ORIGINAL RESEARCH

MEDIAL FOOT LOADING ON ANKLE AND KNEE BIOMECHANICS

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ABSTRACT

Background. The incidence of anterior cruciate ligament (ACL) injuries among females continues at disproportionate rates compared to males, with research indicating inconclusive multifactorial causality. Data from previous retrospective studies suggest an effect of abnormal foot and ankle biomechanics on pathology at the knee, including the ACL.

Objective. To determine if a relationship exists between plantar foot loading patterns during normal gait and high risk biomechanics purported to increase risk of ACL injury.

Methods. Dynamic barefoot plantar pressure distribution was measured on 33 female collegiate soccer players. Groups were divided according to their predominant gait loading pattern (medial or lateral). Three dimensional (3-D) motion analysis was conducted during drop vertical jumps to assess vertical ground reaction force and discrete angle and joint moment variables of the lower extremities.

Results. No significant differences occured in sagittal or coronal plane knee joint kinematics and kinetics between the medial and lateral loading groups.

Discussion. Dynamic foot and ankle biomechanics during gait do not appear to be related to lower extremity kinematics or kinetics during landing in collegiate female soccer players.

Conclusion. The exact cause of the abnormal differences in female landing biomechanics has not been irrefutably defined. This study suggests no effect of foot and ankle biomechanics exists on the landing mechanics of female soccer players.

Key words. anterior cruciate ligament, foot pressures, valgus, pronation

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INTRODUCTION

The incidence of anterior cruciate ligament (ACL) injuries among females is disproportionately greater in females compared to male athletes. Escalating numbers of ACL injuries in the last three decades has led to many investigations to determine the underlying factors for this important health disparity. The current evidence indicates that multiple factors exist regarding the causality of this disproportionate rate of ACL injuries.[1,2] Though prior studies have isolated solitary significant factors related to the increased rates in females, attempts continued to more clearly define a comprehensive understanding of the pathogenesis for these injuries, as well as to facilitate the development of preventative strategies to decrease the incidence of these injuries.[1,3-12] Most ACL injuries in females are non-contact in nature and occur during deceleration, cutting, pivoting, and jumping; either independently or in combination.[9,13] Prior work indicates that females sustaining ACL injuries demonstrate the previously mentioned actions with the lower extremity in a position of dynamic knee valgus at ground contact.[9,14] In this position of dynamic knee valgus, the lower extremity is described to demonstrate excessive coronal and transverse plane motion, with hip adduction and internal rotation, knee abduction with subsequent tibial rotation, and ankle eversion.[4,5,9,10,14-18] In addition, many studies have implicated deficient biomechanics and decreased neuromuscular control during activities which simulate the mode in which females sustain non-contact ACL injuries.[1,4,7-10,12,14,16,17,19-26]

Although the evidence is controversial, improper foot and ankle kinematics may influence more proximal joints and may also be a factor which underlies increased susceptibility to ACL tears.[27,28] The lower extremity functions in a closed kinetic chain during certain phases of activities such as ambulation, running, jumping, and cutting.[27,28] It is commonly accepted in biomechanics that structure dictates function; however, a lack of consistent support exists for structural variability as a measure of function during dynamic activities.[29] Pathological biomechanics of the foot have been implicated in the etiology of ankle, knee, hip, and even low back, pathology.[27,30] Some authors have suggested excessive pronation is an underlying factor contributing to the dynamic knee valgus position associated with the increased rates of ACL injuries.[30-32] Retrospective analyses by Becket et al,[30] Woodford-Rogers et al,[32] and Loudon et al[31] have demonstrated a significant correlation between excessive pronation and ACL injuries. The authors suggested excessive pronation with subsequent internal tibial rotation during the stance phase of gait limits the ability of the ACL to restrain the natural increase in anterior tibial translation and internal rotation torque increasing stress to the ACL, ligamentous laxity, and susceptibility to injury.

Positive correlations between abnormal foot and ankle biomechanics with tibiofemoral joint pathomechanics have also been previously reported. Trimble et al[17] demonstrated a significant correlation between sex and navicular drop as indicators of excessive anterior tibial translation measured by a KT 1000 athrometer©. Similarly, Coplan and colleagues[33] demonstrated that females with excessive pronation exhibited excessive passive transverse plane rotation at the tibiofemoral joint. Female athletes are also reported to exhibit greater hip adduction, knee valgus, and foot pronation during landing. Results from one study suggested knee valgus and foot pronation to be the most significant factors affecting the increased motion in the coronal plane.[24]

Physical therapists and other health professionals often visually assess barefoot gait and implement their interventions, such as orthotic prescription, based upon their observations of an abnormal foot loading pattern. Technology continually evolves and enhances the ability to more accurately and objectively assess biomechanics. These associations of the effects of abnormal foot and ankle kinematics with pathomechanics and injuries in more proximal kinetic chain structures warrants further investigation by an accurate and objective measurement system to more precisely define the relationships between the biomechanics of the foot/ankle complex and the tibiofemoral joint. Therefore, the primary purpose of this study was to determine if subjects with more medial foot loading patterns compared to lateral foot loading patterns, as measured by the emed-x system (Novel GMBH, Munich), would correlate with differences in ankle and knee coronal plane motion and torque measures during a drop vertical jump task. The hypothesis to be tested was if greater ankle eversion and knee abduction motion and torque, measured during a drop vertical jump, would occur in female collegiate soccer players which have more medial as compared to lateral foot loading patterns.

METHODS

Subjects

A power analysis was performed a priori with sagittal plane kinematic measures in the sample population.[1]

Based on the group differences measured during the drop vertical jump performance, it was determined that in order to achieve 80% power (alpha level 0.05) a minimum of 31 measures were required in each group. Based on these analyses, 33 subjects (66 legs) were recruited to participate in the current investigation. Thirty-three female collegiate soccer players (Division I and III) volunteered to participate in the study. The mean age of the subjects was 19.8 + 1.2 years, height was 165.1 + 5.9 cm, and mass was 62.6 + 8.3 kg. All participants read and signed informed consent approved by the Institutional Review Board of the Cincinnati Children's Hospital Medical Center.

Barefoot Plantar Pressure Measures

Dynamic barefoot plantar pressure distribution was obtained on each subject. The subjects were positioned on a 6 m walkway. An emed-x system was mounted in the middle of the walkway and level to the surface. The platform consisted of a 48x32cm matrix of capacitive sensors (4 sensors/cm2) collected at 100Hz. Subjects were instructed to walk normally at a self-selected speed[34] until five successful trials on each side were collected. A trial was accepted if the entire foot was within the sensor area. Morag and Cavanaugh[35] and Cavanaugh et al[36] reported on the reliability of foot pressures to represent differences in foot structure during dynamic activity. Most importantly, they reported the arch structure reliably dictated the function of the foot and pressures under the midfoot during gait.[35,36] Hughes et al[37] demonstrated excellent reliability of the emed-f system, which has the same technology as the emed-x system, as high as .91, when the mean result of three trials was utilized. The authors recommended utilizing three trials or more to obtain reliable data as reliability increased reciprocally with the number of trials analyzed.[37] Gurney et al[38] demonstrated the between day reliability of the emed technology to be of high reliability with an average ICC value of 0.85.

Motion Analysis

Each subject was instrumented with 37 retroreflective markers placed on the sacrum, left posterior superior iliac spine (PSIS), sternum, and bilaterally on the shoulder, elbow, wrist, anterior superior iliac spine (ASIS), greater trochanter, mid thigh, medial and lateral knee, tibial tubercle, mid shank, distal shank, medial and lateral ankle, heel, dorsal surface of the midfoot, lateral foot (5th metatarsal), and toe (between 2nd and 3rd metatarsals). A static trial was first collected in which the subject was instructed to stand still and to allow for alignment with the laboratory coordinate system. This static measurement was used as each subject's neutral (zero) alignment; subsequent kinematic measures were referenced in relation to this position. Each subject performed a drop vertical jump (DVJ) which consisted of starting on top of a 31 cm box with their feet positioned 35 cm apart (distance measured between toe markers).[10] They were instructed to drop directly down off the box and immediately perform a maximum vertical jump. Three successful trials were recorded for each subject.

Trials were collected with EVaRT (Version 4, Motion Analysis Corporation, Santa Rosa, CA) using a motion analysis system consisting of eight digital cameras (Eagle cameras, Motion Analysis Corporation, Santa Rosa, CA) positioned in the laboratory and sampled at 240 Hz. Prior to data collection the motion analysis system was calibrated as previously described Cowley et al.[39] Two force platforms were sampled at 1200 Hz and time synchronized with the motion analysis system. The force platforms were embedded into the floor and positioned 8 cm apart so that each foot would contact a different platform during stance phase of the drop vertical jump.

Data Analysis

Motion analysis data were imported into Visual3D (Version 3.65, C-Motion, Inc. Germantown, MD) and MATLAB (Version 7.0, The Mathworks, Natick, MA) for data reduction and analysis. Three-dimensional Cartesian marker trajectories from each trial were filtered through a low-pass fourth order Butterworth filter at a cutoff frequency of 12 Hz. Three dimensional (3D) joint angles were calculated for both the left and right side according to the cardan/euler rotation sequence.[40] To minimize possible peak impact errors in joint moment calculations, the force plate data were filtered through a low-pass fourth order Butterworth filter at a cutoff frequency of 12 Hz.41 These data were used with the kinematic data to calculate joint moments using inverse dynamics.[42] Net external moments are described in this paper and represent the external load on the joint.

The vertical ground reaction force (VGRF) data were utilized to calculate initial contact with the ground immediately after the subject dropped from the box. Initial contact was defined when VGRF first exceeded 10 N. Toe off was subsequently calculated after initial contact when the VGRF fell below 10 N. Kinematic and kinetic data were normalized to 100% of stance phase (between initial contact and toe off). The following discrete angle and joint moment variables were calculated during stance phase for each lower extremity: maximum ankle dorsiflexion, maximum knee flexion, maximum and minimum ankle inversion/eversion, and knee abduction/adduction.

Pressure distribution trials were analyzed within a commercial software package (Projects, Novel GMBH, Munich). From each walking trial the midfoot and forefoot were combined and subdivided into separate medial and lateral regions based on an algorithm dividing the entire foot previously described by Cavanagh et al.[43] The force time integral within the two regions were calculated and then divided by the total foot force time integral in order to determine the relative load in each region.[44] The region (medial or lateral) which underwent greater loading during the walking trials was used to stratify the foot as a medial (MLP) or lateral (LLP) load pattern. Each leg from the box drop trials was analyzed separately based on the load pattern from the initial plantar pressure analysis.

Table 1
Coronal Plane Knee and Ankle Kinematics

	Descriptive Statistics			**Univariate Statistical Significance**
	Lateral Load Pattern	Medial Load Pattern	Total	Task
Ankle Eversion/Inversion (°)				
Max Eversion	- 7.05 (4.17)	- 6.28 (5.82)	- 6.67 (5.01)	$F_{1,65}$ = .379, p= 0.540
Max Inversion	8.64 (4.35)	9.43 (4.33)	9.03 (4.32)	$F_{1,65}$ = .539, p = 0.465
Knee Abduction/Adduction (°)				
Max Abduction	- 8.81 (7.43)	- 6.31 (5.41)	- 7.60 (6.60)	$F_{1,65}$ = 2.415, p= 0.125
Max Adduction	- 0.131 (6.61)	1.27 (4.58)	0.546 (5.72)	$F_{1,65}$ = .985, p= 0.325

Statistical Analysis

Statistical means and standard deviations were calculated for each subject. A one-way analysis of variance (ANOVA) was utilized to determine the effect of plantar load (MDL and LDL) of the foot on each dependent variable. An alpha level of .05 was selected to identify statistical significance. Statistical analyses were conducted in SPSS (Version 15.0, Chicago, IL).

RESULTS

Analysis of the 33 subjects (66 extremities) plantar pressure distributions revealed 34 lateral load patterns and 32 medial load patterns. The relative load for the medial plantar region (MLP = 33.8 ± 4.5%; LLP = 26.8 ± 3.6%) and lateral plantar region (MLP = 26.4 ± 5.5%; LLP = 37.6 ± 5.5%) were significantly different between groups ($p < 0.001$). Ensemble average knee joint angles (abduction/ adduction) during landing are shown in Table 1. No significant differences existed in coronal plane knee joint kinematics during landing between the medial (MLP) and lateral (LLP) load pattern groups. The LLP mean knee abduction angles were 8.8 ± 7.4 o compared to MLP mean abduction angles of 6.3 ± 5.4o (p= 0.125). The LLP mean knee adduction angles were -0.1 ± 6.6 o compared to MLP mean adduction angles were 1.3 ± 4.6 o (p= 0.325).

Table 2

Sagittal Plane Knee and Ankle Kinematics

	Descriptive Statistics			**Univariate Statistical Significance**
	Lateral Load Pattern	Medial Load Pattern	Total	Task
Ankle Dorsiflexion (°)				
Max Dorsiflexion	25.9 (5.59)	25.7 (5.48)	25.8 (5.49)	$F_{1,65}$ = 0.011, p= 0.919
Knee Flexion (°)				
Max Flexion	- 80.1 (10.3)	- 82.1 (10.8)	- 81.1 (10.5)	$F_{1,65}$ = 0.603, p= 0.440

Ensemble average ankle joint angles (eversion/inversion) during landing are also shown in Table 1. There were also no significant differences in coronal plane ankle joint kinematics during landing between the MLP and LLP groups. The LLP mean ankle eversion angles were 7.1 ± 4.2 o as compared to the MLP mean eversion angles of 6.3 ± 5.8 (p= 0.540). The LLP mean ankle inversion angles were 8.6 ± 4.4 o compared to mean MLP inversion angles, which were 9.4 ± 4.3o (p = 0.465).

