sway indices were similar to overall index scores. As indicated by the smaller sway, VFFs provided better stability for these two indices than BF. No differences were found for ML stability under any footwear condition (Table 1). Table 2 shows that, when participants wore athletic shoes, they spent the most time in the innermost concentric circular zone (0-5 degrees from center). Shod participants spent 76.1% of the time in the innermost zone; VFF, 39.7%; BF, 38.8%. Shod participants spent 23.5% of the time in the 6-10 degree zone; VFF 53.1%; BF, 47.9%. Along with sway indices; the percent of time spent in the 0-5 degree zone indicates better postural stability.

**DISCUSSION**
While VFF and BF overall and AP stability indices were statistically different, the results confirmed the hypothesis that static balance in VFFs would be similar to barefoot. In both indices, differences between VFF and BF measurements were less than 0.5 degrees. This evidence suggests that VFFs could be worn during the non-running part of a training program for those wishing to transition from running shod to running barefoot. Experts recommend at least 4-8 weeks of transition training.2 The program should include non-running and running.

<table>
<thead>
<tr>
<th>Table 1. Static Overall stability index, Anterior/Posterior stability index, and Medial/Lateral stability index in degrees for three footwear conditions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static balance index</td>
</tr>
<tr>
<td>Overall Stability (mean +/- SD)</td>
</tr>
<tr>
<td>Anterior/Posterior Stability (mean +/- SD)</td>
</tr>
<tr>
<td>Medial/Lateral Stability (mean +/- SD)</td>
</tr>
</tbody>
</table>

*Significantly different p < .05, shoes vs. VFF
b Significantly different p < .05, shoes vs. barefoot
c significantly different p < .05, VFF vs. barefoot
Menant and Perry et al compared young and old adults in various shod conditions. They reported that soft insoles led to poor balance because they offered less mechanical support, which may be detrimental to joint position sense, especially in the elderly. Balance failures while walking on a balance beam occurred least when subjects wore thin hard-sole shoes: significantly fewer than BF or any other combination of sole thickness and hardness. The contrast in results between this and previous research may stem from the small amounts of postural disturbance measured by the BSS-SD. With regard to time spent in zones, these findings support the literature that normal individuals remain near the center platform position during static balance. However, the force plate recordings of the ground reaction force and the electromyographic assessment used by Tropp and Odenrick were very different from the methods used in the current study. Arnold and Schmitz studied only single limb stance using the BSS-SD.

Proprioception from different areas of the foot may play a role in balance reactions when wearing VFFs. Four static postural control variables were studied in physically active adults wearing a five-toed sock, a regular sock, and BF in single leg stance. The authors hypothesized that wearing a five-toed sock would improve balance because of the novel tactile sensation between the toes. No significant differences were found in any variables for any condition. Researchers who study results comparing VFFs, BF or to the shod condition argue that each of these conditions provides different information from around the toes and from the sole. Most published results in which participants wear VFFs evaluate measurements are taken from the sole while running. Paquette et al and McCarthy et al found that VFFs provided the greatest ankle range of motion, especially in plantarflexion, compared to BF running. VFFs provided a better perception of ankle range of motion while standing and running compared to BF.

This study is not without limitations. Only volunteers without ankle or foot injury participated. Treatment.

### Table 2. Percentage of time spent in the four zones with subjects in three footwear conditions (does not add to 100% due to rounding).

<table>
<thead>
<tr>
<th>Zone</th>
<th>Shoes</th>
<th>VFF</th>
<th>Barefoot</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (0-5 degrees from center)</td>
<td>76.1 (33.9)\textsuperscript{a,b}</td>
<td>39.7 (42.6)\textsuperscript{a}</td>
<td>38.8 (44.6)\textsuperscript{b}</td>
</tr>
<tr>
<td>B (6-10 degrees from center)</td>
<td>23.5 (33.3)\textsuperscript{a}</td>
<td>53.1 (39.2)\textsuperscript{a}</td>
<td>47.9 (42.1)</td>
</tr>
<tr>
<td>C (11-15 degrees from center)</td>
<td>0.4 (1.9)\textsuperscript{a,b}</td>
<td>6.9 (16.4)\textsuperscript{a,c}</td>
<td>12.7 (27.5)\textsuperscript{b,c}</td>
</tr>
<tr>
<td>D (16-20 degrees from center)</td>
<td>0.0</td>
<td>0.4 (2.4)</td>
<td>0.5 (2.6)</td>
</tr>
</tbody>
</table>

All values are mean +/- standard deviation
\(\textsuperscript{a}\) shoes significantly different from VFF \(p<0.05\)
\(\textsuperscript{b}\) shoes significantly different from barefoot \(p<0.05\)
\(\textsuperscript{c}\) VFF significantly different from barefoot \(p<0.05\)
ing results of individuals with acute ankle injuries, those prone to chronic ankle instability, or those with other lower extremity orthopedic conditions may differ from current findings. Assessing static postural control may not be the most possible relevant measure of the effectiveness of VFFs. Balance measurements taken while participants perform recommended exercises would provide information about dynamic balance. With VFFs, each toe is individually wrapped potentially increasing proprioceptive and cutaneous information by augmenting tactile sensations and providing pressure to the skin between the toes. Enhancing appropriate proprioceptive input from between the toes may not be possible because an even fit around each toe in VFFs unlikely. However, none of the participants in the current study had experienced wearing VFFs and this novel sensation may have interrupted the participants’ concentration. Providing the same style of athletic shoe was not an option, and no effort was made to characterize the type of athletic shoes worn by participants. A general definition taken from the literature was used, but no formal assessment was done such as the one developed by Menz and Sherrington.

CONCLUSIONS
Wearing VFFs provided better OA and AP static balance than going barefoot. No differences were found for ML lateral stability. While differences between VFF and BF are significant, results may reflect statistical significance rather than any clinical difference in young, uninjured individuals. It would appear that VFFs mimic going barefoot and may be a bridge for exercising in preparation for non-running barefoot exercise as part of a clinician-directed exercise program or as self-preparation for barefoot running.

REFERENCES


ABSTRACT

Purpose/Background: Ultimate Frisbee (Ultimate) is a limited-contact team sport growing in popularity, particularly as a collegiate club sport. In 2011, over 947,000 people played Ultimate. Sex, age, skill level, and physical demands of the sport place each player at risk for injury, yet there is limited information on the number of injuries with regard to clinical research. The purpose of this study is to identify injury reporting trends in Ultimate Frisbee against other collegiate club sports and examine correlation with sex, body region, and medical recommendations and to discuss associated risk of injury.

Methods: Athletes who sustained an injury related to participation in their respective club sport attended a physical therapy sports clinic, underwent screening, and were provided direction for injury management. Data was collected on various elements of each case with descriptive statistical analysis performed to catalog injury characteristics. Chi-square analyses were performed to compare proportions between sports, sex, and body region.

Results: Ultimate accounted for 143 (31.0%) of the 461 reported injury cases collected from all club sports. Female injuries represented 101 (70.6%) of the 143 Ultimate cases, whereas men totaled 42 (29.4%) (p<0.001). Women had significantly more foot/ankle (26) than men (4) (p<.001) and more lumbar/flank (9) injuries than men (2) (p = .022).

Conclusions: Ultimate accounted for one of the highest number of reported injuries among all club sports. Women reported injuries more than twice as frequently as men. The majority of reported Ultimate injuries involved the lower extremity. Injury trends observed are similar to those previously reported in several NCAA Intercollegiate sports.

Level of Evidence: IV

Keywords: College club sports, epidemiology, Ultimate Frisbee

CORRESPONDING AUTHOR
David Logerstedt
Address: Department of Physical Therapy, Samson College of Health Sciences
University of the Sciences in Philadelphia, 108 Woodland
600 S. 43rd St., Philadelphia, PA 19104
E-mail: d.logerstedt@usciences.edu
INTRODUCTION

Ultimate Frisbee (Ultimate) is a fast paced, limited-contact, mixed team sport played with a flying disc, which combines features of other sports such as American football, soccer, and basketball, into a simple yet demanding game. Two teams of seven athletes compete on a 70 by 40 yard playing field (with 25 yard deep end zones) with the aim of scoring goals, which is achieved when a player catches the disc in the end zone. The disc is advanced only by being thrown through the air as players are not allowed to run with it (United States Ultimate 11th edition Rules).1

As an alternative or lifestyle sport,2 Ultimate is one of the fastest growing sports in the United States (US). USA Ultimate is the association that serves as the national governing body of the sport of Ultimate in the US. By the end of 2009, the association had grown to over 30,000 members. In 2011, USA Ultimate reported 947,000 people played Ultimate frequently (≥25 times/year) in the US alone.3 Ultimate has grown in popularity as a collegiate club sport; with teams playing in various tournaments throughout the country.

Players run, cut, guard, jump, throw, catch, and dive in a fully outstretched position in order to catch the disc and advance to score a goal. Frequent cutting, physical contact, and jumping amidst other players have all been described as possible risk factors for injury in Ultimate.1, 4 Incidental contact is common during gameplay. Ultimate athletes are subject to considerable biomechanical stresses. Incidental contact and various impact forces expose each player to considerable risk for injury. Constant running, with athletes moving unrestricted throughout the entire playing field (similar to soccer or lacrosse), also places them at risk for overuse injuries. Injuries sustained during Ultimate are similar to those in occurring during NCAA field sports, such as soccer. Data from the NCAA Injury Surveillance System (ISS), (which monitors injuries that occur across 15 NCAA sanctioned sports between 1988-1989 to 2003-2004) demonstrated that more than half the injuries sustained were to the lower extremities.5 This is a trend also observed in Ultimate.1, 4 Contact during gameplay in Ultimate (between athletes or with the ground) results in a significant number of the reported injuries, similar to soccer or basketball, where contact occurred in 60% to 80% of injuries.4

Despite its growing popularity, increasing number of participants, and injury risk, there is a paucity of published literature characterizing the rates and types of injuries specific to this sport. Defined as a limited contact sport, it has received very little attention with regard to prospective injury epidemiology or injury prevention and management research.4 Very few teams have professional medical coverage for games or tournaments (unlike counterparts such as soccer or basketball), and most games are self-refereed. USA Ultimate has different requirements depending on age for gameplay and tournament staffing. With respect to the college-age subjects represented in this study, USA Ultimate requires a non-participating First Responder only when the number of participants is between 250 and 500 people. An onsite certified athletic trainer (ATC) is only required if the event size is greater than 501 participants, and less than 999.

Two retrospective studies explored injuries that occurred during participation in Ultimate.1, 4 Reynolds & Halsmer1 evaluated the injuries associated with Ultimate using a retrospective, self-reported survey of 135 adult athletes at a Midwestern Ultimate tournament. Of the respondents, 88% had missed Ultimate activity due to injury, and 71% sought medical care for Ultimate related injuries. Yen and colleagues4 conducted a cross-sectional study at the 2007 Ultimate Players Association College Championships in Columbus, Ohio. They quantified and characterized the injuries incurred by Ultimate players using an interview of athletes who called an injury timeout. They identified potential activities associated with risk for injury, including laying out (while catching the disc), covering cutters (athlete cutting to gain position to receive a pass), cutting, jumping, running, and catching. They proposed that the “limited contact” sport classification for Ultimate was inappropriate. Additionally, contact between players and with the ground (e.g. during a layout) resulted in over 50% of the injuries reported. Reynolds & Halsmer1 reported that the majority of Ultimate athletes in their sample experienced some injury with many going on to pursue medical care. Subsequently, the authors of the current study sought to educate health care professionals on the particular profile of injuries sustained
among collegiate Ultimate athletes. This is the first study to follow one specific Ultimate club consisting of two teams (men's team and women's team) in a collegiate setting, comparing their injury rate to other club sports and performing arts activities. Where previous studies represented data collected at a single game or tournament, this longitudinal study follows the collegiate Ultimate teams (men and women) at a University with over 20,000 undergraduate and graduate students. The purpose of this study is to identify injury reporting trends in Ultimate Frisbee against other collegiate club sports and examine correlation with sex, regional distribution, and medical recommendations and to discuss associated risk of injury.

METHODS
This is a retrospective analysis of data collected during a twelve-year period from 2000 to 2012. Injured collegiate club athletes (including Rugby, Ultimate, Soccer, and Basketball) and performing arts members (e.g. figure skating, marching band, theatre) attended a weekly Club Sports & Performing Arts Injury Clinic (Sports Clinic) where they could be screened and offered direction for management of their injuries. All participants were eligible for inclusion. A licensed physical therapist verified injury and diagnosis for data to be recorded and included in the study. Athletes who sustained injuries not related to participation in their club sports were excluded.

Procedure
Each Sports Clinic was conducted by one to three licensed physical therapists: One Orthopaedic or Sports Clinical Specialist and two physical therapy residents. During Sports Clinic, the physical therapist would complete a screen, record the athlete’s subjective history, and perform tests and measures in order to determine whether the individual required urgent medical attention, referral to student health services, referral to an orthopedic surgeon, or recommendation for skilled physical therapy. Whereas a formal physical evaluation might be performed in order to determine specific problems, impairments, and limitations for each athlete to direct treatment, these screens were intended to triage and provide direction for each athlete. If an individual’s injury was such that they did not require additional professional medical attention, then he/she was educated on methods to reduce his/her impairments and facilitate safe return to play/activity. This process was completed weekly at the Sports Clinic over a 12 year period. Data regarding complaints, the results of clinical examination, which body region was injured, the clinical impression of diagnosis, and recommendations for management of injury were recorded. Injury was defined as any condition for which an athlete sought medical attention at the Sports Clinic. Each injury/condition was recorded only once. Athletes who returned for follow-up for the same condition were not counted as a separate case. While multiple personnel were involved during the 12-year period during which data was collected, standardized procedures and criteria for data collection were maintained throughout the study.

Upon completion of each athlete’s subjective interview and physical screen, the evaluating physical therapist made recommendations to each participant based on the clinical impression of the individual’s diagnosis and immediate needs. A second therapist and board certified specialist in sports and/or orthopedic physical therapy verified diagnosis to minimize bias and support appropriate medical recommendations.

STATISTICAL METHODS
Descriptive statistical analysis was performed to catalogue injury types and rates for injuries reported by participants in various sports/activities seen at Sports Clinic. Injuries per body part among reported Ultimate injuries were totaled and reported as percentages of the total number of injuries. Assessment of further medical utilization for Ultimate injuries was also performed based on recommendations for injury management. Chi-square analyses were performed to compare proportions between sex and regional distribution of injuries. Calculations were performed using a Microsoft Excel™ spreadsheet. Statistical significance was set at p < 0.05.

RESULTS
Participants
Participants in thirty-two club sports and performing arts activities were followed over a 12-year span from 2000 to 2012. The men's and women's Ultimate teams at the University were comprised of at least 28 play-
ers, divided into A and B teams of at least 14 each. This allows for a full squad of 7 players with reserves. At the time of last data collection, the women’s team had 37 players and the men’s team had 60 players. The teams play year round, but the main competitive season is 13 weeks long, occurring in the spring. Teams practice four times per week, and typically play in two-day weekend tournaments at a rate of 3-5 tournaments per semester, with additional tournament play if teams qualify for regionals or nationals.

**Injury Rate**

A total of 461 injuries were reported and screened among those presenting at the Sports Clinic over a twelve-year period. Ultimate (men’s and women’s) accounted for 143 (31%) cases, exceeded only by Rugby (men’s and women’s) with 156 cases (33.8%) (p<0.45). Ninety-four (94) different Ultimate athletes reported to Sports Clinic, representing 143 distinct cases (Table 1). Sixty-four Ultimate athletes reported to Sports Clinic for only one case, 18 reported for two

<table>
<thead>
<tr>
<th>Table 1. Number of injuries for each club sport/activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Club Sport/Activity</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Ultimate (M)</td>
</tr>
<tr>
<td>Ultimate (W)</td>
</tr>
<tr>
<td>Rugby (M)</td>
</tr>
<tr>
<td>Rugby (W)</td>
</tr>
<tr>
<td>Soccer (M)</td>
</tr>
<tr>
<td>Soccer (W)</td>
</tr>
<tr>
<td>Lacrosse (M)</td>
</tr>
<tr>
<td>Lacrosse (W)</td>
</tr>
<tr>
<td>Baseball (M)</td>
</tr>
<tr>
<td>Baseball (W)</td>
</tr>
<tr>
<td>Softball (W)</td>
</tr>
<tr>
<td>Wrestling (U)</td>
</tr>
<tr>
<td>Volleyball (M)</td>
</tr>
<tr>
<td>Volleyball (W)</td>
</tr>
<tr>
<td>Basketball (M)</td>
</tr>
<tr>
<td>Basketball (W)</td>
</tr>
<tr>
<td>Tennis (M)</td>
</tr>
<tr>
<td>Tennis (W)</td>
</tr>
<tr>
<td>Track/Field/XC (M)</td>
</tr>
<tr>
<td>Track/Field/XC (W)</td>
</tr>
<tr>
<td>Crew/Rowing (M)</td>
</tr>
<tr>
<td>Crew/Rowing (W)</td>
</tr>
<tr>
<td>Equestrian (W)</td>
</tr>
<tr>
<td>Synchronized Skating (W)</td>
</tr>
<tr>
<td>Figure Skating (W)</td>
</tr>
<tr>
<td>Roller Hockey (M)</td>
</tr>
<tr>
<td>Ice Hockey (M)</td>
</tr>
<tr>
<td>Ice Hockey (W)</td>
</tr>
<tr>
<td>Field Hockey (W)</td>
</tr>
<tr>
<td>Climbing (U)</td>
</tr>
<tr>
<td>Acting—Professional Theatre Training Program (U)</td>
</tr>
<tr>
<td>Marching Band (U)</td>
</tr>
<tr>
<td>ROTC (U)</td>
</tr>
<tr>
<td>Unknown Sport/Activity</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

M= Men’s; W= Women’s; U = Unisex; XC = Cross Country
separate cases (36 total), seven reported for three cases (21 total), three reported four different injury cases (12 total), and two reported five separate injuries (10 total). The remaining sports/activities that contributed to injury totals are reported in Table 1. Seventy-nine of the 143 injuries from Ultimate were reported by athletes who sustained more than one (separate, not repeat) injury during the twelve-year study period. Women outnumbered their male counterparts in injury reporting for more than two separate injuries during the study period, with up to five separate injuries reported by two female Ultimate athletes (Table 2).

