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ACL Research Retreat V

RISK-FACTOR ASSESSMENT: TRUNK AND SPINAL CONTROL

Abstract #1

Influence of Trunk Neuromuscular Control on Run-to-Cut Maneuver: A Risk Factor for ACL Rupture

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Context: Deficits in neuromuscular control of the trunk have recently been correlated to knee injury incidence in collegiate athletes. However, the mechanism by which trunk control may influence ACL injury risk remains unknown. Previous studies have shown that both knee abduction moment and tibial internal rotation moment strain the ACL.

Objective: To determine whether trunk control measures are correlated to knee abduction and tibial internal rotation moments during unanticipated run-to-cut maneuvers.

Design: Descriptive cohort study.[1]

Setting: Controlled, laboratory setting.

Patients or Other Participants: Fourteen subjects (9 male, 5 female; height = 1740.8 ± 98.9 mm; mass = 72.7 ± 14.4 kg; age = 24.3 ± 4.0 yrs) with no current history of lower extremity injury or previous history of lower extremity or abdominal surgery.

Interventions: Trunk neuromuscular control was quantified using a previously described sudden force-release (SFR) device, in which sudden, unexpected perturbations are applied to the trunk at the T10 level via a force-release apparatus. Subjects held a fixed position before the release of an isometric load (30% MVIC) and attempted to maintain that position after the load released. Subjects then performed 45° unanticipated cutting, planting with the dominant foot. Lower extremity kinematics were estimated using the Point-Cluster Technique, and inverse dynamics used to estimate net external knee moments.

Main Outcome Measures: Trunk control in each direction was defined as the average peak angular deviation of the trunk after release of the cable attached from that direction from 3 SFR trials. Normalized peak knee abduction moment (pKAB) and peak tibial internal rotation moment (pTIR) [%BW * ht] from 3 successful cutting trials were calculated. Correlations between trunk control and knee moments during cutting were analyzed.

Results: Significant correlations were found between SFR performance and knee moments during cutting. pKAB during cutting had a significant positive correlation to SFR peak angle in the nondominant direction ($R = 0.665$, $P = .01$), while pTIR during cutting had a significant positive correlation to SFR peak angle in the anterior direction ($R = 0.532$, $P = .05$). Correlations between pKAB and peak angle after back and dominant side SFR approached, but did not reach, significance. pTIR was not correlated with any other SFR peak angle.

Conclusions: The significant correlations between both lateral and anterior/posterior trunk control and pKAB and pTIR suggest that trunk control directly affects the dynamic mechanical environment of the knee. In this study, the different directions used in the sudden force-release task were found to be specific to the two knee moments examined. pKAB was correlated to lateral performance on the nondominant side but not to anterior performance, while pTIR was correlated to anterior performance but not to lateral performance. These results suggest that the different muscles of the trunk are recruited differently to control coronal vs. transverse plane knee moments.

Previously presented at the 56th Annual Meeting of the Orthopaedic Research Society; March 6–9, 2009; New Orleans, LA.

Abstract #2

Frontal Plane Trunk Position: Compensatory Strategy for Decreased Hip Strength

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Context: Decreased hip strength has been suggested to contribute to dynamic malalignment of the lower extremity during landing tasks. However, a relationship between hip strength and lower extremity joint motion has not been confirmed. To date, the frontal plane position of the trunk has not been examined. If the trunk's mass is more axially positioned, relative to its base of support, it would decrease the demands on the posterior lateral hip muscles. Thus, it may be a potential compensatory strategy for insufficient hip strength.

Objective: To determine the relationship between hip strength and frontal plane trunk position during a single-leg hop (SLH).

Design: Descriptive cohort.

Setting: Controlled laboratory.

Participants: Seventy three (37 M, 36 F) healthy participants (22.2 ± 3.6 yrs, 169.9 ± 10.2 cm, 71.6 ± 16.1 kg).

Interventions: Hip strength and 3D kinematics during SLH trials were assessed on the dominant stance leg. Hip abduction (standing, hip abducted 5°), external rotation (semireclined, hip flexed 40°, knee flexed 90°), and extension (supine, hip flexed 90°) torques were measured during maximal isometric voluntary contractions using an instrumented dynamometer. SLH trials began while standing on the dominant stance leg and taking a hop forward, landing on the same leg (hop distance = 40% of

height, minimal vertical height = 5″). The peak torque over 3 trials for each strength measure and average frontal plane trunk position at initial ground contact (GRF ≥ 10 N) over 5 SLH trials were used for analysis. Step-wise linear regression determined the extent to which hip torques predicted frontal plane trunk position at initial ground contact.

Main Outcome Measures: Hip abduction, external rotation and extension torques were normalized to body mass (Nm/kg). Frontal plane trunk position (cm) represented the medial/lateral linear displacement of thorax relative to foot center of pressure at initial ground contact.

Results: Means ± SDs for normalized hip abduction, external rotation, and extension torques were 0.71 ± 0.17 Nm/kg, 0.84 ± 0.22 Nm/kg, and 4.35 ± 1.02 Nm/kg, respectively. Frontal plane trunk position at initial contact was 3.0 ± 17.6 cm lateral to the foot center of pressure. Decreased hip extension (R^2 = .417, P < .001), external rotation (R^2_{change} = 0.059, P = .006), and abduction (R^2_{change} = 0.019, P = .116) torques were predictive of greater lateral trunk position (P < .001), explaining 49.5% of the variance

Conclusions: Decreased hip extension and external rotation strength was predictive of increased lateral trunk position at initial contact during a SLH. This laterally positioned trunk may be a compensatory strategy for lesser hip strength by decreasing the demands on the hip musculature to control lower extremity motion. This may be one explanation why no relationship has been established between hip strength and lower extremity joint motion. Future research should consider the influence of trunk position on hip muscle function when examining their role in controlling dynamic joint motion.

Data were collected during a funded appointment supported by NIH-NIAMS Grant R01- AR53172.

Abstract #3

Spinal Control Differences Between the Sexes

Johnson ST, Hoffman MA: Oregon State University, Corvallis

Context: The sexes differ in the performance of functional tasks, such as landing and cutting. However, the underlying control mechanisms responsible for these differences remain unidentified.

Objective: To evaluate spinal control mechanisms and functional neuromuscular variables in males and females.

Design: Cross-sectional.

Setting: Research laboratory.

Participants: Volunteer sample of 19 males (23.0 ± 4.3 yrs, 177.45 ± 5.44 cm, 77.52 ± 13.18 kg) and 18 females (24.7 ± 2.9 yrs, 165.31 ± 5.85 cm, 62.44 ± 8.76 kg).

Interventions: While seated on an isokinetic dynamometer with the ankle of the dominant leg secured at 9°, the following recruitment curves were collected at the soleus: H-reflex, intrinsic presynaptic inhibition (IPI), and extrinsic presynaptic inhibition (EPI). The first derivative of each of the recruitment curves was then determined. Additionally, percent of recurrent inhibition (RI), V-wave (V_{max}:M_{max}), rate of torque development (RTD), and electromechanical delay (EMD) of the soleus were assessed. IPI testing used the paired pulse conditioning protocol (interstimulus interval = 100 ms). EPI was measured through common peroneal nerve conditioning (100 ms conditioning interval). RI was assessed by setting stimulus 1 to 25% of M_{max} and stimulus 2 to M_{max}. V-waves were tested via Mmax stimulation to the tibial nerve during an isometric maximum voluntary contraction (iMVC). Additionally, three trials of iMVC with the instruction to contract as hard and fast as possible were collected to assess RTD. EMD, the time lag between EMG and torque activity, was measured during the RTD trials. A 2 (sex) × 7 (neural variable) MANOVA was used to compare means of the dependent variables.

Results: The Wilks lambda multivariate test of overall differences among groups was statistically significant (P = .001). Univariate between-subjects tests revealed males had significantly greater RI (males = 0.86 ± 0.21, females = 0.68 ± 0.30; P = .042). Males also had greater RTD (males = 387.93 ± 180.90 n·m·s^{-1}, females RTD = 263.89 ± 85.15 n·m·s^{-1}; P = .033). The sexes did not differ on first derivative of the following: H-reflex (males = 9.80 ± 3.71, females = 10.38 ± 4.58, P = .773), IPI (males = 2.23 ± 2.27, females = 2.14 ± 2.23, P = .778), or EPI (males = 8.39 ± 4.15, females = 9.79 ± 6.15, P = .668). V-waves (males = 0.22 ± 0.21, females = 0.27 ± 0.17, P = .526) and EMD (males = 46.35 ± 29.76 ms, females = 58.50 ± 23.47 ms, P = .278) were not different.

Conclusions: The sexes differ on modulation of spinal control of movement and activation of the neuromuscular system. Males were able to produce maximal torque more quickly than females. Additionally, RI, a postsynaptic regulator of torque output, was greater in males. Based on these findings, males and females clearly utilize neural control mechanisms differently.

Previously presented at the 60th National Athletic Trainers' Association Annual Meeting and Clinical Symposia; June 17–20, 2009; San Antonio, TX.

Abstract #4

H-Reflex Profile Differences Between the Sexes

Hoffman MA: Oregon State University, Corvallis

Context: Based on a vast collection of biomechanical studies it is widely accepted that men and women move differently in landing and cutting tasks. However, there is little understanding of potential neural control differences between the sexes that may contribute to these observed differences in gross motor tasks.

Objective: The objective was to compare spinal reflex profiles between men and women.

Design: A cohort study design was utilized.

Setting: The study took place in a controlled laboratory setting.

Patients or Other Participants: Twenty-eight regularly menstruating women (mean age = 22.4 ± 3.4 yrs) and 15 men (mean age = 22.3 ± 3.7 yrs) participated in the study. Subjects were recruited from a university setting and none had ever experienced a significant lower extremity injury. Each subject volunteered and provided informed consent.

Interventions: As part of the larger study, the women reported to the laboratory for testing every other day during the course of one menstrual cycle. The control male subjects reported to the lab for testing every fourth day over 28 days. To account for unequal data points between the sexes, only female data points corresponding in time to the male control data points were utilized for analysis. This resulted in both sexes having data from every fourth day. These 7 data points were averaged and used for analysis. Each data point represents the ratio between the maximum H-reflex and maximum M wave (Hmax/Mmax ratio) collected on that day. These responses were elicited in the soleus muscle through the use of 1-ms square wave pulse delivered to the tibial nerve in the popliteal fossa. EMG electrodes were placed on the soleus muscle of the right

leg to measure the evoked responses. Sex was the sole independent variable.

Main Outcome Measures: The dependent variable was the mean Hmax/Mmax ratio in the soleus muscle. A two-sample *t* test was used to determine if the Hmax/Mmax ratio was different between the two sexes ($\alpha = .05$).

Results: The mean ratio for the women (0.86 ± 0.017) was significantly higher ($P < .001$) than the mean ratio for the men (0.58 ± 0.019).

Conclusions: These data are part of a larger project in which the relationships between spinal reflexes and sex hormones were reported to be minimal. The current analysis clearly shows the Hmax/Mmax ratio is higher in women. Interestingly, the Hmax/Mmax ratio is also known to be lower in power-trained individuals compared to endurance runners. It remains unclear as to why this ratio is higher in some groups or populations, but several authors have speculated that a lower ratio suggests a greater ability to produce explosive movements.

RISK-FACTOR ASSESSMENT: MUSCLE STRENGTH AND FATIGUE

Abstract #5

Muscle Strength Differences in Elite Female Team Handball and Football Players With and Without Previous Anterior Cruciate Ligament Injuries

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Context: Anterior cruciate ligament (ACL) injuries represent a serious problem among female team handball and football players and require several months of rehabilitation. The players are recommended to regain muscle strength to the level of at least 90% of their uninjured leg before returning to sport. However, previous studies have shown side differences in strength even several years after injury.

Objective: To assess side differences in muscle strength among elite female handball and football players with and without a previous unilateral ACL injury.

Design: Cross-sectional study.

Setting: Controlled, laboratory.

Methods: This study is part of a large cohort study aimed to investigate risk factors for noncontact ACL injuries among elite female handball and football players. Since study start in 2007, a total of 425 players from the Norwegian elite handball ($n = 233$) and football league ($n = 192$) have been included. Of these players, 42 (9.9%) had previous ACL injuries (left, 21; right, 16; bilateral, 5).

Main Outcome Measures: All players have been tested for isokinetic concentric muscle strength of the quadriceps and hamstrings muscles at 60°/s. Strength normalised to body weight was compared between players with unilateral injuries ($n = 37$) and noninjured players ($n = 377$) and between the injured and noninjured leg for injured players. Players with bilateral injuries or incomplete test results were excluded ($n = 11$).

Results: There were no muscular side-to-side differences observed among the noninjured players. Players with a previous injury were significantly stronger in their noninjured leg compared to their injured leg, both for quadriceps (2.52 vs 2.33 Nm/kg, $P = .001$) and hamstrings (1.49 vs 1.40 Nm/kg, $P = .001$). However, there were no strength differences between the injured leg compared to noninjured players, neither for quadriceps (2.33 vs 2.39 Nm/kg, $P = .35$) nor hamstrings (1.40 vs 1.39 Nm/kg, $P = .85$). Injured players were significantly stronger in their noninjured leg compared to noninjured players, both for quadriceps (2.52 vs 2.39 Nm/kg, $P = .01$) and hamstrings (1.49 vs 1.39 Nm/kg, $P = .001$). These findings did not differ between handball and football players.

Conclusions: There was no difference in muscle strength between noninjured players and the injured leg of players with a previous ACL injury. Previously injured players were significantly stronger in their noninjured leg compared to their injured leg and compared to players with no previous injury. Side-to-side differences among injured players may leave them prone to new injuries.

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Abstract #6

A Single Session of Repeated Wingate Anaerobic Tests Caused Alterations in Peak Ground Reaction Force During 60-cm Drop Landings

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Context: Anterior cruciate ligament (ACL) injury is prevalent in individuals participating in sports, specifically females. Numerous variables have been reported as predisposing factors. Muscle fatigue contributes to alteration in landing mechanics, predisposing athletes to knee injury.