Ensemble average knee joint angles (flexion) during landing are shown in Table 2. There were no significant differences in sagittal plane knee joint kinematics during landing between the LLP and medial foot load patterns. The LLP mean knee flexion angles were 80.1 ± 10.3 o as compared to MLP mean flexion angles of 82.1 ± 10.8 o (p= 0.440). Ensemble average ankle joint angles (dorsiflexion) during landing are shown in Table 2. No significant differences were found in sagittal plane ankle joint kinematics during landing between the MLP and LLP. The LLP mean ankle dorsiflexion angles were 25.9 ± 5.59 o compared to MLP mean dorsiflexion angles of 25.7 ± 5.48 o (p=0.919).

Ensemble average knee joint moments (abduction/adduction) during landing are shown in Table 3.

There were no significant differences in coronal plane knee joint kinetics during landing between the MLP and LLP. The LLP mean knee abduction moments were -0.504 ± 0.288 N.m/kg) as compared to MLP mean abduction moments of -0.388 ± 0.230 N.m/kg (p= 0.077). The LLP mean knee adduction moments were 0.069 ± 0.162 N.m/kg compared to MLP mean adduction moments of 0.100 ± 0.110 N.m/kg (p= 0.362). Ensemble average ankle joint moments (eversion/inversion) during landing are shown in Table 3. There were no significant differences in coronal plane ankle joint kinetics during landing between the MLP and LLP. The LLP mean ankle eversion moments were -0.455 ± 0.202 N.m/kg compared to MLP mean eversion moments of -0.385 ± 0.197 N.m/kg (p=0.161). The LLP mean ankle inversion moments were .077 ± 0.098 N.m/kg as compared MLP mean inversion moments of 0.115 ± 0.120 N.m/kg (p=0.161).

Table 3
Coronal Plane Knee and Ankle Kinetics

	Descriptive Statistics			Univariate Statistical Significance
	Lateral Load Pattern	Medial Load Pattern	Total	Task
Ankle Eversion/Inversion (N'm/kg)				
Max Eversion	- .455 (.202)	- .385 (.197)	- .421 (.201)	$F_{1,65}$ = 2.007, p= 0.161
Max Inversion	.077 (.098)	.115 (.120)	.095 (.110)	$F_{1,65}$ = 2.011, p= 0.161
Knee Abduction/Adduction (N'm/kg)				
Max Abduction	- .504 (0.288)	- .388 (0.230)	- .448 (2.66)	$F_{1,65}$ = 3.225, p= 0.077
Max Adduction	.069 (0.162)	.100 (0.110)	.084 (0.139)	$F_{1,65}$ = 0.844, p= 0.362

Ensemble average knee joint moments (flexion) during landing are shown in Table 4. No significant differences existed in sagittal plane knee joint kinetics during landing between the MLP and LLP. The LLP mean knee flexion moments were -1.92 ± 0.578 N.m/kg as compared to MLP mean flexion moments of -1.70 ± 0.454 N.m/kg (p=0.080). Ensemble average ankle joint moments (dorsiflexion) during landing are shown in Table 4. No significant differences occurred in sagittal plane ankle joint kinetics during landing between the MLP and LLP. The LLP mean ankle dorsiflexion moments were 1.56 ± 0.465 N.m/kg as compared to MLP mean dorsiflexion moments of 1.42 ± 0.349 N.m/kg (p=0.159).

Table 4

Sagittal Plane Knee and Ankle Kinetics

	Descriptive Statistics			Univariate Statistical Significance
	Lateral Load Pattern	Medial Load Pattern	Total	Task
Ankle Dorsiflexion (N'm/kg)				
Max Dorsiflexion	1.56 (0.465)	1.42 (0.349)	1.49 (0.416)	$F_{1,65}$ = 2.033, p= 0.159
Knee Flexion (N'm/kg)				
Max Flexion	-1.92 (0.578)	-1.70 (0.454)	-1.82 (0.530)	$F_{1,65}$ = 3.171, p=0.080

DISCUSSION

The primary purpose of this study was to determine if subjects with primarily medial foot loading patterns compared to lateral foot loading patterns would exhibit differences in ankle and knee coronal plane motion and torque measures. Our original hypothesis was females that demonstrated increased medial foot loading during gait as measured by the emed-x pressure system would also demonstrate greater deviations in ankle and knee angles and moments in the coronal plane during a dynamic landing task. However, no significant differences were found with ankle and knee measures between lateral and medial foot loading patterns identified from foot pressure and motion analysis. Contrary to our original hypothesis, the results from this study suggest additional mechanisms are likely responsible for contributing to dynamic knee valgus apart from foot pressure during gait.

Previous studies have examined the effects of the structure and function of the foot and ankle complex on tibiofemoral biomechanics and ACL injury.[30-32,45] Studies by Becket et al,[30] Loudon et al,[31] and Woodford-Rogers et al[32] reported that subjects with ACL injuries demonstrated a significant association with excessive foot pronation. These retrospective studies presented useful data but the retrospective design of the studies caused speculation and limited their power. These studies lacked the ability to determine if the condition of the foot was causative or resultant of the injury. Similar to the current study, Smith et al[46] found no significant difference in navicular drop height between groups of ACL injured subjects and uninjured subjects. Contrary to the current study and Smith et al,[46] biomechanical studies by Kernozek et al[24] and Ford et al[47] demonstrated that females landed with increased coronal plane ankle kinematics and kinetics during drops jumps as compared to their male counter parts. These authors concluded that the ankle joint may demonstrate this excessive motion to compensate for increased force absorption. Ankle motion may have an influence on the less advantageous landing biomechanics in females and more in depth exploration should be considered.[24,47] In a recent study, McLean et al[48] examined the effects of fatigue on the differences in landing mechanics between males and females. Females demonstrated greater peak stance ankle supination in conjunction with greater dynamic knee valgus measures than their male counterparts. The authors attributed the difference to possible skill level differences or error in obtaining position of the talocrural joint axis. The lack of definitive certainty derived from the studies previously mentioned highlights the necessity for the more detailed analysis conducted during the present study.

Clinical studies, patient evaluations, and orthotic assessment, clinicians assess the function of the medial longitudinal arch utilizing static and dynamic clinical measurements.[49,50] The dynamic function of the medial longitudinal arch is commonly assessed in clinical situations, with visual observation and less frequently, video analysis. This study was the first to utilize both of these highly technological dynamic measurements of foot pressures and motion analysis of lower extremity biomechanics to determine the association of the foot and ankle complex biomechanics with the tibiofemoral joint during dynamic activities. In the present study, foot characteristics were measured with the emed-x system to determine the differences in foot pressures during the dynamic activity of gait and then correlated with biomechanical data obtained during landing. The present findings differed from those of the clinical studies by Woodford-Rogers et al,[32] Beckett et al[30] and Loudon et al.[31]

The exact cause of the abnormal differences in female landing biomechanics has yet to be irrefutably defined and is likely multifactorial. While the necessity for additional research on the etiology and prevention of ACL injuries continues to perpetuate, current evidence supports that identifying and subsequently correcting disadvantageous biomechanics and neuromuscular control will have a significant effect on decreasing the risk for ACL injuries.

CONCLUSION

The results of the present study did not demonstrate any statistical significance regarding the difference in foot loading pressure patterns during gait and dynamic biomechanics during landing in female collegiate soccer players. Data collection with an in-shoe pressure distribution system during drop landings may have proved useful in determining what pressures occurred under the foot during these landings. With this information a correlation may have been established between lower extremity biomechanics and foot pressures during drop jumps. However, clinically, dynamic assessment of an individual's foot mechanics is most often through visual observation of gait and not drop jumps. Future studies may concentrate on utilizing the emed-x pressure system or an in-shoe system during the drop jumps to evaluate the differences in foot loading pressures that occur during landing.

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The contributing authors were not listed with the original publication of the Original Research article "The Effects of Loaded Versus Unloaded Activities on Foot Volumetrics in Older Healthy Adults" in Volume 3, Number 2. We would like to correct the exclusion of these contributors.

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CASE REPORT

ANTERIOR CRUCIATE LIGAMENT TEAR IN AN ATHLETE: DOES INCREASED HEEL LOADING CONTRIBUTE TO ACL RUPTURE?

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ABSTRACT

Rupture to the anterior cruciate ligament is a common athletic injury in American football. The lower extremity biomechanics related to increased ACL injury risk are not completely understood. However, foot landing has been purported to be a significant contributing factor to the ACL injury mechanism. In this case report, information is presented on an athlete previously tested for in-shoe loading patterns on artificial turf and subsequently went on to non-contact ACL rupture on the same surface. This case report describes the specific findings in a study participant who suffered an ACL rupture after testing and suggests that flatfoot tendency in running and cutting maneuvers might lead to an increased risk of ACL injury.

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INTRODUCTION

The mechanisms of anterior cruciate ligament (ACL) injury during competition are the subject of intense and ongoing research. Previous authors have quantified the pattern of limb kinematics as they relate to the actual ACL injury in both non-injured and ACL-injured limbs.[2-4] The pattern of in-shoe foot loading and the potential relationship to ACL injury has been theorized by Ford et al.[1] Interestingly, one of the study subjects from this prospective study sustained an ACL rupture during the subsequent competitive football season. In the current case report, in-shoe foot loading patterns are presented on athletes who sustained a subsequent non-contact ACL rupture. The subject's results of pre-participation examination are compared and contrasted to the other study subjects.

CASE DESCRIPTION

The patient had previously undergone in-shoe foot loading pattern analysis as part of a prior prospective study.[1] Prior to testing, the subjects signed an informed consent form approved by the Cincinnati Children's Hospital Institutional Review Board. Seventeen male subjects participated in the data collection *(Figure 1)*. Each subject was fitted with a football-specific molded cleat (14-stud molded Speed TD, Nike, Beaverton, OR) *(Figure 1C)* and was tested while cutting and running through a pre-set obstacle course demarcated by cones.[1-5] Flexible in-shoe pressure distribution measuring insoles were inserted in the right cleat (Pedar, Novel, Inc. St. Paul, MN) *(Figure 1A-B)*. A telemetric signal was sent from the backpack to a laptop computer to allow wireless data collection. Two digital video cameras collected simultaneously at 60 fields per second to assist in identification of the three, right foot cutting steps during data reduction *(Figure 2)*. The results were then analyzed as reported previously.[1] A regional analysis of the foot was performed utilizing nine separate "masks" consisting of medial and lateral heel, medial and lateral midfoot, medial, central and lateral forefoot, hallux, and the lesser toes *(Figure 1C)* (Groupmask Evaluation, Novel, Inc. St. Paul, MN). Regional analysis of in-shoe forces have been utilized and described in depth by several authors.[5-7] The maximum force for each region was calculated. The specific recordings from the athlete in question were compared to all other subject participants. Figure 3 depicts the distribution of the maximum ground reaction force from the plantar surface of the foot while participating in cutting maneuvers. The case patient demonstrated increased force in the medial and lateral heel, greater than one standard deviation above the mean (Figures 3-4). The load patterns noted in this patient suggest increased heel and flatfoot landing, as the pressure on the posterior aspect of the foot increased. Figure 5 represents the case patient (A) and a representative subject (B) during a cutting trial.

OUTCOME

During a football scrimmage, a 17 year-old Caucasian male football player suffered a non-contact injury to the right knee. The injury occurred while the athlete attempted to "turn the corner" on an outside sweep running play. The athlete noticed minimal discomfort at the

Figure 1. *Subjects were instrumented with a custom backpack (A) to secure the telemetry Pedar system. A pressure distribution insole (B) was inserted into each cleat. A standard football specific cleat (C) was utilized and an analysis of each region was performed.*

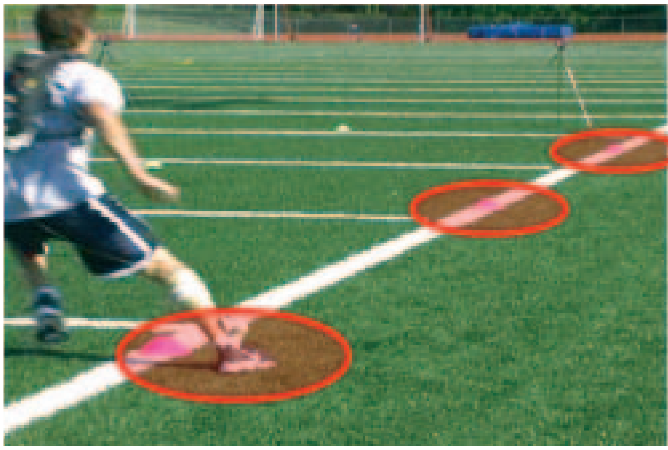

Figure 2. *A slalom course was setup on a synthetic football field and three right cutting steps were analyzed for each of the three timed trials.*

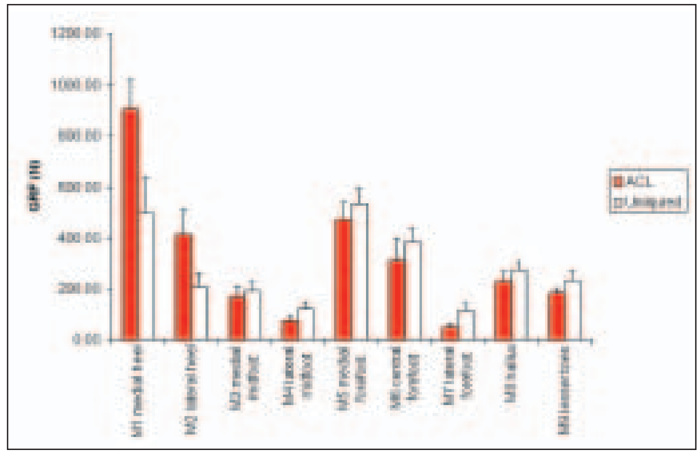

Figure 3. *Maximum ground reaction force (GRF) in Newtons (N) from each foot region. Data presented is the mean (±SD) for the control subjects and the mean (±SD) of the nine steps for the case patient.*

time, but developed increased swelling and pain in the knee, and was referred for further evaluation. On initial examination, he denied popping, clicking, or feeling of giving way of the knee. He did complain of persistent lateral-sided knee pain, but no instability. He ambulated without an assistive device four days post-injury.