**Relationship Between Ultimate Injuries, Sex, and Body Region**

Injuries to females represented 101 (70.6%) of the reported cases from Ultimate, whereas injuries to men totaled 42 (29.4%) (p < 0.001). Of the 143 injuries associated with Ultimate, the body part most commonly affected was the knee, accounting for 50 (35%) injuries, followed by foot/ankle at 33 injuries (23.1%), 11 (7.7%) each of lumbar/flank, hamstrings & shins/Achilles related injuries, 10 (7%) hip/groin injuries, 7 (4.9%) calf/leg injuries, 4 (2.8%) quad/thigh injuries, and 3 (2.1%) each of shoulder & wrist/hand injuries (Table 3).

Among injuries reported in Ultimate, women reported significantly more than men overall (Table 3) (p < .001). For each defined body region, women reported more injuries than men with the exception of hip/groin for which men and women both reported five injuries (p = 1.00), and shoulder and wrist/hand with two men and one woman reported injuries (p = 1.00) for each. While women reported nearly twice as many knee injuries as men (32 vs. 18, respectively), this difference was not statistically significant (p = .065). Despite the higher injuries among women overall within Ultimate, only foot/ankle and lumbar/flank injuries demonstrated a significant difference. Twenty-six foot/ankle injuries were reported among the women, whereas men reported only four (p < .001). Women reported nine lumbar/flank related cases, as opposed to two cases among the men (p = 0.022) (Table 3).

---

**Table 2. Number of injuries for each club sport/activity**

<table>
<thead>
<tr>
<th>Number of Reported Ultimate Injuries</th>
<th>Ultimate Athletes</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>18 (77% female)</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>7 (100% female)</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>3 (67% female)</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>2 (100% female)</td>
<td>10</td>
</tr>
</tbody>
</table>

---

**Table 3. Ultimate Frisbee Injury per Body Region**

<table>
<thead>
<tr>
<th>BODY REGION</th>
<th>Men</th>
<th>Women</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee</td>
<td>18</td>
<td>32</td>
<td>.065</td>
</tr>
<tr>
<td>Foot/Ankle</td>
<td>4</td>
<td>26</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Shin(s)/Achilles</td>
<td>3</td>
<td>11</td>
<td>.057</td>
</tr>
<tr>
<td>Low back pain/Lumbar Spine/Flank</td>
<td>2</td>
<td>9</td>
<td>.022*</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>4</td>
<td>7</td>
<td>1.00</td>
</tr>
<tr>
<td>Hip/Groin</td>
<td>5</td>
<td>5</td>
<td>1.00</td>
</tr>
<tr>
<td>Calf/Leg</td>
<td>1</td>
<td>6</td>
<td>.13</td>
</tr>
<tr>
<td>Quad/Thigh</td>
<td>1</td>
<td>3</td>
<td>.63</td>
</tr>
<tr>
<td>Shoulder</td>
<td>2</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>Wrist/Hand</td>
<td>2</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td>42</td>
<td>101</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*p < .05 between men and women
Further Medical Recommendations

Of the total 143 cases of Ultimate athletes, 50 were educated on independent management strategies, or required no follow-up. Forty-eight athletes were encouraged to initiate skilled Physical Therapy (PT) pending a trial of independent management (ranging from one to three weeks) or a follow-up with a physician, whereas 40 were instructed to immediately initiate skilled PT, and nine were referred to an orthopaedic physician for consultation, imaging, or injections. Four female athletes who were referred to an orthopedic physician also went on to initiate PT (Table 4).

Specifically, with respect to further medical recommendations in response to injuries reported by men vs. those reported by women, 35 (34.65%) women sustained minor injuries (those incurring recommendations for education on independent management strategies) versus 15 (35.7%) male Ultimate cases. Thirty-five (34.65%) women reported mildly severe injuries (those where athlete was encouraged to initiate skilled PT pending a trial of independent management or follow-up with a physician), versus 13 (31%) men. Truly severe injuries (those given recommendations to pursue an orthopaedic consult or immediately initiate skilled PT) accounted for 28 (27.7%) of female Ultimate cases, versus 12 (28.6%) men. Seven (6.9%) women and two (4.7%) men were referred to an orthopaedic physician for consults, imaging, or injections with four (3.9%) women also immediately initiating PT. There was no statistically significant difference between the proportion of men or women receiving each recommendation (Table 4).

DISCUSSION

This study represents the largest collection of injuries associated with Ultimate participation in a single setting to date, and the results give an overview of injuries sustained in the sport. Among participants in the 32 club sports and performing arts activities who participated in the Sports Clinic during the twelve-year study period, Ultimate-related sports injuries accounted for the second highest number of reported cases surpassed only by Rugby.

Jumping and diving are frequently performed maneuvers that increase each athlete’s risk for injury.6-8 Yen et al 4 reported that diving was one of the most common activities at time of injury timeout (29% and 22% in men’s and women’s divisions, respectively) and accounted for all of the men’s closed head injuries and two of the three women’s closed head injuries. Additionally, continuous running in open field competition can contribute to athletes’ risk for overuse injuries, particularly if associated with declining performance related to fatigue.9

In this sample, many less skilled athletes may have tried out for Ultimate, or were unaware of the stresses athletic participation places on the body, therefore increasing their risk for injury. Peterson et al 10 examined the association between age, skill level, and injury of 264 soccer players, and found a twofold increase in the incidence of injury among young players with a lower skill level compared to more skilled athletes. Chomiak et al 11 reported similar findings in soccer players, with a twofold increase in severe injury incidence among lower skilled athletes compared to those of higher skill level.

<table>
<thead>
<tr>
<th>Type of Recommendation</th>
<th>Men (% of 42)</th>
<th>Women (% of 101)</th>
<th>Total (% of 143)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthopaedic visit†</td>
<td>2 (4.7%)</td>
<td>7† (6.9%)</td>
<td>9† (6.3%)</td>
</tr>
<tr>
<td>Immediate Skilled PT</td>
<td>12 (28.6%)</td>
<td>28† (27.7%)</td>
<td>40† (28%)</td>
</tr>
<tr>
<td>PT Pending ‡</td>
<td>13 (31%)</td>
<td>35 (34.65%)</td>
<td>48 (33.6%)</td>
</tr>
<tr>
<td>No further professional services</td>
<td>15 (35.7%)</td>
<td>35 (34.65%)</td>
<td>50 (35%)</td>
</tr>
</tbody>
</table>

* Orthopaedic physician visit:= consult, imaging, or injections
† Four female athletes were instructed to pursue an Orthopaedic physician visit AND initiate physical therapy
‡ PT Pending: PT pending trial of independent management (1-3 weeks) or pending physician follow-up
Injuries identified in this study were similar with those reported by Reynolds & Halsmer\textsuperscript{1} where knee & ankle injuries accounted for the majority of injuries reported at a Midwestern Ultimate tournament. Similarly, Yen et al\textsuperscript{2} found that the majority of injury time-outs were due to lower extremity injuries. Ultimate injury patterns in the current study closely resembled those reported for 15 NCAA Intercollegiate sports over a sixteen year period.\textsuperscript{12} Over half of all injuries were lower extremity, with knee and ankle injuries accounting for the greatest number of the lower extremity injuries.\textsuperscript{12}

Data from men's and women's Collegiate Soccer NCAA Injury Surveillance System revealed that lower extremity injuries accounted for almost three quarters of all game and practice injuries.\textsuperscript{5,13} In men's soccer, ankle ligament sprains were the most common injury sustained during practices and games, and knee internal derangements were the most common “severe” injury during those exposures.\textsuperscript{5,14} Similar findings were seen in women's soccer athletes during games, with the addition of upper leg muscle-tendon strains seen in practices.\textsuperscript{14}

In the collegiate setting used for the current investigation, women reported Ultimate-related injuries more than twice as frequently as their male counterparts during the twelve-year study period despite the fact that the number of women playing Ultimate was likely smaller. Each year the squad size in this collegiate setting was at minimum of two teams of 14 players each, with the current women's team having 37 players, and the men's team having 60. Injury incidence has been shown to correlate strongly with the number of individuals registered to participate.\textsuperscript{15} Although incidence rate was not calculated, it was likely higher in women than men.

Interestingly, one of the most notable differences between male and female injury reporting is the number of athletes returning for separate injuries. Among Ultimate injuries reported, the majority of athletes reporting two or more injuries were women. Two women reported five separate injuries during the study period (Table 2). The higher number of injuries in women compared to men may indicate underlying neuromuscular biomechanical deficits, in particular related to lower extremity injuries. Women have demonstrated the reduced ability to adequately absorb ground reaction forces, reduced knee flexion during landing and cutting, and limb-to-limb asymmetries during task-specific activities.\textsuperscript{16-19} Seventy-nine of the 143 reported Ultimate cases were associated with athletes who sustained multiple injuries during the 12-year study period. The majority of athletes who reported to Sports Clinic more than once were women. Women appear to be more likely to sustain multiple injuries during their careers than men. This may be related to the interaction between movement strategies, alignment, body composition, and physiology. Women generally have less lean body mass than men\textsuperscript{20, 21} with less developed musculature\textsuperscript{22-24} and greater laxity present in connective tissue,\textsuperscript{25, 26} further contributing to injury risk.

While women globally reported significantly more injuries than men, the foot/ankle and lumbar/flank were the only body regions for which a statistically significant difference was identified. Controversy exists on the role of sex in sports related foot and ankle injuries.\textsuperscript{27, 28} Beynnon et al\textsuperscript{29} reported that ankle injuries per 1000 person-days of exposure were 1.6 for men and 2.2 for women. Though not significantly different, women who played soccer had a higher incidence of ankle injury than women who played field hockey or lacrosse.\textsuperscript{29}

Significantly more women reported lumbar/flank injuries than men in the current study. Agel et al\textsuperscript{5} and Dick et al\textsuperscript{14} reported similar numbers of low back injuries sustained in collegiate men's (135 injuries) and women's (162 injuries) soccer. Similar numbers of injuries were also seen in collegiate lacrosse.\textsuperscript{13} While it is unclear why women in the current study reported more lumbar/flank injuries than men compared to other published reports, women have musculoskeletal risk factors that may increase their risk for injury. Springer et al\textsuperscript{30} reported significantly decreased transversus abdominis muscular thickness in women as compared to men with a positive correlation between muscle thickness and body mass index. Norton et al\textsuperscript{31} reported that lumbar curvature angle was significantly larger for women than for men, with a significant relationship between sex and different types of low-back pain.

While the quantity of injuries reported by women was significantly higher than men, no statistically significant differences were reported in the num-
ber of recommendations for Orthopedic physician follow-ups or recommendation for skilled PT. The severity of the injuries as measured by the medical recommendations rendered at the Sports Clinic was no different in proportion. The injuries sustained in Ultimate during the study period were largely mild in severity.

Actual follow-through for initiation of skilled PT was not recorded. Some attrition, therefore, may have occurred between athletes encouraged to initiate rehabilitation and their actual pursuit of skilled care. While each recorded case was a distinct injury, the same body part may have been involved, presenting a circumstance where such attrition may contribute to multiple cases. Athletes that do not pursue rehabilitation in spite of clinician recommendations are at considerable risk for sustaining another injury or worsening their condition. Incomplete or improper rehabilitation for specific injuries has been shown to contribute to risk of reinjury.32,33

Limitations and Future Directions
This study presents a retrospective analysis of injuries from a sample of convenience of club sport athletes and performing arts members in a collegiate setting. There are limitations to this study that are related to its design. As athletes were not followed from pre-injury to post-injury, common characteristics of each injured athlete could not be assessed to determine how strong the correlation was between a given characteristic and actual injury onset.

Another limitation of this study is the inability to report on injury prevalence specific to each sport due to incomplete recording of each club’s roster sizes over the twelve years. As such, the higher percentage of injuries reported in Ultimate might in fact be simply related to higher participation rates. Additionally, more detailed injury rates and risk levels could not be assessed as the specific number of athlete exposures was not monitored. Additionally, clinical significance of the injury rate for this study may be limited by the fact that some athletes returned for injuries to multiple body parts.

The Sports Clinic where athletes were screened represents a secondary “off-site” healthcare facility. Ideally, screening/evaluation, treatment and recommendations would be provided on-site. On-site medical coverage would allow for more specific observation of injury trends, rules enforcement, and playing surfaces (natural grass, artificial turf, field conditions, etc). It is worth noting that a potential bias may exist where the current study captures data on individuals with increased likelihood to seek medical care/advice. Future research should include injury surveillance on-site at tournaments or within each Ultimate Club in order to capture all relevant data.

The severity of each injury was not independently measured for this study. Specific information on each athlete’s ability or time to return to play/time loss was not systematically recorded. This information might provide one means of measuring the impact of each injury to the athlete and the team. Similarly, a systematic and consistent follow-up was not performed. Recommendations for further medical utilization were provided as appropriate to each athlete, but specific actions taken by each athlete were not recorded. This information would serve to describe the impact of the sustained injury on the athlete; as well as the community/health administration impact. With such data, a true cost-analysis for medical utilization could be measured.

Regarding training habits, the expectations and culture surrounding training within sports like club soccer and lacrosse have mostly been adopted from their official intercollegiate counterparts. Ultimate is not (nor has ever been) a NCAA sponsored program, and therefore does not have the history or background of athletes being formally instructed about proper training. For example, in the setting in which this study was conducted, there are no strength & conditioning coaches or athletic trainers assigned specifically to Ultimate clubs, in contrast to intercollegiate sports which have one or more of both. Subsequently, there is a considerable amount of variability in the training approaches used among different Ultimate Clubs. Future research should include injury surveillance within a club, where a specific club’s training practices are observed against injury trends.

This study highlights one means by which rehabilitation specialists can affect change in the health outcomes of their community. Using the injury clinic
implemented in this study design as a starting point, one can make modifications to address aforementioned design limitations, along with continued adjustments, critical review, and retrospective analysis to continue to describe and analyze injury in sports like Ultimate.

CONCLUSION
Ultimate has traditionally been characterized as a limited contact sport with subsequently marginal attention in literature, and an assumed minimal need for on-site professional medical coverage. The epidemiological analysis of club sports athletes in this collegiate setting suggests that Ultimate athletes are at risk of sustaining injuries, supporting the need for further studies and perhaps even on-site sports medicine management. Given the number of athletic injuries that garnered recommendations for further medical utilization, additional investigation may be warranted regarding the cost benefit of on-site medical management of Ultimate injuries, including acute injuries before they become chronic conditions. Furthermore, the information provided in studies like this are useful in planning and preparation for medical coverage at Ultimate games & tournaments as well as establishing injury prevention programs tailored to the sport's specific injury profile.1,4

REFERENCES


ABSTRACT

Background/Purpose: Exercise induced lower leg pain (EILP) is a commonly diagnosed overuse injury in recreational runners and in the military with an incidence of 27-33% of all lower leg pain presentations. This condition has proven difficult to treat conservatively and patients commonly undergo surgical decompression of the compartment by fasciotomy. This case series investigates the clinical outcome of patients referred with exertional lower leg pain symptoms of the anterior compartment of the lower leg following a gait re-training intervention program.

Case Description: 10 patients with exercise related running pain in the anterior compartment of the lower leg underwent a gait re-training intervention over a six-week period. Coaching cues were utilized to increase hip flexion, increase cadence, maintaining an upright torso, and to achieve a midfoot strike pattern. At initial consult and six-week follow up, two-dimensional video analysis was used to measure kinematic data. Patients self reported level of function and painfree running were recorded throughout and at one-year post intervention.

Outcomes: Running distance, subjective lower limb function scores and patient's pain improved significantly. The largest mean improvements in function were observed in 'running for 30 minutes or longer' and reported 'sports participation ability' with increases of 57.5% and 50%, respectively. 70% of patients were running painfree at follow-up. Kinematic changes affected at consultation were maintained at follow-up including angle of dorsiflexion, angle of tibia at initial contact, hip flexion angle, and stride length. A mean improvement of the EILP Questionnaire score of 40.3% and 49.2%, at six-week and one-year follow up, respectively.