Objectives: To investigate the effects of a single session of repeated muscle fatigue on ground reaction forces (GRF) during drop landings.

Design: A univariate ANOVA with repeated measures was used to determine differences between gender, fatigue, and GRF. Rate of perceived exertion (RPE), peak power, mean power, and percent power drop were collected to assess fatigue and effort during the fatigue protocol.

Setting: Controlled laboratory setting.

Participants: Ten female (22.5 ± 0.85 yrs) and ten male (24.1 ± 2.6 yrs), healthy recreational athletes involved in jumping sports at least twice a week with no history of lower extremity injury, cardiovascular disease, pulmonary disorder, or any previous injury that would impair them from exercising.

Intervention: Participants performed five experimental conditions. The first condition consisted of five nonfatigued double-leg drop landings from a 60-cm platform onto a force platform, followed by four conditions of a fatigue protocol. Fatigue was induced by a 20-sec Wingate Anaerobic Test (WAT). Following each fatigue condition, participants completed two drop landings with 30 sec rest between drops and 5 min of active rest that included 4 min of cycling at 60–70 W resistance between each fatigue condition. All drop landings were averaged for each condition and peak force was normalized to body weight.

Main Outcome Measures: Kinetic data was used to identify peak magnitude of force for forefoot force (F1), rearfoot force (F2), anterior/posterior (AP), and medial/lateral (ML) at both F1 and F2.

Results: No main effect was observed between gender across all GRF variables. A main effect was observed ($P \leq .05$) between the nonfatigue and fatigue conditions in respect to peak F2 force. The greatest significant difference was shown

between the first fatigue drop landing condition (F2 = 7.15 ± 2.68 bw) compared to the last fatigue drop landing condition (F2 = 9.38 ± 2.19 bw) in respect to peak F2 ($P \leq .05$). No difference was observed between gender and peak F2 ($P \leq .05$), and no difference was observed across AP and ML at peak F1 and F2.

Conclusions: A single session of repeated bouts of muscle fatigue induced by WAT caused an initial reduction in peak F2 followed by an increase in peak F2 across conditions. Muscle fatigue consequently alters landing kinetics, potentially increasing the risk for an ACL injury by increasing joint stiffness.

Abstract #7

The Effect of Hamstrings Fatigue on Landing Knee Mechanics

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Context: The function of the hamstrings (HAMS) in protecting the knee joint from injury is not fully understood. During participation in sport, muscles may become fatigued and the hamstrings may lose their potential ability to protect the ACL. One approach to understanding the role of the hamstrings is to selectively impair their function and observe acute compensating effects.

Objective: To determine the effects of weakened hamstrings on knee mechanics during single-leg side cut maneuvers.

Design: Descriptive cohort study design.

Setting: Controlled laboratory setting.

Patients or Other Participants: Ten female healthy college-aged participants (21.3 ± 1.2 years, 170 ± 5 cm, 64.8 ± 9.0 kg) with no current or previous history of lower extremity injury that would affect the alignment of the lower limb.

Interventions: Two experimental sessions were conducted. In both sessions, HAMS strength was reduced through a 180°/sec concentric HAMS fatigue protocol on an isokinetic dynamometer. The first two sets consisted of 40 repetitions and the final set continued until 3 consecutive repetitions fell below 25% of the participant's peak knee flexor torque. In one session, strength recovery of the HAMS were assessed 75 seconds postexercise on the dynamometer, which was the time required in the next session to begin recording landing mechanics. In the next session, three-dimensional stance-leg knee kinetics and kinematics were collected on single-leg stride land and cut maneuvers (LC) before and after the exercise protocol. Single-leg vertical jumps (VJ) were also collected as an indicator of fatigue state.

Main Outcome Measures: Three-dimensional stance leg knee kinetics and kinematics were calculated and reported as touchdown angles, ranges of motion, and peak moments during stance phase. PRE- and POST-exercise HAMS strength, VJ jump height, and LC stance leg knee mechanics were analyzed using paired *t* test ($P < .05$).

Results: HAMS strength was significantly reduced (PRE = 59.4 ± 5.6 Nm, POST = 54.7 ± 8.5 Nm, $P = .03$). However, VJ height was not significantly different (PRE = 0.13 ± 0.03 m, POST = 0.12 ± 0.3 m, $P = .08$). During the LC maneuvers there were no significant differences in touchdown angles in any plane, but there was decreased range of motion in the transverse plane (PRE = 16.5 ± 7.5°, POST = 13.9 ± 7.2°, $P = .02$). The peak extensor moment also decreased (PRE = 2.75 ± 0.60 Nm/kg, POST = 2.55 ± 0.42 Nm/kg, $P = .03$).

Conclusions: The fatigue protocol resulted in decreased HAMS muscle force that had not fully recovered by the time postexercise landing data were collected. The kinematic and kinetic changes suggest a protective landing strategy was employed by the subjects. Post hoc analysis revealed that the decreased knee extension moment was also accompanied by a decreased hip extensor moment. Given the hamstrings role in assisting hip extension, the decreased knee extension moment was likely in response to the hip. The results indicate that the role of the hamstrings at the knee are complicated by its biarticular role.

Abstract #8

Changes in Lower Extremity Coordination and Variability Following Neuromuscular Fatigue and Verbal Feedback

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Context: Evaluation of movement coordination may provide more integrated information than traditional biomechanical methods with respect to ACL injury risk factors. Relative phase (RP) measures of motion based on dynamical systems theory allow movement coordination and stability to be analyzed for an entire extremity. Few ACL injury risk-factor studies have incorporated RP measures, and none has been performed using fatigued, unanticipated motions. Additionally, it is unclear how interventions like verbal feedback influence these measures.

Objective: To quantify effects of fatigue and verbal feedback on coordination and variability of the lower extremity during an unanticipated cutting task.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Fifty-nine club-sport athlete volunteers (31 M, 28 F; 19.8 ± 1.6 yrs, 176.7 ± 9.2 cm, 71.2 ± 10.0 kg) were randomly assigned to either receive verbal feedback (FB) or no feedback (NFB) postfatigue.

Interventions: Subjects performed an unanticipated sidestep cutting task using their dominant leg. Subjects jumped over a hurdle onto a force platform and responded to a randomized directional cue by cutting 60° in the indicated direction. Participants then performed a fatigue protocol, followed by reassessment of the sidestep cutting task. During this second assessment the FB group received instruction to "land softly, keep the knee over the toes, and make the movement smooth," while the NFB group received no instruction.

Main Outcome Measures: Sagittal and frontal plane segment angles and velocities were calculated relative to the global reference system for the foot, shank, thigh, and trunk. Phase-plane plots and RP angles were created for each segment, continuous RP portraits for each segment pairing (foot-shank, shank-thigh, and thigh-trunk) were generated, and the mean absolute relative phase (MARP) and deviation phase (DP) derived. Comparisons were made between the FB and NFB groups prefatigue and postfatigue using mixed-model ANOVAs with Bonferroni post hoc tests ($\alpha < .05$).

Results: Significant fatigue × group interactions for coordination (MARP) were observed in the sagittal plane for foot-shank ($F_{1,55} = 4.641$, $P = .036$), shank-thigh ($F_{1,55} = 4.719$, $P = .034$), and thigh-trunk ($F_{1,55} = 4.967$, $P = .030$), and in the frontal plane for shank-thigh ($F_{1,55} = 4.464$, $P = .039$) and thigh-trunk ($F_{1,55} = 7.708$, $P = .008$). The NFB group displayed decreased sagittal plane MARP for the foot-shank (−18.3%), shank-thigh (−12.7%), and thigh-trunk (−10.8%), while FB

resulted only in decreased thigh-trunk frontal plane MARP (−13.1%). Significant main effects for fatigue were also observed for variability (DP). Fatigue caused decreased DP for foot-shank sagittal plane (−11.9%, $F_{1,55} = 13.634$, $P = .001$), foot-shank frontal plane (−19.1%, $F_{1,55} = 41.262$, $P < .001$), shank-thigh sagittal plane (−7.3%, $F_{1,55} = 4.078$, $P = .048$), and shank-thigh frontal plane (−13.1%, $F_{1,55} = 21.093$, $P < .001$).

Conclusions: Fatigue causes a more in-phase coordination pattern and a loss of variability during unanticipated sidestep cutting. However, feedback counteracts the coordination changes, suggesting cognitive control over movement organization. These results suggest feedback may be used to acutely retain motion patterns in the lower extremity, which may help prevent ACL injury postfatigue.

RISK-FACTOR ASSESSMENT: ANATOMICAL AND HORMONAL

Abstract #9

Relationship of Foot Type and Fatigue to Hip Neuromuscular Control and Lower Extremity Kinetics

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Context: Hip strength, muscle activation, and fatigue affect lower extremity alignment. Foot type may influence hip biomechanics and landing force attenuation and contribute to noncontact ACL injury risk.

Objective: To determine the effect of foot type and fatigue on hip neuromuscular control and lower extremity kinetics during a functional landing task.

Design: Cross-sectional design.

Setting: Research laboratory.

Patients or Other Participants: Twenty-four healthy National Collegiate Athletic Association Division I male and female athletes with either a rectus or planus foot type (14 rectus: 19.5 ± 1.7 years, height = 166.1 ± 6.7 cm, mass = 64.1 ± 4.9 kg, navicular drop = 7.1 ± 0.92 mm; and 10 planus: 20.1 ± 1.3 years, height = 169.2 ± 7.3 cm, mass = 68.4 ± 8.4 kg, navicular drop = 11.9 ± 2.0 mm) volunteered to participate.

Interventions: Independent variables were foot type (planus and rectus) and fatigue (pre and post). Vernier calipers were used for the navicular drop test to measure arch height. A MicroFET Hand-Held Dynamometer was used to measure hip strength, a Noraxon Telemyo Electromyography (EMG) system was used to measure muscle activation, and a Kistler 9287-BA Force Plate was used to measure lower extremity kinetics during a standing broad jump-to-vertical jump maneuver in both prefatigue and postfatigue conditions. Statistical analyses consisted of multiple analyses of variance (ANOVA) and *t* tests. Alpha level was set at $P \leq .05$.

Main Outcome Measures: Dependent variables were hip extensor, abductor, and external rotator strength (pounds); EMG activation for the gluteus maximus, gluteus medius, and biceps femoris (reactive area by %MVC); and peak vertical, anterior shear, medial shear, and lateral shear ground reaction forces; and rate of loading at ground contact.

Results: ANOVA tests revealed the following significance: Postfatigue, the planus group showed a 49% decrease in biceps femoris EMG area ($F = 4.53$, $P = .045$, pre = 22.67 ± 18.94, post = 11.45 ± 9.78), a 35% decrease in coagonist gluteus maximus and biceps femoris EMG area ($F = 5.47$, $P = .029$, pre = 41.26 ± 27.83, post = 26.77 ± 20.42), and a 31% increase in medial shear force ($F = 50.72$, $P = .001$, pre = .174 ± .030, post = .228 ± .030). Rate of lower extremity loading decreased 24% postfatigue ($F = 16.97$, $P = .001$, pre = 56.83 ± 21.81, post = 43.43 ± 23.35) for both groups. No other significant differences were noted between foot types or prefatigue and postfatigue.

Conclusions: Under fatigue, athletes with a planus foot type have a reduced capacity to attenuate medial shear force. This may influence hip muscle activation strategies and lower extremity force attenuation, potentially increasing the risk of knee valgus and noncontact ACL injury.

Previously presented at the 60th Annual National Athletic Trainers' Annual Meeting and Clinical Symposia: Stearne DJ, Sato N, Sitler MR, Tierney RT. Relationship of foot type and fatigue to hip neuromuscular control and lower extremity kinetics; June 17–20, 2009; San Antonio, TX.

Abstract #10

The Relationship Between Hamstring Properties and Anterior Knee Joint Stability

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Context: The ACL is loaded via anterior tibial translation (ATT), and excessive ATT has been identified prospectively as an ACL injury risk factor. ATT lengthens the hamstrings, and the hamstrings respond by generating tensile force which resists further lengthening. Stiffness refers to the ratio of change in force to change in length (ΔForce/ΔLength), and stiffer hamstrings may limit ACL loading by providing greater resistance to ATT. Hamstring strengthening is essential to ACL injury rehabilitation and prevention, and likely influences the hamstrings' ability to resist ATT. However, the relationships between these hamstring properties and ATT have yet to be identified.

Objective: To evaluate relationships between hamstring stiffness, hamstring strength, and ATT. We hypothesized that hamstring stiffness and strength would be positively correlated, greater stiffness and strength would correspond with less ATT, and the correlation between stiffness and ATT would be stronger than that for strength and ATT.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Thirty healthy, physically active volunteers (15 males, 15 females; mass = 74.9 ± 18.1 kg; height = 1.7 ± 0.1 m, age = 22.7 ± 2.4 years).

Interventions: Hamstring stiffness was assessed by evaluating the damping effect imposed by the hamstrings on oscillatory knee flexion/extension (ICC [2,1] = 0.70; SEM = 1.63 N/cm). ATT was assessed by applying a 20% body weight load to the posterior proximal shank via a custom-built perturbation device and was defined as the difference in anterior displacements of electromagnetic motion-capture sensors on the thigh and shank (ICC [2,1] = 0.98; SEM = 1.49 mm). Hamstring strength was defined as the peak force during maximal isometric contraction.

Main Outcome Measures: Pearson correlation coefficients were used to evaluate relationships between hamstring strength, hamstring stiffness, and ATT. Stiffness and strength distributions were arranged into tertiles (n = 10), and ATT was compared between highest and lowest tertiles using independent-samples *t* tests. All dependent variables were correlated with body mass and, thus, were standardized to body mass prior

to analysis. Statistical significance was established a priori as $\alpha \leq .05$.