Physical examination revealed a right knee with 2+ effusion, limited range of motion from 5-100 degrees, and tenderness over the lateral joint line. Anterior drawer was positive, and Lachman testing was 1+ with a soft endpoint. Magnetic resonance imaging confirmed an ACL rupture, lateral meniscal tear, and bone contusion of the lateral tibial plateau. No varus or valgus instability was present, and external rotation-recurvatum testing was negative. Posterior drawer was negative, as well.

With the intention to return to high-level competitive football, the patient elected to undergo ACL reconstruction. Arthroscopy confirmed the ACL rupture and complex unrepairable posterolateral meniscus tear. Partial lateral meniscectomy was performed, as well as ACL reconstruction with bone-patella tendon-bone autograft from the ipsilateral knee. The patient tolerated the procedure well, and range of motion exercises were instituted early in the post-operative course. At two months his range of motion was 0-135 degrees with no pain. At 6 months post operative he returned to spring track and was pursuing a collegiate football career.

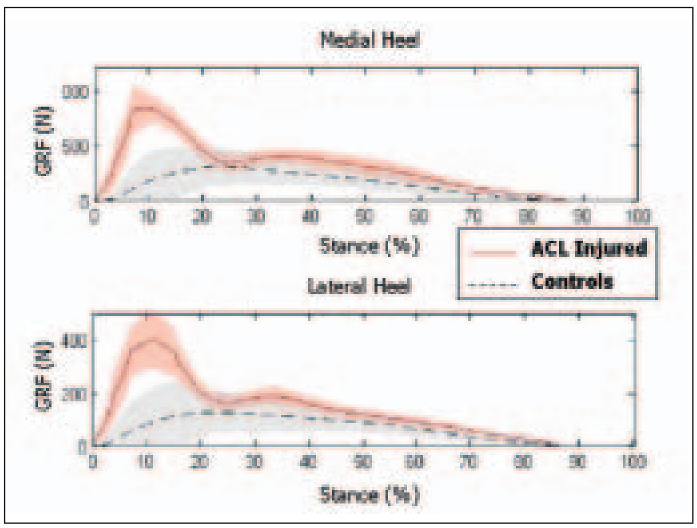

Figure 4. *Ensemble averaged (±SD) ground reaction force time normalized to the ground contact time in the medial heel and lateral heel regions of the case patient and control subjects.*

DISCUSSION

The ACL rupture is a common and intensely studied injury. Many studies have been performed that attempt to elucidate the pattern of limb movement at the time of ACL rupture. If limb kinematics in the ACL-injury prone athlete can be elucidated, perhaps prophylactic measures could be taken to reduce the risk of rupture of the ACL. However, no prospective studies of foot pressure measurements prior to ACL injury have been reported in the literature.

A number of authors have made attempts to analyze limb position at the time of ACL failure. Teitz[8] reviewed video clips of 54 athletes with ACL ruptures in an attempt to more accurately determine limb position in non-contact ACL injury. These authors noted that ACL injury tended to occur when the center of gravity was behind the knee and when ground contact with the entire foot occurred. Two-thirds of the women, and all of the men in this study had a flatfoot position at the time of injury.[8]

A significant amount of foot pressure research has been dedicated to the position of the foot while participating in certain sports. Eils et al[5] noted that soccer players performing cutting maneuvers tended to load the anterior portion of the foot, implying a plantarflexed position. Ford et al[1] noted that different playing surfaces may affect the loading pattern of the cutting athlete.

Other authors have used video analysis of ACL ruptures, with mixed results. Krosshaug and Bahr[9] showed that uncalibrated video from multiple angles could be used to estimate kinematics. Boden et al[4] used video analysis and noted that initial contact of the foot in a flatfoot position might indicate a risk for ACL injury.

The shoe to surface interaction has also been studied to determine its relationship to ACL injury. Scranton et al[10] monitored non-contact ACL injuries in the National Football League over five seasons and examined the relationship of the variables of playing surface, shoe type, and playing conditions to the occurrence of these injuries. More ACL injuries occurred on natural grass than on an artificial surface. Almost half of all injuries (47.5%) occurred during game-day exposures, despite the finding that the practice versus game-day exposure rate was 5:1. Over 95% of ACL injuries occurred on a dry field.[10] Orchard and Powell[11] examined the relationship between knee and ankle sprains, playing surface, and the weather conditions on the day of the game. They reported a reduced risk of significant knee sprains on grass compared with indoor synthetic (plastic resin) turf. They found that cold weather was associated with a lower risk of significant knee sprains and ACL injuries when compared to hot weather in outdoor stadiums. The authors concluded that cold weather was associated with lower ACL injury risk in outdoor grass stadiums related to the reduced shoe-surface traction.[11] Baker et al[12] concluded from a review of the literature that no strong association exists between playing surface or footwear and ACL injury risk. Although the available data on shoe-surface interaction have not lead to a consensus on its relation to ACL injury risk, biomechanical examination of the possible mechanisms of ACL injury presented in the current football player should be studied further.

CONCLUSION

The presented case of a football athlete indicated a flatfoot landing pattern that may be associated with a non-contact ACL injury mechanism. In the study reported by Ford et al[1] only one ACL injury occurred in the tested athletes. This injury occurred in an athlete with heel to flat-foot loading more than one standard deviation above the mean. Future research should investigate the potential evidence that flatfoot tendency in running and cutting maneuvers might lead to an increased risk of ACL injury. Further studies might attempt to identify those athletes with increased flatfoot landing patterns and determine if these foot loading patterns relate to increased ACL incidence during competitive play.

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ORIGINAL RESEARCH

CHANGES IN VERTEBRAL COLUMN HEIGHT (VCH) AT DIFFERENT DISTANCE INTERVALS DURING A 3-MILE WALK

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ABSTRACT

Background. The purpose of this study was to determine the changes in vertebral column height (VCH) of males and females, at every one-half mile, for a total walking distance of 3 miles.

Methods. Twenty males and twenty females between the ages of 21 and 40 years walked 3 miles on a treadmill maintaining a walking speed that the subject rated between 12 and 14 on Borg's rate of perceived exertion scale. Blood pressure, heart rate, and VCH measurements were taken initially and at each half-mile interval throughout the three-mile walk. Vertebral column height (VCH) was measured from the spinous process of C7 to S2 using a standard tape measure.

Results. Significant differences existed in vertebral column height according to sex ($F = 16.18$; $p < .05$) and significant differences in vertebral column height at the different distances ($F = 65.02$: $p < .0001$). Significant changes occurred in the VCH between half-mile intervals only between 0.5 miles and 1.0 mile and between 1.0 mile and 1.5 miles during the walk. As found with a regression analysis, curvilinear relationship exists between the distance walked and VCH; with VCH decreasing throughout the distance of the walk.

Conclusions. Vertebral column height decreased in a curvilinear relationship throughout the distance of walking 3 miles in both males and females.

Key Words: vertebral column height, spinal shrinkage, walking

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INTRODUCTION

One of the most simplistic means of weight loss is walking. According to the American College of Sports Medicine (ACSM),[1] Center for Disease Control and Prevention (CDC),[2] Surgeon General of the United States,[3] and the American Heart Association,[4] the suggested recommendations for exercise are an accumulated 30 minutes of moderate physical activity three-to-five days weekly. An example of the CDC-ACSM criteria is brisk walking over uneven ground at 3-4 mph, for 10-15 minutes, 5-7 times per week.[1] Using the Borg Scale, which is a 20-point scale system used to monitor exercise intensity,[2] it was estimated that the rate of perceived exertion (RPE) for the average individual participating in brisk walking would fall between 12 and 18. Although walking, jogging, and running on normal ground surfaces or a treadmill have multiple physiological benefits, detrimental effects such as vertebral compression may occur as well.

Various studies have been conducted related to the vertebral column and loss of vertebral column height (VCH).[5-17] Koeller et al[16,17] stated that the mean water content of the disc decreases in a non-linear fashion in both the thoracic and lumbar regions (T9-S1) with increased age. Research has shown that disc height loss occurs with dynamic activities rather than with static loading,[14,15] varies depending on position,[8] results from different load placement,[14] and occurs in a non-linear fashion with most of the compression occurring early in the activity.[14] Various researchers have noted that compressive forces on the vertebral column lead to decreased disc height, reduced shock absorption capability, decreased elasticity of the disc tissue, and decreased vertebral flexibility, thereby, putting the vertebral column at risk for injury and ultimately resulting in decreased VCH.[11,12]

The average adult takes 5,000 to 10,000 steps daily, which amounts to 3-5 miles per day, respectively.[18-20] Subsequently, information as to how the spine responds to walking this distance is important. Garbutt et al[19] observed changes in overall body height in elite runners using a stadiometer and found overall body height decreased 3.26 cm after 15 minutes of running and 2.12 cm between 15 and 30 minutes of running. Garbutt et al[19] may have assumed that only changes in spinal height occurred during running. Roush et al[14] investigated changes in VCH in male runners over a distance of three miles and found a curvilinear relationship between distance and VCH. However, no studies have been conducted to assess changes in VCH during walking for a distance of three miles. The purpose of this study was to determine the changes in VCH of males and females, at every one-half mile, for a total walking distance of three miles.

METHODS

Subjects

The investigation was approved by the Investigational Review Board of A. T. Still University of Health Sciences – Mesa, Arizona Campus. Each subject was informed of the risks associated with the study and was required to sign a consent form. Twenty, healthy males (mean age: 26.83 years; height: 176.10 cm + 9.61; weight: 75.81 kg + 10.17; BMI: 24.90 + 3.00) and twenty, healthy females (mean age: 25.60 years; height: 167.04 cm + 6.19; weight: 64.60 kg + 6.87; BMI: 23.5 + 2.30) who routinely exercised at a moderate intensity at least three times a week volunteered to participate in this study. Subjects were excluded if they had back pain within the last month, any type of diagnosed scoliosis, or any medical condition that prevented them from walking at a moderate pace on a treadmill. The subjects were introduced to the testing procedures and instrumentation prior to data collection.

Pilot Study

A pilot study was conducted to determine the reliability of the investigators as measurers. Both investigators with over 15 years of experience measured the VCH for a sample of twelve females and eight males. A standard tape measure was used to measure VCH. During data collection, the subject was standing and the investigator palpated the spinous process of C7.[20] The investigator then palpated the location of S2.[20] Using a standard tape measure, the investigator recorded the distance between C7 and S2 in centimeters. An Interclass Correlation Coefficient (ICC) was calculated to assess the reliability of the investigators. The ICC (2,2) for the first investigator was 0.98, and for the second investigator was 0.94.

Testing Protocol

Prior to data collection, subjects were instructed to receive at least six hours of sleep in the recumbent position the night prior to testing and to arrive within 90 minutes of arising from bed. During the initial visit, subjects completed a medical questionnaire. In addition, subject's height (cm), body mass (kg), resting heart rate (HR), blood pressure (BP) and rating of perceived exertion (RPE) was obtained. Body Mass Index (BMI) was calculated as the ratio of weight (kg) and the square of the subject's height (m).

Treadmill Walking

Prior to walking, HR, BP, RPE, and VCH were obtained. The VCH measurements from spinous process of C7 and S2 were acquired using a standard measuring tape. The slope of the treadmill was set to zero. Subjects were instructed to walk "normally" at a pace that fell between 12 and 14 on the rating of perceived exertion (RPE) scale, signifying moderate intensity. At each half mile, up to a total of 3 miles, subjects stepped off the treadmill and their BP, HR, RPE and VCH was recorded. This data were collected to ensure that subjects were maintaining a walking speed within a 12 to 14 rating on RPE scale and exercising at a safe intensity.[21]

Statistical Analysis

Means and standard deviations of heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were calculated according to sex. Means and standard deviations of VCH and changes in VCH between intervals were recorded for each 0.5-mile interval during the 3-mile walk. A repeated-measures analysis of variance was calculated for VCH at each one-half mile interval, with sex as an independent variable. Significance was accepted at $p<.05$. Confidence intervals were used to determine individual differences between intervals for each sex. A relationship between VCH and distance interval, and a regression equation using a polynomial for the variables, were also calculated for each sex. All statistical calculations were performed using the Statview Statistical Package 5.0 (Cary, NC).