Discussion: This case series describes a conservative treatment intervention for patients with biomechanical overload syndrome/exertional compartment syndrome of the anterior lower leg. Three of the four coaching cues affected lasting changes in gait kinematics. Significant improvements were shown in painfree running times and function.

Level of Evidence: 4

Keywords: Chronic exertional compartment syndrome, biomechanical overload syndrome, overuse injury, gait analysis, running

1 Department of Sports Medicine, Sports Surgery Clinic, Santry Demesne, Dublin Ireland
2 Centre for Health, Exercise and Sports Medicine, University of Melbourne, Australia

The protocol for this study was approved by the Sports Surgery Clinic Research Ethics Committee, Santry, Dublin 9, Ireland.

Financial Disclosure and Conflict of Interest:
We affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as disclosed in an attachment and cited in the manuscript. Any other conflict of interest (ie, personal associations or involvement as a director, officer, or expert witness) is also disclosed in an attachment.

CORRESPONDING AUTHOR
Mr. David Breen
Department of Sports Medicine
Sports Surgery Clinic
Santry Demesne
Dublin, Republic of Ireland
Tel: +353.1.5262030
Fax: +353.1.5262046
E-mail: mrdavidbreen@gmail.com
BACKGROUND / PURPOSE
Exertional lower leg pain is a commonly diagnosed overuse injury in recreational runners and in the military with an incidence of 27-33% of all lower leg pain presentations.1-3 Typically, patients present with incremental pain on exercise, which is described as ‘tightness’, or ‘constricting pain’. Symptoms can increase with up-hill running or by increasing running speed with a fixed cadence. Symptoms tend to worsen to a point whereby continued running is impossible. The pain and symptoms are alleviated by rest and are occasionally accompanied by temporary paraesthesia or foot slapping, however typically the individual is able to briefly recommence running prior to a recurrence of symptoms. Classically the patient is pain free when not exercising.

Zhang et al describe the underlying pathophysiology as transient muscle ischemia,4 where due to increased intra-compartmental pressure the arterial blood supply to muscle is reduced, causing ischemic pain similar to acute compartment syndrome (a surgical emergency) but termed chronic exertional compartment syndrome (CECS) due to its progressive sub acute nature. The underlying pathology is suggested as fascial non-compliance or muscle hypertrophy but to date no conclusive proof of tissue necrosis or cell hypoxia has been demonstrated.5 CECS has been described in the anterior, peroneal and deep posterior compartments of the lower leg but the anterior is the most commonly affected.7 The diagnosis is typically confirmed with intra-compartmental pressure measurement but a systematic review of diagnostic pressures revealed substantial overlap of criteria and significant confounding variables of measurement technique, throwing doubt on the diagnostic process,8 and recent work byRoscoe et al suggests that a major revision of diagnostic criteria may be needed.8 Other diagnoses exist including medial tibial stress syndrome, stress fracture, popliteal artery and common peroneal nerve entrapment, all of which may need to be excluded.

Historically, first line treatments such as myofascial release, orthotic intervention, stretching, massage, and training load modification2 have been tried in an attempt to alleviate CECS. However, none have proved successful in a return to similar levels of activity. This was primarily due to an inability to modify the intra-compartmental pressures with short term intervention.13 To date, the only definitive treatment is surgical decompression of the compartment by fasciotomy, an operative technique used to open the fascia covering the muscle compartment thereby de-tensioning the purported constrictive effect on muscles. However, a high proportion of surgical interventions are unsuccessful.14 Published outcome data on operative data is good in the short term but studies are limited with regard to duration of follow up, use of outcome measures, and demonstrate wide variation in operative technique.14,15

Recent work on running technique and kinematic and kinetic changes of gait by Davis and Heiderscheit may provide details relating to the underlying mechanism behind the propagation of muscle overload. Reduction in the stride length, ground contact time, vertical oscillation and lower extremity angle all contribute to improved running economy,16 reduced ground reaction force, and movement efficiency.17,18

During running gait, tibialis anterior (TA) and extensor hallucis longus have a high state of preactivation19 prior to rear foot initial contact. TA activity decreases rapidly with running induced metabolic fatigue.7,20 This led the authors of this case series to believe that, based on clinical observations in a military population, chronic exertional compartment syndrome is a mechanical muscular overload rather than a pathological process. The authors suggest it be considered as a Biomechanical Overload Syndrome.3

Recent researchers have shown it is possible to change muscle loading patterns by altering kinematics.21-23 Therefore, the authors designed a gait re-training program to reduce the overload pattern. The aim of this gait re-training was to reduce the eccentric activity in TA, the proposed mechanism of increased compartment pressure in anterior compartment syndrome, by promoting a slight forefoot or midfoot ground contact pattern.7,24,25 This was facilitated via the use of visual feedback. Visual feedback has been shown to improve patient compliance and successful adoption of technique with lasting benefit.26 This teaching tool was utilized within the gait re-training to improve the training effect.

This case series is intended to examine the clinical outcome of patients referred with exertional lower
leg pain symptoms of the anterior compartment of the lower leg following a gait re-training intervention program. A patient reported outcome tool and overall running distance competence, along with maintenance of kinematic changes were used to help track these outcomes.

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

Ten adult subjects, nine males and one female (mean +/- SD: 30.5 +/- 8.8 years, weight 80.8 +/- 11.4 kg, height 182.6 +/- 6.7 cm, BMI 24.2 +/- 2.4 kg/m), presenting with anterior exertional lower leg pain were recruited for the trial. Subjects were included after giving their informed consent to participate in this study, which received ethical approval (Study 25-AFM-003).

**CLINICAL IMPRESSION #1**

Subjects were recruited based on a primary complaint of exercise induced lower leg pain localized to the anterior shank. Subjects presented with incremental pain, which worsened to a crescendo such that they were unable to continue running. Symptoms typically alleviated by rest following running cessation.

**EXAMINATION**

On initial presentation a full clinical history was taken and an examination performed by a sports medicine physician and physiotherapist. Any further investigation required was performed including magnetic resonance imaging (MRI) to exclude stress fracture and medial tibial stress syndrome. The subjects’ current running shoes were used during retraining without orthotics, which were removed if prescribed.

**CLINICAL IMPRESSION #2**

Based upon the clinical reasoning of both the sports medicine physician and physiotherapist, and supported by history and MRI examination to exclude stress fracture or periostitis and any muscle pathology, subjects were diagnosed with ‘anterior biomechanical overload syndrome’ (ABOS) and deemed suitable for the study intervention. Subjects agreed to undergo a six week gait re-training intervention using kinematic measures pre- and post-intervention combined with a self-report outcome measure of functional ability, and the exercise induced leg pain (EILP) questionnaire, to ascertain intervention success. The EILP is a validated and reliable self-report measure of exercise-induced leg pain symptoms. It measures the perceived severity of symptoms that impact function and sports ability.

**INTERVENTION**

On initial assessment subjects were asked to run at a self-selected pace for 2.5 to 3 minutes on a commercial treadmill at 0 degree incline (Nordic-Track, Icon Health and Fitness™, Beaumont, California). Treadmill speed was then self-selected by the subject between 9 to 12 kph. When subjects informed the tester they were comfortable running at their preferred pace a video recording was taken. Video recording was taken prior to the onset of symptoms to minimize any pain effect on running biomechanics. A 10 second digital recording was taken using 2HD video cameras (Panasonic HDC-SD80, Panasonic Corporation™, Japan) recording at a frame rate of 60fps (resolution 1920 x 1080i) from sagittal and coronal viewpoints obtained against a fixed reference backdrop (MAR Systems™, England). Subjects were instructed to maintain their running position in the center of the treadmill belt during data recording. Both cameras were fixed to wall mounts maintaining a consistent field of view between subjects. Angular and kinematic data from each recording was interpreted using a 2D motion analysis system connected via HDMI cabling to a plasma screen (Contemplas™ TEMPLO V6.0 GmbH, Germany).

Sagittal plane two-dimensional (2D) analysis has previously been assessed for validity and reliability against the ‘gold standard’ of three-dimensional (3D) analysis in previous studies of treadmill running. Moreover a pilot comparative analysis (2D versus 3D) demonstrated comparable reliability in measures across five consecutive foot contacts while treadmill running (Appendix A). Initial foot contact was matched synchronously for both 2D and 3D measurement. Stance phase kinematics, such as foot inclination and tibial angle, were found to be highly agreeable between both methods at identical gait cycle time points. While there was some differences in absolute magnitudes (e.g., max hip flexion [2D versus 3D] of 56.23° and 64.91°, respectively),
these would not be unexpected due to the difference in how 2D and 3D measures are obtained.\textsuperscript{28}

Following initial 2D analysis, gait re-training began immediately in session one in the form of verbalized cues to alter kinematics at the foot, ankle, knee, hip, and torso. Gait re-training sessions were 60 minutes in duration with each subject receiving a maximum of three sessions over a six-week period. Sessions consisted of running drills and walk-run interval training with the aid of video feedback to facilitate kinematic change. The use of video feedback was progressively withdrawn over the three sessions.

Cues were individualized to each subject in order to reduce ankle dorsiflexion at the landing position. Various cues were used to achieve this goal. Typical coaching cues involved landing with a mid-foot strike pattern, slightly increasing hip flexion, promoting an earlier foot lift-off and running with a more upright torso position. Previous clinical experience in delivering coaching cues suggests that slightly increasing hip flexion was sometimes more effective in reducing ankle dorsiflexion angle at foot-strike rather than instructing subjects to land with a mid-foot strike, although to date there is no research to support this. The authors chose to cue an earlier and slightly higher foot lift-off as it was hoped this would have the double effect of increasing step-rate, which has been shown to reduce ankle dorsiflexion at foot-strike as well as promote increased hip flexion.\textsuperscript{18} A more upright body position was promoted if necessary as the authors previous experience in delivering coaching cues had suggested this was often complimentary to achieving greater hip flexion with resultant reduction in ankle dorsiflexion at foot-strike.

Between one and three individualized coaching cues were used until the therapist felt that desired changes were achieved. This allowed for individualization of coaching cues based on the therapist’s observation and feedback from the subject on whether they thought the change was sustainable. Care was taken to cue only minimal kinematic change to avoid early fatigue in subjects. At this stage a ‘walk-run’ program as a template for embedding these motor patterns was given. This training program was performed three times per week with a minimum of one days rest between sessions (Appendix B). Only two additional independent training sessions were performed on weeks where the subject was reviewed by the sports medicine team. A review of the subjects running gait was typically carried out fortnightly, with kinematic adjustments made as needed. Each subject had three video coaching sessions in total. The EILP questionnaire was also repeated prior to retesting and at one-year post intervention. In addition, a 15-point global rating of change (GROC) was included at one-year follow up to measure subjects perceived change and overall improvement.\textsuperscript{33} The scale directed the subject to rate his or her change from ‘a very great deal worse’ (-7) to ‘a very great deal better (+7).

The running kinematics were quantified from digital video recordings obtained during testing. Running cycle phases of interest and angular data assessed at each event are outlined in Table 1. Kinematic variables were measured for five consecutive strides on both sides, pre- and post- retraining intervention. Stride length was measured from the point of initial contact to the point of toe off. The midstance phase was defined as the last point at which the heel stays in contact with the ground before lifting; given no subjects were forefoot runners.

Initial contact was identified from the rearview coronal imaging, which proved more accurate than sagittal views due to rearfoot supination, which occurs before contact. Thereafter, sagittal imaging was used to measure kinematic data. Foot inclination angle was measured from the sole of the shoe to treadmill. Tib-

---

<table>
<thead>
<tr>
<th>Table 1. Kinematic gait cycle variables for both sides at each phase, with pre-, post- and p-values for each.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GAIT PHASE</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td><strong>VARIABLE</strong></td>
</tr>
<tr>
<td>PRE</td>
</tr>
<tr>
<td>POST</td>
</tr>
<tr>
<td>P-VALUE</td>
</tr>
</tbody>
</table>
ial angle was measured from malleolus center to mid shaft tibia at tibial tuberosity level, against the vertical. Lumbar flexion angle was measured from the L5 level to the thoraco-lumbar junction, against the vertical in order to represent change in body position.

At midstance, ankle dorsiflexion was measured from mid shaft tibia at tibial tuberosity level through malleolus center against the horizontal at shoe sole level. The point of maximum hip flexion was identified and hip angle measured through mid thigh at femoral condyle level to lumbo-sacral junction, against lumbar flexion angle.

**Data analysis and statistics**

Statistical analysis was carried out on all data sets for each variable. Paired t-tests showed significant changes in all but two sets of kinematic variables (p < 0.05), lumbar flexion (p = 0.102) and cadence (p = 0.354). A Wilcoxon matched pairs test (p < 0.05) was used to analyze the paired datasets. Using the EILP questionnaire, the percentage improvement for each subject was identified and average improvement ascertained. A scatterplot graph (Figure 1) was produced to represent the pre and post intervention differences in time to first onset of pain and time to pain limit/threshold.

**OUTCOME**

At six week follow up there was a mean improvement of the EILP Questionnaire score of 40.3%. At the one-year follow up, with 9 out of the 10 subjects responding, there was a mean improvement of 49.2% from baseline measures. Eight patients were running pain free over 30 minutes and the other two patients significantly increased their running distance before symptom onset. Running symptoms reported at one year after intervention reported 7 of the 10 subjects running entirely painfree with one subject symptom free for at least 80 minutes. One subject was not running due to a foot injury and one was subject did not respond. GROC scores at one-year follow up were an average of 4.9 or ‘quite a bit better’.

Persistent changes were observed in foot inclination angle, tibial angle, and maximum hip flexion angle (Table 1). Foot inclination angle at initial contact on the right and left foot changed from an average dorsiflexion angle of 18.32 and 18.26, respectively, to plantar flexion angle of 1.89 (p = 0.001) and 3.43 (p = 0.001), respectively. This represents a technical change from heel strike foot position to slight forefoot/midfoot strike position.

Similarly, mean tibial angle at initial contact changed on the right and left lower leg from 11.72 and 11.98, respectively, to 2.89 (p = 0.001) and 2.48 (p = 0.001), respectively. This represents a reduction in tibial angulation to an almost vertical tibia on initial contact.

Maximum hip flexion angle averages on the right and left changed from 35.99 and 35.10, respectively, to 45.74 (p = 0.003) and 45.17 (p = 0.002), respectively. Small but statistically significant changes were observed in right and left ankle dorsiflexion at midstance changing from 63.18 and 63.27, respectively, to 64.92 (p = 0.03) and 65.1 (p = 0.04), respectively. A significant reduction in stride length was observed of 67.58cm to 46.8cm (p = 0.001) on the right, and 69.59cm to 50.36cm (p = 0.001) on the left. There was no significant change in lumbar flexion at initial contact (p = 0.102).

Mean differences in EILP questionnaire scores of function are outlined in Table 2. Significant changes (p ≤ 0.05) in EILP questionnaire scores (Table 2) were seen in all four running activities and perceived ability scores. An average increase in function of 40.3% was observed for EILP scores, pre versus post intervention. Importantly, the largest changes in function were observed for ‘Running after 30 minutes or longer’ and ‘Ability to participate in your desired sport as long as you like’, 57.5% (p = 0.005) increase and 50% (p = 0.007) increase in scores, respectively.

![Figure 1. re-training versus post-training time to pain onset (first onset of exertional lower limb pain) and pain limit (time taken to pain limit/threshold), where x-axis ‘PF’ = ‘pain free’](image-url)
Figure 1 illustrates the change in subjective report of time taken (minutes) to pain onset and pain limit during each subject’s run. All but three subjects achieved pain-free (PF) status for exertional lower leg pain, with all subjects showing improvements.

DISCUSSION

The authors hypothesized that by altering key elements of running kinematics in patients with exertional anterior lower leg pain, with no demonstrable stress response in bone, that the symptoms would be alleviated by a more vertical tibial strike angle, reduced stride length, increased running cadence and a more vertical torso angle. In this cohort, all subjects showed an improvement in their pain free running tolerance and 70% of subjects were running entirely symptom free post-treatment. Subjects also reported improvements in their outcome scores and demonstrated lasting kinematic changes in running gait following running re-education training. The only interventions used were coaching cues and intermittent visual feedback over a six-week period.

Subjects demonstrated statistically significant improvements in exercise induced leg pain score (EILP), and changes in foot inclination angle, mean tibial angle, hip flexion, ankle dorsiflexion and stride length following running re-education training. The results were maintained at follow-up six weeks later. The EILP inventory is highly specific to running function and athletic performance comparing favorably to other lower leg function tools previously used in the monitoring of exercise induced CECS.