Results: ATT was correlated with hamstring stiffness ($r = -0.51$, $P < .01$) but was not related to hamstring strength ($r = -0.08$, $P = .67$). Hamstring stiffness and strength were not correlated ($r = 0.05$, $P = .78$). ATT was greater in the lowest hamstring stiffness tertile compared to the highest tertile (0.20 vs. 0.07 mm/kg; $P = .011$) but did not differ between lowest and highest hamstring-strength tertiles (0.15 vs. 0.10 mm/kg; $P = .362$).

Conclusions: Individuals with greater hamstring stiffness demonstrate less ATT. As musculotendinous stiffness can be modified via numerous mechanisms, these findings suggest that enhancement of hamstring stiffness may be an important consideration for future ACL injury prevention programs.

Abstract #11

Cyclic Variations in Varus/Valgus and Internal/External Torsional Knee Joint Laxity and Stiffness Across the Menstrual Cycle

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Context: Greater joint laxity continues to be implicated as an ACL injury risk factor. Females have greater anterior knee laxity (AKL), genu recurvatum (GR), general joint laxity (GJL), and varus-valgus (VV_{LAX}) and internal-external (IER_{LAX}) rotational laxities (and decreased stiffness; VV_K, IER_K) compared to males. Although these sex differences may be mediated by sex-hormone concentration changes across the menstrual cycle, only AKL has been examined.

Objective: To examine whether cyclic variations in AKL are accompanied by cyclic variations in GR, GJL, VV_{LAX}, IER_{LAX}, VV_K, and IER_K.

Design: Females were prospectively measured on AKL for 6 days after menses onset and 8 to 10 days postovulation over two cycles. In the subsequent month, females and males were measured for laxity and stiffness at two time points (the estimated day of minimum [T1] and maximum [T2] AKL in females; males matched in time interval).

Setting: Controlled laboratory.

Participants: Recreationally active females (normal menstruating) (N = 64; 21.5 ± 2.7 yrs, 164.3 ± 6.9 cm, 61.2 ± 8.7 kg) and males (N = 43; 22.3 ± 2.8 yrs, 177.5 ± 9.5 cm, 80.1 ± 12.0 kg).

Interventions: AKL was measured as the anterior displacement of the tibia relative to the femur at 133-N anterior-directed load. GR was measured in supine as active knee hyperextension. GJL was measured using the Beighton and Horan Joint Mobility Index. VV_{LAX} and VV_K were assessed across 0 to 10 Nm of VV loadings. IER_{LAX} and IER_K were assessed across 0 to 5 Nm of IER loadings. Reliability was established on all laxity measures (ICC [2,3], SEM = 0.96 [0.3 mm] for AKL, 0.97 [0.5°] for GR, 0.99 [0.3] for GJL, 0.70 to 0.96 [2° to 4°] for VV_{LAX} and IER_{LAX}).

Main Outcome Measures: Repeated measures ANOVAs compared males and females between T1 and T2 on AKL (mm), GR (°), GJL (score 0 to 9), VV_{LAX} (° at 10 Nm), IER_{LAX} (° at 5 Nm), and incremental VV_K (Nm/° per 2-Nm increment) and IER_K (Nm/° per 1-Nm increment).

Results: Females increased AKL, GR, and GJL from T1 to T2, resulting in 9.5% vs. 3.7% greater AKL, 31.4% vs. 2.7% greater GR, and 56.0% vs. 52.6% greater GJL in females vs. males at T2 vs. T1, respectively (All $P < .028$). A sex × time interaction revealed 37% vs. 26.9% less overall VV_K stiffness in females than males at T2 vs. T1 ($P = .001$), and this was consistent across increment ($P = .454$). Although sex × time interactions were not observed for VV_{LAX}, IER_{LAX}, or IER_K ($P = .320$ to .758), females had 30.2% greater VV_{LAX}, 20% greater IER_{LAX}, and 24.3% less overall IER_K (sex main effects, $P < .001$).

Conclusions: Cyclic increases in AKL were accompanied by cyclic increases in GR and GJL and decreases in VV_K. While VV_{LAX}, IER_{LAX}, or IER_K did not vary by time, females were consistently more lax/less stiff than males. Whether these findings implicate changes in injury risk potential across the menstrual cycle is not yet known.

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Abstract #12

Presence of a Bony Ridge on the Anteromedial Aspect of the Femoral Intercondylar Notch Among Noncontact ACL Injured Patients

Everhart JS, Flanigan DC, Chaudhari AMW: Ohio State University, Columbus

Context: While notch width has been previously examined as a risk factor for noncontact ACL injury, evaluation of the femoral notch along the path of the ACL may elucidate risk factors previously unseen with conventional imaging.

Objective: To determine whether the geometry of the anteromedial outlet of the intercondylar notch differs between noncontact ACL injured patients and matched controls.

Design: Retrospective case-control study.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Fifty-four volunteers were recruited (20 female, 34 male), resulting in twenty-seven case-control pairs matched for gender, height, weight, and age. Cases consisted of subjects who have previously sustained a noncontact ACL injury, and controls consisted of subjects with no prior history of knee injury.

Interventions: Sagittal MRIs of the contralateral knee of injured subjects and randomized knees of the healthy subjects were examined. The uninjured knee was utilized among injured subjects because of the common practice of intraoperative widening of the femoral notch during primary ACL reconstruction and to permit blinded observation of femoral-notch characteristics.

Main Outcome Measures: Distal femurs were segmented from MRIs, and the computer-generated surface models were evaluated for abnormalities of femoral-notch outlet shape. MR datasets were also digitally transformed to enable measurements of notch narrowing in the oblique plane containing the ACL. When determining the presence of a bony ridge or measuring notch narrowing, the evaluator was blinded to injury status. Fisher exact tests were utilized to compare the presence of an anteromedial bony ridge between injured and healthy subjects, and stepwise regression was utilized to compare the strength of the associations of notch narrowing and the bony ridge to noncontact ACL injury.

Results: Presence of a bony ridge at the anteromedial notch outlet was strongly associated with noncontact ACL injury ($P = .0002$, 24/27 injured v. 11/27 uninjured). Anterior and posterior femoral-notch outlet widths were both associated with noncontact ACL injury when considered independently ($P = .0008$, $R^2 = 0.18$, 14.5 ± 2.9 mm; $P = .02$, $R^2 = 0.08$, 21.76 ± 2.62 mm, respectively), though the final regression model only included posterior outlet width and presence of the anteromedial bony ridge ($R^2 = 0.31$, $P < .001$).

Conclusions: The presence of an anteromedial bony ridge in the femoral notch has been identified as a potential risk factor for noncontact ACL injury. A biomechanical injury model involving the femoral-notch ridge in ACL tears is proposed in which the ACL may be tented and stretched over the anteromedial-notch ridge during knee valgus and internal tibial rotation; alternatively, the ACL may be impinged at the lateral anterior outlet wall during knee valgus and external tibial rotation. Further investigation to determine the etiology of the bony ridge and the validity of the proposed injury model is recommended.

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POSTER PRESENTATIONS: SESSION I

Abstract #13

Sex Differences in Lower Extremity Alignment in Japanese Collegiate Athletes

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Context: Sex differences in lower extremity alignment (LEA) have been previously identified as risk factors for noncontact anterior cruciate ligament (ACL) injuries. As athletes participate in competitive sport for extended periods of time, they may have altered LEA secondary to sport-specific demands on the body and subsequent adaptations to these stresses. Differences in LEA sex differences may exist in competitive athletes than those reported in nonathletic populations.

Objective: To examine sex differences in lower extremity alignment measurements in competitive collegiate athletes.

Design: Descriptive cohort design.

Setting: Controlled, laboratory.

Patients or Other Participants: A total of 110 (50 males, 61 females) Japanese competitive athletes (167.7 ± 9.25 cm, 62.4 ± 9.7 kg, 19.7 ± 1.1 yrs, yrs of sport participation: 9.3 ± 2.9 yrs) with no current lower extremity injuries.

Interventions: We measured the quadriceps angle (QA, °), tibiofemoral angle (TFA, °), hip anteversion in both prone (HVprn, °) and supine (HVspn, °), genu recurvatum (GR, °), and navicular drop (ND, mm). The average values of three measurements in each alignment for each subject were used for analyses. All measures were performed on the right side. Independent-sample *t* tests examined sex differences ($P \leq .05$).

Main Outcome Measures: QA, TFA, HVprn, HVspn, and GR were measured to the nearest degree while ND was measured to the nearest millimeter.

Results: Day-to-day measurement consistencies for all measures were excellent (ICC [2,k] ranges: 0.90–0.97). There were significant differences in QA ($t = -5.097$, $P < .001$; male = 14.2° ± 3.4°, female = 17.4° ± 3.3°) and TFA ($t = -2.825$, $P = .006$; male = 8.1° ± 2.4°, female = 9.4° ± 2.2°), while no significant differences were found in HVprn ($t = 0.646$, $P = .653$; male = −4.4° ± 5.9°, female = −5.2° ± 6.6°), HVspn ($t = 0.112$, $P = .911$; male = 14.9° ± 6.4°, female = 14.8° ± 6.4°), GR ($t = 0.680$, $P = .498$; male = 0.5° ± 3.7°, female = 0.0° ± 4.3°), and ND ($t = 0.474$, $P = .636$; male = 6.6 ± 4.5 mm, female = 6.3 ± 3.3 mm).

Conclusions: Japanese competitive collegiate athletes exhibited significant sex differences only in TFA and QA, while the other 4 LEA measures did not show sex differences. Japanese female athletes who have had extended participation in competitive sports may not show the same sex-specific LEA characteristics as those in nonathletic populations, as previously reported. However, even in such a competitive athletic population, Japanese female athletes showed greater QA and TFA than male athletes. These two LEA characteristics may be important risk factors for ACL injuries in female collegiate athletes. However, such sex-specific characteristics may be unique in Japanese collegiate athletes, and research should further elucidate if LEA sex differences differ among different populations or athletes who have participated in different sports.

Abstract #14

Influence of Hip Motion, Strength, and Postural Alignment on Hip Internal-Rotation Angle: The JUMP-ACL Study

Goto S*, Marshall SW*, Beutler AI†, Boling MC‡, Goerger BM*, Padua DA*: *University of North Carolina at Chapel Hill; †Uniformed Services University of the Health Sciences, Bethesda, MD; ‡University of North Florida, Jacksonville

Context: Hip internal rotation (HIR) influences knee valgus motion and is a risk factor for ACL injury. Understanding factors that influence HIR may improve our understanding of ACL risk factors and ability to decrease ACL injury risk.

Objective: To determine the association between HIR during a jump-landing task with hip and knee kinematics, muscle strength, and postural alignment.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: A total of 2622 healthy, physically active subjects (M = 1602; F = 1060; age = 18.6 ± 0.6 yrs, ht = 173.5 ± 9.2 cm, wt = 71.9 ± 12.9 kg) subjects volunteered for this study.

Interventions: Joint angles were measured during a jump-landing task using an electromagnetic motion analysis system. The jump-landing tasks consisted of subjects jumping from a 30-cm-high box, landing on a force plate set at 50% distance of participants' height, followed by an immediate vertical jump. Muscle strength was assessed during five-second maximal voluntary isometric contraction trials for each muscle tested using a handheld dynamometer. Postural alignment was quantified using the navicular drop (mm) and quadriceps angle (Q angle, °) tests.

Main Outcome Measures: Joint angles at initial contact (IC) (vertical ground reaction force >10 N) and peak (PK) during the landing phase (IC to first local minimum in vertical ground reaction force) were assessed and averaged across three trials. The following motions were analyzed: hip abduction, hip rotation, hip flexion, knee valgus, and knee flexion. Mean strength values for the hip extensors, hip external rotators, hip internal rotators, hip abductors, knee extensors, and knee flexors were assessed and normalized to body weight. The average of 3 navicular drop (mm) and Q-angle (°) values were also determined. Pearson product moment correlations were performed for each of the joint angles, strength, and postural alignment variables. Forward stepwise multiple regression analyses were performed to determine the relationship between HIR PK with joint angles, strength, and postural alignment variables.

Results: The following variables were significantly correlated to HIR PK ($P < .05$): knee extension MVIC ($r = -0.161$), knee flexion MVIC ($r = -0.143$). Regression analyses demonstrated HIR at IC to be the strongest predictor of HIP PK (R^2 adjusted =

0.737, $P < .001$). Other variables were included in the regression model, but together explained less than 2% of HIP PK variance.

Conclusions: Greater hip internal rotation motion during the landing phase was largely influenced by hip rotation position at initial contact. Muscle strength and postural alignment variables did not explain any additional variance in HIR PK. These findings suggest that control of hip internal rotation during landing is largely influenced by neuromuscular control mechanisms associated with initial contact positioning and not strength or postural alignment.

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Abstract #15

The Influence of an External Versus Internal Focus of Attention With Regard to Motor Learning and Skill Acquisition for ACL Injury Prevention

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Context: For a variety of movement skills in select populations (Wulf, 2009, 2004) it has been demonstrated that using an external attentional focus (EAF) during instruction of a motor task, compared to the traditional type of instruction that uses an internal attentional focus (IAF), leads to more effective learning of that motor task.

Objective: To determine whether training programs using EAF lead to more desirable and effective muscle onset patterns compared to training methods using IAF when complex motor tasks to prevent ACL injury are taught.

Design: Descriptive cohort study design.

Setting: Controlled, laboratory setting.

Participants: Thirty-two healthy active female college students (24.5 ± 1.9 yrs) were recruited for the study and randomly assigned to either the EAF (n = 16) or IAF (n = 16) group.

Interventions: Each group of subjects underwent a 6-week, biweekly exercise training program that was specifically designed to prevent ACL injury. The first group received training of the motor tasks using EAF; the second group received the same training but with cues that utilized IAF. Prior to the implementation of the training program and 1 week after the completion of training, all subjects underwent biomechanical testing. Testing included the monitoring of muscle activity using surface EMG on the seven muscles of the dominant lower extremity (LE) during a side-step maneuver.

Main Outcome Measures: A custom MATLAB program was used to determine muscle onset times (seconds) for each muscle from initial foot contact. A nonparametric Wilcoxon signed rank test ($P \leq .05$) was used to compare the muscle onset times between EAF and IAF groups.