RESULTS

Means, standard deviations, and 95% confidence intervals of VCH can be found in Figure 1. The results of the analysis of variance were that were significant differences existed in VCH according to sex ($F = 16.178$; $df = 1,38$; $p < .05$). Significant differences also existed in VCH at the different distances ($F = 65.02$; $df = 5,190$; $p < .05$). No significant interactions were found between sex and distance ($F = 0.51$; $df = 1,5$; $p > 0.05$). Differences in VCH were noted to be significant between interval distances of one-mile or greater, up until mile two; thereafter, no significant changes were seen. Significant changes occurred in the VCH between half-mile intervals only between 0.5 miles and 1.0 mile and between 1.0 mile and 1.5 miles during the walk.

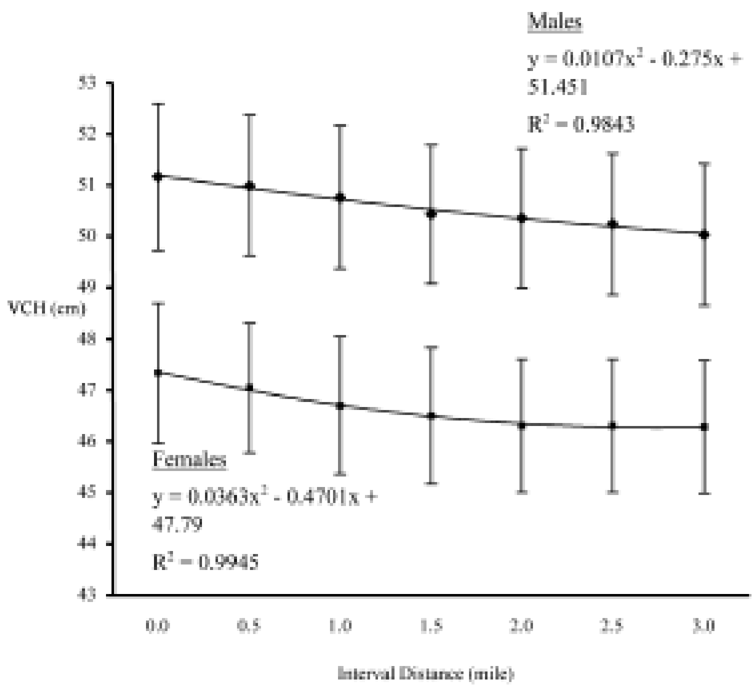

FIGURE 1. Plot of means and 95% confidence intervals of vertebral column height (VCH) at each interval distance for males and females

A regression analysis was also calculated to determine the change in the means of the VCH of both males and females throughout the 3-mile walk. A regression plot for a second-degree polynomial is shown in Table 1. Coefficients of determination were calculated between the regression equation and the actual data points. The coefficients were 0.98 and 0.99 for males and females, respectively. The regression plot indicates that a curvilinear relationship exists between the distance walked and VCH. The VCH decreased throughout the distance of the walk.

Mean changes in VCH can be found in Table 2. Overall, the maximum decrease in VCH was 1.14 cm for males ($F = 2.36$; $df = 5,19$; $p < .05$) and 1.10 cm for females ($F = 2.34$; $df = 5,19$; $p < .05$). Males exhibited changes in VCH during each interval of walking, with a maximum amount of change in VCH of 0.33 cm between 1.0 and 1.5 mile *(Figure 2)*. The average decrease between intervals was 0.25 cm + 0.07.

Females exhibited significant decreases in VCH for each interval up to 2.0 miles, with a maximum amount of change between .05 and 1.0 mile of 0.33 cm *(Figure 3)*. The average decrease between intervals up to 2.0 miles was 0.09 cm + 0.11. Changes in VCH from 2.0 to 2.5 miles and from 2.5 to 3.0 were not significantly different from zero.

DISCUSSION

Previous investigators have concluded the VCH will decrease in height during physical activity.[13,21] The purpose of this study was to determine if VCH changed and how it changed when walking a distance of 3 miles. Americans are walking greater distances in order to achieve health and weight loss benefits as marketed by the American Heart Association,[4] America on the Move,[22] and the 10,000 steps program.[23] The overall change in VCH was relatively small (males = 1.14 cm; females = 1.10) when compared to the changes in overall body height in running.[19]

TABLE 1. Means (in cm), standard deviation (SD), and 95% confidence intervals of each interval for each gender for vertebral column heights (VCH)

		Interval Distance (mile)						
		0.0	0.5	1.0	1.5	2.0	2.5	3.0
Males (n = 20)	Mean	51.16	50.99	50.76	50.43	50.35	50.24	50.03
	SD	3.26	3.14	3.18	3.11	3.10	3.14	3.14
	95% CI	49.73 - 52.59	49.62 - 52.36	49.37 - 52.15	49.07 - 51.79	48.99 - 51.71	48.86 - 51.62	48.65 - 51.41
Females (n = 20)	Mean	47.33	47.04	46.7	46.5	46.3	46.3	46.28
	SD	3.21	3.12	2.89	3.06	3.03	2.97	2.96
	95% CI	45.96 - 48.70	45.78 - 48.30	45.36 - 48.04	45.17 - 47.83	45.00 - 47.60	45.00 - 47.60	44.98 - 47.58

The data indicate that the VCH decreased in a curvilinear fashion over the distance walked in both males and females. It is assumed that the changes in VCH are due to the compressive forces that are placed on the disc and resultant hydrostatic changes that occurred as a result of the load. Holm et al[24] found that as hydration decreased, pressure on the disc was increased. As water content decreases so does the height of the disc; the result is a decrease in total vertebral column height.

TABLE 2. Mean changes (in cm) (with 95% confidence intervals) in VCH between distances *

	Differences in VCH (cm)	Between 0.0 and 0.5 mile	Between 0.5 and 1.0 mile	Between 1.0 and 1.5 mile	Between 1.5 and 2.0 mile	Between 2.0 and 2.5 mile	Between 2.5 and 3.0 mile
Males (n=20)	Mean	0.18	0.23	0.33	0.08	0.11	0.21
	SD	0.23	0.38	0.28	0.16	0.22	0.25
	95% CI	0.07 - 0.28	0.07 - 0.40	0.21 - 0.45	0.00 - 0.15	0.02 - 0.21	0.10 - 0.32
Females (n = 20)	Mean	0.29	0.34	0.20	0.12	0.08	0.08
	SD	0.28	0.51	0.32	0.26	0.18	0.18
	95% CI	0.17 - 0.41	0.11 - 0.56	0.06 - 0.34	0.01 - 0.23	0.00 - 0.15	0.00 - 0.15

* 1 mile = 1.609 kilometers

Interestingly, no changes were shown to occur during the first half-mile walked. It could be hypothesized that the loading forces were not enough at this point to cause hydrostatic changes within the intervertebral disc. Koeller et al[16,17] found that the mean water content of the disc decreases in a non-linear fashion in both the thoracic and lumbar regions (T9-S1) with increased age and that when subjected to the same compressive load, the intradiscal pressure was greater in the upper lumbar discs versus the lower. This change is mainly due to the disc's cross-sectional area, which is increased in the inferior aspect of the vertebral column.[7,16,17] Leatt et al[12] and Hirsch[11] suggested that the vertebral column may be at risk for injury as a decrease in vertebral flexibility may occur.

No changes in VCH occurred after walking 2 miles, which may suggest a plateau exists in the vertebral column height (VCH) between miles two and three. Two miles may approximate the recommended accumulated 30 minutes of daily activity suggested in the ACSM Guidelines,[1] Surgeon General's Recommendation,[3] and Center for Disease Control and Prevention (CDC).[2]

This study conveys the changes in the VCH to walking over a period of 3 miles. No previous research is available with which to compare these findings. Previous research has been performed on the effects of running on the VCH.[9,14] Roush et al[14] investigated changes in vertebral column height in male runners over a distance of 3 miles and found a curvilinear relationship between distance and VCH. A decrease in vertebral column height is noted as a result of varying activities and from different loads that are placed upon the body.[15] White and Malone[15] found that loss of disc height occurs with dynamic activities, such as running, rather than with static loading. Carrigg and Hillemeyer[9] reported that static axial pressures are lowest while lying down, higher with standing, and even higher still while sitting and that these static changes occur in a non-linear fashion with most of the compression occurring early in the activity.[9] Vertebral column height may decrease with daily activities and even more so with activities that cause an increased axial compressive load throughout the spine.[11]

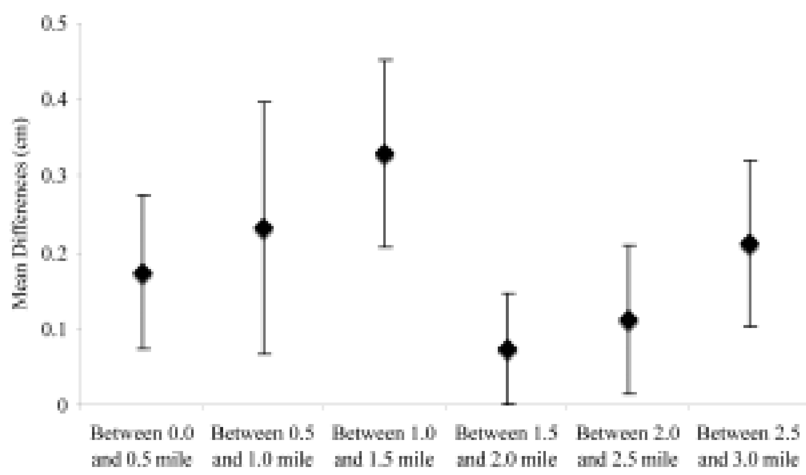

FIGURE 2. Mean differences and 95% confidence intervals in VCH between intervals for males

With respect to age and sex, evidence from this study has suggested that walking distances of 1-mile or more will have a compressive effect on the VCH in both healthy males and females between the ages of 20 and 40. Ahrens[6] showed that significant compression occurred in the spine in both young males ages 20 to 27 and older males ages 50 to 57. It is not evident how height, weight and body mass content, leg length, stride length, shoe type, posture, and length of sleep in a horizontal position the night prior to the study impacted the findings of this study.

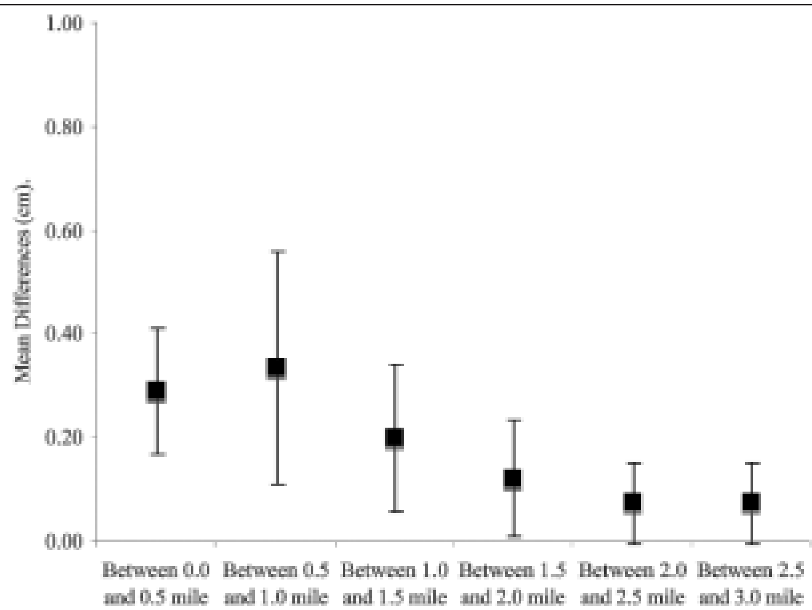

FIGURE 3. Mean differences and 95% confidence intervals in VCH between intervals for females

The findings from this study suggest that clinicians need to be aware of and consider not only the physiological changes that occur with physical activity, but also our role in the prevention and treatment of such changes. As clinicians, it is important to appreciate the changes that occur in the vertebral column height as a result of repeated compression, such as those that occur with walking, jogging, and running.

The limitations of this study should be noted. Although the sample used to gather results consisted of young healthy adults who had no current complaint of back pain, other age groups with limited walking tolerances due to various medical conditions, specifically low back pain were not included. Given that individuals with chronic low back pain were not measured in this study, it is recommended that a study be performed to investigate the changes in VCH with subjects who have experienced chronic back pain. Another limitation was that the walking pace was uncontrolled, with the exception of participant's maintaining a pace between 12 and 14 on a Borg rating of perceived exertion scale,[21] making the effect on the results uncertain. Another major limitation to this study was that the sample consisted of individuals who were all aerobically fit and participating in moderately vigorous exercise three to five times per week. While this sample may not be indicative of the normal population seen in a clinical environment, it does provide a baseline for future studies.