To date there has been limited evidence of the effectiveness of conservative management of chronic exertional anterior compartment syndrome. Diebal et al used forefoot running to reduce the symptoms in a case series of 10 patients with associated reduction in intracompartmental pressures. However, despite significant improvements in their running performance, none were symptom free and pain remained the limiting factor. Results from the cohort in the current study demonstrate all but three subjects running entirely pain-free. Coaching cues utilized in the current study were individualized in an attempt to alter the kinematic variables selected. Coaching aims were to reduce ankle dorsiflexion at the landing position using a combination of coaching cues including increased hip flexion, early foot lift-off, and a more upright torso.
Mid-Foot Strike position
The focus for the cohort group was on adopting a mid-foot strike in order to reduce TA activity as this has been shown to be highest in late swing through to the foot flat position. All subjects were able to achieve this within six weeks. It has been shown that TA activity increased primarily in late swing for the purpose of altering the landing posture of the limb in preparation for subsequent joint moments and energy absorption.

Excessive tibialis anterior (TA) eccentric activity has been proposed as a major contributor to the mechanism of increased compartment pressure in anterior compartment syndrome. Eccentric muscle activity is strenuous and results in more rapid muscle fatigue ad by products of breakdown, and possible edema. It may be possible to reduce the eccentric activity in TA by promoting earlier ground contact of the forefoot or adopting a midfoot strike. This also results in a more vertical tibia at foot contact, reducing the preload of the anterior compartment

Step rate
An increase in step rate has been shown to reduce tibialis anterior activity. Emphasis was placed on an earlier and higher foot lift-off to achieve this increase while maintaining the same running speed. It had been observed that simply instructing subjects to increase step-rate often resulted in a fast shuffle-like gait pattern. As this was considered undesirable, the former cue was used. This was reflected by a significant reduction in stride length of 20cm (p = 0.001) measured post gait re-training. Step rate is inversely proportional to step length and a 10% increase in step frequency has been shown to significantly decrease foot inclination angle.

Hip Flexion
All subjects maintained increased hip flexion in this study after intervention. Hip flexion angle has not been addressed in the literature in relation to foot strike but the authors hypothesized a higher knee position in late swing allows the subject more time to align the tibia and foot to achieve the desired vertical tibia and midfoot strike pattern. While vertical ground reaction force may increase as a result of a more direct downward foot drive, evidence is lacking to make a direct connection between impact forces and many running injuries, and in this population no evidence of stress fracture was present.

Torso Position
A more upright torso position was sometimes advocated as a complementary cue to achieve greater hip flexion. However, this was only encouraged if increasing hip flexion was a necessary cue. In this case series, the authors were unable to effect lasting kinematic change in lumbar flexion during the six week intervention but this did not appear to limit an average increase in hip flexion at late swing of 10°. The method of measurement using 2D kinematics may be too inaccurate to record small differences in lumbar flexion angulation. It may be that lumbar flexion angle was not a good measure of torso positioning and mid-thoracic angulation using electro-goniometers would have been a better method for recording this variable.

As the rate of perceived exertion is initially higher with a step rate increase of 10% the authors' used a graduated walk/run program while the new running technique was being learned to limit fatigue. Although not recorded it was found that subjects reported initially increased rating of perceived exertion (RPE), which reduced after four weeks of training. Many studies report that running economy (RE) in experienced runners is best at self-selected step rate. However inexperienced runners have been shown to have better RE at step rates 9% higher than preferred. It seems likely that adoption of a new technique and step-rate causes initial increase in RPE and reduction in RE. Improvements in both these values may be possible with training adaption but further research is needed to confirm this observation.

The ability to make both short and long term kinematic changes in running technique is often challenged. In practice, the authors identified changes occurring very rapidly but few studies have looked at the retention of changes made. It has been shown that after only two weeks of retraining, retention is possible and...
maintained up to six months later. Further work is required to demonstrate optimal training techniques and time frames but it is apparent that once kinematic changes are learned, subjects are able to retain these changes in the absence of continued feedback.

This case series has a number of limitations. No biomedical markers were placed on patients to act as reference points and this has been shown to introduce possible error in the reporting of kinematic angles. Error was minimized by comparing five steps on each leg and taking the mean value and using fixed angle cameras and backdrops, however it is recognized either using reference markers or 3D analysis, despite being available to the authors, would have been more accurate but too time consuming and costly for the clinical population.

The effect of being tested/observed influences the performance of motor tasks so the authors cannot be sure that running technique observed in lab conditions mimics technique performed outside in varying conditions. Treadmill running is capable of being used to obtain a representation of the typical human running action but the problem of being observed may be overcome in future with wearable inertial sensors currently being developed. In this way we hope to improve compliance, feedback and recording of kinematic change and also in longer-term compliance. Further studies are required to identify whether kinematic variables are maintained and the extent of follow up required and whether other exertional lower leg conditions can be successfully treated using the biomechanical overload principles on a larger scale.

**CONCLUSIONS**

This case series provides further evidence that anterior exertional lower leg pain symptoms can be alleviated by kinematic changes in running gait. Follow-up assessment with 2D kinematics at the six-week stage confirmed that 100% of patients had retained their new running form with significant reduction of symptoms as measured using the EILP Questionnaire. The changes in gait kinematics and resultant improvement in self-reported scores of function and pain free running distance supports the authors’ contention that this clinical condition represents a biomechanical overload without irreversible pathological pressure change. As such the authors’ recommend the use of gait re-training as the primary treatment of choice. This case series demonstrated the effective use of visual and verbalized coaching cues to alter running technique and reduce the symptoms of anterior biomechanical overload syndrome. The use of such cues improved the ability of the subjects to adopt a modified gait pattern. These changes in gait were adopted and retained over a six-week period.

**REFERENCES**


APPENDIX A

APPENDIX 1A  Comparison measures (in degrees) between two-dimensional (2D) and three-dimensional (3D) kinematic analysis of gait cycle variables for both sides at each phase pre intervention and post intervention. Initial contact: foot inclination (Foot Inclin), tibial angle (Tib angle), Back flexion angle (Back flx); Midstance: ankle dorsi-flexion angle (Ankle DF); Maximum hip flexion: hip flexion angle (Hip flx)

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>INITIAL CONTACT</th>
<th>MIDSTANCE</th>
<th>MAX HIP FLEXION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foot Inclin (°)</td>
<td>Tib angle (°)</td>
<td>Back flx (°)</td>
</tr>
<tr>
<td>POST RRED R L R</td>
<td>-7.2 -7.04 -3.3 0.5 5.2 5.18 25.58 27.52 53.4 59.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POST RRED 3D</td>
<td>-9.52 -8.74 0.14 1.96 5.28 5.42 17.48 18.9 62.68 67.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POST RRED 2D</td>
<td>-7.12 -7.12 -1.4 5.19 26.55 56.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POST RRED 3D</td>
<td>-9.13 -9.13 1.05 5.35 18.19 64.91</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX B

Running re-education

NAME_____________
WALK/RUN PROGRAM
DATE_____________

GOAL: 30 minutes continuous running in 4-6 weeks
Your therapist will help advise you at what level to start.

<table>
<thead>
<tr>
<th>Level</th>
<th>WALK TIME (mins)</th>
<th>RUN TIME (mins)</th>
<th>TOTAL TIME (mins)</th>
<th>TOTAL RUN TIME</th>
<th>Runs at this level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>20</td>
<td>10</td>
<td>1-2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
<td>21</td>
<td>14</td>
<td>1-2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>3</td>
<td>20</td>
<td>15</td>
<td>1-2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>3</td>
<td>24</td>
<td>18</td>
<td>1-2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>4</td>
<td>25</td>
<td>20</td>
<td>1-2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>5</td>
<td>24</td>
<td>20</td>
<td>1-2</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>5</td>
<td>30</td>
<td>25</td>
<td>1-2</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>6</td>
<td>28</td>
<td>24</td>
<td>1-2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>8</td>
<td>27</td>
<td>24</td>
<td>1-2</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>10</td>
<td>33</td>
<td>30</td>
<td>1-2</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>11</td>
<td>36</td>
<td>33</td>
<td>1-2</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>14</td>
<td>30</td>
<td>28</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>1-2</td>
</tr>
</tbody>
</table>

Note: Walking pace should be sufficient to ease any symptoms. If discomfort rises to 4 out of 10 on a pain scale, go back to previous level. Perform on alternate days. Eg Monday, Wednesday, Friday Progress to next level if pain does not rise above 3 out of 10 within 24 hours.
CASE REPORT
RETURN TO SPORT FOLLOWING SURGERY FOR A COMPLICATED TIBIA AND FIBULA FRACTURE IN A COLLEGIATE WOMEN’S SOCCER PLAYER WITH A LOW LEVEL OF KINESIOPHOBIA

Luis A. Feigenbaum, PT, DPT, SCS, ATC, LAT, CSCS1
Michael Baraga, MD1
Lee D. Kaplan, MD1
Kathryn E. Roach, PT, PhD2
Kathryn M. Calpino, SPT2
Katie Dorsey, SPT2
Cristina Martorelli, SPT2
Beatriz Sagarduy, SPT2
Lesley-Anne King, ATC, LAT3
Vincent A. Scavo, ATC, LAT3

ABSTRACT

Background & Purpose: Much attention has been solely paid to physical outcome measures for return to sport after injury in the past. However, current research shows that the psychological component of these injuries can be more predictive of return to sport than physical outcome measures. The purpose of this case report is to describe the successful return to sport following surgery of a complicated tibia and fibula fracture of a Division I collegiate women’s soccer player with a low level of kinesiophobia.

Case Description: A 22-year-old female sustained a closed traumatic mid-shaft fracture of her tibia and fibula. During a high velocity play she sustained a direct blow while colliding with an opposing player’s cleats. As a result of the play, her distal tibia was displaced 90° to the rest of her leg. She underwent a closed reduction and tibial internal fixation with an intramedullary rod. Outcome scores were tracked using the IKDC and TSK-11. The IKDC measures symptoms, function, and sport activity related to knee injuries. The TSK-11 measures fear of movement and re-injury, which was important to assess during this case due to the gruesome nature of the injury.

Outcomes: At 4 months, the subject became symptomatic over the fibula and was diagnosed with a fibular nonunion fracture. This was unexpected due to the low incidence of and usual asymptomatic nature of fibular nonunion fractures, which required an additional surgery. TSK-11 scores ranged from 19-20 throughout, signifying low levels of kinesiophobia. IKDC scores improved from 8.05 to 60.92. The subject ultimately signed a professional soccer contract.

Discussion: The rehabilitation of this subject was complex due to her low levels of kinesiophobia, self-guided overtraining, and the potential role they may have had in her fibular nonunion fracture. This case study demonstrates a successful outcome despite a unique injury presentation, multiple surgeries, and low levels of kinesiophobia. While a low level of kinesiophobia can be detrimental to rehabilitation compliance, it may have benefited her in the long-term.

Level of Evidence: 5

Keywords: Fracture, kinesiophobia, soccer

CORRESPONDING AUTHOR
Luis A. Feigenbaum, PT, DPT, SCS, ATC, LAT, CSCS
UHealth Sports Performance and Wellness Institute
Department of Physical Therapy, University of Miami (FL), Miller School of Medicine
5915 Ponce de Leon Boulevard, 5th Floor
Coral Gables, FL 33146 (USA)
Phone: (305) 284-4876
Fax: (305) 284-6128
E-mail: lfeigenbaum@med.miami.edu

1 UHealth Sports Performance and Wellness Institute, University of Miami (FL), Miller School of Medicine, Miami, FL, USA
2 Department of Physical Therapy, University of Miami (FL), Miller School of Medicine, Coral Gables, FL, USA
3 Department of Athletics, Athletic Training, University of Miami (FL), Coral Gables, FL, USA
BACKGROUND AND PURPOSE

There is a high prevalence of fractures in Division I college sports, especially in athletes participating in contact sports such as soccer. In fact, the majority of injuries that soccer players experience are high impact traumas, with slide tackles being the most common lower extremity fracture mechanism. While lower extremity fractures are common in soccer, research regarding prognosis and outcomes for high impact fractures is lacking. This is problematic due to the variables associated with making a safe return to play decision. Therefore, prognostic factors that may positively or negatively affect the rehabilitation process and ultimately return to sport must be recognized.

Previous attention has been paid to physical outcome measures for return to sport. However, current research shows that the psychological component of these injuries can be more predictive of return to play than physical outcome measures. Athletes that sustain traumatic injuries may never return to their sport due to fear of re-injury. This fear of re-injury is an example of how a negative psychological state can hinder an outcome. Inversely, a positive psychological response to injury and rehabilitation correlates with a more rapid return to sport within a year.

Kinesiophobia has been defined as an “excessive, irrational, and debilitating fear of physical movement and activity resulting from a feeling of vulnerability to painful injury or re-injury.” The fear associated with kinesiophobia can be heightened in injuries due to trauma. Behavior that is guided by kinesiophobia has the potential to negatively impact outcomes for patients with pain. According to the fear avoidance model (FAM) of exaggerated pain perception proposed by Lethem et al, pain perception involves both a sensory and an emotional reaction component. Fear of pain is an important feature of the emotional reaction in that it can bring out two different forms of coping responses: confrontation or avoidance. An individual motivated by fear typically avoids both painful experiences and activities. Fear avoidance behaviors can also be indicative of high psychological distress, which has further been associated with poor clinical outcomes.

Evidence supports the assessment of pain-related fear in patients across multiple musculoskeletal conditions ranging from sub-acute to chronic conditions. Higher levels of pain have been shown to be predictive of higher levels of disability, and fear of pain has been associated with kinesiophobia. In order to help produce the best clinical outcomes it is important to identify patients who are at risk for kinesiophobia. Outcome tools such as the Tampa Scale for Kinesiophobia (TSK) and its shortened-version the TSK-11, can be used to better understand the psychological impact of an injury. The TSK questionnaire involves items that incorporate fear of injury, fear of pain and a person’s ability to perceive and report symptoms. The combination of both physical and psychological outcome tools can help to facilitate a safe return to play.

The purpose of this case report is to describe the successful return to sport following surgery of a complicated tibia and fibula fracture of a Division I collegiate women's soccer player with a low level of kinesiophobia.

CASE DESCRIPTION: PATIENT HISTORY AND SYSTEMS REVIEW

A 22 year-old female Division I collegiate soccer player with no previous significant medical history or history of injury sustained a displaced, closed mid-shaft right tibia and fibula fracture while playing in a soccer game. During a high-velocity play, she received a direct impact to her anteromedial tibia by an opponent in an attempt to win a 50/50 ball. Despite the use of shin guards, the force of the impact was so great that they did not prevent this injury from occurring. As a result, her distal tibia was medially displaced 90° to the rest of her leg. She was immediately transported to the local emergency department. Radiographs confirmed a comminuted and displaced fracture of her right tibia and fibula (Figure 1). She was immediately admitted and underwent closed reduction and intramedullary nailing of the tibia, which is considered to be more advantageous for closed tibial fracture healing and function than casting (Figure 2). The fibula was reduced but was not fixated. There were no surgical complications.

Clinical Impression #1

At the time of her initial physical therapy evaluation the subject was informed that the data concerning her case would be submitted for publication. Subject
confidentiality was protected according to the U.S. Health Insurance Portability and Accountability Act (HIPPA) and IRB approval for this case report was granted. The subject participated in a sport-specific physical therapy program in the university athletic training facility days after being discharged from the hospital (Table 1). Rehabilitation for this injury follows a plan of care that is predicated on progressions through weight-bearing activities, gradually increasing physiologic responses to exercise, and limiting any pain-inducing activity. Impairments were assessed at the time of the initial evaluation and in conjunction with her physician's order.

Her post-operative presentation was normal for after this procedure. Due to the surgical sites for the procedure, most of her impairments were present at the knee (Figure 3). The subject participated in daily treatment sessions under the supervision of her physical therapist and athletic trainer. She was extremely eager to get back to soccer and was thus progressed quickly within the constraints of the protocol.

Due to the traumatic nature of her injury, the treating therapist believed the subject may have been at an increased risk for developing kinesiophobia. However, this subject's extreme desire to return to soccer as soon as possible, as well as her intense work ethic, made her clinical impression unique. For these reasons, her kinesiophobia was assessed and tracked throughout her treatment.