Results: Pretraining mean ± SD for the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), gastrocnemius (GS), gluteus medius (Gmed), and gluteus maximus (Gmax) in the IAF group were 0.316 ± 0.29, 0.267 ± 0.33, 0.353 ± 0.29, 0.391 ± 0.26, 0.412 ± 0.22, 0.049 ± 0.27, and 0.149 ± 0.28, respectively. Pretraining mean ± SD in the EAF group were 0.404 ± 0.40, 0.450 ± 0.41, 0.490 ± 0.43, 0.316 ± 0.33, 0.533 ± 0.27, 0.260 ± 0.31, and 0.402 ± 0.45, respectively. Posttraining mean ± SD in the IAF group were 0.271 ± 0.35, 0.091 ± 0.16, 0.203 ± 0.22, 0.386 ± 0.33, 0.500 ± 0.16, 0.210 ± 0.35, and 0.170 ± 0.35, respectively. Posttraining mean ± SD in the EAF group were 0.338 ± 0.37, 0.439 ± 0.43, 0.331 ± 0.34, 0.421 ± 0.32, 0.528 ± 0.22, 0.226 ± 0.35, and 0.273 ± 0.41, respectively. There were no significant differences in muscle onset times for the VM ($P = .881$), VL ($P = .294$), RF ($P = .525$), BF ($P = .433$), GS ($P = .257$), Gmed ($P = .120$), and Gmax ($P = .166$) in the EAF group compared to the IAF group.

Conclusions: Preliminary evidence suggests that training using EAF may not be superior to methods of training using IAF, when used for the instruction of programs designed to prevent ACL injury. Further analysis of data, including the amplitude (magnitude) of muscle activation and kinematic variables for the LE, is warranted prior to confirming the current results.

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Abstract #16

Patterns of Hip Flexion Motion Predict Knee Abduction Torques During a Single-Leg Land-and-Cut Maneuver

Kipp K, McLean SG, Palmieri-Smith RM: University of Michigan, Ann Arbor

Context: Impulsive frontal plane knee joint torques directly strain the anterior cruciate ligament (ACL) and therefore may contribute to ACL injury risk. The ability to predict these deleterious torques based on kinematic movement patterns may assist in the development of screening protocols and aid in the refinement of current injury prevention strategies. Principal component analysis (PCA) provides a means to examine common sources of variation in motion patterns and may prove particularly suitable to establish relationships between lower extremity kinematic movement patterns and peak knee joint torques.

Objective: To establish a prediction model for frontal plane knee joint torques based on motion patterns derived from PCA.

Design: Cross-sectional study.

Setting: Controlled research laboratory setting.

Patients or Other Participants: Convenience sample of 18 healthy NCAA Division 1 (soccer, volleyball, basketball) female athletes (19.2 ± 1.7 yrs) with no history of lower extremity injury.

Interventions: Kinematic and kinetic data were collected while participants performed a single-leg land-and-cut maneuver with their dominant limb. Five trials were collected for each participant. Three degree-of-freedom lower extremity joint angles for the hip, knee, and ankle along with normalized external knee abduction torques were calculated. All data were ensemble averaged across the entire stance phase. The ensemble kinematic data were individually submitted to a PCA. The PCA extracted kinematic principal components (PCs) that were used calculate PC scores. These scores capture unique characteristics associated with the movement pattern at each respective joint. The PC scores were used in a forward stepwise regression model to establish a prediction equation for peak ensemble-averaged knee abduction torque.

Main Outcome Measures: Peak ensemble-averaged external knee abduction torque normalized to body mass and height (N·m/kg·m).

Results: The PCA extracted 3 to 4 PCs for each joint rotation. Collectively, each set of PCs accounted for more than 96% of

the variance for each joint rotation. The regression model accounted for approximately one-third of the variance in knee abduction torque ($R^2 = 0.309$; $P = .017$). Hip flexion PC2 score was the only significant ($P < .05$) PC entered into the regression model (standardized β-coefficient = 0.556) and captured the magnitude of hip flexion motion during the first half of the stance phase.

Conclusions: Greater hip flexion motion during the first half of the stance phase of a single-leg land-and-cut maneuver is associated with greater external knee joint torques in the frontal plane. Injury screening and prevention protocols should consider hip flexion motion upon landing as a modifiable characteristic that could decrease the magnitude of frontal plane knee joint torques and potentially decrease the likelihood of ACL injury.

ACL INJURY-PREVENTION STRATEGIES

Abstract #17

Knee Kinematics During Single- and Double-Legged Jump Landings Following Six Weeks of Neuromuscular Training

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Context: Noncontact anterior cruciate ligament (ACL) injury rates have not diminished despite purported success of neuromuscular training programs (NTP). Current NTP analyze landing mechanics during double-legged jump landings, even though the noncontact injury episode typically occurs during single-legged landing and/or pivoting. Training benefits may not be upheld during single-legged landings, and evaluating these high-risk landings may provide insight as to why ACL injury rates have not decreased.

Objective: To determine the effects of an NTP on lower extremity biomechanics during single-legged and double-legged landings.

Design: Case-control.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Twenty trained (1.64 ± 0.06 m, 59.6 ± 7.2 kg, and 19.2 ± 1.3 years) and eleven control (1.66 ± 0.08 m, 59.9 ± 8.8 kg, and 19.6 ± 1.3 years) female subjects between the ages of 18 and 24 were recruited for participation. Subjects could not have any current lower extremity pain or injury and previous history of lower extremity injury that would affect landing mechanics.

Interventions: Initial contact (IC) and peak stance (PS) phase (0% to 50% of stance) knee kinematics were analyzed during a series of single-leg land-and-cut and double-leg maximal vertical jump landings. Subjects were tested prior to and immediately following a six-week NTP. The NTP was composed of core strength and balance, plyometrics, resistance, and speed components and consisted of three 90-minute sessions per week.

Main Outcome Measures: Subject-based mean values of sagittal, frontal, and transverse plane knee kinematics were submitted to three-way repeated measures ANOVAs to test for the main and interaction effects of group, movement, and time.

Results: PS knee flexion exhibited significant group by time by movement ($P = .008$) interaction. Subjects in the training group (−70.94 ± 8.81°) when completing double-legged landings exhibited greater PS knee flexion following NTP than control participants (−63.66 ± 11.88°; $P < .050$). Furthermore, a significant main effect was noted for movement type. Subjects demonstrated substantially greater ($P < .001$) IC knee flexion (double: −25.38° ± 6.20°; single: −14.32° ± 6.85°) and PS knee abduction (double: −15.46° ± 5.36°; single: 13.43° ± 5.51°) and external rotation (double: −10.31° ± 5.70°; single: −5.31° ± 4.32°) during double-legged landings compared to single-legged landings.

Conclusions: Lower extremity biomechanical adaptations differ between single- and double-legged jump landings following a six-week NTP. Specifically, training participants exhibited greater peak knee flexion during double-legged landings following NTP compared to controls; however, the increased peak knee flexion posture was not apparent during single-legged landings. Current NTP methods may fail to improve single-legged landing mechanics potentially minimizing their potential to reduce ACL injury risk. NTP should incorporate methodologies that improve high-risk single-legged landing mechanics.

Abstract #18

Posttraining Increases in Knee and Hip Flexion During Landing Decrease Tibiofemoral Joint Shear and Compressive Loads

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Context: Most ACL injury prevention programs emphasize greater shock absorption by encouraging greater degrees of hip and knee flexion during landing. However, whether an increase in hip and knee flexion during landing can decrease loading at the knee joint remains unknown.

Objective: To determine whether a landing strategy that utilizes greater knee and hip flexion can decrease tibiofemoral joint shear and compressive forces as quantified using a subject-specific, EMG-driven knee joint model.

Design: Repeated measures design.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Eight (4 M, 4 F) healthy adults (27.4 ± 4.5 yrs, 169.6 ± 6.4 cm, 64.3 ± 9.9 kg) with no history of lower extremity injury.

Interventions: Each participant underwent 2 data collection sessions: 1) biomechanical analysis during a drop land task (EMG, kinematics, and kinetics); and 2) MRI assessment of muscle physiological cross-sectional area (PCSA) and patellar tendon orientation. Participants performed a drop-landing task before and after an instruction session that emphasized greater knee and hip flexion during landing. Muscle activation of the quadriceps, hamstrings, and gastrocnemius was quantified using surface EMG. Tibiofemoral shear and compressive forces during landing were then quantified using a subject-specific, EMG-driven knee model that incorporated lower extremity joint kinematics, EMG, and subject-specific muscle PCSA and patella tendon orientation estimated from MRI.

Main Outcome Measures: The primary dependent variables were the peak anterior tibial shear and tibiofemoral compressive forces (normalized to body mass) during the deceleration phase of drop-landing. Paired *t* tests were performed to examine whether the peak anterior shear and compressive forces decreased after instruction. Secondary analyses were performed to analyze the changes in muscle forces and ground reaction forces that contributed to the peak anterior shear and compressive forces following instruction.

Results: Following instruction, peak hip flexion significantly increased (92.0° ± 19.4° vs. 97.6° ± 18.8°; $P = .019$), as did peak knee flexion (105.3° ± 20.6° vs. 114.6° ± 19.5°; $P =$

.013). The observed increases in hip and knee flexion following instruction was accompanied by a significant decrease in peak tibiofemoral compressive force (75.5 ± 12.1 vs. 66.2 ± 9.3 N·kg^{-1}; $P = .043$) and anterior tibial shear force (12.9 ± 4.5 vs. 11.1 ± 3.7 N·kg^{-1}; $P = .024$). The decrease in the peak anterior tibial shear force was mainly the result of a decrease in quadriceps muscle force (15.5 ± 4.4 vs. 13.2 ± 4.5 N·kg^{-1}; $P = .014$), while the decrease in the peak compressive force was primarily the result of a decrease in the ground reaction force (13.0 ± 4.9 vs. 10.1 ± 4.0 N·kg^{-1}; $P = .048$) and hamstring muscle force (0.4 ± 1.2 vs. −0.2 ± 1.6 N·kg^{-1}; $P = .009$).

Conclusions: Our data support the premise that knee joint loading can be reduced when utilizing a landing strategy that emphasizes greater hip and knee flexion.

Abstract #19

Neuromuscular Warm-Up Reduces Injury Rates Among Female Athletes in Urban Public High Schools: A Cluster-Randomized Controlled Trial

Huxford M*, LaBella C*, Grissom J*, Kim K†, Peng J†, Christoffel K*: *Children's Memorial Hospital, Chicago, IL; †Northwestern University Biostatistics Collaboration Center, Chicago, IL

Context: Neuromuscular training has been shown to reduce lower extremity injuries among certain populations of female athletes. However, few of these studies were randomized, and none focused on athletes from nonwhite racial backgrounds.

Objective: To determine the effect of a structured neuromuscular warm-up on lower extremity injury rates among female soccer and basketball athletes in an urban public high school league, where most students are nonwhite.

Design: Cluster-randomized controlled trial, Level I Evidence.

Setting: Forty-six Chicago public high schools.

Patients or Other Participants: Sixty-three basketball and 31 soccer coaches and their athletes (837 and 655).

Interventions: After stratifying for team competitiveness and school population socio-economic status, we randomized teams by school to intervention (INT) or control group (CON). We instructed CON coaches to use their usual warm-up. We trained INT coaches to implement KIPP (Knee Injury Prevention Program), a 20-minute structured neuromuscular warm-up before team practices. KIPP begins with jogging variations and dynamic stretching, followed by strengthening exercises including push-ups, squats, lunges, planks, and prone lifts, and then proceeds to plyometric exercise that gradually progress over the course of the season from two-legged jumps to single-legged jumps and from jumping in place to travelling jumps. KIPP concluded with agility running, focusing on safe techniques for deceleration and change of direction. Proper form and control were emphasized for all exercise.

Main Outcome Measures: Coaches in both groups submitted weekly reports of athlete exposures and all injuries resulting in a missed practice or game. Study personnel interviewed all injured athletes. We compared injury rates between INT and CON groups with Chi square and Fisher's exact tests. Athletes with parent consent reported race.

Results: Total athlete exposures (AEs) were 28 023 (INT) and 22 925 (CON). INT coaches reported warm-up use in 1425 of 1773 practices (80.4%). Compared to CON athletes, INT athletes exposed to warm-up for ≥50% of practices had significantly lower rates of overuse lower extremity injuries (0.37 vs. 1.22 per AE; $P < .001$), acute, noncontact, lower extremity injuries (0.69 vs. 1.61 per AE; $P < .01$), noncontact ankle sprains (0.28 vs. 0.74 per AE; $P < .05$), and noncontact knee sprains (0.12 vs. 0.48 per AE; $P < .05$), and a lower rate of noncontact anterior cruciate ligament injuries that was marginally significant (0.04 vs. 0.26 per AE; $P = .05$). Of the 1492 athletes, 1078 (55%) had parent consent to report their race: Hispanic (38%), black/African American (37%), white (15%), mixed race (4%), other (6%).

Conclusions: This is the first study demonstrating a neuromuscular warm-up reduces lower extremity injuries in female soccer and basketball athletes in urban, public high schools.

Previously presented at American Medical Society for Sports Medicine (AMSSM) 2009 19th Annual Meeting; April 2009; Tampa, FL. Previously presented at American Academy of Pediatrics (AAP) National Conference and Exhibition (NCE) Council on Sports Medicine and Fitness (COSMF) Program; October 2009; Washington, DC.

Abstract #20

Effects of an Age-Specific Anterior Cruciate Ligament Injury Prevention Program on Cutting Biomechanics in Youth Athletes

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Context: Anterior cruciate ligament (ACL) injury prevention programs may be more effective for reducing injury rates if they are implemented to children at an early age. There is minimal evidence to suggest young athletes can modify potential risk factors for ACL injury after completing an integrated program. An age-specific program that addresses differences in motor development and learning between children and adults may be more effective in children under twelve.

Objective: To compare the effects of pediatric and traditional ACL injury prevention programs on lower extremity biomechanics in youth soccer athletes. We hypothesized the pediatric program would be the most effective program for modifying biomechanics.