Future research should investigate the changes in VCH when walking on different surfaces, at different inclinations, at varying levels of exercise training, and at differing ratings of perceived exertion. In addition, the impact of limb length, body mass index, height, weight, age, and varying speeds and distances should be investigated.

CONCLUSIONS

The purpose of this study was to determine the changes that occur in VCH at every one-half mile, when walking a total distance of 3 miles. The changes were relatively small and much less than reported for running. The loss of VCH was noted within all distance intervals of 1 mile or greater up to 2 miles. These findings support the hypothesis that a change occurs in VCH in healthy males and females over the course of a 3-mile walk.

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CLINICAL COMMENTARY

THE CHOP AND LIFT RECONSIDERED: INTEGRATING NEUROMUSCULAR PRINCIPLES INTO ORTHOPEDIC AND SPORTS REHABILITATION.

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ABSTRACT

The upper extremity bilateral PNF patterns, better known as the "chop and lift" are well known to physical therapists. These patterns which utilize spiral and diagonal motions of the upper extremity can be used for both assessment and treatment of sports and orthopedic injuries. Half kneeling and tall kneeling postures fall between low-level postures such as rolling and 4-point, and high-level postures of standing and walking. Half kneeling and tall kneeling can be considered transitional postures. When the chop and lift patterns are used in conjunction with the half and tall kneeling developmental postures, the techniques are an excellent assessment of core stability/instability. Combinations of the upper extremity patterns and the developmental postures can be powerful corrective training techniques. The combined experience of the three authors is used to describe techniques for equipment setup, testing, assessment, and treatment of athletic imbalances. These techniques require and promote instantaneous local muscular activity as developmental postures and balance reactions are incorporated. The therapeutic use of both PNF and developmental patterns has been a hallmark of rehabilitation of patients with neurologic dysfunction, but can be equally and effectively applied in the sports and orthopedic rehabilitation setting.

Key Words: PNF, chop and lift patterns, reflex stabilization

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INTRODUCTION

In orthopedic rehabilitation and conditioning, discovering a totally "new" exercise, testing method, or performance enhancement technique is rare. Although many skilled clinicians frequently create alternate versions of traditional exercises, a totally unique exercise or theory of exercise is uncommon. What often serves the professional involved in rehabilitation of patients and clients is a "new twist" on an older exercise or exercise concept. The bilateral upper extremity proprioceptive neuromuscular facilitation (PNF) patterns known as the chop and lift have a long history in rehabilitation, with roots in rehabilitation of clients with neuromuscular diagnoses. Equally time honored are the postures and patterns of growth and development such as kneeling and half kneeling.

The upper extremity chop and lift patterns are well known to most rehabilitation providers from the concepts and theory attributable to PNF. The original descriptors of these concepts were published by Margaret Knott and Dorothy Voss in 1956.[1] Despite early historical rehabilitation strategies that promoted "one motion, one joint, one muscle at a time," [1] the upper extremity chopping and lifting patterns arose from the upper extremity PNF diagonal patterns that are both spiral and diagonal in nature. The use of such spiral and diagonal patterns are observed to be much like normal human movements that are integrated and efficient without conscious attention to and awareness of the neurophysiologic input.

Unilateral PNF diagonal patterns have been used in sports physical therapy, athletic training, and orthopedic rehabilitation for many years with additions of manual resistance, weights, and elastic resistance in a variety of positions (supine, sitting, standing, etc.). The chop and lift patterns are applications of the upper extremity diagonals that involve the use of bilateral upper extremities. One upper extremity is performing the diagonal one pattern, while the other upper extremity is performing the diagonal two pattern, either both moving into flexion, "the lift" (figure 1A) or extension "the chop" (figure 1B) while using rotational (spiral) and diagonal/combination movements that cross the midline. The chop and lift patterns are combined movements of paired extremities which are asymmetrical.[1]

Figures 1A and 1B. *The traditional PNF lift pattern, 1A: Start position, 1B: Finish position.*

Interestingly, these same movements can be used to address impairments or movement asymmetries. Detecting a muscular imbalance requires a thorough musculoskeletal examination. Special tests such as the Thomas test or FABER test of the hip assist in identification of asymmetrical dysfunction. Knapik et al[2] noted that although weakness of a particular muscle group could be linked with injury, a significant number of injuries were noted in athletes with right-left strength or flexibility asymmetry. Use of a gross movement assessment may assist in identification of movement pattern imbalances and asymmetries. It is efficient and appropriate to look first at gross movement patterns for the presentation of limitation and asymmetry in order to utilize a consistent and reliable system to assist in the deductive problem solving process. If impairments are resolved but dysfunction remains, further clinical investigation is needed. Either additional impairments are present or the dysfunction needs to be addressed at a functional level where timing, muscular recruitment, and reflex stabilization can be addressed in order to retrain the pattern.

The chop and lift represent distinct spiral and diagonal movements that mimic functional patterns occurring in both sport and activities of daily living. These movements capitalize on the principles of proximal to distal and distal to proximal overflow (also known in the PNF literature as irradiation)[1]. According to Knott and Voss,[1] distal to proximal sequencing is essential to improvement of motor abilities. Reinforcement of the movements by addition of resistance may strengthen the response in a weaker portion of the pattern. Coordinated movements of multiple muscles acting in a kinetic sequence helps to provide sequential, fine-tuned muscular actions.

The chop and lift motions also are excellent at recruiting the musculature of the core either for mobility or stability. When a destabilizing force acts on the trunk, a proper temporal and spatial recruitment of the core musculature is required to protect the spine.[3,4] Research has shown that when a limb is used to challenge the position of the body, a reactive force is produced within the body that is equal in magnitude but opposite in direction to the forces producing the destabilizing movement.[5-8] In other words, when the shoulder girdle and upper extremity moves in a diagonal chopping movement pattern, the destabilizing force acting on the center of mass is anterior causing the trunk to flex. The reactive stabilizing force (reactive strategy) is downward and backward to counteract the trunk movement. If these forces are equal or balanced, no net movement of the trunk occurs. In individuals without dysfunction, movement of the upper extremity is preceded by contraction of the erector spinae, multifidi, transversus abdominis, and both the internal and external oblique muscles. The early activation of these core muscles is not direction specific with regard to upper extremity movement.[7, 9] This muscle activation must be preprogrammed by the central nervous system because the muscles activation occurs in advance of the onset of activity of the muscles responsible for limb movement. Because proximal stability precedes distal mobility and postural adaptations are necessary for purposeful extremity movement, the use of these motions can be very effective in training the core. In individuals with dysfunction, the contraction of the core stabilizing muscles is delayed and, therefore, absent from the period preceding the onset of movement.

Figure 2. *The chop pattern performed in half kneeling with tubing resistance and stick.*

Figure 3. *The chop pattern performed in tall kneeling with tubing resistance and stick.*

The "new twist" in this article, is the use of tall kneeling and half kneeling postures during the chop and lift patterns to add another dimension to functional assessment and training. The tall and half kneeling postures are developmental steps on the ladder of function. These two lower body postures are familiar to rehabilitation providers who practice neuro-developmental strategies during treatment of patients whose central nervous system function is compromised. Earliest or lowest developmental postures include bridging, quadruped, planking, and rolling. The highest level developmental posture is standing ("floor based" upright postures) or other functional postures which offer challenges to multiple systems (neuromuscular, proprioceptive/coordination, vestibular, etc.) with little external input. The authors of this article prefer the term "transitional postures" to describe the two kneeling postures. These transitional postures will be emphasized due to their ability to stress or recruit the smaller stabilizing muscles of the core.[10] The standing posture offers a wide, adaptable base of support that utilizes all portions of the lower extremity kinetic chain. In contrast, tall- and half-kneeling offer narrowed bases of support, rendering distal portions of the kinetic chain unable to assist in corrective movements. When these narrowed bases are combined with the chop and lift patterns, problems that appear minimal with a wider base are magnified. Wider than necessary bases of support are often used to compensate for poor stability, and subsequently reduce efficiency, compromise fluid movement transitions, and diminish the appropriate weight shifting during activities. Tall kneeling creates challenge to balance reactions in anterior and posterior directions. Half kneeling creates challenge to balance reactions laterally. Transitional postures can also aid the orthopedic rehabilitation specialist who is retraining movement patterns*(Figure 2,3)*.

For athletes, the legs often are the driving force behind complex, multi-segmental kinetic chain movements, such as the swing of a bat or the act of throwing a ball. Patients and clients place themselves in potentially injurious conditions if they use only their global muscles to stabilize the trunk during functional activities.[11] The small, local stabilizers of the core cannot possibly be stronger than the large, global muscles; therefore, the goal of training is not to isolate and selectively condition groups of stabilizers with conventional concentric exercises, but rather to work on reflex stabilization. Reactive neuromuscular training attempts to bridge the gap from traditional isolation strength training and quick reflexive muscle activation.[12] Many treatment philosophies use the concept of reflex stabilization or training of a motor program for effective stabilization of the core.[13-15] The global and local muscles must be programmed to react quickly in order to provide normal, effective reflex stabilization.[15] Frequently the muscles of the core do not receive adequate training, and the legs are used to compensate for the weakness of the torso. By using the kneeling postures during assessment, inappropriate compensatory strategies are temporarily removed from the activity in order to examine right-left asymmetry with respect to chop and lift patterns.

Figure 4. *End position of the lift pattern performed with cable column.*

Asymmetry of chop and lift performance may implicate deficits within the underlying reflex stabilization mechanism. Likewise, if the legs are removed from the task, upper extremity or core dysfunction and asymmetries will be magnified. If the movement imbalance happens to be within the legs, the imbalance will be obvious when the legs are added back into the movement. By using spiral and diagonal movements that challenge the core through upper extremity movement, proximal stability is emphasized with the distal mobility training. As such, proximal to distal overflow and distal to proximal overflow principles inherent to the practice of PNF are utilized in simple testing and training techniques.[1]

The techniques described in this clinical commentary do not "excuse" the therapist from treatment for basic mobility issues prior to training for stability. Since the half and tall kneeling chop and lift corrective strategies are classified as stabilization activities, it is important to manage soft tissue and articular mobility issues that would compromise the posture or movement pattern. If stabilization exercise is performed in the presence of limited mobility, the level of mobility will be reinforced. Proper positioning of the half and tall kneeling require a tall neutral spine and near 0° of hip extension (not hyperextension). The chop and lift patterns require mobility of thoracic extension and rotation, as well as scapulothoracic and glenohumeral articulations.

SPECIFIC EQUIPMENT

A high-low pulley system or cable machine is the most user friendly piece of equipment with which to perform the chop and lift exercises. On a high-low cable machine, a cable from a low pulley can be pulled up or a cable from a high pulley can be pulled down. A large amount of weight is not needed because a long lever arm exists and many body parts contribute to the movement *(Figure 4)*.

An elastic tubing system can also be used to create the resistance necessary for training using the chop and lift pattern. With a conventional pulley system, the weight does not change throughout the movement, whereas elastic tension builds as elongation occurs. In addition, elastic resistance does not develop inertia. Thus, quicker and brisker movements can be used without inertia or jerking that would be noted on in a pulley system. An appropriate handle attachment is important, preferably a rigid stick with a secured eyelet in one end *(Figures 5,6)*.

Half-Kneeling Chop and Lift as Testing and Training Movements

Once a functional movement assessment/screen has been performed, take note as to whether a symmetrical (bilateral) or asymmetrical (unilateral) dysfunction is identified. Half kneeling chopping and lifting is usually performed when an asymmetrical problem is identified. Asymmetrical movements are movements where a left-right assessment reveals obvious functional differences either qualitatively or quantitatively. Chopping and lifting

Figure 5A-5B. *Half kneeling chop using tubing resistance and stick, A = start position, B = finish position.*

patterns are not used in the context of this commentary to enhance performance of the specific task of chop and lift. Rather, the patterns represent a unique way to standardize assessment of and magnify dysfunction in patients. A good rule to follow is to use the tall kneeling chop/lift posture when no stability asymmetry is present in the lower quarter but when upper quarter stability asymmetry is suspected. This position will provide the same base when testing chops and lifts to the left and right sides. When movement patterns show lower quarter stability asymmetries or a combination of lower and upper quarter stability asymmetries, use half kneeling posture for assessment and treatment. If the patient has an functional asymmetry in the lower quarter (Trendelenberg dysfunction in single limb stance, valgus collapse in stepping, inappropriate weight shifting in squatting) as compared to stability problem in the upper quarter (scapular instability, inappropriate tone of the upper trapezius muscle, inconsistencies of thoracic spine motion in standing which resolves in sitting) or they have a combination of symmetrical and asymmetrical dysfunction, focus on the asymmetry first. By first assessing and correcting the side to side asymmetry, the body is best prepared to then address symmetrical dysfunction. When a unilateral lower extremity test or screen shows a deficit, a half kneeling position on that side will demonstrate adaptations made by the core in order to compensate for the problems of static stability of lower body. The compensation may be identifiable when comparing the half kneeling position between sides. However, adding the chop or lift motion to the position will magnify the difference in mobility and stability, so the quality of the movement must be closely monitored. The use of a video camera may capture data that might not be apparent to the naked eye.