EXAMINATION

The IKDC Subjective Knee Form measures pain, symptoms, function, and sport activity related to knee injuries. The survey contains 18 items with a maximum of 87 points related to these domains. A score of 0 on an item demonstrates the least amount of function for the specified activity. Once a final score is determined, it can be plugged into an equation to give a percentile based on the person's age and gender category if the individual is between 18 and 65 years of age. Scoring is achieved through the summation of the first four subtest scores. These scores are then transformed into a scale ranging from 0 to 100 through a formula:

\[
\text{IKDC Score} = \frac{\text{sum of all questions} - \text{lowest possible total score}}{\text{range of possible scores}} \times 100
\]

Higher scores are indicative of less disability. A score of 100 would indicate no disability. A change
in score of greater than 9 points marks the threshold for the minimal detectable change of the IKDC.\textsuperscript{30} To distinguish between those who were or were not improved across a wide variety of knee conditions using the IKDC, revealed that a change score of 11.5 points had the highest sensitivity (.82), and a change score of 20.5 points had the highest specificity (.84).\textsuperscript{29}

The IKDC has been shown to be reliable across a broad range of knee pathologies including ligament and meniscal injuries, articular cartilage lesions, and patellofemoral pain.\textsuperscript{31,33-38} The test battery of questions that comprise the IKDC give reliable results across all age ranges and genders.\textsuperscript{30}

The TSK-11 is a self-report questionnaire used to measure fear associated with pain and fear associated with re-injury.\textsuperscript{11} The TSK-11 is scored on a 4-point scale from 1 (strongly disagree) to 4 (strongly agree). Scores range from 11 to 44 points. Higher scores (>22) are indicative of fear-related pain or re-injury. Initially the (17-item) Tampa Scale for Kinesiophobia (TSK) was used as a fear-avoidance predictor for chronic low back pain, but it has been more

---

**Table 1. Rehabilitation Protocol for Post-Operative Leg Fractures**

<table>
<thead>
<tr>
<th>PHASE</th>
<th>ACUTE</th>
<th>SUBACUTE</th>
<th>CHRONIC</th>
<th>FUNCTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td>Protect surgery</td>
<td>Full AROM 5/5 MMT</td>
<td>Pain-free jogging</td>
<td>Return to sport</td>
</tr>
<tr>
<td></td>
<td>Control inflammatory response</td>
<td>Normalized gait</td>
<td>Return to modified soccer specific activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control pain, edema, spasm</td>
<td>SLS ≥ 30 seconds</td>
<td>Progression to plyometrics</td>
<td></td>
</tr>
<tr>
<td>Weight-bearing</td>
<td>WBAT</td>
<td>FWB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Support</td>
<td>Axillary crutches</td>
<td>Aircast</td>
<td>Taping or bracing PRN</td>
<td>PRN</td>
</tr>
<tr>
<td>ROM</td>
<td>PROM → AAROM → AROM</td>
<td>Static stretching</td>
<td>PNF stretching</td>
<td>Ballistic stretching Self-stretching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNF stretching</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ballistic stretching</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Self-stretching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strengthening</td>
<td>Isometrics</td>
<td>Isotonics OKC Ankle</td>
<td>Isotonics OKC Ankle</td>
<td>Olympic lifts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foot</td>
<td></td>
<td>Olympic lifts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hip</td>
<td></td>
<td>Soccer program</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CKC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg Press</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Squats</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lunge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBA</td>
<td>SLS</td>
<td>Tilt board</td>
<td>Soccer-specific ball drills</td>
<td>Plyometrics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plyometrics</td>
<td></td>
</tr>
<tr>
<td>Complimentary</td>
<td>Hip/ knee isotonic strengthening</td>
<td>Core strengthening</td>
<td>Treadmill</td>
<td>Soccer conditioning</td>
</tr>
<tr>
<td></td>
<td>Upper body ergometry</td>
<td>Stationary cycling</td>
<td>Stair climber</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elliptical</td>
<td>Jogging → Running</td>
<td></td>
</tr>
<tr>
<td>Modalities</td>
<td>Ice</td>
<td>Scar massage</td>
<td>PRN</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>HVGS</td>
<td>Contrast baths</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effleurage</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AROM= Active range of motion; MMT= Manual muscle test; SLS= single limb stance; WBAT= weight bearing as tolerated; FWB= full weight bearing; PROM= passive range of motion; AAROM= active assisted range of motion; PNF= proprioceptive neuromuscular facilitation; OKC= open kinetic chain; CKC= closed kinetic chain; HVGS= high voltage galvanic stimulation.

**Figure 3. Overhead view of post-operative knee following IM fixation of the tibia.**
recently studied as a strong predictor of knee, ankle, and shoulder reinjury.\textsuperscript{8-9,12,16-18,24-25,39} The TSK-11 has been proven to have similar reliability and validity to the original TSK.\textsuperscript{39} Kvist et al\textsuperscript{9} demonstrated that those patients who did not return to their previous level of activity were more afraid of re-injury due to movement and had a worse knee-related quality of life than those who had returned to their previous level of activity, as measured by the TSK. Woby et al\textsuperscript{39} found that a decrease in score by four points on the TSK increases the likelihood of identifying patients who have undergone an important reduction in fear or movement (sensitivity = 66%; specificity = 67%). A change of 3 points on the TSK-11 is needed to be 95% confident that a change has occurred.\textsuperscript{7} Furthermore, a reduction of 4 or more points maximizes the likelihood of correctly identifying patients with an important decrease in their fear of movement or re-injury.

**Clinical Impression #2**

The subject’s extreme work ethic and strong desire to return to soccer became more evident as time progressed. Only days after her physical therapy began, it became clear that she was independently exercising beyond what was prescribed. Against medical advice, the subject was simultaneously involved in a self-directed and intensive conditioning program. The conditioning program took place at the University Wellness Center and involved several hours of weight-bearing activities on machines such as the elliptical, Jacobs Ladder\textsuperscript{TM}, stair climbers, and treadmills. While the subject did not freely admit to her extra conditioning activity, her teammates did report to the medical staff that it indeed was taking place.

The subject began reporting lateral leg pain during the 11\textsuperscript{th} post-operative week. Radiographs were taken at that time and revealed incomplete healing of both fractures. The subject was advised to reduce her workload and would be re-evaluated if her symptoms persisted. However, the authors believe she again acted against medical advice and continued on her self-directed conditioning program. During the 17\textsuperscript{th} post-operative week, the subject reported worsening of her symptoms and was reevaluated. Radiographs showed a one centimeter translational deformity of the fibula and an intervening butterfly fragment revealing nonunion of the fibular fracture.

The nonunion required a second surgical intervention to fixate the fibula (Figure 4). This procedure was performed in the 21\textsuperscript{st} week after her initial procedure. This time however, her recovery became complicated due to a surgical site infection with an eventual hospital admission for medical treatment. The subject was instructed to remain non-weight bearing for the subsequent four weeks after the second surgical procedure. The authors believe this time the subject was compliant with her care and adhered to all precautions. She continued a rehabilitation program at the university training facility until eight months after the incident before leaving to coach and train independently without orthopedic restrictions. One year after the initial incident the subject was able to return to play internationally at the professional level without restrictions. For a detailed timeline of events throughout the course of her recovery, see Table 2.

**Outcome**

In addition to typical impairment and physical function tests and measures, the main outcome measures discussed in this case study include the TSK-11 and the IKDC (Table 3). The subject improved 52.87 points on the IKDC over the course of four months indicating a high reliability for improved self-reported function.
The decrease seen from November, 2012 to January, 2013 was a result of the second surgery performed to fixate the fibular head. Total TSK scores can range from between 11-44. In this case, the patient’s TSK-11 scores ranged from 19-20 throughout the treatment process. Although her scores did not decrease by four points her scores throughout were low, which is indicative of low kinesiophobia.

**DISCUSSION**

High velocity traumatic injuries are common in high level contact sports. Tibia-fibula fractures are seen in soccer players. Researchers have found that surgical fixation of the tibia followed by physical therapy have been efficient in promoting successful union of the fibula. Specifically, immediate weight bearing of the lower extremity without discomfort or loss of position following lower leg fracture has been proven to have definite advantages in non-surgical patients. Despite fractures of both the tibia and fibula, surgical fixation of the tibia without surgical intervention of the fibula is an acceptable protocol. Tyllianakis et al indicated that interlocking intramedullary nailing of the tibia is a reliable method of treatment associated with high rates of union and low incidence of complications. Non-union fractures are often the result of non-optimal healing environments (mechanical or biological). Excess movement at the fracture site, due to excess weight bearing in non-physical therapy activities chosen by the subject of this case report may have

<table>
<thead>
<tr>
<th>Week</th>
<th>Relevant Events</th>
</tr>
</thead>
</table>
| Week 0 | - Initial incident  
        - Hospitalization  
        - Surgical Intervention: tibia reduction and fixation, fibula reduction |
| Week 1 | - Weight bearing as tolerated |
| Week 11 | - Reports pain with movement in the lateral aspect of the leg  
         - Radiographs show interval healing of both fractures |
| Week 17 | - Patient reports movement and pain on the lateral leg  
        - Recommended for surgical intervention |
| Week 18 | - Radiographs show complete union of tibia and a translation deformity of fibular with more than 1 cm translation and intervening butterfly fragment |
| Week 21 | - Surgical reduction and fixation of fibula  
        - Tibia screws removed |
| Week 23 | - Surgical site infection  
         - Admitted to hospital for IV antibiotics, discharged with home antibiotics |
| Week 24 | - Infection resolved  
         - Radiographs show fibula and mortise in alignment, tibia healing  
         - Cleared to begin full weight bearing |
| Week 29 | - Radiographs show early bridging of nonunion site and integration of bone graft  
         - Cleared to begin strength training as tolerated |

<table>
<thead>
<tr>
<th>Week</th>
<th>Post-Operative TSK-11 and IKDC Scores</th>
</tr>
</thead>
</table>
| Week 3 | 20/44  
         | 19/44  
         | 19/44  
         | n/a † |
| Week 7 | 19/44  
         | 19/44  
         | 19/44  
         | n/a † |
| Week 17 | 19/44  
         | 19/44  
         | 19/44  
         | n/a † |
| Week 21 | 19/44  
         | 19/44  
         | 19/44  
         | n/a † |

<table>
<thead>
<tr>
<th>Score</th>
<th>Post-Operative TSK-11 and IKDC Scores</th>
<th>Score</th>
<th>Post-Operative TSK-11 and IKDC Scores</th>
</tr>
</thead>
</table>
| TSK-11 | 8.05 (<5%)  
         | 45.98 (5%)  
         | 36.78 (<5%)  
         | 60.92 (10%)  |
| IKDC | 20/44  
         | 19/44  
         | 19/44  
         | n/a † |

*Percentages based on the same age and gender group of the athlete.  
†Score was not taken due to her consistency with previous scores.  
TSK= Tampa Scale for Kinesiophobia;  
IKDC= International Knee Documentation Committee
inhibited the fibula’s ability to heal properly.

Prognosis for return to sport in a tibia-fibula fracture due to a soccer injury is approximately 40 weeks, however many factors can influence the outcome. Kinesiophobia, or pain related fear of movement, has recently received attention as a psychological factor that contributes to the timeline for progression of rehabilitation. An athlete’s level of kinesiophobia, either high or low, may greatly impact their recovery timeline and their prognosis for return to competitive sport.7,9 Athletes with low levels of kinesiophobia should be monitored for signs of overtraining and lack of adherence to physical therapy restrictions. However, these athletes may also be more likely to ultimately return to their sport.

Athletes with high levels of kinesiophobia will likely be more hesitant to return to sport.7,9 These athletes may need special attention in order to encourage them throughout therapy and reassure them that it is safe to return to activities. At either extreme, an athlete may also benefit from sports psychological counseling during injury rehabilitation as an adjunct to physical therapy. The TSK-11 can be a helpful tool in identifying and monitoring an athlete’s level of kinesiophobia throughout rehabilitation.

The TSK and TSK-11 are currently being used across a wide array of diverse patient populations.5,6,8,12,13,15-26 Chmielewski et al7 used the TSK-11 to measure fear of movement in patients undergoing ACL reconstruction rehabilitation and found that it was highest shortly after surgery and gradually decreased as more time passed. They also discovered that as the athletes started to return to sport the lower TSK scores were recorded in the higher functioning patients. Prugh et al10 studied TSK-11 in throwing athletes with elbow injuries and found that a specific subscale of the TSK-11 dealing with ‘fear of re-injury’ has the potential to accurately depict fear of movement, however it was concluded that more research is required to better understand the scale’s accuracy as well as the psychological component of an athlete’s return to play.10

While the current study did not focus on performing psychometric tests related to the TSK-11, the results shed light on how it can be clinically used in the rehabilitation of high-level athletes. The subject’s low level of fear after such a gruesome injury could have contributed to her desire to vigorously train outside of rehabilitation and ultimately could have led to the fibular nonunion fracture. This case report suggests a new use for the TSK-11 in the athletic population. The TSK-11 can help clinicians monitor how each individual psychologically perceives their injury in order to ensure the proper guidance and education necessary for optimal physical outcomes as needed.

CONCLUSION

While the subject’s psychological state may have been contributory to be a setback initially, it ultimately contributed to her return to sport. Her low level of kinesiophobia may have negatively impacted her compliance with weight bearing restrictions. This non-compliance may have been what led to her nonunion fracture and the need for a second surgery. Previous studies have found that psychological affect is more predictive of return to sport after injury than physical outcome measures.5 However, it is possible this subject’s low level of kinesiophobia allowed her to return to a high level of play following a traumatic injury and subsequent complicated rehabilitation.

REFERENCES


ABSTRACT

Background and Purpose: Neck pain is a common complaint treated by the physical therapist. Trigger points (TrPs) have been studied as a source of neuromusculoskeletal pain, though the ability of clinicians to accurately locate a TrP is not well supported. Dry needling (DN) is an intervention utilized by physical therapists where a monofilament needle is inserted into soft tissue in order to reduce pain thereby facilitating return to prior level of function. The purpose of this case report is to report the outcomes of DN as a primary treatment intervention for acute, non-specific cervical region pain.

Case description: The subject was an active 64-year-old female who self-referred for cervical pain following lifting heavy boxes while moving into a new home. She had a history of multi-level cervical fusion and recurrent cervical pain that physical therapy helped to control over the past few years. Physical examination supported a diagnosis of acute cervical region strain. Objective findings included decreased cervical active range of motion (AROM) and upper extremity strength, as well as, reproduction of pain symptoms upon palpation indicating the likelihood of TrPs in the right upper trapezius, levator scapula, supraspinatus, and infraspinatus musculature. She was treated using DN to the aforementioned muscles for two sessions, and no other interventions were performed in order to determine the effectiveness of DN as a primary intervention strategy without other interventions masking the effects of DN.

Outcomes: Clinically meaningful improvements were noted in pain and disability, as measured by the Neck Disability Index and Quadruple Visual Analog Scale. Physical examination denoted minimal to no change in cervical AROM (likely associated with multi-level fusion), except for right lateral flexion, and no change in shoulder flexion/abduction MMT.

Discussion: The patient was able to return to daily and work activities without further functional limitations caused by pain. This case report shows promising outcomes for the use of DN in the treatment of non-specific cervical region strain. Further research is recommended to determine if DN is clinically beneficial independent of other therapeutic interventions/postural corrections such as general or specific exercises targeting the affected musculature, or other “manual” therapy techniques such as manipulation or non-thrust mobilization.

Level Of Evidence: Level 4

Keywords: Cervical strain; dry needling; myofascial trigger points; neck pain

CORRESPONDING AUTHOR

Ron Pavkovich, PT, DPT, Cert. DN, Cert. SMT, Dip. Osteopractic, CIDN
1 Advantage Physical Therapy, Lexington, KY, USA

1 Advantage Physical Therapy, Lexington, KY, USA
INTRODUCTION
Dry Needling (DN) has risen in the rehabilitation community to become one of the preeminent treatment strategies employed by physical therapists. There are a number of schools of thought regarding proper DN techniques in order to address a host of pathological conditions. Literature is easily found upon a search for treatment of trigger points (TrPs), but there is minimal scientific research comparing DN to other interventions. Several authors have investigated and reported the physiological make-up of a TrP, as well as the reliability of current attempts to accurately clinically diagnose a TrP.\(^1\)\(^-\)\(^7\) TrPs have been studied extensively over the years, beginning with Simons and Travell, who originally reported that TrPs could be identified by focal tenderness to palpation along with restricted stretch range of motion when the muscle was placed on stretch.\(^8\) The presence of a TrP was also described as identifiable by palpation by the presence of a local twitch response (LTR) and reproduction of predicted referred pain patterns, which matches the distribution of the subject's pain.\(^8\)

A clinical diagnostic criterion for identification of a TrP consists of palpation of a tender nodule in a taught band of muscle and subject pain recognition of tender spot palpation.\(^4\) Some authors, such as Hong et al.\(^9\) continue to promote the notion that the (LTR) described by Simons and Travell\(^10\) is necessary for maximum effectiveness of trigger point dry needling (TrP-DN), but current research by Tough et al\(^4\) indicates that of the original four criteria most commonly used to diagnose TrPs according to Simons and Travell\(^8\), LTR, and predicted pain referral pattern are no longer considered essential for diagnosis. An issue with accurate diagnosis of TrP location is the lack of a clinician's lack of ability to reliably identify a specific TrP.\(^2\)\(^,\)\(^4\)\(^,\)\(^6\)

The exact mechanism(s) as to the physiological response elicited by DN is unclear. Though the literature proports the effectiveness of acupuncture, DN has not been extensively studied, and a distinction needs to be made noting that DN is not synonymous with acupuncture. The mechanisms of needle insertion, though similar in nature, are differentiated in the application and theory behind the two different types of needling interventions. Several studies have been performed to attempt to describe the pathophysiology, biomechanical, and mechanical characteristics of TrPs, as well as, the effects of acupuncture/ DN on TrPs. A summary of these investigations provide the following proposed explanatory mechanisms:

- Afferent signal barrage from localized TrPs sensitize neuronal receptive fields in the dorsal horn, thereby widening the receptive field and activating silent synaptic connections in the same or other muscles causing pain.\(^11\)\(^,\)\(^12\)

- Excessive acetylcholine release affects formation of the taught band causing a palpable nodule in the muscle causing localized hypoxia of the muscle caused by increased energy consumption and decreased energy supply, creating an “energy crisis” within the muscle\(^13\), and the release of energy consuming localized contracture via sarcomere lengthening leading to tissue ischemia. This situation can be positively affected by eliciting the local twitch response.\(^14\)

- Analgesia may be attained via the gate control theory occurring during needle insertion (afferent pain input may be mitigated by another noxious stimulus input); the elevation of opioid peptides (endorphins, enkephalins, serotonin, and acetylcholine) in the CNS; and/ or diffuse noxious inhibitory control where the noxious stimulation regulates the pain originating area).\(^12\)\(^,\)\(^15\)

- DN techniques may have a local and/ or remote therapeutic effect based on mechanical coupling of connective tissue and the needle thereby causing a “downstream” effect on the generation of a mechanical signal caused by needle grasp pulling (or twisting of the needle in-situ to wind collagen fibers around the needle). These downstream effects may include cell secretion, modification of extracellular matrix, enlargement and propagation of the pain signal along connective tissue planes, and afferent input modulation by changes in the connective milieu.\(^16\)\(^-\)\(^19\)

- Multiple regions of deactivation occur in limbic, para-limbic, and subcortical gray structures (to including the nucleus accumbens, amygdala, hippocampus, para-hippocampus, hypothalamus, ventral
tegmental area, anterior cingulate, caudate nucleus, putamen, anterior insula, and the temporal pole) demonstrating modulation (decreasing pain signal intensity) of several cortical and subcortical limbic/paralimbic structures while increasing pain-mitigating signal intensity in the somatosensory cortex.20-24

• Analgesia may occur via stimulation of the hypothalamus and mid-brain structures (endogenous anti-nociceptive modulation system) and the given the hypothalamus’ descending raphe nucleus and deep periaqueductal gray (dPAG) projections, stimulation of this region may be critical for analgesia.24,25

The purpose of this case report is to illustrate the use of DN as a primary treatment intervention in a subject with acute, non-specific cervical pain. Informed consent to participate in the study was obtained by the subject prior to the start of the intervention. Human subjects research review was not required for this case report.