Design: Randomized controlled trial.

Setting: Research laboratory.

Patients or Other Participants: Sixty-five healthy youth soccer athletes from seven teams (males: n = 38, mass = 34.2 ± 5.4 kg, height = 143.1 ± 6.3 cm, age = 10 ± 1 years; females: n = 27, mass = 33.8 ± 5.4 kg, height = 141.0 ± 6.6 cm, age = 10 ± 1 years) volunteered to participate. Teams were cluster-randomized to either a pediatric or traditional injury prevention program or a control group.

Intervention(s): Teams assigned to the pediatric or traditional program performed the program as part of a team warm-up two to three times per week for 9 weeks. The pediatric program was modified from previously published ACL injury prevention programs by including basic progressions, additional feedback time, and more variety. The traditional program was similar to previously published programs. The control group did not perform a prevention program. Participants were assessed before (PRE) and after (POST) the intervention period. An infrared video camera system synchronized with a force plate collected three-dimensional lower extremity biomechanics during three trials of a sixty degree sidestep cutting task.

Main Outcome Measures: Change scores (POST-PRE) of three-dimensional hip and knee kinematics and kinetics were

calculated from the average of the three trials. Separate one-way analyses of variance were performed to evaluate group differences ($\alpha \leq .05$). A Bonferroni correction was used for post hoc testing via independent-samples *t* test.

Results: The pediatric program decreased knee external rotation at initial contact compared to the control group after the intervention period ($F_{2,62} = 3.79$, $P = 0.03$; change scores: Pediatric = 7.73° ± 10.71°, Control = −0.35° ± 7.76°). No other significant differences were observed ($P > .05$).

Conclusions: Athletes under age twelve were only able to modify transverse-plane knee kinematics during a cutting task after completing an ACL injury prevention program regardless of whether the program was tailored to their developmental abilities. These findings suggest children under age twelve may not be responsive to injury prevention programs. This is one of the first studies to evaluate cutting biomechanics after injury prevention programs, so future research should evaluate simpler tasks in this population.

Abstract #21

The Effect of Core Stability and Plyometric Training Programs on Hip Biomechanics During a Drop Vertical Jump in High School Female Athletes

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Context: Anterior cruciate ligament (ACL) injuries are common in female athletes and are related to poor neuromuscular control. The hip serves as the proximal stabilizer for the knee and neuromuscular deficits may increase ACL injury risk. Alterations in biomechanical patterns have been shown as a result of comprehensive neuromuscular training programs. It is unknown which component of these programs are responsible for the neuromuscular alterations.

Objective: To assess the efficacy of either a 4-week core stability (CS) program or plyometric (PLY) program on altering hip joint kinetics and kinematics during a drop vertical jump (DVJ).

Design: Cohort study.

Setting: High school athletic field and motion analysis laboratory.

Patients or Other Participants: 23 healthy junior varsity female lacrosse and soccer players (14.8 ± 0.8 yrs, 1.7 ± .07 m, 57.7 ± 8.5 kg).

Intervention(s): Independent variables were group (CS, PLY, control) and time (pretest, posttest). Subjects performed five trials of a DVJ before and after completion of a four-week period during which intervention subjects engaged in a coach-directed CS or PLY program. Exercises were performed 3 times a week for 20 minutes and required no additional equipment.

Main Outcome Measures: Dependent variables were 3-dimensional hip kinetics and kinematics during the stance phase of a DVJ. Group means and associated 95% confidence intervals were calculated via bootstrapping across the entire landing phase for pretest and posttest. A curve analysis was performed for each group to identify time periods in the stance phase where 95% confidence intervals from pretest to posttest did not cross. Standardized effect sizes with 95% confidence intervals were calculated between pretest and posttest measures when curve analyses revealed significant differences for kinetic variables over time.

Results: The PLY group had no significant differences between times throughout the entire stance phase. CS hip internal rotation angle decreased by a mean difference of 15.3° ± 0.4° from 36% to 42% of the stance phase and 13.1° ± 0.4° from 61% to 65% of stance. CS hip flexion moments significantly decreased and strong effect sizes were found at 32% to 43% d = −1.8(−2.8, −0.1), 48% to 61% d = −2.8(−4.0, −1.3), and 65% to 80% d = −2.2(−3.3, −0.9) of the landing phase. Strong effects, d = 2.35(1.0 to 3.5), were found for CS hip adduction moment increases from 37% to 48% of stance. The CS hip internal rotation moment significantly decreased and exhibited strong effect sizes from 9% to 12% d = −1.9(−3.0, −0.6), 20% to 24% d = −2.2(−3.3, −0.9), 28% to 81% d = −3.4(−4.7, −1.7), and 89% to 94% d = −1.8(−2.9, −0.6) of stance. The control group showed no significant changes over time.

Conclusions: Significant differences with strong effects were found for hip kinematics and kinetics following a 4-week in-season, coach-directed CS training program in junior varsity female athletes. Interestingly, no changes in hip biomechanics were found following PLY training. Targeting younger, less skilled athletes using a manageable CS program can lead to changes in hip joint biomechanics suggesting improved lower extremity neuromuscular control.

INJURY-MECHANISM STUDIES

Abstract #22

Simulated Noncontact ACL Injuries Using A Stochastic Biomechanical Model

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Context: Understanding mechanisms and risk factors is critical for preventing noncontact ACL injury. The traditional epidemiological methods for determining risk factors of diseases have significant limitations when applied to noncontact ACL injuries. Stochastic biomechanical modeling is an effective and efficient method to understand mechanisms and risk factors of musculoskeletal system injuries.

Objectives: To compare selected lower extremity biomechanics between simulated stop-jump tasks with and without noncontact ACL injuries.

Design: Stochastic biomechanical modeling design.

Setting: Controlled laboratory setting.

Patients or Other Participants: 40 male and 40 female college-aged recreational athletes without known history of lower extremity injuries.

Interventions: Three-dimensional lower extremity kinematics and kinetics in a stop-jump task were collected. The distribution of each lower extremity biomechanical variable was determined for each gender. A stochastic biomechanical model for the risk and risk factors of noncontact ACL injuries was developed and validated. 10 Monte Carlo simulations of the peak ACL loading in the stop-jump task were performed for each gender with 100 000 iterations in each simulation. A simulated peak ACL loading equal to or greater than the ACL strength was considered a non-contact ACL injury. The ACL strength was set at 1800 N for female subjects and 2250 N for male subjects. Lower extremity biomechanics of each simulated stop-jump trial were recorded. Two-way ANOVAs were performed to compare

lower extremity biomechanics between injured and noninjured trials and between genders.

Main Outcome Measures: Lower extremity biomechanics related to ACL loading.

Results: Simulated injury trials, on average, had significantly smaller knee flexion angles, shorter distance between center of pressure and heel, lower hamstring muscle force, and greater posterior ground reaction forces, and knee valgus and internal rotation moments at the peak ACL loading than did noninjury trials ($P < .001$). Simulated injury trials of females had significantly greater knee flexion angle and hamstring muscle force than did those of males ($P < .001$). Sagittal plane biomechanics contributed significantly more to the ACL loading in the simulated injury trials of females than those of males ($P < .001$).

Conclusions: Stiff landing with small knee flexion angle, great posterior ground reaction force, and a heel-landing primary mechanism were all risk factors of noncontact ACL injury in the stop-jump task. Increased knee valgus and internal rotation moment also significantly contribute to the injury. Hamstring cocontraction may assist in reducing ACL loading only when the knee is in a large flexion angle. The mechanisms of noncontact ACL injury in the stop-jump task are qualitatively similar in both males and females. Training programs for ACL injury prevention should emphasize modifying sagittal plane as well as nonsagittal plane biomechanics in landing tasks.

Abstract #23

Reconstruction of the Mechanism for Noncontact ACL Injury Among Female Basketball and Team Handball Players Using a Model-Based Image-Matching Technique

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Context: The mechanism for noncontact ACL injury is a matter of controversy and several theories have been proposed. Video analysis of injury tapes is the only method available to extract biomechanical information on the mechanism.

Objective: To describe knee joint kinematics in actual ACL injury situations using a model-based image-matching (MBIM) technique we have developed.

Design: Case series.

Setting: Video analysis.

Materials: Ten video sequences with at least two views of ACL injuries from women's handball (n = 7) and basketball (n = 3).

Interventions: The videos were analyzed using the MBIM method, providing an estimate of the time course of knee joint kinematics and ground reaction forces for the injury sequence. Unpaired *t* tests were used to compare knee joint angle changes between different time points.

Main Outcome Measures: Knee flexion, valgus, and rotation angles were measured while peak vertical ground reaction force was calculated and normalized to body weight.

Results: Mean knee flexion angle was 23° (range, 11° to 3°) at initial contact (IC) and had increased by 24° (95% CI, 19°–29°, $P < .001$) within 40 ms later. Valgus angle was neutral, 0° (range, −2° to 3°) at IC, but had increased by 12° (95% CI, 10°–13°, $P < .001$) 40 ms later. The knee was externally rotated 5° (range, −5° to 12°) at IC, but abruptly rotated internally by 8° (95% CI, 2°–14°, $P = .017$) during the first 40 ms. From 40 to 300 ms after IC, however, we observed an external rotation of 17° (95% CI, 13°–22°, $P < .001$). Peak vertical ground reaction force was 3.2 times body weight (95% CI, 2.7–3.7), and occurred at 40 ms (range, 0 to 83) after IC.

Conclusions: Based on when the sudden changes in joint angular motion and the peak vertical ground reaction force occurred, we assumed that the ACL injury occurred about 40 ms after IC. Knee kinematics was remarkably consistent for the ten injury situations analyzed. An average flexion angle of 23° suggests that a quadriceps drawer mechanism may contribute to ACL injury. However, valgus loading also seems to be an important factor, because all players had immediate valgus motion within 40 ms after IC. Moreover, the knee rotated internally during the first 40 ms, and then an external rotation was observed, which seemed to have occurred after the ACL was torn. These results suggest that valgus motion coupled with internal tibial rotation appears to be important components of the injury mechanism. Therefore, prevention training programs should focus on acquiring a cutting and landing technique with adequate knee flexion and avoiding knee valgus.

Abstract #24

Musculoskeletal Modeling of a Forward Lunge Movement: Implications for ACL Loading

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Context: The forward lunge is widely used among athletes for training and rehabilitation purposes. The forward lunge movement has also been suggested as a model to study functional adaptation to ACL rupture. Previous investigations indicate that the absence of the ACL influences the movement pattern of many patients during a forward lunge, while direct measurements of ACL strain show that except for cases close to full extension, quadriceps activity does not seem to influence the ACL strain. The question is whether there are other external forces present in the lunge movement that may cause an anterior force on the tibia, requiring the ACL to be intact to stabilize the knee?

Objective: To establish a musculoskeletal model of the forward lunge to computationally investigate the force equilibrium in the knee during forward lunge and answer the following questions: 1) Which structures in the knee are loaded during forward lunge? 2) Does the mechanical equilibrium cause ACL loads?

Design: Computational modeling.

Setting: The biomechanical forward lunge model was based on experimental motion capture data.

Patients or Other Participants: One healthy female subject (height = 169 cm, weight = 59.6 kg, age = 20 years).

Interventions: Three-dimensional coordinates of skin-mounted markers were obtained via five video cameras. The subject performed a forward lunge on a force plate, targeting a knee flexion angle of 90°. A model of the lunge movement was developed using the AnyBody Modeling System. The model comprised two legs, including femur, tibia, rigid foot segments, and the pelvis. The hips were modeled as spherical joints, the knees as hinge joints, and the ankles as universal joints. Each leg was equipped with 35 independent muscle units recruited according to a minimum fatigue criterion.

Main Outcome Measures: Muscle and joint reaction forces that pulled the tibia in anterior or posterior direction. The forces were normalized in terms of the total anterior and posterior force.

Results: No stabilization by the ACL was needed during the forward lunge. Quadriceps pulled the tibia anteriorly by less than 25% (420 N) in the beginning and the end of the movement, while it created a posterior drag of 3% (−98 N) on the tibia at the time of peak knee flexion. At peak knee flexion, the knee reaction was the only force that pulled the tibia anteriorly (2880 N). This was primarily counterbalanced by the musculus gluteus maximus (−1940 N).

Conclusions: The loading of the knee joint during lunging never required any stabilization by the ACL. The forward lunge model explored the muscle and reaction forces, which can be used for further examination of ACL injury mechanisms and prevention strategies by applying parameter and optimization studies to the model.

Abstract #25

Biomechanical Response of the Knee to Injury Level Forces in Sports Loading Scenarios

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Context: Little data exist on the force levels and joint motions that occur in sports situations. Recently, surveys and video studies of ACL injuries attempt to determine the most common loading mechanisms. Tibial rotation and valgus bending were frequently identified, but it is not clear if these motions are the cause or result of ACL injury.

Objective: Measure the maximum force and joint motions occurring under different types of loading to determine their potential role in the mechanism of ACL failure.

Design: Controlled laboratory study.

Specimens: Forty knees from male cadavers (48.3 ± 10.5 yrs) with no knee injury history.

Methods: Repeated, increasing forces were applied to isolated knee joints until gross ligamentous failure occurred. Four types of forces were applied: internal tibial torsion (ITT), valgus bending (VB), hyperextension (HE), and tibiofemoral compression (TFC). For each type of loading 4/6 degrees of freedom were unconstrained and, except for HE experiments, the knee flexion angle was fixed at 30°.

Main Outcome Measures: The motions between the tibia and femur were recorded during each test and peak joint motions occurring during the injury-producing test and test immediately prior to injury were compared. Damaged tissues were documented from dissection following injury.