The half-kneeling chop and lift is an excellent starting point for movement imbalance training. In order to determine where to begin with training, an assessment of function in the chop and lift patterns must be undertaken. In order to assess function, find a weight that is comfortable for more than eight repetitions and then perform the chop and lift movement for as many repetitions as possible without compensation, loss of form, or excessive fatigue on one side. Take special note of left and right differences with both the chop and the lift. Repeat this on the other side. The left-right differences in those repetitions will indicate the extent of movement imbalance. Both the chop and lift will probably show left-right differences, but identify the movement that had the greatest discrepancy between left and right. Differences in the ability to perform repetitions of 10 to 15 percent as compared to the opposite side are acceptable and considered to be a

Figure 6A-6B. *Half kneeling lift using tubing resistance and stick, A = start position, B finish position.*

result of the fact that most people have a dominant upper extremity for functional tasks and activities of daily living. Anything in excess of a 10 to 15 percent right/left difference is considered an unnecessary movement imbalance and should be targeted for intervention.

When progressing from assessment to training using the chop and lift patterns, note that by improving one pattern, you will probably change the other, as they are related. Begin training by targeting the weakest link. Train only that one movement and then retest the right chop, left chop, right lift, and left lift. Note the differences. If improvement is noted but complete symmetry is not achieved, continue with the same program. If adequate improvement is not demonstrated after this exercise intervention, train both the chop and lift imbalances or modify other parameters of the exercise, or reconsider other impairments.

A tip for developing exercise proficiency in the weak pattern (weak quadrant) is to not prescribe a set of 6 or 12 but rather to require 6 to 12 "sets of one". By this, the authors mean separating each repetition into a separate motor performance event, with a small pause in between reps. This helps the therapist and the patient/client focus on precision and correct execution of the movement. Programming and setting up to perform an exercise accurately is more important than performing multiple reps. It should be noted that the body often will sacrifice quality of movement for quantity of repetitions. Precision is the key. Remember the intent is to train reflex stabilization, not attempt to "strengthen" the core stabilizers. Make sure the patient/client does not use momentum. Use proper breathing[14] and solid gripping to stimulate better natural stabilization.

Half-Kneeling Chop

With one knee down (0/90) and one knee up (90/90) kneel with the designated and reproducible orientation to the source of resistance. The base of support should be narrow with approximately six inches width between the knee of one leg and the heel of the other leg. Use a floor grid or strip of tape on the floor in order to standardize the position of the lower extremities during testing and training *(Figure 7)*.

Figure 7. *Half kneeling chop showing the use of floor tape for consistent alignment of the lower extremities during assessment.*

The hips should be directly under the body. The spine should be erect, the pelvis stabilized in neutral position, and the shoulders should be in line with the trunk. When viewing the patient from the side, the ear should be in line with the shoulder, the shoulder in line with the hip, and the hip in line with the knee upon which the patient is kneeling. The knee closest to the side of the resistance is up; the knee furthest away from the resistance is down in the hip extended position. The arms should be elongated with the palms in the down position.

The resistance or tubing should be pulled down and across the body into the open space created by the half-kneeling position, in a spiral and diagonal fashion. When using a stick or long rope, pull the stick or rope to the midpoint of the chest with the lower arm. The angle of pull should remain steady from start to finish. Hold the cable close to the body, forcing a bend in the elbows in the middle of the movement when the cable is closest to the body.

Make a conscious transition into a push with the upper arm downward, continuing the same angle of the initial pull. Keep the cable close to the body. The angle of the cable should not change during the descent, and its orientation in front of the body should stay the same.

Finish the movement by relaxing the lower hand and pushing through to extension with the upper arm. The shoulders should turn minimally or not at all. All of the motion should be in the arms. The trunk and hip are being used in an isometric or stabilizing mode. By pulling down and across the body with the arms, a torque is imposed both on the core and on the hip of the weight bearing knee. The ability to manage this imposed stress and not alter trunk and pelvis/hip posture demonstrates stability. This stability is the foundation of a strength and endurance program.

A common a mistake in the half-kneeling chop is flexion at the hip or in the trunk. Throughout the entire movement, a gentle stretch should be felt over the front thigh in the muscles that flex the hip and extend the knee. If the trunk is weak, the muscles of the thigh are often activated as a compensatory strategy. The purpose of this exercise is to maintain a stable trunk while the hip provides a stable base. If the hip is moving, a stable base cannot be provided. If the trunk is moving, the exercises will not develop stability. A gentle stretch across the front thigh demonstrates that these muscles are not being contracted. The minute the stress disappears, the front thigh muscles are being incorporated instead of activating the core muscles. Maintain the front thigh stretch throughout the movement.

This exercise is valuable for making left-right comparisons. Ability to hold the position and the quality of movement are the first things to consider when comparing performance between sides. Only after ability to hold and quality of movement is demonstrated bilaterally should the focus be on how many quality repetitions can be completed. An athlete may be able to do the same number of repetitions on each side, but one side may demonstrate constant postural adjustments or display poor mechanics during the movement.

Half-Kneeling Lift

The half-kneeling lift is the reverse of the half-kneeling chop. Kneel with the designated and reproducible orientation to the source of resistance with the inside knee down, hip extended, and the outside knee up. This position puts the open space in the cable's path. Use a narrow base and an erect vertical spine. To achieve a more vertical line of pull, it may be necessary to elevate the down, weight bearing knee on a 4-8 inch step *(Figure 8)*.

This position will put the patient further away from the pulley and allow the patient to increase the vertical inclination of the cable. Taller people will need more of a vertical path in the chop and lift, and shorter people will need a less vertical path. Once the patient masters the arm movement, he/she will feel the natural spiral and diagonal nature of the pattern.

Figure 8. *Alteration of the half-kneeling lift posture, showing elevation of the down knee 4-8" to adjust line of pull of the upper extremities.*

If the patient is using a stick or long rope, pull it up to the center of the chest with the palms down, beginning with the outside arm and then finishing with a press of the inside arm. The shoulders should have minimal turn. The movement is a total-arm movement on a stabilized trunk, much like the chop pattern. Maintain the front thigh stretch throughout the entire exercise and compare the left and right side for both quality and repetitions as previously described.

Tall Kneeling Chop and Lift

After the half kneeling testing and training sequence has restored symmetry, the tall kneeling testing sequence commences. The tall kneeling chop and lift is the next step to identify an imbalance. If the patient had difficulty with the deep squat during screening, it would be wise to explore chop and lift movement patterns with respect to the tall kneeling. When squatting or forward bending patterns are identified as faulty, tall kneeling is used as a corrective exercise for trunk stability. The tall kneeling position holds both hips in a symmetrical stance and complements spinal stability strategies for squatting. Tall kneeling takes away all compensation occurring at the hip, knee, ankle, and foot. Excessive out-turning of the feet, caving in of the knees, rolling of the ankles, and loss of a stable foot position, compensate for a lack of range of motion or stability within the hips and core. The patient who is quad dominant and hip-flexor dominant is moved into a position where they are unable to use anything but appropriate core stability for performance of the chop and lift movements.

To assume the starting position, the patient kneels so he/she is sitting on their heels with the torso upright. Extend the knees so that an imaginary vertical line connects the ear, shoulder, hips and knees from a side view. Make sure that the hips are fully extended and the pelvis is in neutral alignment. Follow the same instructions for the performance of the half-kneeling chop and lift, but from the tall kneeling position. Maintain the correct position throughout the movement by not flexing the hips, losing pelvic neutral, or losing the tall spine position. If a symmetrical problem has been identified, perform a chop to the right and to the left with the exact same amount of weight for each direction in a tall kneeling position. Then, perform a lift with the exact same amount of weight for each direction in a tall kneeling position both to the left and to the right. Perform the chop first and use approximately 2/3 greater weight than the lift (this is due to gravity and leverage). Choose a weight, or resistance, that the client can perform 6-12 repetitions and then look for discrepancies in quality and the ability to reach maximum repetitions. Use the description recording grid as described previously for subjective observations. Do not simply pick a weight and have the patient/client perform a set number of repetitions. Lifting the weight should be a mild struggle. This activity is a test for investigating posture, control, stability, strength, body awareness, symmetry, and mobility. The patient should max out on repetitions within 6 to 12 repetitions. Take the test to the point of fatigue, loss of appropriate posture, absence of smooth movement, or to the point where a struggle is demonstrated. Again, video analysis can assist the clinician to capture subtle postural or movement control losses. Follow the same format as the half kneeling chop and lift and remember to compare the right and left sides for both movements. Standardize cable column or tubing position for repeatability during testing. When the test is complete make an assessment of both quality and quantity in four quadrants – the right and left chop and the right and left lift in the tall kneeling position. Find the weakest quadrant and work there until symmetry is restored.

CONCLUSION

Finding the weakest link chop and lift quadrants is a completely different way to look at core issues in patients. Do not think of the chop and lift patterns as simple, bilateral, asymmetrical, upper extremity exercise. These patterns do not have to look like a functional activity or sport movement in order to be valuable. The movements are primitive patterns that expose the core to three dimensional stresses, incorporating both lower-body weight shifting and upper-body movement. The patterns also work at a slow enough speed to provide feedback about the way a movement is achieved and allow the patient to make corrections. These movement patterns are excellent methods to teach core stability, by laying the foundation for other strength training. The patterns are also simple, reproducible tests of left-right movement pattern balance. Choose half kneeling for asymmetrical problems (half kneeling, lunging, and single leg stance) problems involving one hip to a greater extent than the other and choose tall kneeling for symmetrical problems (squatting, dead-lifting, and simple forward bending) and problems involving the back and hips equally.

Combining the PNF chop and lift patterns with the half kneeling and tall kneeling postures will help the clinician bridge the gap between low level patterns and postures (rolling, crawling, creeping) and high level, functional patterns and postures (squatting, lunging, stepping, pushing, pulling). To this end, the intermediate postures can also be referred to as "transitional patterns and postures." The patterns require and promote instantaneous local muscular activity as they tap into early developmental reflex movement and balance reactions. The therapeutic use of both PNF and developmental patterns has been a hallmark of rehabilitation of patients with neurologic dysfunction, but can be equally and effectively applied in the sports and orthopedic rehabilitation setting. Use of the patterns and postures described in this commentary illustrate the principle of mass movement, described as "characteristic of normal motor activity…that the brain knows nothing of individual muscle action, but knows only of movement."[1] After use of these techniques, the end result is that the patient or client's neuromuscular system becomes integrated and highly organized for action, without awareness of individual muscle action, conscious programming, and other neurophysiologic compensations.[1]

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CLINICAL COMMENTARY

FUNCTIONAL REHABILITATION AFTER MEDIAL MENISCUS REPAIR IN A HIGH SCHOOL FOOTBALL QUARTERBACK: A CASE REPORT

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ABSTRACT

Background. Rehabilitation guidelines and functional progression of isolated medial meniscus repair is not well documented in the literature. Due to the importance of the knee menisci, surgical repair of these structures has been very common. Physical therapists need to be aware of the imposed precautions and proper progression of patients post meniscus repair surgery.

Objectives. The objective of this case study is to describe rehabilitation guidelines, functional progression, and functional outcomes for a high school football player status post medial meniscus repair.

Case Description. The rehabilitation approach started with an early protection phase, followed by progressive neuromuscular training, then aggressive functional rehabilitation utilizing functional tests and measures to gauge return to play. Data collected for this case included joint range of motion, joint effusion, neuromuscular facilitation, isokinetic strength, and functional test scores.

Outcomes. This patient was able to return to full level of participation in 140 days (20 weeks), and was without re-injury 10 months after surgery.

Discussion. The rehabilitation approach of meniscus repair described in this case study may provide guidelines in clinical decision making for a safe return to competitive athletics.