CASE DESCRIPTION

The subject for this case report was an active 64-year-old female who self-referred to physical therapy for evaluation of generalized right-sided cervical regional pain following activities related to moving into a new house the day prior. She participated in lifting and carrying boxes, which led to pain in the right upper trapezius and levator scapular regions. Pain in these regions affected her ability to perform independent exercise activity, which she reported to engage in several times per week. Medical history of cervical spine fusion (C4-7) was noted. Pain was reported with all cervical active range of motion (AROM) and any activity requiring use of the right upper extremity. There were no reported symptoms of neurovascular radiculopathy such as paresthesia, anesthesia, or dysesthesia in either upper extremity. Her general health was good and absent of signs suggestive of non-musculoskeletal origin. She was already taking anti-inflammatory medication for ongoing chronic intermittent neck and low back pain. Her goal was to eliminate her increased neck pain in order to return to work as a real estate agent to finishing moving into her new house.

The outcome measures employed in this case report were the Neck Disability Index (NDI) and the Quadruple Visual Analog Scale (QVAS) (Table 1). Upon initial evaluation per the QVAS, the subject reported her current, average, best, and worst pain levels during the last 24-hour period. The visual analog scale (VAS) and its derivatives, such as the QVAS, have moderate to good reliability (correlation coefficient 0.60-0.77) to detect disability and high reliability for acute pain (correlation coefficient 0.76-0.84).26,27 All QVAS measures are shown in Table 1. The NDI was used to assess functional disability. The NDI is a quick and moderately reliable tool that can be easily completed and has been found to have moderate to high degree reliability (0.69-0.70) and internal consistency regarding the assessment of disability.28 According to Young et al., the minimal detectible change is 13.4 points and the minimal clinically important difference is 8.5 points. Validity is thought to be low per Young et al. but for a standardized, fast, and reliable measure, the NDI was chosen. The results of the NDI are shown in Table 1. Outcomes measures were assessed initially for baseline, then immediately following the initial treatment session, and at the completion of the last session.

EXAMINATION

The subject in this case report was a long time patient of the clinic, as she has been seen over the years for various issues including neck pain. She reported pain with cervical AROM in all planes, though most significantly with bilateral rotation, right lateral flexion, and flexion and abduction of the right upper extremity.

Given the subject’s previous complaints of cervical pain and history of cervical fusion, and previous shoulder pathology including rotator cuff repair, it was necessary to rule out cervical radiculopathy and pain associated with shoulder etiology. Cervical radiculopathy was ruled out via upper quarter neurological screen including dermatomal, myotomal, deep tendon reflex (DTR), and symptom centralization testing. Symptom centralization was assessed via repetitive cervical extension to rule out the likelihood of discogenic pathology. She had no complaints of upper extremity radicular symptoms, but there were reports of pain into the upper trapezius (UT)/levator scapula (LS), and posterior scapular regions (specifically the infraspinatus muscle belly and superomedial border of the scapula). Shoulder pathology was ruled out via comprehensive assessment of the shoulder
including the tests performed for cervical radiculopathy) with added special tests focused on ruling out the following etiologies: rotator cuff injury/pathology (belly squeeze test, manual muscle testing of the cuff musculature, full can resistance test), labrum complex pathology (crank test, O’Brien’s, and clunk test), biceps pathology (Speed’s, Yergason’s, and Dynamic Speed’s), and acromioclavicular joint pathology (AC compression and manual palpation). Due to the subject’s subjective reports, and based upon her previous history and current injury mechanism, differential diagnoses included cervical disc pathology, rotator cuff involvement, and pain of cervicogenic origin (specifically joint-based pathology).

Assessment of posture was performed in a seated position, rather than standing, as she reported a significant amount of pain while standing, and a standing position was not able to be tolerated per her subjective report. This included assessment of cervical positioning and shoulder complex (scapulothoracic) observation. Physical examination revealed cervical positioning at rest maintained in a mild right laterally flexed position with right shoulder depression. There was observed forward bilateral shoulder positioning while sitting in a relaxed position. No other postural abnormalities were noted.

Cervical complex and right upper extremity AROM were both assessed for deficit. An inclinometer and goniometer was used to assess AROM of the cervical spine, but was not necessary for the shoulder, as AROM was normal. According to Hole et al., intra-tester interclass correlation coefficients (ICCs) for single inclinometer assessment is as follows: 0.84 and 0.94 (flexion/ extension), 0.82 and 0.92 (lateral flexion), and 0.81 and 0.89 (rotation). For cervical AROM, the inclinometer was placed directly over the external auditory meatus for flexion, extension, and lateral flexion. For rotation, a goniometer was utilized and used landmarks of the midline of the nose and an imaginary line drawn between the acromion processes. ROM was recorded at baseline, immediately after the first and last treatment sessions and the results are shown in Table 1. Scapulothoracic rhythm was also observed with shoulder elevation in all planes for abnormality. No deficit was observed. Right upper extremity AROM was normal, although the patient reported pain in the upper trapezius region with active elevation of the shoulder. Strength was also assessed in the right upper extremity using manual muscle testing (MMT), and the results are shown in Table 1.

An upper quarter neurological examination was performed to screen for spinal symptom etiology. This included dermatomal, myotomal, and DTR’s. Dermatomal testing assessed light touch sensory palpation to the C4 to T2 dermatomal regions of the upper extremities. Myotomal testing was assessed via manual muscle testing of the same nerve root representations just mentioned. DTR’s were assessed by testing the C5 through C7 nerve roots (Brachial, Radial, and Triceps) with a reflex hammer. There were no neurologic abnormalities noted.

Provocative testing was not utilized for the cervical spine, as the subjective reports of symptoms did not warrant evaluation of symptoms of radiculopathic origin. Given her cervical fusion history with hardware implantation, subjective and objective testing ruled out the need for provocative testing. Given her normal AROM and only mild strength deficit of the right shoulder, it did not appear the pain was of shoulder origin. Nonetheless, special tests including the Hawkins Kennedy (SN-sensitivity = 79%, SP-specificity = 59%).

<table>
<thead>
<tr>
<th>Table 1. Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome Measures</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>NDI</td>
</tr>
<tr>
<td>QVAS Current</td>
</tr>
<tr>
<td>QVAS Average</td>
</tr>
<tr>
<td>QVAS Best</td>
</tr>
<tr>
<td>QVAS Worst</td>
</tr>
</tbody>
</table>

NDI= Neck Disability Index
QVAS= Quadruple Visual Analog Scale

Neer (SN = 79%, SP = 53%), Speed (SN = 32%, SP = 62%), Full Can (SN = 66% pain/ 77% weakness; SP = 64% pain/ 74% weakness), Yergason (SN = 43%, SP = 79%), and Crank Test (SN = 56%, SP = 46%), tests were performed to rule out shoulder pathology, and the results of the special tests did not reveal pathology that originated glenohumeral joint complex.

Palpation revealed tender/taught bands in the upper trapezius, levator, supraspinatus, and infraspinatus musculature on the right side. There were no autonomic responses noted (e.g. temperature change, diaphoresis, etc.) and no sensory issues were identified. Trophic changes were also absent (skin dryness, color changes, dermatomal hair loss, and edema).

EVALUATION/ DIAGNOSIS

Following subjective history and physical examination, TrPs in the upper trapezius and levator scapular were suspected as the underlying pathology. According to the literature, the ability to definitively ascertain the exact location of a TrP is questionable, and examiner experience plays a positive role in determining the presence of a TrP. Identification of a tender nodule in a taught band of muscle along with reproduction of the subject’s subjective report of pain is the most clinically accurate way to recognize the presence of a TrP, especially in the upper trapezius muscle.

Cervical AROM deficit and mild shoulder flexion and abduction strength deficits were noted. Cervical AROM was already limited due to previous multilevel cervical fusion, and pain in the upper trapezius and levator scapula regions were reported to cause decreased ability to raise her right upper extremity for daily use needs. This may or may not have contributed to strength deficit in the right shoulder. Hyperirritable taught bands were palpable in the noted musculature and flat palpation confirming the location to be used for DN was utilized. These tender bands were suggestive of TrP involvement, as described by Simons and Travell. There was tenderness to palpation in the supraspinatus and infraspinatus muscle bellies, and the levator scapula muscle belly and insertion at the scapular superior angle.

DN was performed as outlined in the intervention section. Clinical reasoning determined DN should be the intervention employed due to the palpable taught bands and reported pain reproduction. Given her cervical fusion history, the author chose not to employ spinal manipulation. Also, due to her reports of severe pain upon presentation, it was not believed that stretching and exercise interventions would provide the immediate pain relief the subject was seeking. This decision was also based upon the author’s training through the Dry Needling Institute of the American Academy of Manipulative Therapy and Integrative Dry Needling concept, and three years of clinical experience utilizing DN for acute muscular pathology.

INTERVENTION

Risks and potential complications were advised and written consent was obtained outlining common and serious adverse events associated with DN interventions. Common complications include muscle soreness, bruising, and vasovagal reaction. More serious (but rare) complications include infection, broken needle, and pneumothorax. There were no reported contraindications to the use of DN. Contraindications include, but are not limited to: local infection, recent cancer/history of immune suppression, bleeding disorders, current/chronic use of anti-coagulant medications, pregnancy, compromised sterility of equipment, and lack of practitioner practical knowledge.

The subject was treated for two sessions with 26 days between sessions. She was placed prone on a hi-low table for therapist comfort, ease of access to treatment regions, and to reduce the effects of vasovagal response, which could occur in sitting.

The following muscles were treated: the LS at the insertion on the superior angle of the scapula and in the muscle belly; the UT muscle belly at the area determined by deep palpation as a possible location of the TrP; the infraspinatus muscle belly; and the supraspinatus muscle at the tenoosseus (T-O) junction superior to the scapular spine.

The needles used for the treatment of the patient in this case report were solid monofilament Seirin J-type sterile needles, No. 5 (0.25 diameter) x 30 mm. in length. Needles were used one time and discarded, as the risk of needle injury to the therapist is increased with techniques that utilize “re-sheathing” of the needles to use in other locations on the same sub-
Each needle was held in the therapist's dominant hand for application of and manipulation of the needle through the tissue. Prior to insertion of the needle(s), an application of 70% isopropyl alcohol was performed to the areas and allowed to dry for at least ten seconds in order to reduce the resident microflora of the skin by 80-91%, yet given the fact there are an average of 1,000 microbes per square centimeter on the skin’s visible surface, and 10,000 microbes per square centimeter in the ducts, glands, and follicles below the skin’s surface, effective cleansing of the tissue by topical means to prevent infection is unlikely.35

All DN was performed according to the Dry Needling Institute of the American Academy of Manipulative Therapy’s current educational programming.35 The patient was prone for all DN insertions. DN to the LS (Figure 1) was performed using a 30 mm. needle inserted through the muscle belly and tangential to the plane of the chest wall. The DN technique utilized ten fast-in/out movements in a cone pattern to attempt to target as many sensitive loci as possible within the tender nodule in the taught band of muscle. The needle was then wound clockwise repeatedly to attain needle grasp and was left in-situ for 15 minutes.

A second 30 mm needle (Figure 2) was inserted into the teno-osseous (T-O) junction of the levator at the superior angle of the scapula, and periosteal pecking was used at the T-O junction. This needle was not left in-situ unattended due to the location and proximity of the pleural cavity. The needle was removed after 20 “taps” of periosteal pecking at the T-O junction.

DN of the UT muscle (Figure 3) was performed utilizing a 30 mm needle. A tender nodule was located, using flat palpation, in the middle of the muscle belly. The needle was inserted perpendicularly through the muscle using ten fast-in/out movements in a cone pattern. As with the previous needle, this needle was wound clockwise repeatedly until needle grasp caused a slight discomfort reported by the subject. This needle was then left in-situ for 15 minutes.

DN of the supraspinatus muscle T-O junction (Figure 4) was performed using palpation to locate the tender nodule in the muscle belly. A 30 mm. needle was inserted toward the supraspinous fossa, where periosteal pecking (ten “taps”) was performed just superior to the scapular spine. The needle was then left in-situ for 15 minutes.

Figure 1. Levator Scapula musculoskeletal junction needle insertion

Figure 2. Levator Scapula teno-osseous junction needle insertion
DN of the infraspinatus muscle (Figure 5) was performed using flat palpation to identify the location of the tender nodule in the taught band of muscle located one-third the distance from the scapular spine and center of the inferior angle of the scapula in the muscle belly. A 30 mm. needle was cautiously inserted perpendicularly to a bony backdrop, as there are rare cases of unknown scapular foraminae that need to be considered. Periosteal pecking was performed 10 times and after twisting the needle clockwise, it was left in-situ for 15 minutes.

**OUTCOMES**

The efficacy of the DN intervention was measured by assessment of pain and disability levels per the NDI and QVAS outcome measures, and subjective reports of improvement in the subject's overall ability and quality of life. Immediately following both treatment sessions, the subject was assessed via the NDI and QVAS outcome measures. The results of these outcome measures are shown in Table 1. The NDI improved from 24% at baseline to 0% after both DN sessions. This was maintained for almost one month following the initial treatment session (as follow up was made by phone to determine status periodically) and is is considered to be a meaningful improvement based on the MDC and MDIC of the NDI. The QVAS (current) score improved from 71 cm at baseline to 2 cm at completion. The
QVAS (average) improved from 71 cm to 14 cm. The QVAS (best) improved from 7 cm to 1 cm. The QVAS (worst) improved from 76 cm to 22 cm. Though cervical AROM and shoulder MMT were recorded at baseline and following the two treatment sessions, it was not believed nor intended that these objective findings would significantly improve via DN intervention, rather, that pain and disability were the items being assessed.

Table 2 shows objective results including cervical AROM and right upper extremity strength results. The subject subjectively reported improved function with regard to daily activities such as standing, working on her computer for work needs, and with abilities such as lifting boxes for moving into her new home. Upon completion of the intervention sessions, there were no further subjective reports of functional limitation related to the recent injury, and pain was present intermittently and minimally with all daily and work activities. This was consistent with her pre-injury status, and the remaining pain was controlled with NSAID medication, which she was taking prior to the recent injury.

**DISCUSSION**

The subject had no further reports of cervical region pain during daily activities, including all functional cervical mobility and right upper extremity activities. She was able to work without limitation. Significant improvement in pain and disability was seen immediately following the initial treatment intervention per the QVAS and NDI, and this carried over almost one month to the second and final treatment session. Her busy schedule did not allow for her to get back for further intervention prior to 26 days after the initial treatment session. Cervical AROM did not change significantly, and this likely due to her previous cervical fusion. Shoulder strength did not improve following any treatment session, but this was not an expected benefit being assessed in this case report. These findings support the use of DN as an initial intervention strategy for acute, nonspecific cervical strain injury.

This case report uses only a single-subject, as is typical of a case report. This is an inherent limitation to a case report, offering only results that relate to this single patient that cannot be generalized. Larger randomized control studies looking at DN interventions need to be performed in order to fully assess the effectiveness of DN as a primary intervention for acute cervical strain injuries. Longer assessment periods looking at long-term benefit versus immediate or short-term benefit also need to be assessed, as this case study showed immediate and short-term (one month) improvements in pain and disability. Further research is recommended to determine if DN is clinically beneficial independent of other therapeutic interventions such as general or specific exercises targeting the affected musculature, or other “manual” therapy techniques such as manipulation or non-thrust mobilization.