Results: Prior to failure, ITT and VB had strongly coupled internal and valgus rotations. These motions were smaller in HE and TFC. TFC induced a large anterior tibial subluxation in prefailure tests. Significant anterior subluxations were also produced in ITT and HE, but little in VB. Medial/lateral motions were small in all types of loading. With gross failure, the primary motions were significantly increased. The failure torque from ITT was 45.7 ± 14.9 Nm and occurred at 61° ± 18.8°. The failure moments and angles from VB and HE were 107 ± 63.8 Nm at 29.1° ± 7.2° and 108 ± 46 Nm at 33.6° ± 11°, respectively. TFC failure load was 6.6 ± 1.6 kN. ITT produced ACL combined with some MCL injuries, while VB produced MCL combined with some ACL injuries. In both cases internal and valgus rotations were increased significantly with injury. There was an increase in extension angle after combined ACL and PCL ruptures in HE. In TFC the anterior tibial subluxation was more than doubled with isolated ACL rupture. TFC produced small internal and valgus rotations in prefailure tests, but after failure there was external tibial rotation or significantly increased valgus rotation.

Conclusions: With the exception of anterior tibia subluxation, the motions observed after isolated ACL failure are not representative of the relative displacements that produce excessive tension in the ACL. VB and HE did not produce isolated ACL injuries. This study will provide data showing the relative importance of the TFC and ITT loading mechanisms on the extended knee in producing noncontact, isolated ACL injury.

POSTER PRESENTATIONS: SESSION II

Abstract #26

What is the True Evidence for Gender Related Differences in ACL Injury During Plant and Cut Maneuvers? A Systematic Review

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Context: Female athletes are at greater risk of sustaining an anterior cruciate ligament (ACL) injury compared to male athletes. Biomechanical and neuromuscular factors have been reported as the main cause. However, the methodological quality of this literature is unknown.

Objective: The purpose was to analyze the literature on gender differences regarding biomechanical and neuromuscular movement patterns during plant and cut maneuvers.

Data Sources: Searches in PubMed (1966 to 2008), EMBASE (1947 to 2008), and CINAHL (1981 to 2008) were performed using key words: sex, gender, electromyography, biomechanics, neuromuscular, hip joint, knee joint, ankle joint, side, step, cross, cut, and task. Searching was limited to humans. A hand search was done on the reference lists of included studies.

Study Selection: Two authors independently tracked the results of the searches to identify potentially relevant manuscripts for full review. Inclusion criteria were 1) written in English, German, or Dutch; 2) biomechanical/neuromuscular analysis; 3) analysis of side step or cut preceded by running; 4) healthy adult subjects; 5) gender comparative cross-sectional design; and 6) data reported in numbers. Studies were excluded if only an abstract was available.

Data Extraction: EMG data, 3D angles, and moments of hip, knee, and ankle joints were the variables of interest. Methodological quality of the studies was independently assessed by two authors using a protocol with 10 criteria.

Data Synthesis: Seven studies meeting the inclusion criteria were heterogeneous in study methodology and results. A post hoc effect size (ES) calculation was conducted. Results with Cohen $d \geq 0.80$ are as follows. Females had smaller peak hip flexion (ES = 1.16 [95% CI, 0.04–2.15]), abduction (ES = 0.89 [95% CI, −0.95–0.91]), and internal rotation (ES = 0.82 [95% CI, −0.24–1.79]) angles. Only one study showed knee valgus being greater in females (ES = 0.99 [95% CI, 0.21–1.72]). Females had less peak knee internal rotation (ES = 0.87 [95% CI, −0.20–1.84]) and greater peak ankle pronation angles (ES = −0.94 [95% CI, −1.92–0.13]). Females had smaller internal peak knee flexion (ES = 0.93 [95% CI, 0.15–1.66]) and greater external peak knee valgus moments (ES = −0.12 [95% CI, −0.97–0.75]). Quadriceps dominance (ES = 1.05 [95% CI,

0.27–1.42]) or less hamstrings activity (ES = 0.83 [95% CI, 0.07–1.56]) was not found in females.

Conclusions: Gender differences during plant-and-cut maneuvers did not show patterns as frequently postulated in the literature. Perhaps the biggest issue is standardization of this maneuver. Caution is warranted in making inferences, as no standardized prospective studies have confirmed that gender differences found in these maneuvers during laboratory studies are indeed causative factors. This review adds to the literature as to how to improve on designing experiments to draw valid conclusions, in order to direct future ACL injury prevention programs.

Abstract #27

Reliability of the Landing Error Scoring System-Real Time (LESS-RT): The JUMP-ACL Study

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Context: There is a need for the development of reliable clinical assessment tools that can be used to identify individuals who may be at risk for noncontact anterior cruciate ligament (ACL) injuries. The Landing Error Scoring System (LESS) is a reliable and valid clinical assessment tool that was developed to identify individuals at risk for noncontact ACL injury. One limitation of this tool is that it cannot be assessed in real time and requires the use of video cameras.

Objective: To determine the interrater reliability of a real-time version of the LESS (LESS-RT).

Design: Reliability study.

Setting: Controlled research laboratory.

Patients or Other Participants: Forty-three cadets (24 females, 19 males) between the ages of 18 and 23 volunteered to participate in this investigation. All participants were free from lower extremity injury at the time of testing.

Intervention(s): The LESS-RT evaluates 10 jump-landing characteristics that may predispose an individual to ACL injury. The jump-landing characteristics assessed include sagittal and frontal plane motion at the trunk, hips, knees, and feet. A total of three raters (raters 1, 2, and 3) utilized the LESS-RT during two separate testing sessions to evaluate participants' landing mechanics across four trials of a jump-landing task. The jump-landing task required participants to jump forward and down from a 30-cm-high box a distance of half their body height, land in a target area, and jump for maximal vertical height upon landing. Raters 1 and 2 evaluated 24 participants (13 males, 11 females) during session 1, while raters 1 and 3 evaluated 19 participants (13 females, 6 males) during session 2.

Main Outcome Measures: Intraclass correlation coefficient (ICC [2,1]) values and standard error of measurements for the final composite score of the LESS-RT were calculated to assess interrater reliability of the LESS-RT for each set of raters (raters 1 and 2; raters 1 and 3).

Results: During session 1, the mean LESS-RT scores were 5.8 ± 1.6 for rater 1 and 6.2 ± 1.5 for rater 2. During session 2, the mean LESS-RT scores were 5.3 ± 1.3 for rater 1 and 4.9 ± 1.5 for rater 3. Good interrater reliability was observed for the LESS-RT in session 1 (ICC [2,1] = 0.81, SEM = 0.69) and session 2 (ICC [2,1] = 0.72, SEM = 0.79).

Conclusions: Based on the results from this investigation, the LESS-RT is a quick, easy, and reliable clinical assessment tool that may be utilized by clinicians to identify individuals who may be at risk for noncontact ACL injuries. Further research is needed to determine the concurrent validity of the LESS-RT with the LESS and to determine if LESS-RT score predicts risk of incident noncontact ACL injury.

Abstract #28

Validation of a Single-Camera 3D Motion Tracking System

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Context: Three-dimensional kinematics of the lower limb during dynamic activities have been shown to be predictive of ACL injury. Motion tracking outside of a laboratory environment is a critical next step in applying ACL research findings to the general population. The Retro-Grate Reflector (RGR) is a new technology that allows for 3D motion capture using a single camera. Previous studies have shown that orientation and position information recorded by the RGR system has high measurement precision and is strongly correlated with a traditional multi-camera system across a series of static poses.

Objective: The purpose of this study was to compare motion data for a standard athletic movement recorded simultaneously with the RGR and multi-camera systems.

Design: Descriptive cohort study design.

Setting: Controlled laboratory setting.

Patients or Other Participants: Nine individuals were recruited to participate in this study. Volunteers were accepted in the study if they had not suffered a knee injury requiring surgery and had been free of any other injury within the previous six months that could interfere with normal movements.

Interventions: All participants performed three single-leg land-and-cut maneuvers from a 35-cm-high box.

Main Outcome Measures: Thigh and shank three-dimensional kinematics were collected with the RGR and Eagle camera systems simultaneously at 100 Hz. Plates with four reflective spheres were attached to the thigh and shank, and an RGR target was mounted to the center of the plate. The coefficient of determination (R^2) and root mean square (RMS) error between the time series were calculated to depict the similarity of the two systems. Additionally, touchdown (TD) and peak angles of the knee were reported in all three planes and compared using a paired test ($P < .05$).

Results: Most of the R^2 values between the two measurement systems were >0.9. The RMS errors for the thigh and shank angular degrees of freedom were 2 to 3 degrees. The spatial measurement RMS errors were ~1 cm in the vertical and anterior-posterior directions, while the mediolateral differences were 1.5 to 2 cm. There were no statistical differences in the discrete knee kinematic variables between the Eagle and RGR measurements in any plane. The only discrepancies appeared in the frontal plane, where there was trend suggesting a difference in peak angles ($P = .107$) and only a moderate correlation in touchdown angles ($r^2 = 0.57$).

Conclusions: The results of this study demonstrate the ability of the RGR system to record moving-pose information from multiple RGR targets at a sampling rate adequate for assessment of human movement and strongly support the ability to use the RGR technology as a valid 3D motion capture system. RGR motion capture technology offers the promise of making 3D motion capture accessible to larger subject pools

than can be currently accomplished by bringing athletes to specialized laboratories.

Previously presented at the 33rd Annual Meeting of the American Society of Biomechanics; August 26–29, 2009; State College, PA.

Abstract #29

Influence of High Knee Abduction Angle During Landing on Ambulation: Do ACL Injury Programs Negatively Impact Walking Biomechanics?

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Context: High knee adduction moment (KADDM) during walking may be a risk factor for development of knee osteoarthritis. Conversely, high knee abduction angle (KABDA) during landing is correlated with increased risk of ACL injury. Although injury prevention programs commonly seek to alter frontal plane biomechanics, there have been no studies which have investigated the relationship between KABDA during landing and KADDM during ambulation to assess the possible effects of these programs on ambulatory biomechanics.

Objective: The hypothesis is that subjects with high peak KABDA during a drop vertical jump (DVJ) would demonstrate significantly lower peak KADDM at midstance, terminal stance, and overall stance during walking.

Design: Retrospective cross-sectional study.

Setting: Research laboratory.

Patients or Other Participants: 27 male and 5 female healthy recreational athletes who were enrolled in two prior studies which collected data during both a DVJ task and during walking were analyzed retrospectively.

Interventions: Two cohorts were created: 1) subjects with $>5°$ of peak KABDA in their dominant limb during a DVJ task (n = 9, age 21.7 ± 2.5 yrs, ht 1.75 ± 0.08 m, wt 84.1 ± 15.9 kg, KABDA 8.3° ± 3.2°); and 2) subjects with $<5°$ of peak KABDA in their dominant limb during a DVJ task (n = 23, age 22.6 ± 3.5 yrs, ht 1.81 ± 0.1 m, wt 78.9 ± 12.2 kg, KABDA 2.70° ± 1.24°). The cutoff point of 5° was selected based on the median value of peak KABDA during a DVJ with a previously collected dataset. The DVJ task consisted of dropping off a 41.5-cm box onto a set of force plates, followed by a vertical jump at maximal effort. The ambulation task consisted of level walking at a self-selected speed. Lower extremity kinetics and kinematics were collected during the trials using three-dimensional videography.

Main Outcomes Measures: Dependent variables included peak KADDM during midstance, terminal stance, and overall stance. Statistical analyses were performed using separate two-tailed independent-samples *t* tests with significance set a priori at $P < .05$.

Results: Significant differences were observed in peak KADDM at terminal stance (2.88 ± 0.14 vs 1.74 ± 0.60 %BW × H, $P = .022$) and overall (4.32 ± 2.0 vs 2.87 ± 0.78 %BW·× H, $P = .046$), but not at midstance (4.25 ± 0.20 vs 2.83 ± 0.81 %BW·× H, $P = .053$) between the small and large KABDA groups, respectively. There were no significant differences between the two groups in walking stance time or speed.

Conclusions: The results indicate that there may be an inverse relationship between poor frontal plane biomechanics during landing and walking. This suggests that injury prevention programs seeking to alter frontal plane biomechanics during landing activities may have an adverse effect on walking biomechanics such that there may be an increase the risk of knee osteoarthritis. Further studies using larger sample sizes, more heterogeneous gender samples, differing athlete levels and types, and prospective designs are necessary to confirm these results.

LANDING AND CUTTING STRATEGIES

Abstract #30

Knee Kinematics and Kinetics at Two Landings in a Vertical Stop Jump Task

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Context: The majority of anterior cruciate ligament (ACL) injuries occur with noncontact mechanisms in maneuvers that involve sudden deceleration such as landings. Initial posture and movement before a landing and subsequent movement following a landing can influence the knee biomechanics. Understanding the knee loading during different landing tasks can provide information toward developing injury prevention programs.

Objective: To compare knee kinematics and kinetics at two landings in a vertical stop jump task.

Design: Single task measure design.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Eleven NCAA female volleyball players (19.2 ± 1.2 yrs, 179 ± 6.7 cm, 71.3 ± 5.9 kg) with no history of ACL injury, meniscus damage, or substantial ligament damage to the lower extremity.

Interventions: All measures were performed on the dominant leg (preferred to kick a ball). Retroreflective markers were attached on the subjects. Subjects performed five trials of a vertical stop jump task with the dominant foot landing on a force plate. A vertical stop jump task consists of an approach run, a 2-footed landing, and a takeoff for maximal jump height followed by another 2-foot landing. The knee joint resultant force and moment vectors were calculated, transformed to the tibial reference frame, and expressed as internal loading. Forces were normalized to body weight, and moments were normalized to a product of body weight and height. Wilcoxon signed-rank tests were used to compare variables between the two landings with a Type I error rate set at 0.05.

Main Outcome Measures: First local peak vertical ground reaction force (FLPF) during each 2-footed landing was determined and knee angles and moments at FLPF were calculated.