Key Words. knee, meniscus, repair

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INTRODUCTION

The menisci of the knee are essential for proper knee function. They act in shock absorption, load transmission, stress reduction, joint stability, joint nutrition, and joint lubrication.[1,2] The menisci also have been found to have a significant role in neuromuscular control of the knee, providing proprioceptive information regarding joint awareness such as position, direction, velocity, acceleration, and deceleration.[3-5] Therefore, injury to the menisci resulting in partial or complete meniscectomy can lead to mechanical dysfunction, including decreased joint stability, increased joint degeneration, or neuromuscular deficits.[4,6-8] Meniscectomy results in 50% reduction of contact area between the femur and tibia, increasing the contact pressure on articular cartilage, and reducing the shock absorption capacity of the knee by 20%.[9]

Due to the importance of the menisci to the knee joint, from both a mechanical and neuromuscular standpoint, surgeons have focused more attention to preserving the integrity of the meniscus through repair procedures.[10] Procedures to repair meniscus include inside-out, outside-in, open, and all inside repairs.[1] The fixations vary from suture repairs to biodegradable devices. Inside-out fixation involves passing sutures arthroscopically from inside the knee, with the suture knots being tied outside the joint. Outside-in fixation involves passing the sutures from outside the knee joint, and tying the sutures arthroscopically inside the joint. Open repairs involve suture fixation with an open incision. All inside repairs vary from suture fixation passed with a suture hook, to commercial biodegradable fixation devices such as meniscus arrows.[1,11] These procedures have been applied to menisci in both the vascular and avascular zones, with an 80-90% success rate reported.[1,11,12]

Very little evidence exists in the current literature on rehabilitation following meniscus repair. No investigation has reported into the healing timeframes, strength capacity, or the effects of weight bearing or rotational stresses to a healing, repaired meniscus. Currently, both conservative and aggressive approaches exist for rehabilitation of meniscus repairs. The traditional conservative approach calls for partial weight bearing for the first 4-6 weeks with a post-operative brace locked in full extension and passive ROM limited from 0 - 90 degrees for the first 4 weeks.[13,14] These early restrictions in the conservative approach are likely due to the reported 50% of compressive loads in the knee passing through the menisci when the knee is in full extension. In 90 degrees of flexion, 85% of the load passes through the menisci.[9] Activation of the hamstring muscles are also limited due to the evidence that knee flexion results in displacement of posterior horn meniscal tears.9 Thus, the conservative approach limits end range of flexion range of motion (ROM), does not allow resistive hamstring exercises, and avoids closed kinetic chain positions such as squatting or lunging beyond 30-40 degrees of knee flexion. This approach aims to protect the shear forces on the repair for up to 4 months, with return to sports delayed for 4 to 6 months.[13, 14]

In the accelerated approach to rehabilitation of meniscus repairs, authors have reported return to play after as little as 10 weeks.[15,16] This approach integrates unlimited flexion ROM, hamstring muscle contraction, and weight bearing in the early stages of rehabilitation.[15] These two different approaches provide some insight into the current rehabilitation of meniscus repair. One promotes the necessity for protection of the repair,[13,14] while the other approach is less restrictive.[15]

Some authors have attempted to outline return to play guidelines.[9,15,17] Shelbourne et al[15] addresses some predetermined goals to gauge return to play, including full ROM, 75% quadriceps strength, completion of a running program, and completion of functional, sport-specific exercise.9 Brotzman and Wilk[9] calls for return to full activity between 11-15 weeks upon full, pain-free ROM, satisfactory clinical examination, and satisfactory isokinetic test results for strength. In addition to these approaches, neuromuscular rehabilitation and training has most recently been addressed as a key component of rehabilitation from meniscus injuries.[3,17] These studies address sport-specific neuromuscular control as the point of emphasis for rehabilitation and progression to return to activity.

The purpose of this case report is to integrate the approaches of early conservative treatment, neuromuscular and proprioceptive training, and functional progression into recommended guidelines for rehabilitation status post meniscus repair. This case will also present functional testing as useful clinical outcome measures of rehabilitation from meniscus repair.

CASE DESCRIPTION

The patient was a 17-year-old football quarterback in his junior year of high school. The patient initially injured his right knee in a pivoting mechanism of injury during the middle of his football season. He reported experiencing medial knee pain, swelling, and popping the right knee.

The team orthopedic surgeon evaluated him, and he was without definitive signs for meniscal pathology. According to the physician's office notes and his athletic training staff, his symptoms subsided and he was able to continue the season without major findings such as popping, buckling, pain, or swelling. After the season, the patient experienced a sharp pain and recurrence of previous symptoms while participating in the discus throw in track practice.

He was evaluated by his team orthopedic surgeon 3 days later. According to the physician's office notes, he presented with moderate joint effusion, lack of terminal 15 degrees of flexion, and a positive McMurray's sign. After clinical examination by the physician the patient had an MRI. According to the physician's office report, the MRI findings were consistent with a medial meniscus tear. The patient opted for arthroscopic surgery of the right knee one week later so he could have full recovery in time for his senior year football season.

The patient underwent surgery on 3/10/06. According to the operative report, a large tear was noted in the vascular portion of the medial meniscus, coursing from the posterior horn to the anterior horn and body. The meniscus repair was performed using six bio-absorbable staples. Per his orthopedic surgeon, the patient was placed in a post-operative knee brace (TROM, Donjoy, Vista, California) locked in full extension. He was instructed in ambulation non-weight bearing on the right lower extremity using standard axillary crutches. Additionally, he was instructed to progress to weight bearing as tolerated by week 2 and full weight bearing with the locked brace and crutches on week 3 (21 days post-op). He was also instructed by his orthopedic surgeon not to flex his knee beyond 90 degrees until week 3. Physical therapy was to begin exactly 3 weeks post surgery.

INITIAL PHYSICAL THERAPY EXAMINATION

Initial Presentation

The patient presented to physical therapy 3 weeks and 3 days (24 days) post arthroscopic medial meniscus repair. The history of his current injury was as noted previously. He presented with a mildly antalgic gait, with decreased toe off and stance phase of gait. He was ambulating full weight bearing without an assistive device and wearing a post-operative knee brace locked in full extension. The patient had minimal joint effusion, which measured at +0.5 centimeters with a circumferential measure at the joint line. The knee was minimally warm to touch. Three portal incisions existed, one at the lateral joint line, one at the medial joint line, and one at the far medial joint line, just anterior to the medial collateral ligament. The portal incisions were closed, with minimal redness, and without evidence of drainage or abnormal tenderness. The patient did have an additional far lateral portal incision, which he reported was due to the complexity of the meniscus tear. Palpation for condition revealed swelling at the joint line and superior pouch, and involuntary muscle tone of the distal hamstring musculature involving the distal biceps femoris and distal semimembranosis / semitendinosis.

Functional Status

The patient was limited in all activities of daily living that involved flexion of the right knee or excess weight bearing on the right lower extremity. These restrictions included, but were not limited to, rising from or lowering to squat positions, and stair ambulation. The patient avoided unilateral stance daily activities due to pain and feelings of instability.

Systems Review

The patient appeared to be a healthy, athletic 17-year-old male. At the time of evaluation the patient was 6'4" and 180 lbs. He had no significant medical history or family medical history. Patient denied having previous injuries or surgeries. At the time of the initial evaluation he had no gross warmth to touch in the lower extremity or gross sensory deficits in the lower extremities.

Range of Motion

The patient's classical, active ROM was 0-100 degrees in a pain-free manner, versus 0-130 degrees on the left knee. Range of motion was taken measured with a goniometer and taken via heel slide in a long sitting position. Patient presented with a mild decrease in mobility of the patella.

Pain

The patient reported 3/10 on a numerical pain intensity scale. The scale was defined as 0/10 for no pain and 10/10 as the worst pain.

Muscle Strength

The patient had a fair quad set / facilitation, versus excellent on the left lower extremity. A surface EMG biofeedback unit (CARE EMG, CARE Rehab, McLean, Virginia) with electrodes placed over the vastus medialis oblique muscle and 10 cm proximally to the superior border of the patella on the rectus femoris muscle during active quad sets resulted in an average output of 54.9 microvolts on the right, versus 117.6 microvolts on the left. The resultant deficit of 56% was recorded. The accuracy of this unit is reported as 4% of the microvolt reading.[18] Strength of the quadriceps and hamstring muscles using a manual muscle test measured at 4-/5 on the right versus 5/5 on the left. Muscle testing was performed in a sitting position, resistance was applied in a pain free manner, and measures were taken as a global measure of hamstrings and quadriceps muscles contraction due to patient's postoperative status.

Assessment

This patient's primary impairment was an acutely repaired right knee medial meniscus secondary to sports related trauma. Physical therapy evaluation revealed decreased ROM, decreased strength, decreased functional mobility such as general ambulatory status and squatting activities of daily living, swelling, pain, and decreased ability to perform desired athletic activities. These findings were the patient's secondary impairments. Due to the operative procedure, this patient was also not permitted to squat, climb, pivot, ambulate stairs, or run until instructed due to the excess forces placed upon his meniscus.[9,13,14] These limitations were placed upon the patient by his orthopedic surgeon due to the meniscus repair procedure itself and the size of the tear. Taking into account his prior level of function, age, pain levels, and examination findings, his rehab potential was deemed as excellent.

Plan of Care Design

The rehabilitation program was divided into four phases. The program integrated aspects of the previously discussed treatment approaches,[9,13,15-17] including conservative treatment, neuromuscular and proprioceptive training, and dynamic functional rehabilitation to include agility drills and lower extremity functional capacity testing. Physical therapy interventions were initiated during the end of the first phase of his rehabilitation.

PHASE 1 (post-op weeks 0 to 4)

Goals

In Phase 1, the knee was in the early protection phase. The goals of this phase were to obtain 0-90 degrees of active ROM, decrease inflammation, restore normal patellofemoral joint mobility, and protect the repair. This phase lasted until post-op week 4 (28 days), when the patient was allowed to increase ROM as tolerated based on pain level and wean from crutches for ambulation to full weight bearing as tolerated with the brace locked in full extension.

Intervention

The patient wore a brace locked in full extension during all activities. He utilized bilateral axillary crutched in a non-weight bearing fashion. During Phase I, he progressed to weight bearing as tolerated and eventually full weight bearing without crutches by the time he presented for his initial PT evaluation. The patient was initially instructed in quadriceps facilitation exercises via a quad set with a surface EMG biofeedback unit (CARE EMG, CARE Rehab, McLean, Virginia)[18] during quad sets, straight leg raises, and multi-angle quadriceps isometrics in sessions supervised by the physical therapist. The patient was also instructed to perform quad sets, active assisted ROM heel slides, straight leg raises, hamstring stretches, grade II-III patella mobilizations inferior and superior, and calf stretching followed by icing as part of a home exercise program. All activities were to be performed 3 times per day, every day. This patient also performed weight shifting and single leg stance while wearing a brace locked in extension for proprioceptive input, and stationary cycling without resistance for ROM in supervised physical therapy during the end of this phase. These exercises were performed to facilitate quadriceps muscle activation, reduce the tonic contraction of the hamstring muscle, improve ROM, improve joint proprioceptive awareness, and reduce swelling. In addition to this, the patient performed gross hip strengthening via straight leg raises, lower abdominal and core strengthening, and cardiovascular training with the upper body ergometer. The patient was closely monitored for any increase in pain and swelling.

Outcomes

The patient attended physical therapy sessions three times per week during the last week of Phase I. By the end of Phase I the patient was able to perform full revolutions on a stationary bike without discomfort or tightness and tolerate unilateral stance without pain but with intermittent upper extremity support. The patient was able to perform a quad set with fair muscle tone. The surface EMG revealed an average workload of 91.0 microvolts on the right quadriceps muscle, which resulted in a 22% deficit in quad facilitation.

PHASE 2 (post-op weeks 5-9)

Goals

Phase 2 was from post-op weeks 5 through 9. In this phase, the goals were to achieve full ROM, normalize gait, and improve strength and neuromuscular control for daily activities. The patient was to perform unsupported squatting to 60 degrees of knee flexion without pain or compensation by post-op week 6 and unsupported squatting to 90 degrees of knee flexion by post-op week 9. By week 10, the patient was to restore full, pain-free ROM, with good quadriceps tone, strength, and motor control to initiate interval-jogging program without pain or compensation.

Intervention

In the early portion of this phase, emphasis was placed on proprioceptive activities, normalizing ROM, improving quadriceps and hamstring muscles strength, and limited arc closed chain strengthening, allowing no more than 90 degrees of flexion. As the patient progressed to the Phase 2 of rehabilitation, he continued to respond with increased ROM, quad facilitation, motor control, and tolerance to open and closed chain strengthening. The patient was able to perform closed chain exercises within the restrictions of no greater than 90 degrees of flexion. He performed supported partial squats without pain and progressed to unsupported squatting and step-up activities. Motor control improved as he was able to perform box step ups, box step downs, and box side stepping with decreased dyskinesis and improved balance. Proprioceptive exercises were initiated with supported bilateral rocker board activities, progressing to unsupported exercises, followed by unilateral stance. The unilateral stance exercises were progressed to unstable surfaces when he was able to perform static stance on level surfaces without need for upper extremity assist, loss of balance, or pain. Toward the end of Phase 2 oscillatory and impulse stabilization exercises were introduced and performed on level ground then un-level ground.[3, 8, 17] During this phase, the patient performed open and closed chain strengthening exercises, gradual ROM exercises, and motor control / proprioceptive exercises all within the imposed less than 90 degrees of knee flexion limitations until he reached the final weeks of this phase.

Once the patient was confident with unilateral weight acceptance, demonstrated good unilateral neuromuscular control, and displayed no deficit on surface EMG[18] during quad facilitation exercises, he was permitted to begin light throwing while in standing position. At this time his throwing was limited to minimal level of exertion, short distances, and a fairly static, step-and-throw technique to a static target to avoid any rotation stress to his knee. The patient was a right-handed quarterback. Thus, his involved lower extremity was used as his push-off leg when throwing. He was again cautioned to discontinue throwing if he experienced pain or swelling in the right knee.

As this patient entered the late stages of Phase 2, he went through a significant transitional period in his rehabilitation. He began closed kinetic chain exercises with increasing resistance, but still within the 90-degree limitation due to the size of his repair. He also initiated isokinetic exercise on the Biodex19 at 180 deg/sec and 300 deg/sec. These speeds were selected for exercise based on the planned testing in later phases. He was able to achieve full knee flexion during week 9. It was at this time the patient began performing functional deep squatting with no knee flexion limitation, with no added resistance beyond that of his body weight, and within pain free ROM. With this patient's goal of initiating running by week 10, he began straight plane, low-level agility (ladder) exercises to improve motor control at a faster cadence. Once he demonstrated ability to perform these agility drills without compensations or discomfort, he was allowed to practice straight drop back footwork, as well as step-and throw drills with the high school football team training staff.