**CONCLUSIONS**

DN was tolerated well by this subject, demonstrating improvements in pain and function, without adverse effects. Given her reduction in pain and improvements in reported function, the use of DN for acute cervical region strain injuries shows promise. Future research is needed to determine the full effectiveness of DN for strain-related injury of the cervical spine region, as well as, to determine longer-term outcomes.

**Table 2. Objective Measurements for Active Range of Motion and Manual Muscle Tests**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial/Baseline</td>
<td>60°</td>
<td>40°</td>
<td>35°</td>
<td>35°</td>
<td>60°</td>
<td>60°</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Treatment #1</td>
<td>65°</td>
<td>45°</td>
<td>42°</td>
<td>37°</td>
<td>60°</td>
<td>60°</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Treatment #2</td>
<td>65°</td>
<td>40°</td>
<td>45°</td>
<td>35°</td>
<td>60°</td>
<td>60°</td>
<td>4/5</td>
<td>4/5</td>
</tr>
</tbody>
</table>
REFERENCES


ABSTRACT

Background and Purpose: The majority of all soccer injuries affect the lower extremities. Regardless of whether the injured limb is an athlete’s preferred kicking or stance leg, a lower extremity injury may affect their ability to impact the ball. Sport-specific biomechanical progressions to augment loading and gradually reintroduce a player to the demands of sport have been developed for upper extremity sports such as baseball, softball, tennis, and golf. Generalized return to soccer progressions have also been published in order to assist clinicians in safely returning athletes to sport; however, there are no specific progressions for the early stages of kicking designed to introduce stance leg loading and kicking leg impact. Thus, the purpose of this clinical commentary was to review the existing literature elucidating the biomechanics of kicking a soccer ball and propose a progressive kicking program to support clinicians in safely returning their soccer athletes to the demands of sport.

Description of Topic: The interval kicking program (IKP) describes clinical guidelines for readiness to begin a kicking program as well as possible readiness to return to sport measures. The program is performed on alternate days integrating therapeutic exercise and cardiovascular fitness. The IKP gradually introduces a player to the loading and impact of kicking. The progression increases kicking distance (using the markings of a soccer field as a guide), volume, and intensity and uses proposed soreness rules, effusion guidelines, and player feedback in order to assist clinicians in determining readiness for advancement through the stages. The IKP also recommends utility of specific tests and measures to determine readiness for return to sport.

Discussion: Gradual reintroduction to sport specific demands is essential for a safe return to soccer. This return to sport progression provides a framework integrating injury specific therapeutic exercise, cardiovascular fitness, and the return to kicking progression, to assist clinicians in initiating an athletes’ return to soccer.

Keywords: Kicking, Lower Extremity Injury, Soccer

Level Of Evidence: Level 5
INTRODUCTION

Approximately 265 million people play soccer, making it the most popular sport in the world. Unfortunately, the demands of the sport place the lower extremities at high risk for injury. Sport-specific biomechanical progressions can augment loading, reducing the risk of re-injury as an athlete attempts to return to sport. Interval programs, integrated as part of a return to sports progression, gradually expose upper extremity athletes to the demands of their sports as they return to baseball, softball, golf, and tennis. Similarly, interval running programs are also common, gradually reintroducing the biomechanical and cardiovascular demands of running. However, to the authors' knowledge there are no published interval kicking programs to prepare soccer players for return to sport after sustaining a lower extremity injury. Therefore, the purpose of this clinical commentary was to examine the existing literature relevant to kicking in soccer and propose an interval kicking program (IKP) that can be used as a framework to return an athlete to kicking a soccer ball following lower extremity injury.

INJURIES IN SOCCER

Injuries occur at a rate of 8.0 per 1000 player hours in European men's professional soccer for an average of two injuries per player per season, which for a team of 25 players, translates to 50 injuries of varying severity per season, resulting in significant medical costs, diminished club performance, and lost playing time. Between 60-87% of soccer injuries involve the lower extremities. The majority of injuries are acute or traumatic, with chronic or reinjures accounting for only a small proportion of all injuries. Approximately 57-80% of injuries occur in matches, up to one quarter of these stemming from foul play. These rates of injury are similar for amateur and youth players. Among youth players injury incidence increases with age, women between the ages of 15-19 having the highest incidence. Goalkeepers at all levels have a lower injury incidence than field players. Studies examining soccer injury incidence indicate that injuries occur more frequently in games than in training sessions, but some professional leagues have unique patterns of injury occurrence across a season. In European men's professional soccer, for instance, injury occurrence increases both in the latter portion of the season and when game frequency increases. Women's professional soccer in Germany shows a similar trend, with a higher overall number of injuries occurring in the second half of the season. In contrast, injury occurrence in US men's professional soccer spikes twice, once early in the season and then again in mid to late season.

Muscle strains account for 31% of all injuries in women's soccer, and approximately 35% in men's soccer. In men's soccer the risk of muscle injury increases with age, history of injury, and during the later portions of a game. Injuries to the thigh region are the most common, with hamstrings strains accounting for 16% of all reported injuries. The adductors are the next most commonly injured muscle group, followed by quadriceps and calf muscles. Furthermore, patterns of injury occurrence vary by muscle group, with adductor strains stemming from overuse rather than trauma. Quadriceps strains are more commonly seen on the kicking leg, often occurring during preseason, in contrast to adductor and calf injuries which occur later in the season. In European men's professional soccer, hamstrings injuries are sustained more commonly late in the season, whereas in US men's professional soccer hamstrings injuries are reported more often early in the season.

Ligament sprains make up a smaller portion of all injuries; 19.1% in women's soccer and 18% in men's soccer. In men's soccer the majority of these sprains occur at the ankle, representing 51% of all sprains and 6.9-7.5% of all injuries. Knee sprains are less common than ankle sprains in both men's and women's soccer, though often more serious. In men's soccer, isolated medial collateral ligament (MCL) sprains are the most common knee ligamentous injury, in contrast to women's soccer where anterior cruciate ligament (ACL) injuries are the most common. ACL injuries are a significant problem in women's soccer, with injuries in professional soccer occurring at a rate of 0.09 per 1000 playing hours and between 0.1-0.31 per 1000 playing hours in amateur and collegiate soccer. The risk of ACL injury for adolescent female players has been reported to be even higher, at 1.0 per 1000 playing hours.
Lower extremity injuries may affect the kinematics of kicking, as the kicking leg requires adequate range of motion (ROM), muscle strength, and neuromuscular control in order to move through the kicking motion, in addition to having the stability to withstand and dissipate the impact force of striking a ball. The health of the stance leg is of equal importance, as its ROM, strength and neuromuscular control are essential to stabilizing the body throughout the kicking motion. Regardless of whether the injury involved the stance or the kicking limb, both limbs should be analyzed for pathokinematic patterns potentially involved in the development of the initial injury.

**OVERVIEW OF KICKING BIOMECHANICS**

The three common kicking techniques in soccer are the instep kick, the curved kick (a variation of the instep kick which generates ball spin and a curved flight pattern of the ball), and the side-foot kick. During an instep kick (Figure 1b) a player strikes the ball with the laces of the shoe, along the first metatarsal. In contrast, during a side-foot kick (Figure 1a) a player uses the medial side of the foot, striking the ball with the medial arch. Brophy et al describe five phases of kicking (Table 1 and Figure 2) that are proportionally the same duration for instep and side-foot kicking; however, instep kicks occur at a higher velocity.26

Other important soccer-specific techniques include dribbling, volleying, and juggling (for additional detail see Appendix 1). Dribbling is the use of numerous small touches of the ball with the foot/feet allowing a player to run with the ball at his or her feet. Players generally use the distal lateral dorsum of the foot to push the ball, though all surfaces of the foot can be used, especially when attempting to evade a defender. Volleying is a technique using the side or instep of the foot in order to strike a lofted or airborne ball. Juggling uses the feet, thighs, chest, head, and occasionally other body parts to

---

**Figure 1.** Example of Side-foot and Instep kick. a.) Side-foot kick: A kick using medial side of the foot, particularly the medial arch, to strike the ball. b.) Instep kick: A kick using the dorsum of the foot, particularly along the first metatarsal, to strike the ball. Both techniques can be used for short or long distance kicking, however the instep kick is more frequently used for long distances and/or higher speeds.
keep the ball in the air. Rarely used in games, juggling is commonly used to practice controlled and accurate touches of the ball. In addition to each of the aforementioned techniques, Goalkeepers use one additional technique which will not be covered in this paper, the drop-kick or punt. The drop-kick is similar to that used in Aussie Rules Football, rugby, or American football, though there are slight variations due to the shape of the ball.

Players often take two to four steps at an angle of 42-45°27,28 leading up to a kick (with the last step being the longest, particularly for long-range kicks29,30) with their bodies inclining posteriorly and laterally towards the side of the support leg by 25° (Figure 2: Preparation).31 This angle of approach coupled with the angle of the support leg facilitates a steeper swing plane for the kicking leg, allowing greater extension of the kicking leg at ball contact, thereby creating higher foot velocities and better ball contact, as well as a more stable support-leg position.32

At backswing the arm of the support leg is abducted and gradually adducts as the body moves through leg cocking and leg acceleration (Figure 2: Backswing). The trunk also rotates in preparation for the kick, returning to neutral as the athlete progresses towards the ball.33 Elevation of the arm has been hypothesized as a technique for providing a counterbalance to stabilize the body or for creating an arc of tension to use potential energy. The arc is created by increased tension from abduction of the arm, rotation of the trunk, and extension of the hip in backswing. Through a stretch shortening cycle potential energy is converted as the leg swings forward and arm adducts.32,33 Skilled players use a greater hip and arm range of motion, allowing them to create greater ball speeds without expending additional energy.33

Pelvic protraction and posterior tilting occurs as the body progresses towards ball contact. During backswing, the pelvis of the kicking leg begins lowered relative to the support leg and rises to a position superior to the support leg at ball contact facilitating greater knee extension of the kicking leg, greater foot speed (Figure 2: Backswing, Leg Cocking, Leg Acceleration),32,34 and avoidance of catching the toes on the ground.35 Brophy et al report that women have significantly more hip adduction on the support leg than men, particularly during backswing, leg cocking, and leg acceleration; however, overall pelvic obliquity remains the same.36

At the beginning of backswing, the support leg knee is flexed at approximately 26° and continues flexing until ball contact in order to absorb the force of landing and provide stability (Figure 2: Backswing, Leg Cocking, Leg Acceleration). Immediately following ball contact the knee begins to extend slowly, allowing for stability, muscle fiber recruitment, and the generation of additional force (Figure 2: Follow Through).37 This eccentric action of the quadriceps during most of the stance phase allows the stance leg more stability and thus generation of greater kicking speed.35

During an instep kick the hip is the primary mover, contributing more to the angular acceleration of the shank than the knee.38 In a side-foot kick, however,
the knee has higher power, likely due to the effort required at the hip to maintain the foot position. A strong relationship exists between foot-swing velocity and resultant ball velocity. The findings of Nunome et al indicating that the foot continues to accelerate through contact are consistent with traditional coaching advice to "kick through the ball."32

Ball impact lasts 10ms and occurs near the center of gravity of the foot. For a ball moving at 16.3 m/s the peak impact force at the foot is 1200N, but peak foot impact force can reach as high as 2900N. Upon impact the foot is passively plantarflexed (unless barefoot, in which case the foot is already in maximal plantar flexion), everted and abducted. Men experience less plantar flexion angular displacement during ball impact than women. Some studies have reported men also achieve higher average ball velocities and ball-to-foot velocity ratios. This may be due to smaller plantar flexion displacement, such a mechanism would be similar to the higher velocities achieved when kicking barefoot as compared to shod. Nevertheless, because there is no normative data on kicking, further research is needed in order to fully understand all mechanics involved in this action.

**Table 2.** Muscle activity as a percent of maximal volitional isometric contraction (% MVIC) as measured by electromyography during each phase of an instep kick based on data from Brophy et al (2007).

<table>
<thead>
<tr>
<th>% MVIC</th>
<th>Preparation</th>
<th>Backswing</th>
<th>Leg Cocking</th>
<th>Leg Acceleration</th>
<th>Follow Through</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iliacus</td>
<td>57</td>
<td>96</td>
<td>149</td>
<td>131</td>
<td>95</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>104</td>
<td>75</td>
<td>57</td>
<td>71</td>
<td>89</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>148</td>
<td>74</td>
<td>73</td>
<td>114</td>
<td>129</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>65</td>
<td>78</td>
<td>99</td>
<td>94</td>
<td>70</td>
</tr>
<tr>
<td>Vastus Medialis</td>
<td>63</td>
<td>39</td>
<td>26</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Vastus Lateralis</td>
<td>30</td>
<td>72</td>
<td>104</td>
<td>94</td>
<td>64</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>60</td>
<td>36</td>
<td>50</td>
<td>87</td>
<td>52</td>
</tr>
<tr>
<td>37</td>
<td>38</td>
<td>93</td>
<td>107</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>128</td>
<td>23</td>
<td>78</td>
<td>100</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>37</td>
<td>60</td>
<td>202</td>
<td>228</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>99</td>
<td>33</td>
<td>42</td>
<td>57</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>14</td>
<td>40</td>
<td>75</td>
<td>70</td>
<td>41</td>
<td>41</td>
</tr>
</tbody>
</table>

Kicking Leg

<table>
<thead>
<tr>
<th>0-10%</th>
<th>11-20%</th>
<th>21-30%</th>
<th>31-40%</th>
<th>41-50%</th>
<th>51-60%</th>
<th>61-70%</th>
<th>71-80%</th>
<th>81-90%</th>
<th>91-100%</th>
<th>&gt;101%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

Support Leg

<table>
<thead>
<tr>
<th>0-10%</th>
<th>11-20%</th>
<th>21-30%</th>
<th>31-40%</th>
<th>41-50%</th>
<th>51-60%</th>
<th>61-70%</th>
<th>71-80%</th>
<th>81-90%</th>
<th>91-100%</th>
<th>&gt;101%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

*Values greater than 100% represents muscle activity that exceeded measured during maximal volitional isometric contraction

Muscle activity varies by muscle group as well as by leg (Tables 2 and 3). A side-foot kick requires greater hamstrings activation (62% of maximal volitional isometric contraction-MVIC) during follow through than an instep kick (50% MVIC), while the instep kick requires greater overall iliacus, vastus medialis, gastrocnemius, and adductor activation (Tables 2 and 3). On the support leg, a side foot kick requires higher gastrocnemius activation (84% MVIC) during leg acceleration than an instep kick (74% MVIC). Overall, men have greater gluteus medius (124% MVIC) and vastus medialis (139% MVIC) muscle activation (women have 55% MVIC and 69% MVIC respectively) on their support limb and greater iliacus activation (123% MVIC) on their kicking limb as compared to women (34% MVIC). Although greater iliacus activation may be protective at the knee it may contribute to a higher risk of...
Hip and groin pathology.\textsuperscript{30} Hip extension during an instep kick not generated from higher gluteus maximus activation, may necessitate increased iliacus activation in order to flex the hip farther and faster.\textsuperscript{26}

Greater foot speeds and ball speeds are achieved kicking with the dominant leg;\textsuperscript{35,50} however, there are no differences between the dominant and non-dominant limbs in support limb vertical, braking, or medial-lateral GRF.\textsuperscript{35} The linear velocity of the kicking leg knee is similar, for both the dominant and non-dominant leg, but the shank angular velocity is greater on the dominant leg, meaning more work is done on the shank of that leg.\textsuperscript{50} In any case, there is no difference in muscle moment or rate of force development.\textsuperscript{30} Clagg et al found that women kicking with their non-dominant leg used greater amounts of braking torque (hip, knee, and ankle extension, external rotation, and abduction); in contrast, greater pulling torque (flexion, internal rotation, and adduction) was exerted when kicking with their dominant leg.\textsuperscript{51} While there seems to be little kinematic differences between the dominant and non-dominant legs when kicking a stationary ball as compared to a rolling ball, further research is needed to assess kinetic differences.\textsuperscript{32}

### PROPOSED CLINICAL MEASURES

Although some objective measurements related to kicking exist, many are not relevant to an IKP. Thus, the authors have separated clinical measures into two categories: readiness for a return to kicking program and readiness for return to sport.