Results: For first and second landing respectively, FLPF were 1.9 ± 0.6 (mean ± SD) and 1.2 ± 0.4 BW ($P = .01$); anterior shear forces were 0.7 ± 0.3 and −0.1 ± 0.3 BW ($P < .01$); knee extension moments were −0.03 ± 0.04 and 0.05 ± 0.07 BW *BH ($P = .01$); knee abduction moments were −0.06 ± 0.05 and 0.08 ± 0.04 BW*BH ($P < .01$); knee external rotation moments were −0.03 ± 0.02 and −0.04 ± 0.03 BW*BH ($P = .07$); knee flexion angles were 22.6 ± 5.7 and 27.0° ± 7.7° ($P = .15$); knee abduction angles were 4.6 ± 2.9 and 5.3° ± 2.8° ($P = .52$); knee external rotation angles were 22.1 ± 10.9 and 16.8° ± 8.6° ($P < .01$).

Conclusions: The results of this study demonstrated significant biomechanical differences between two landings during a vertical stop jump task. The horizontal approaching speed, more posterior inclined tibia, and subsequent takeoff imposed on the first landing compared to the second landing could be the causes of these differences. The results confirmed the influences of initial posture and movement and subsequent

movement on joint mechanics during similar landing tasks. Further work with musculoskeletal models or in vivo measurements is needed to determine if these differences induce changes in ACL loading.

Abstract #31

The Effect of Single-Leg Landing Style on Hamstrings Muscle Forces

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Context: Anterior cruciate ligament (ACL) injury occurs most frequently in noncontact athletic maneuvers. A sagittal plane injury mechanism has been suggested to contribute, and investigators have created injury prevention programs intended to reduce injury risk by promoting increased knee flexion during landing ("soft" technique). However, there is little experimental evidence substantiating that increased knee flexion decreases force experienced by the ACL. It has been proposed that the hamstrings can protect the ACL, but this muscle group is affected by both hip and knee flexion and the dynamics of this muscle group are unclear.

Objective: To determine the effect of soft and stiff single-leg landing styles on estimated hamstrings forces.

Design: Descriptive cohort study design.

Setting: Controlled laboratory setting.

Patients or Other Participants: Two male (22 and 24 years, 1.72 and 1.77 m, 105.7 and 80.2 kg) and one female (20 years, 1.69 m, 55.9 kg) participants with no current or previous history of lower extremity injury affecting limb alignment.

Interventions: Participants performed single-leg landings from ~37 cm on their dominant limb. Investigators instructed the subjects to land with a stiff and a soft landing. Three trials of each landing task were collected. Kinematic and kinetic data were input into a 12-segment, 23 degree-of-freedom (DOF) subject-specific musculoskeletal model with 96 musculotendon actuators created using OpenSim. Muscle forces were estimated using a computed muscle control algorithm.

Main Outcome Measures: All measures were analyzed in the first 100 ms of landing when ACL injury is most likely to occur. Three-dimensional stance-leg kinetics and kinematics were calculated (touchdown angles, ranges of motion (ROM), and peak knee and hip moments) for data analysis. Total hamstring force was calculated by summing the individual hamstrings actuators.

Results: While all subjects successfully achieved greater final knee flexion angles for the soft landing, the flexion angles at IC and ROM during the first 100 ms were not systematically greater for the soft landing. Peak hamstring forces all occurred during the first 100 ms and were 165% greater in the soft landing (soft = 1486.7 N, stiff = 898.3 N). Peak hip and knee moments for soft and stiff landings varied between subjects and did not occur at the same time as the peak muscle forces.

Conclusions: While the knee kinematics during the first 100 ms of landing were similar, the peak hamstring forces increased in the soft landing. The peak occurred between 40° to 50° of knee flexion suggesting an increased ability for these muscles to protect the knee joint. There appears to be a complex interaction between hip and knee dynamics affecting hamstrings force profiles that may be influenced by individual coordination differences. The results from this limited sample suggest that a soft landing may enhance the hamstrings ability to protect the ACL.

Abstract #32

Gender Differences in Lower Extremity Landing Mechanics in Youth Soccer Players Performing a Single-Leg Landing

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Context: As relatively few studies have examined landing mechanics in younger (<12 yrs) populations, this study compared male and female youth soccer players' landing mechanics.

Objective: To test the null hypothesis that there would be no gender difference in lower extremity landing kinetics and kinematics in the landing leg.

Design: Descriptive, nonrandomized cohort study.

Setting: Controlled laboratory setting.

Patients or Other Participants: Twenty-nine (11 M, 18 F) healthy youth soccer players (11.3 ± 0.7 yrs, 150.2 ± 7.6 cm, 41.7 ± 11.2 kg) with no history of lower extremity injury.

Interventions: Subjects hung from a horizontal bar, dropped 38 cm, landing on one leg. Kinematic and kinetic data were collected to calculate joint angles and moments at the pelvis, hip, knee, and ankle. Trials were trimmed and normalized to 100 ms pre and 300 ms post initial contact. Data were averaged over 5 drop landings for each subject. A principal component analysis was performed on the waveform of all kinematic and kinetic variables. To determine gender differences, a MANOVA was performed on the scores of the extracted principal components (PC).

Main Outcome Measures: Three-dimensional pelvis, hip, knee, and ankle kinematics and kinetics.

Results: Males displayed greater pelvic flexion range of motion (Pelvis PC2: 9.83 ± 2.05 vs. 6.01 ± 1.63), pelvic rotation magnitude (Pelvis PC1: 4.14 ± 7.44 vs. −2.53 ± 6.26), and hip extension moments (Hip PC1: 15.56 ± 1.59 vs. −9.51 ± 2.39) than females. In the frontal plane, males displayed greater changes in hip abduction (Hip PC2: 10.11 ± 2.16 vs. −6.18 ± 1.44) and external rotation moments (Hip PC3: 3.31 ± 6.02 vs. −2.02 ± 5.76). Males also displayed greater knee flexion near the end of the landing (Knee kinematic PC4: 6.66 ± 5.89 vs. −4.07 ± 7.64). Males experienced greater knee moments (Knee kinetic PC3: 5.72 ± 8.27 vs. −3.50 ± 7.65) in the sagittal plane along with rapid changes in knee rotation moments (Knee kinetic PC2: 2.49 ± 4.10 vs. −1.52 ± 4.33; Knee kinetic PC4: 0.98 ± 8.95 vs. −0.61 ± 7.19) in the transverse plane compared to females. Greater flexion motions, coupled with a larger extension moments suggest males absorbed more energy in the sagittal plane. The patterning of the frontal and transverse plane moments in males appeared to be more ballistic throughout the landing phase.

Conclusions: These results support the premise that males used a different landing strategy than females, a strategy that relies on impulsive rather than gradual dissipation of energy. This strategy may become deleterious at the knee as rapid changes in knee rotation moments could cause excessive strain in the ACL, considering that there are no large muscle groups that dissipate energy in the transverse plane at the knee.

Abstract #33

The Influence of Sex and Maturation on Landing Strategies: Implications for ACL Injury

Sigward SM, Pollard CD, Cheng W-C, Lee S-P, Powers CM: University of Southern California, Los Angeles

Context: Females are thought to utilize a strategy that limits knee and hip flexion during landing, and instead, rely more on

passive restraints in the frontal plane (ie, ligaments) to decelerate. It has also been suggested that females favor use of the knee extensors over the hip extensors to attenuate impact forces during landing. Although this pattern has been generalized to females, it is not known at what point in maturation this pattern emerges.

Objective: 1) examine sex differences in sagittal plane and knee frontal plane loading during landing, 2) determine if differences exist across stages of maturation.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: The 119 athletes (9 to 22 years) with no history of knee injury were classified into maturation groups (n = male, female, respectively); prepubertal (n = 16, 15), pubertal (n = 15, 15), postpubertal (n = 14, 15), and adult (n = 15, 15).

Interventions: Three-dimensional kinematics and internal net joint moments (inverse dynamics equations) of the dominant limb were quantified during deceleration of a drop land. Sagittal plane joint power was computed as the scalar product of angular velocity and net joint moment. Energy absorbed was calculated by integrating the power-time curves. Kinetic data were normalized to body mass.

Main Outcome Measures: Average knee adductor moments, average knee extensor moment/average hip extensor moment ratio, and knee energy absorption/hip energy absorption ratio during deceleration. To determine differences in landing strategies between sex and maturation levels, 2 $\times$ 4 ANOVAs were performed. LSD post hoc testing was performed for significant main effects for maturation ($P < .05$).

Results: Main effects for sex and maturation were found for all three variables. No sex $\times$ maturation interactions were found. Data reported as mean $\pm$ SE. Knee/hip extensor moment (1.4 $\pm$ 0.2 vs. 2.0 $\pm$ 0.1; $P < .001$) and absorption (1.9 $\pm$ 0.1 vs. 2.8 $\pm$ 0.2; $P < .001$) ratios as well as knee adductor moments (0.02 $\pm$ 0.02 vs. 1.0 $\pm$ 0.02 Nm/kg; $P = .005$) were greater in females compared to males. When collapsed across sex, pubertal and postpubertal athletes had greater knee/hip extensor moment (1.9 $\pm$ 0.2 and 2.0 $\pm$ 0.2 vs. 1.4 $\pm$ 0.2 and 1.4 $\pm$ 0.2; $P < .05$) and energy absorption ratios than the prepubertal and young adult athletes (2.8 $\pm$ 0.2 and 2.9 $\pm$ 0.2 vs. 2.1 $\pm$ 0.2 and 2.0 $\pm$ 0.2; $P < .02$). Postpubertal athletes exhibited greater knee adductor moments than young adult athletes (0.1 $\pm$ 0.03 vs. -0.004 ± 0.03 Nm/kg; $P = .002$).

Conclusions: Females exhibited a landing strategy that included greater frontal plane loading and relied more heavily on knee extensors relative to hip extensors for attenuation of impact forces. We propose that the higher knee valgus moments are representative of a strategy aimed at attenuating impact forces that should ideally be absorbed in the sagittal plane at the hip. This sagittal plane strategy is more prominent during periods of maturation associated with greater changes in growth (pubertal and postpubertal), suggesting that athletes undergoing rapid growth may be more susceptible to developing patterns of impaired sagittal plane shock absorption.

Partial data previously presented at the 33rd Annual American Society of Biomechanics Meeting: Sigward SM, Pollard CD, Cheng W-C, Lee S-P, and Powers CM. The Influence of gender and maturation on landing strategies: implications for ACL injury; August 26–29, 2009; State College, PA.

Abstract #34

Sex Differences in Frontal-Plane Kinematics and Kinetics of the Knee and Hip During Running and Rapid Change-of-Direction Tasks

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Context: Frontal-plane knee kinematics and kinetics have been implicated in ACL injury risk. While sex differences in frontal plane mechanics exist for sidestep cutting (SSC), the SSC may not be entirely representative of the rapid change-of-direction tasks associated with ACL injury.

Objective: To identify differences in frontal-plane knee and hip kinematics and kinetics between sexes and tasks for variations of the SSC maneuver.

Design: Mixed-factor, sex-by-task design, with repeated-measures for task.

Setting: A biomechanics laboratory.

Patients or Other Participants: Twenty-one healthy collegiate basketball and soccer players (women: n = 11, 19.8 $\pm$ 1.5 yrs; men: n = 10, 20.7 $\pm$ 2.5 yrs).

Interventions: Participants performed 10 trials each of straight-ahead running (RUN), right lateral false step (LFS, 30% of body height), left SSC (45° from the path of travel), and LFS and SSC in combination (LFS-SSC) at 3.5 $\pm$ 0.2 m•s^{-1}. Three-dimensional knee and hip angles and internal moments, normalized to weight and height, were obtained for the right lower extremity. A body-fixed flexion-abduction-external rotation sequence by the distal segment was assumed. Peak values were determined between foot contact and 30° of knee flexion during stance and averaged across trials. Women were tested 6.5 $\pm$ 1.8 days after the start of menses.

Main Outcome Measures: Sex- and task-differences in peak knee abduction angle (KABDa), hip adduction angle (HADDa), knee adduction moment (KADDm), and hip abduction moment (HABDm) were identified using ANOVA with post hoc Tukey's HSD analysis ($\alpha = .05$).

Results: There was a main effect of task ($P < .001$) on peak KABDa (RUN: 3.6° $\pm$ 0.5°; LFS: 5.6° $\pm$ 0.5°; SSC: 6.1° $\pm$ 0.5°; LFS-SSC: 7.1° $\pm$ 0.5°), KADDm (RUN: 0.1 $\pm$ 0.1; LFS: 1.2 $\pm$ 0.2; SSC: 2.0 $\pm$ 0.2; LFS-SSC: 3.9 $\pm$ 0.1% bw•bh), HADDa (RUN: 7.3° $\pm$ 0.5°; LFS: $-7.9° \pm 0.8°$; SSC: $-5.7° \pm 0.9°$; LFS-SSC: $-16.6° \pm 0.8°$), and HABDm (RUN: 5.5 $\pm$ 0.5; LFS: 5.8 $\pm$ 0.8; SSC: 4.3 $\pm$ 0.8; LFS-SSC: 2.7 $\pm$ 0.8% bw•bh). Peak KABDa and KADDm were greater for all three change-of-direction tasks than for RUN ($P < .05$) and greater for LFS-SSC than for LFS or SSC ($P < .05$). Peak HADDa were smaller (more abducted) for the change-of-direction tasks than for RUN and smaller for LFS-SSC than for LFS or SSC ($P < .05$). Peak HABDm were smaller for LFS-SSC than for RUN or LFS ($P < .05$). Across tasks, women demonstrated 4.0° greater peak HADDa than men ($P = .04$). There were no significant interactions between sex and task.

Conclusions: Each variation of SSC was associated with increased abduction angles and adduction moments at the knee during early stance, accompanied by decreased hip adduction angles, a pattern consistent with increased ACL loading. A LFS appears to produce effects similar to a SSC on frontal-plane knee and hip kinematics and kinetics, whereas prefacing a SSC by an opposing LFS amplifies the effects of a SSC. The more adducted stance hip in the women across tasks suggests differences in proximal control at the hip, which may help explain why women are more susceptible to ACL injury.

Previously presented at the 60th Annual National Athletic Trainers' Annual Meeting & Clinical Symposia; June 17–20, 2009; San Antonio, TX.