Outcomes

The patient continued to receive physical therapy three times a week for 5 weeks while in Phase 2 (15 total visits). By week 6, the patient no longer had ROM limitations during closed chain strengthening. Therefore, functional exercises were initiated and full ROM during these activities was expected by the end of phase 2. At week 6, the patient achieved symmetrical values for his average output (microvolts) during a standard quad set exercise. He also had symmetrical circumferential measures at his tibiofemoral joint line, and presented with full, symmetrical ROM. At post-op week 8, the patient performed an isokinetic strength evaluation at 180 degrees per second and 300 degrees per second. He displayed peak torque strength deficits of 26.9% and 20.1% in his quadriceps muscle, and 6.4% and 5.9% in his hamstrings muscles, respectively*(Table 1)*.

Table 1. Week 8 Isokinetic Test Results

	Week 8 180 degrees/sec	Week 8 Deficit% (180)	Week 8 300 degrees/sec	Week 8 Deficit% (300)
Quad Peak Torque (ft-lbs)	109.1	26.9%	97.6	20.1%
Quad Peak Torque/Body Weight (%)	59.0%	-	52.8%	–
Quad Total Work (ft lbs)	1212.1	18.4%	1040.9	25.1%
Hamstring Peak Torque/Body Weight %	50.2%	-	44.1%	-
Hamstring Total Work (ft.lbs)	930.8	4.2%	906.9	8.3%

PHASE 3 (post-op weeks 10-16)

Goals

Phase 3 of rehabilitation focused on progression of functional activities and the goals were to transition this patient back to football related activities. At 12 weeks, the goals were to perform full, pain-free functional deep squat and closed chain pivoting activities without complaints of pain. By post-op week 16, the patient should be able to run on a treadmill and grass, tolerate progression of pivoting and cutting, and advance throwing with incorporated agility drills to safely advance to sport specific demands.

Intervention

Once the patient displayed full knee extension, good quad strength (as displayed by the week 8 isokinetic test results), good quad tone, and good neuromuscular control during low-level, straight plane agility exercises such as agility ladder drills and skipping, the patient was allowed to begin jogging. The patient began jogging with an interval program on a treadmill at post-op week 10. This began with 30-second intervals, followed by 30-second rest periods, with a running speed of 6 mph at 0% incline for 10 repetitions. The interval program was repeated each visit, and times were increased to 60 second running, with speeds eventually increased to 9mph by the end of phase 3. The incline was also progressed up to 5% by the end of Phase 3. The speeds and incline were increased as the patient's strength and fitness improved, adjusting to provide a moderate level of perceived exertion.

As the patient entered Phase 3, he continued with higher level neuromuscular training including oscillatory and impulse techniques for isometric stabilization, open and closed chain strengthening with and without added loads, treadmill jogging, and isokinetic strength training. Neuromuscular training was progressed with oscillations from the upper extremities using tubing, first in a straight plane then diagonal plane of motion. Impulse stabilization was provided with the use of a plyoback while in a unilateral stance. Again, progression occurred with diagonal patterns of throwing, then progression to uneven surfaces. Loads were added to closed chain exercises utilizing weighted vests, varying from 15 to 45 pounds. This activity was performed to add stress to his lower extremities, challenge his neuromuscular control during his lunging and squatting activities, and provide higher demand strength training as the patient was planning on extensive strength training with his football team upon release from rehabilitation. He began with the 15 lb weight, performing bilateral squatting to a box height allowing 90 degrees of knee flexion to maintain low stress at the knee, then progressed to squatting without support of a box. Although the patient was allowed to perform a full, deep squat without resistance, he was not permitted to perform a squat with added loads as it is postulated that this would be excess stress to this patient's knee. Unilateral step-ups were performed with the added loads up to 45 lbs and at a 14-inch box height.

At 12 weeks post-operatively, the patient began pivoting exercises. This exercise was done utilizing a vector board, in which the patient performed drop-step, or diagonal squats, and lunges at 45 degree, 60 degree, and then 90-degree angles. He progressed by adding loads to these closed chain exercises. Crossover footwork drills and pivoting agility cone exercises completed the progression. These exercises emphasized high demand neuromuscular control and placed progressively higher demands on the meniscus.

At football practice, the patient was permitted to increase his distance and exertional levels for throwing. He was also allowed to perform drop backs from his quarterback position, as well as drop backs to a 45 degree angle in either direction. He was also permitted to perform straight plane jogging and only agility ladder drills which he was performing in his rehabilitation program.

Functional rehabilitation activities progressed through higher-level activities including ladder drills, 5-dot drills, plyometrics, and cone drills involving cutting at 16 weeks. The patient also increased speeds of his 40-60 yard running on grass, including some sprinting at week 16. Sprinting was also performed and progressed on the treadmill. He was able to progress treadmill running to 12mph at a 15% incline for 20 second intervals as he completed Phase 3.

Outcomes

The patient was treated 2-3 times per week for seven weeks while in Phase 3 (18 total visits). At the end of Phase 3, the patient was able to perform all agility ladder drills, in-door cone drills, and 5-dot plyometric drills without discomfort, pain, or compensation. The patient was also able to perform jogging and light sprinting up to 12mph with varying inclines up to 15% without discomfort, pain, or compensation. At post-op week 14, the patient performed an isokinetic strength evaluation at 180 degrees per second and 300 degrees per second. He displayed peak torque strength deficits of 6.3% and 8.2% in his quadriceps, and 4.4% and 2.9% in his hamstrings, respectively*(Table 2)*.

Table 2. Week 14 Isokinetic Test Results

	Week 14 180 degrees/sec	Week 14 Deficit% (180)	Week 14 300 degrees/sec	Week 14 Deficit% (300)
Quad Peak Torque (ft-lbs)	136.6	6.3%	112.4	8.2%
Quad Peak Torque/Body Weight (%)	73.8%	-	60.8%	-
Quad Total Work (ft lbs)	1307.4	16.5%	1143.9	15.6%
Hamstring Peak Torque/Body Weight %	51.7%	-	46.3%	-
Hamstring Total Work (ft.lbs)	809.8	21.9%	739.6	12.9%

PHASE 4 (post-op weeks 17-20)

Goals

Phase 4 focused on aggressive sport specific training. The goals were to normalize running and sprinting, normalize lower extremity strength, and perform sport specific athletic demands without pain or compensation.

Intervention

This phase encompassed weeks 17 through 20. Upon completion of functional tests to assess strength, agility, and endurance, the patient entered into Phase 4, which was return to sport participation. The athlete fulfilled this phase through demonstrating the ability to perform all athletic demands of his specific sport prior to returning to unrestricted competition.

As the patient entered and progressed through this phase of his rehabilitation, he began more sport specific cutting and pivoting. The patient began performing roll-out activities at football practice and running drills that emphasized cutting and change of direction. He was unrestricted in exertional levels for throwing. The patient also began functional testing, which included the Lower Extremity Functional Test (LEFT),[20] the T-test,[21] and 300-yard shuttle.[22] The LEFT test assesses multiple lower extremity movement patterns,[20] the T-test is an anaerobic test for agility,[21] and the 300-yard shuttle is an anaerobic capacity test.[22] The patient initially performed these tests at 50% effort level at week 16, then 75% effort at week 17, and finally at maximum effort upon final physical therapy visits at weeks 20-21. This progression in effort was instructed so the patient could become familiar with the tests. It was postulated that familiarization with the tests would assist in gaining an accurate assessment of his functional capacity when permitted to perform the test at 100% effort.

Outcomes

The patient was treated two times per week for the four weeks of Phase 4 (8 total visits). As the patient progressed with his functional rehabilitation, higher demanding agility exercises, and sport specific exercises, he was able to complete all functional testing without discomfort and within acceptable criteria for discharge from physical therapy. He scored 1 minute, 40 seconds on the LEFT test.[20] The patient scored 65.8 seconds on the 300-yard shuttle, which places him 4.8 seconds slower than previously tested Division-I football players at his position.[22] Lastly, the patient scored 10.55 seconds on the T-test, which places him .55 seconds slower than previously reported competitive college male athletes.[21] Upon his final physical therapy visit, he also scored III out of III on each the lower extremity components of the Functional Movement Screen,[23] including the deep squat, hurdle step, and in-line lunge. Since the patient was in the off-season of his particular sport and recovering from significant knee surgery, he was quite pleased with these results on his functional tests.

At post-op week 18, the patient performed an isokinetic strength evaluation at 180 degrees per second and 300 degrees per second. He displayed peak torque strength deficits of 2.0% and 7.1% in his quadriceps, and 11.4% and 3.2% in his hamstrings, respectively*(Table 3)*.

Table 3. Week 18 Isokinetic Test Results

	Week 18 180 degrees/sec	Week 18 Deficit% (180)	Week 18 300 degrees/sec	Week 18 Deficit% (300)
Quad Peak Torque (ft-lbs)	152.1	2.0%	127.4	7.1%
Quad Peak Torque/Body Weight (%)	82.8%	-	68.9%	-
Quad Total Work (ft lbs)	1660.4	11.6%	1369.2	14.7%
Hamstring Peak Torque/Body Weight %	48.9%	-	45.5%	-
Hamstring Total Work (ft.lbs)	1051.8	11.1%	846.1	0.7%

This patient returned to full, unrestricted football practice upon being discharged from physical therapy 140 days after meniscus repair surgery. As of 10-months post medial meniscus repair, he has been without re-injury. He played the fall 2006 football season without complication and is currently playing Division I football as a quarterback.

DISCUSSION

Due to both the neuromuscular and mechanical functions of the menisci of the knee, injury to these structures can be quite detrimental. With improved understanding of these essential roles, surgeons have made a more focused effort on the restoration of knee anatomy by repairing a torn meniscus when feasible.[10] Efforts have been made to guide the rehabilitation from meniscus repair surgery, but no definitive consensus exists on the most effective approach to rehabilitation. Advocates exist for both conservative[13,14] and aggressive rehabilitation.[15, 16]

The rehabilitation guidelines in this case follow early conservative, progressive neuromuscular training, and aggressive functional progression. This patient was limited in weight bearing and closed kinetic chain positions early in his rehabilitation, which correlates with conservative guidelines.[13, 14] However, the patient was also allowed to perform resistive hamstring muscle exercises as soon as week-4, versus week-6 in conservative protocols.[13,14] Additionally, no previous studies have strongly advocated neuromuscular training.[3,8,17] This patient performed extensive neuromuscular training and reactive neuromuscular training early in rehabilitation as soon as weight bearing was permitted and within his restrictions of motion and pain. As this patient was allowed greater angles of knee flexion during closed chain activities, exercises were designed to progressively strengthen, retrain neuromuscular control, and functionally stress the knee and meniscus in the newly allowed range. It is postulated this approach bridged the gap between early protection and progressive neuromuscular training to the aggressive, stressful stages of functional progression and sport specific activities. Conservative approaches outline early restrictions lasting for up to 6 weeks, with some calling for no pivoting activities or deep squatting beyond 125 degrees of flexion for 4 to 6 months.[11] Simply avoiding these types of activities for this duration does not prepare the patient for resuming the activities that involve deep squatting or pivoting, especially in an athletic population. The approach presented in this case outlines progressive neuromuscular training and clinical decision-making process to adequately prepare the patient for returning to these activities.

The individual needs of the patient need to be taken into consideration when addressing return to sport. Many authors have called for the examination of the sport specific demands of the individual when considering the timeframe for safe return,[15,17] similar to this rehabilitation program. Studies suggest the type of repair may impact the outcomes of surgery, with vertical suture fixation being favorable over horizontal suture fixation and commercial biodegradable devices.[1,11] Additionally, other factors suggest a higher failure rate, such as avascularity of tear location,[11] complexity and type of tear,[1,11] and compounding injuries such as ACL deficiency.[12]

The patient in this case had favorable conditions for a successful outcome. Although he had a large tear, the tear was in the vascular zone and was a simple longitudinal tear. No other compounding factors existed, and he had a high level of fitness with no previous injuries, and he was of a young age. He was compliant with his early postoperative restrictions; he managed the early swelling, consistently worked on regaining his ROM and quadriceps muscle activation, and was aware of all of his precautions with respect to pain and reactive swelling throughout rehabilitation. The mixed approach was appropriate for this patient due to the rather large meniscus tear and the activity level of this patient. Due to the size of the tear, he needed to be conservative in the early phase of rehab to ensure adequate healing of the repair. Taking into account his activity level and the demands that this patient would be placing on himself in future athletic activities, this patient needed aggressive functional rehabilitation. The approach taken for this patient integrated an early phase conservative approach, progressive neuromuscular and proprioceptive training, and late phase dynamic functional rehabilitation to return to unrestricted athletic activity.

CONCLUSION

This case report outlined rehabilitation guidelines, functional training, and functional outcomes in the rehabilitation of a high school athlete with medial meniscus repair. This patient achieved a successful outcome, returning to competitive football in 140 days (20-weeks) post medial meniscus repair. The guidelines discussed in this case report, as well as criterion-based functional progression, displayed a safe return to competitive athletics, with no reinjury 10-months after surgery. Further studies are needed to accurately examine the healing rates of a repaired meniscus, correlating rehabilitation considerations so that our patients may have an optimal outcome in rehabilitation from meniscus repair.

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