#### Readiness for a return to kicking program:

Because the IKP is designed to be performed in conjunction with rehabilitation and cardiovascular training it should only be initiated when an athlete has been cleared to begin running, cutting, pivoting, and sport-specific rehabilitation. Athletes should have no pain, full range of motion, and no effusion as measured by reliable techniques such as the Modified Stroke Test\textsuperscript{53} for the knee or the Figure 8 circumferential measurement method for the ankle.\textsuperscript{54} There are currently no valid/reliable tests for measurement of effusion in the hip. Muscle strength, if measured by manual muscle testing should be equal bilaterally. Due to the decreased sensitivity of manual muscle testing as an accurate determinant of strength, the authors recommend quantifying muscle strength using hand-held or electromechanical dynamometers.\textsuperscript{35,56}

Eighty percent strength performance of the involved limb (compared to the
The performance of the uninvolved limb is recommended as a goal when considering readiness for running, a gradual initiation of light plyometric (e.g., hopping), agility, and return to sport activities.\textsuperscript{57,58} Because running is integral to the lead steps of a kick and the GRFs of kicking are slightly larger than those of running,\textsuperscript{35} it is critical that an athlete be able to run with even step lengths and without pain prior to kicking. Step length and impact forces should be assessed for symmetry either clinically, by visually examining step symmetry and ball speed, or if available in a laboratory.

**Readiness for return to sport:** The decision to allow an athlete to return to full team training sessions, contact, and eventually game-play is multifactorial, and, all too often made with few or no objective measures. Objective measures, particularly those with normative values, are essential for making an informed decision concerning an athlete's readiness. While many objective criteria for return to sport have been discussed in the literature there is little agreement on standardization, thus many institutions and practitioners use their own criteria or some combination of criteria. The authors recommend that before returning to full team training with contact an athlete should meet objective criteria that include both performance-based and patient reported outcome measures. An example of such criteria used after ACL injury or surgery is greater than or equal to 90\% (performance of the involved limb compared to the performance of the uninvolved limb) on the single, triple, and cross-over hop for distance and the 6-meter timed hop test; greater than or equal to 90\% isokinetic quadriceps strength; and a score of greater than or equal to 90\% on the Global Ratings Scale, and Knee Outcomes Survey-Activities of Daily Living Scale (KOS-ADLS).\textsuperscript{56,59}

Patient reported outcome measures are important objective tools in order to understand a players' perceived function. Some measures helpful in assessing function include: the Global Ratings of Change Scales,\textsuperscript{60} Knee Injury and Osteoarthritis Outcomes Scale (KOOS) (particularly the sports subscale),\textsuperscript{61,62} the International Knee Documentation Committee 2000 Subjective Kneef orm (IKDC2000),\textsuperscript{63} and the Foot and Ankle Ability Measure.\textsuperscript{64,65} Further, scales that assess kinesiophobia, such as the Modified Tampa Scale of Kinesiophobia-11 (TSK-11),\textsuperscript{66} or confidence and risk appraisal, such as the Anterior Cruciate Ligament-Return to Sport after Injury Scale (ACL-RSI),\textsuperscript{67} may also be valuable in assessing an athlete's readiness and likelihood to return to sport.\textsuperscript{68} By comparing a player's current scores to baseline scores and normative data, these self-report measures can allow the rehabilitation team to judge a player's progress as well as readiness for sport.

Numerous assessments of passing, shooting and kicking are available to assess an athlete's ability to perform soccer-specific tasks. Yet because of the speed of play, the pressure from opponents, and the endurance soccer requires it is difficult to create an objective measure that accurately captures the behavior, accuracy, or performance of a player in competition. Furthermore, many soccer tests require prohibitive amounts of equipment, space, and player/tester training. Two of the most researched tests are the Loughborough Soccer Passing Test and Loughborough Soccer Shooting Test. These were the first, and currently only, tests validated for adolescents and women.\textsuperscript{69,70} The Loughborough Soccer Passing Test is used to assess a player's performance when fatigued, as well as a player's perception and cognitive decision making processes.\textsuperscript{71} No normative data exists on either test and no validated “passing” cut-off score has been established.

Similar to its use in assessing the performance of a baseball pitcher, a radar gun can determine the velocity of a kicked ball, providing information on a player's ability to contact the ball and whether or not pain occurred. This measure requires baseline data for comparison, and is not generalizable to either practice or game play. Due to the limited use of juggling in an actual game, counting the number of times a player can juggle, has poor construct validity;\textsuperscript{72} similarly counting the times a player can volley a ball against a wall without its hitting the ground can be used to assess passing accuracy and control, but lacks ecological validity.\textsuperscript{72} Testing a player's ability to dribble in a figure eight pattern is a valid and reliable indicator of technique.\textsuperscript{72} In the case of return to kicking, such a test could be used to assess speed, agility and readiness for higher level dribbling activities. Other soccer-specific tests include shooting at a plywood target covered in carbon paper. Though
a reliable measure of accuracy, this test is limited because it requires extensive equipment. Russell et al developed a reliable and valid measure of ball speed and precision involving dribbling, passing, and shooting. The test has more reliability than the Loughborough Soccer Shooting Test, but is complex in administration requiring both player and tester training.

Finally, a qualitative assessment of a player’s actual performance during kicking is crucial both during the IKP and prior to return to sport. Knowledge of a player’s prior abilities and playing style is useful, but general knowledge of what a soccer kick should look like is sufficient to observe for antalgic gait or abnormal movement patterns. In a highly competitive atmosphere this qualitative assessment should be performed by unbiased individuals whose primary concern is the player’s health rather than a timeline for their expected return to playing.

**THE INTERVAL KICKING PROGRAM**

The IKP is designed to be performed in conjunction with rehabilitation exercises and cardiovascular training. Della Villa et al and Bizini et al provide examples of broad return to soccer progressions within which the IKP could be integrated. Systematic progression through the IKP (Table 4) should be individualized and based on a player’s response, feedback and injury. In particular, soreness of the surrounding musculature, is to be expected after initiating a kicking program and the proposed soreness rules should be observed in order to determine readiness for progression (Table 5). Similarly, effusion guidelines such as those in White et al should also guide progression. Clinicians may also adapt the IKP based on a player’s injury. For example, a clinician may decrease the number or the intensity of side-foot kicks performed by a player recovering from a MCL injury or adductor strain where as a player with deltoid ligament injury or iliopsoas/rectus femoris strain may require an even more gradual introduction to in-step kicking.

Similar to upper extremity interval sports programs the IKP is designed to be performed on alternate days. The IKP, injury specific strengthening, plyometrics, and neuromuscular control drills should be performed on one day and cardiovascular training and core strengthening performed on the off days. This alternating structure is designed to allow the lower extremities to recover from the reintroduction of kicking, therapeutic exercises, and any plyometric or neuromuscular drills completed. The authors recommend that the IKP be performed prior to other exercises so that it is performed prior to the lower extremities becoming fatigued and to ensure proper form. Swimming, pool running, cycling, or AlterG treadmill running can be used for cardiovascular conditioning to decrease the repetitive impact of running.

A soccer ball should be integrated into exercises at the initial stages of rehabilitation. Once an athlete can demonstrate proper biomechanical movement in basic and simulating exercises, adding a ball increases degree of difficulty. Activities such as single-leg balance while gently pushing a ball anteriorly-posteriorly or medially-laterally with the contralateral foot, are low risk/low force exercises that help progress a player’s proprioception while maintaining touch/feel for the ball. Incorporating heading, or in the case of goalkeepers catching/throwing, can also make rehabilitation exercises sport specific and enjoyable. Further, soccer related exercises may improve an athlete’s mood, confidence, and motivation; all factors linked to a higher likelihood of an athlete returning to sport.

When a player is deemed ready to begin the IKP it is crucial that all kicking techniques are performed with proper biomechanics. Coaches may aid the rehabilitation team in observing a player’s ability with respect to length of passes, lofting balls, and shooting in order to preclude abnormal compensation patterns from being learned, adopted, or reinstituted. A player should perform the IKP in soccer-specific cleats or shoes, as shoes designed for running often have a larger, more elevated sole that may impede stability in landing on the support foot thereby placing the ankle and knee at risk for injury. A soccer ball is required to perform the IKP, but multiple balls are recommended as this allows for more continuous kicking as opposed to time spent retrieving balls. The IKP is based on soccer field distances (Appendix 2), thus performing on a lined a soccer field will reduce set up time. A goal is also useful for the later stages when a player resumes shooting.
### Table 4. The Interval Kicking Program

#### Basic Kicking and Passing

**Step 1:**
- Warm-up dribbling or juggling (5 min)
- Two touch passing, 5.5 meters (5 min)
- Rest (5 min)
- Warm-up dribbling or juggling, performing opposite activity from start (5 min)
- One touch passing, 5.5 meters (5 min)

**Step 2:**
- Warm-up dribbling or juggling (5 min)
- Two touch passing, maximum 16.5m (5 min)
- Rest (5 min)
- Warm-up dribbling or juggling, performing opposite activity from start (5 min)
- One touch passing, maximum 16.5 meters (5 min)

**Step 3:**
- Warm-up dribbling or juggling (5 min)
- Two touch passing, maximum 16.5 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- One touch passing, maximum 16.5 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- One or two touch passing with a maximum 16.5 meters (5 min)

#### Passing and Basic Shooting

**Step 4:**
- Warm-up dribbling or juggling (5 min)
- Two touch passing, maximum 36 meters (5 min)
- Rest (5 min)
- Warm-up dribbling or juggling, performing opposite activity from start (5 min)
- One touch passing, maximum 36 meters (5 min)

**Step 5:**
- Warm-up dribbling or juggling (5 min)
- Two touch passing, maximum 36 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- One touch passing, maximum 36 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- One or Two touch passing with a maximum 36 meters (5 min)

**Step 6:**
- Warm-up dribbling or juggling (5 min)
- One or two touch passing, maximum 36 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- Shooting (10 shots) and chipped/ lofted balls, maximum 11 meters (2-3 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- One or two touch passing, maximum 36 meters (5 min)

#### Advanced Shooting

**Step 7:**
- Warm-up dribbling or juggling (5 min)
- One or two touch passing, maximum 36 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- Shooting (10 shots) and chipped/ lofted balls, maximum 11 meters (2-3 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- Shooting (10 shots) and chipped/ lofted balls, maximum 11 meters (2-3 min)

**Step 8:**
- Warm-up dribbling or juggling (5 min)
- One or two touch passing, maximum 36 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- Shooting (10 shots) and chipped/ lofted balls, maximum 16.5 meters (2-3 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- One or Two touch passing with a maximum 36 meters (5 min)

**Step 9:**
- Warm-up dribbling or juggling (5 min)
- One or two touch passing, maximum 36 meters (5 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- Shooting (10 shots) and chipped/ lofted balls, maximum 16.5 meters (2-3 min)
- Rest (5-10 min)
- Warm-up dribbling or juggling (5 min)
- Shooting (10 shots) and chipped/ lofted balls, maximum 16.5 meters (2-3 min)
Table 4. The Interval Kicking Program (continued)

<table>
<thead>
<tr>
<th>Step 10*:</th>
<th>Step 11:</th>
<th>Step 12:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Warm-up dribbling or juggling (5 min)</td>
<td>- Warm-up dribbling or juggling (5 min)</td>
<td>- Warm-up dribbling or juggling (5 min)</td>
</tr>
<tr>
<td>- One or two touch passing, maximum 36 meters (5 min)</td>
<td>- One or two touch passing, maximum 36 meters (5 min)</td>
<td>- One or two touch passing, maximum 36 meters (5 min)</td>
</tr>
<tr>
<td>- Rest (5-10 min)</td>
<td>- Rest (5-10 min)</td>
<td>- Rest (5-10 min)</td>
</tr>
<tr>
<td>- Warm-up dribbling or juggling (5 min)</td>
<td>- Warm-up dribbling or juggling (5 min)</td>
<td>- Warm-up dribbling or juggling (5 min)</td>
</tr>
<tr>
<td>- Shooting (10 shots) and chipped/lofted balls, maximum 36 meters (2-3 min)</td>
<td>- Shooting (10 shots) and chipped/lofted balls, maximum 36 meters (2-3 min)</td>
<td>- Lofted driven ball maximum 45 meters (25 times)</td>
</tr>
<tr>
<td>- Rest (5-10min)</td>
<td>- Rest (5-10min)</td>
<td>- Rest (5-10min)</td>
</tr>
<tr>
<td>- Warm-up dribbling or juggling (5 min)</td>
<td>- Warm-up dribbling or juggling (5 min)</td>
<td>- Warm-up dribbling or juggling (5 min)</td>
</tr>
<tr>
<td>- Shooting (10 shots) and chipped/lofted balls max 16.5m (2-3min) or One or two touch passing, maximum 36 meters (5 min)</td>
<td>- Shooting (10 shots) and chipped/lofted balls, maximum 36 meters (2-3 min)</td>
<td>- Shooting (10 shots) and chipped/lofted balls, maximum 36 meters (2-3 min) or One or two touch passing, maximum 36 meters (5 min)</td>
</tr>
</tbody>
</table>

Initiating Return to Sport

<table>
<thead>
<tr>
<th>Step 13:</th>
<th>Step 14**:</th>
<th>Step 15***:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- At this point goalkeepers should begin work on punting and drop kicking</td>
<td>- When cleared by medical team player may begin full practices with their team, initially non-contact and progressing to contact.</td>
<td>- Reintroduce game-play first through scrimmages in practice then with gradually increasing periods of game time.</td>
</tr>
<tr>
<td>- Field players may begin to perform &gt;20 min technical portions of practices with their teams as well as shooting and other drills.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The distances listed in each of these steps are maximum distances. Clinicians and players should not spend the entire time passing or shooting at this maximum distance, but rather vary the passing/shooting distances throughout the allotted time.

*Alternatively, once a player reaches step 10 (if cleared by the medical team) a percentage of time spent in warm-up dribbling/juggling and one- or two- touch passing drills (maximum 20 minutes) may be spent working on technical drills with their team, followed by performing the shooting or lofted driven ball practice defined by the progression (with appropriate rest between). This alternative should only be used if the medical team is confident that both player and coach are cognizant of all precautions such as only performing small sided technical drills involving passing and dribbling and avoiding player contact.

†Unlike steps 1-13, steps 14 and 15 require more than one day in between. It is at the rehabilitation team’s discretion to progress a player through these stages.

‡ A gradual increase in game time will allow a player to adjust to the intensity and speed of play, while reducing the amount of time they are exposed to the higher risk game environment.

Table 5. Proposed Soreness Rules for Progression through the Interval Kicking Program, adapted from Axe et al (2001).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>If no soreness:</td>
<td>Advance to next stage</td>
</tr>
<tr>
<td>If sore during warm-up but soreness is gone during dribbling and juggling warm-up:</td>
<td>Repeat previous stage.</td>
</tr>
<tr>
<td>If sore during warm-up and soreness continues through dribbling and juggling warm-up:</td>
<td>Stop; take 2 days off, and upon return to IKP, drop down one stage</td>
</tr>
<tr>
<td>If sore more than 1 hour after kicking, or the next day:</td>
<td>Take 1 day off; repeat most recent stage.</td>
</tr>
</tbody>
</table>
Proper warm-up of the muscles and cardiovascular system is necessary; the authors recommend a dynamic warm-up that integrates stretching, low-level strengthening, and movement. The FIFA 11+ is a soccer-specific warm-up developed as an injury prevention tool. The FIFA11+ is designed to warm up all of the major muscle groups in the lower extremity, and can serve also as a teaching tool to reinforce proper alignment and mechanics. Proper cool-down is also important following performance of the kicking program. This may include stretching, light jogging, and cryotherapy.

Position specific modifications: Unlike rehabilitation in sports such as baseball and softball, little position-specific rehabilitation is needed in soccer. Goalkeepers must be confident and skillful with a ball at their feet, thus in these initial stages of returning to soccer the IKP is as important for goalkeepers as it is for field players. The rehabilitation team may modify later stages of the kicking program for goalkeepers, omitting shooting in favor of similar distance goal kicks (long/lofted instep kicks) or punts. Goalies may also add jumping, catching, diving for and retrieving balls from the air as part of their dribbling or juggling warm-ups. One example of an alternative for goalkeepers is side shuffling along a line 11m long. Each time the goalkeeper reaches the end of the line they receive either a ball on the ground, which they must pass back with their feet, or a ball in the air, which they must catch and throw back. Adding plyometric and diving activities, however, is at the discretion of the rehabilitation team.

The cardiovascular and intensity demands of soccer differ by position. During games midfielders, often wide midfielders, cover the most distance of any field player and cover the most distance at high speeds. In contrast, central defenders cover the least distance and least distance at high intensities. Attackers and central defenders may also have more recovery time between their bouts of high intensity. Consequently the rehabilitation team should modify cardiovascular training to prepare a player for return to sport taking into consideration position, fitness prior to injury, and age.

CONCLUSION
Regardless of whether an injury affects an athlete’s dominant kicking or stance leg, any lower extremity injury may influence the ability to kick. The IKP presents a novel return to kicking framework specific to the sport of soccer. Similar to return to throwing progressions developed for athletes in upper extremity sports, this return to kicking progression guides clinicians from readiness to begin kicking through an athlete’s return to sport. The IKP format integrates a return to kicking into therapeutic exercise and cardiovascular fitness in order to address the broader needs of an athlete. While the IKP presents a starting point for athletes to begin their return to soccer, future research is needed to determine the optimal rehabilitation techniques and additional outcome measures and criteria that will ensure a safe return to sport.

REFERENCES
9. Ekstrand J, Hägglund M, Kristenson K, Magnusson H, Waldén M. Fewer ligament injuries but no preventive effect on muscle injuries and severe