Abstract #35

Hip and Knee Mechanics Following Anterior Cruciate Ligament Reconstruction in the Soccer Athlete During Side-Step Cutting

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Context: Anterior cruciate ligament (ACL) injury is the most common sports-related knee ligament injury. ACL surgical reconstruction (ACLR) is the gold standard treatment for athletes following an ACL tear and is thought to restore functional stability to the knee. However, following an ACLR, athletes have a higher risk of reinjury upon return to sports participation. While the mechanism behind this increased risk of reinjury is unknown, it has been suggested that altered knee and hip biomechanics during sports-specific activities may be a contributing factor.

Objective: To determine if female soccer players post-ACLR demonstrate altered hip and knee mechanics compared to athletes with no history of knee injury.

Design: Controlled descriptive study.

Setting: Biomechanics research laboratory.

Patients or Other Participants: Twelve female soccer players with a history of ACLR served as the experimental group, and twelve female soccer players with no history of knee injury constituted the control group (CON). All subjects in the ACLR group were at least 1 year post-ACLR and had returned to full sports participation.

Interventions: Three-dimensional kinematics (eight-camera Vicon motion analysis system, 250 Hz) and ground reaction forces (AMTI, 1500 Hz) were collected while each subject performed a side-step cutting maneuver. Visual3D™ software was used to quantify kinematics and internal net joint moments.

Main Outcome Measures: All variables of interest were calculated over the deceleration phase, defined as the first 20% of the stance phase. Variables of interest consisted of average knee valgus angles and peak knee adductor (ie, valgus) moments as well as hip and knee sagittal plane average angles and peak moments. Differences between groups were examined using independent-samples *t* tests ($P \leq .05$).

Results: Subjects in the ACLR group exhibited increased average knee valgus angles (ACLR = 3.8° vs. CON = 1.8°; $P = .03$) and increased peak knee adductor moments (ACLR = 1.46 Nm/kg vs. CON = 0.80 Nm/kg; $P = .004$) as compared to the CON group. Subjects in the ACLR group also demonstrated decreased peak knee extensor moments (ACLR = 1.46 Nm/kg vs. CON = 1.72 Nm/kg; $P = .02$) and increased peak hip extensor moments as compared to the CON group. There were no significant differences in the average knee (ACLR = 23.0° vs. CON = 21.1°) and hip (ACLR = 37.3° vs. CON = 35.8°) flexion angles between groups.

Conclusions: Female soccer players who have undergone ACLR and returned to sports participation demonstrate altered hip and knee mechanics during the early deceleration phase of cutting. Even though athletes are able to return to sport following ACLR, they are at an increased risk of reinjury which may be associated with altered hip and knee mechanics. Therefore, it is important that rehabilitation programs post-ACLR focus on the restoration of normal hip and knee mechanics prior to return to sports participation. Future work is needed to better understand the underlying reason for ACL reinjury.

RISK-FACTOR SCREENING

Abstract #36

The Landing Error Scoring System (LESS) Prospectively Identifies ACL Injury

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Context: Identifying modifiable risk factors for ACL injury is a critical step towards developing effective injury prevention programs. Widespread ACL injury prevention efforts will require screening tools that can be easily implemented in clinical settings. The Landing Error Scoring System is a valid and reliable clinical assessment of jump-landing biomechanics. However, the ability of the LESS to identify individuals at risk for ACL injury is unknown.

Objective: To establish the validity of the LESS in identifying individuals at risk for future ACL injury.

Design: Prospective cohort.

Setting: Soccer field.

Patients or Other Participants: A total of 761 healthy soccer athletes (females = 457, males = 304; age = 13.7 ± 2 yrs; wt = 52 ± 13 kg; ht = 163 ± 12 cm) volunteered for the study.

Interventions: Baseline testing for all participants consisted of performing a jump-landing task (3-trials) by jumping forward a distance of half their body height from a 30-cm-high box. Following the initial landing, the participants immediately jumped upward for maximal vertical height. The jump-landing trials were videotaped and later reviewed using the LESS. Participants were followed for approximately two years after baseline testing for diagnosis of an ACL injury, accumulating a total of 1.068 athlete-seasons of follow-up. A total of 14 ACL-injured participants, 9 of whom suffered non/indirect contact ACL injury, were identified during the follow-up period.

Main Outcome Measures: The LESS is scored using a binary system based on jump-landing characteristics including knee flexion angle, knee valgus angle, trunk flexion angle, foot position, and stance width. A higher LESS score indicates a greater number of movement errors committed. The average LESS score across 3 trials was used for analyses. Univariate ANOVAs were performed to determine differences in LESS scores across ACL-injured and noninjured groups ($\alpha < .05$). Additionally, receiver operator curves (ROC) were constructed and the sensitivity and specificity of the LESS in predicting ACL injury were assessed.

Results: Noninjured participants (4.5 ± 1.7) demonstrated lower LESS scores compared to all ACL-injured (6.1 ± 1.3; $P = .001$) and non/indirect contact ACL-injured (6.1 ± 1.9; $P = .006$) participants. Based on ROC curve analyses, we suggest that 5 or higher is the optimal cutpoint for the LESS. The cutpoint of 5 or above generated a sensitivity of 71% for all ACL injury and 78% for non/indirect contact ACL injury, with a specificity of 70% and 69%, respectively.

Conclusions: The LESS shows promise as a screening tool for ACL injury in the youth soccer population. Further research is needed to investigate whether the predictive ability of a LESS-based screening test battery would be enhanced by inclusion of a brief questionnaire addressing topics such as previous knee injuries and family of history of ACL injury.

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Abstract #37

Three-Dimensional Lower Extremity Kinematics Predict Total Score on the Landing Error Scoring System

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Context: The Landing Error Scoring System (LESS) is a valid and reliable lower extremity movement screening tool used to

identify faulty movement patterns that are theorized to lead to noncontact anterior cruciate ligament (ACL) injury. Research has yet to determine the sagittal, frontal, and transverse plane kinematic that most influence total LESS scores.

Objective: To identify the hip and knee three-dimensional kinematic variables that influence total LESS score.

Design: Correlational.

Setting: Field laboratory.

Patients or Other Participants: Forty-five (27 male, 18 female, age = 15.5 ± 1.3 years; height = 175.0 ± 11.9 cm; mass = 68.5 ± 10.8 kg) high school basketball players volunteered for the study.

Interventions: Three-dimensional hip and knee kinematics during a jump-landing task were collected using an electromagnetic tracking system synched with a nonconductive force plate. The task consisted of jumping from a 30-cm-high box set at a horizontal distance of 50% of the participant's height away from the force plate, and upon landing, jump vertically for maximum height. Sagittal and frontal plane views of the task were captured using two mini-DV cameras. Each participant performed three trials of the jump-landing task. The LESS is scored using a binary system (0 = no error, 1 = error) based on several jump-landing characteristics including knee flexion angle, knee valgus angle, trunk flexion angle, foot position, and stance width. A higher LESS score indicates a greater number of errors committed and, thus, poor jump-landing technique.

Main Outcome Measures: Peak three-dimensional hip and knee kinematics were determined during the stance phase (initial contact to toe off) of the jump-landing task. The average of the three trials of total LESS score and peak hip and knee kinematics were used for the data analysis. Pearson product moment correlations were performed to determine the relationship between hip and knee kinematics and total LESS score during the jump-landing task ($\alpha \leq .05$). A forward stepwise multiple regression analysis was performed to determine the combination of hip and knee kinematics that were most predictive of total LESS score ($\alpha \leq .05$).

Results: Decreased peak knee flexion angle ($r = -0.378$, $P = .005$), increased knee valgus angle ($r = 0.418$, $P = .002$), and decreased hip flexion angle ($r = -0.429$, $P = .002$) were significantly correlated with increased total LESS score. Hip internal rotation ($r = 0.140$, $P \geq .05$), hip adduction angle ($r = 0.097$, $P \geq .05$), and knee internal rotation ($r = -0.033$, $P \geq .05$) angle were not correlated with total LESS score. The regression analysis revealed that a combination of knee valgus, hip flexion, and hip internal rotation angles was most predictive of total LESS score ($R^2 = 0.485$, $P < .001$).

Conclusions: Based on these findings, approximately 50% of the variance in total LESS score is explained by a combination of sagittal, frontal, and transverse plane hip and knee kinematics that are theorized to predispose an individual to noncontact ACL injury. Clinicians should use the LESS to identify individuals who may be at an increased risk of noncontact ACL injury.

Portions of these data were previously presented at the 60th Annual National Athletic Trainers' Association Annual Meeting and Clinical Symposia; June 18–20, 2009; San Antonio, TX.

Abstract #38

The Relationship Between Frontal Plane Knee Separation Distance and Lower Extremity Joint Angles During a Drop Land: Implications for Clinical Screening

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Context: Knee abduction during a drop land was shown to be a predictor of anterior cruciate ligament injury risk in female athletes. Consequently, 2-dimensional methods aimed at screening athletes for excessive frontal plane knee motion have been adopted clinically to identify those at increased risk for injury. Commonly, clinical screening includes an assessment of knee separation distance in the frontal plane during landing. While this measure has been used in research studies to identify sex differences and the effects of training, it is not clear how these measures relate to 3-dimensional knee abduction. Given the potential for out-of-plane lower extremity motion to influence 2-dimensional frontal plane measures, it is possible that these techniques do not accurately assess knee frontal plane angles.

Objective: The purpose of this study was to determine 1) the relationship between a 2-dimensional measure of minimal knee separation distance (MKSD) and knee abduction angles and 2) the association between MKSD and lower extremity sagittal, transverse, and frontal plane angles.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Twenty-five female athletes (ages 11–23) with no history of knee injury

Interventions: Subjects performed a bilateral drop land followed by a maximum vertical jump. Kinematic data were collected using an 8-camera, VICON Motion System (250 Hz). MKSD was calculated as the smallest frontal plane distance between lateral femoral epicondyle markers during deceleration of the land. Three-dimensional hip, knee, and ankle kinematics as well as hip separation (intertrochanteric) distances were calculated at the time of MKSD. Kinematic data from the right and left legs were averaged to account for the contribution of each limb to MKSD. Knee separation distance was normalized to hip separation distance. Data were averaged across three trials. Linear regression was used to determine the association between MKSD and bilateral average knee frontal plane angle. Stepwise multiple regression was used to identify the best predictors of MKSD during a drop land ($P < .05$).

Main Outcome Measures: Normalized MKSD, average knee and hip sagittal, frontal, and transverse plane, and ankle frontal plane angles at the time of MKSD.

Results: Bilateral average knee frontal plane angle explained 49% of the variance in MKSD ($P < .001$). Greater knee abduction angle was associated with a smaller MKSD. Of the dependent variables, bilateral average hip frontal plane angle was the only predictor of MKSD, explaining 97% of the variance ($P < .001$). Greater hip adduction angle was associated with a smaller MKSD.

Conclusions: Measures of knee separation distance during bilateral landing tasks are more indicative of frontal plane motion at the hip than the knee. Caution must be taken when relating MKSD to 3-dimensional knee abduction angles.

Partial data previously presented at the 33rd Annual American Society of Biomechanics Meeting; August 26–29, 2009; State College, PA.

Abstract #39

Can Performance in the Star Excursion Balance Test Identify Athletes With Poor Knee and Hip Stability?

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Context: Excessive knee valgus motions and moments assessed by 2D and 3D motion analyses may leave athletes

prone to serious knee injuries. The Star Excursion Balance Test (StarReach) is a clinical test to identify athletes with chronic ankle instability. The potential value of identifying athletes with knee valgus motions and poor hip stability by using the StarReach test has not yet been examined.

Objective: To assess the correlation between subjective evaluation of knee valgus and hip stability during a single-leg squat and StarReach test performance among elite female team sport athletes.

Design: Cross-sectional.

Setting: Controlled, laboratory.

Methods: This study is part of an ongoing cohort study aimed at investigating risk factors for noncontact ACL injuries among Norwegian elite female team sport players. Since 2007, a total of 272 team handball and 192 football players (mean age, 21.8 ± 4.0 years) have been included; 61 (13%) of these with a previous ACL injury.

Main Outcome Measures: Subjectively assessed dynamic knee valgus and hip stability in the frontal plane during a single-leg squat was graded as "good, reduced, or poor" for both knees and hips of 440 athletes. Player balance, measured by the StarReach test in anterolateral, mediolateral, and posterolateral directions on both feet, was ranked as "reaching far, average, or short."

Results: There were significant group differences between StarReach performance (absolute values, adjusted for length) and subjectively assessed "good" vs "poor" knee valgus and hip stability ($P < .01$): anterolateral direction 100.1 cm ± 8.7 cm vs 92.0 ± 9.4 right knee, 93.4 ± 6.4 vs 88.7 ± 7.3 left knee; mediolateral 96.7 ± 6.7 vs 91.0 ± 7.8 right knee, 97.1 ± 6.2 vs 90.3 ± 6.9 left knee; posterolateral 105.7 ± 6.5 vs 98.9 ± 8.7 right knee, 106.0 ± 6.2 vs 98.7 ± 7.8 left knee; anterolateral direction 99.0 ± 8.7 vs 90.5 ± 9.5 right hip, 92.9 ± 6.1 vs 87.4 ± 7.3 left hip; mediolateral 96.2 ± 7.1 vs 88.9 ± 7.8 right hip, 96.9 ± 6.8 vs 90.1 ± 7.4 left hip; posterolateral 105.6 ± 7.0 vs 97.3 ± 8.2 right hip, 105.8 ± 7.1 vs 98.8 ± 8.6 left hip. Each of the three StarReach balance directions contributed significantly to knee and hip stability ($R^2 = 0.06$ to 0.12 [Nagelkerke], $P < .001$). However, the intraclass coefficients between subjective assessment scores of single-leg squats and objective ranking of StarReach performance varied between 0.28 to 0.42 for right and left knee and hip stability. Players with a previous ACL injury did not differ from healthy players in single-leg squat or balance variables.

Conclusions: Poor relationships between objective and subjective scores illustrate why the StarReach test can not identify athletes with poor knee and hip stability. Previously injured players are competing at a high level, with comparable balance and knee and hip control to that of uninjured players.

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