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Abstract #1

Influence of Knee Morphological Characteristics on Peak ACL Strain During Simulated Pivot Landings

Lipps DB, Oh YK, Ashton-Miller JA, Wojtys EM: University of Michigan, Ann Arbor

Context: Variations in knee morphology affect ACL loading during a dynamic maneuver and could help explain why females have a greater risk of ACL injury than males. We have recently shown that ACL cross-sectional area and lateral tibial slope explain 59% of the variance in peak ACL strain in 18 size-matched cadaveric knees undergoing a pivot landing. It is unknown, however, whether a larger sample size would indicate a role for additional morphological parameters, such as medial tibial depth or notch-width index.

Objective: To use a larger sample size to determine whether additional morphological parameters, beyond ACL cross-sectional area and lateral tibial slope, explain additional variance in peak anteromedial bundle (AM)-ACL relative strain.

Design: Cross-sectional repeated measures study.

Setting: Controlled laboratory setting.

Patients or Other Participants: Twenty-nine height- and weight-matched cadaver (20 F & 9 M; 60$\pm$16 yrs; 170$\pm$8 cm; 71$\pm$5 kg) lower extremities were acquired with no visual signs of knee surgery or deformities.

Intervention(s): The knees were subjected to 5 trials of compound impulsive two-times body weight loads in compression, flexion, and internal tibial torque to simulate a pivot landing. Each knee was held in 15 degrees of initial flexion by custom gender-specific non-linear springs used to represent rapid quadriceps stretch behavior during the initial 100 ms of a pivot landing. Peak AM-ACL relative strain was measured with a differential variable reluctance transducer. Tibiofemoral kinematics were recorded at 400 Hz, while muscle forces and tibiofemoral kinetics were recorded at 2 kHz. ACL cross-sectional area, lateral tibial slope, medial tibial depth, and notch-width index were measured from 3T MR images.

Main Outcome Measure(s): A stepwise linear regression model (F-test $>$ 0.1 exclusion criteria) compared main effects and 2-way interactions of the four morphological parameters with peak AM-ACL relative strain ($p < 0.05$ significant).

Results: Lateral tibial slope (mean(SD): 5.1(1.9) deg) ($\beta = 2.68$, $p < 0.001$) and lateral tibial slope x ACL cross-sectional area (mean(SD): 28.3(7.6) mm^2) ($\beta = -0.042$, $p = 0.001$) were significant predictors of peak AM-ACL relative strain (mean(SD): 5.2(2.8) %). Medial tibial depth (mean(SD): 2.2(0.9) mm) ($\beta = -0.859$, $p = 0.062$) and lateral tibial slope x notch width index (mean(SD): 0.26(0.02)) ($\beta = -4.300$, $p = 0.084$) trended towards significance.

Conclusions: Knee morphology clearly affects ACL loading during a simulated pivot landing: greater lateral tibial slope, especially when combined with a decreased ACL cross-sectional area, increased peak ACL strain. Further, a smaller medial tibial depth, as well as a smaller notch width index combined with a greater lateral tibial slope contributed towards an increase in peak ACL strain. Individuals with these high-risk morphologies might be detected prior to injury via MR imaging and enrolled in training programs that focus on reducing ACL injury risk.

Abstract #2

Less Lower Extremity Muscle Mass is Associated With Greater Knee Laxity and Lower Stiffness in the Frontal and Transverse Planes

Pye ML, Schmitz RJ, Shultz SJ: University of North Carolina at Greensboro

Context: Even when matched on sagittal plane knee laxity, females have 25–30% greater Varus-Valgus (VV_{LAX}) and Internal-External Rotational (IER_{LAX}) laxity and reduced varus (VAR_K), valgus (VAL_K), internal (IR_K) and external (ER_K) rotation stiffness compared to males, all of which can contribute to their higher risk knee joint biomechanics. The reason for this sex disparity is not entirely clear, but early evidence suggest that muscle mass about the knee may play a role.

Objective: To examine the extent to which lower extremity lean mass (LELM) contributes to frontal and transverse plane knee laxity and incremental stiffness. We expected that lower LELM would predict greater VV_{LAX} and IER_{LAX} and lower incremental VAR_K, VAL_K, IR_K, and ER_K, particularly at the lower ranges of applied force.

Design: Descriptive cohort study.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Eighty-seven (59F, 28M) participants (20.5 $\pm$ 2.3yrs, 66.7 $\pm$ 10.5kg, 169.6$\pm$9.8cm) with no previous history of ACL or other ligament injury.

Intervention(s): All measures were taken on the left leg. LELM (kg) was assessed via Dual-energy X-ray absorptiometry. Commercial software partitioned the lower extremity into regional bone, lean, and fat mass so that LELM could be quantified. Applied torques and rotational displacements were simultaneously recorded during the application of -10Nm to $+10$Nm frontal plane (VV) and -5 to $+5$Nm transverse plane (IER) loads about the knee joint using the Vermont Knee Laxity Device (Burlington, VT). Linear regressions examined the extent to which LELM predicted each of the dependent variables, once controlling for an individual's sex.

Main Outcome Measure(s): VV_{LAX} and IER_{LAX} were recorded as total varus-valgus and internal-external rotation displacements from $\pm$10Nm and 5Nm respectfully. VAR_K and VAL_K stiffness measures (N/deg) were recorded for the initial (0–4Nm) and terminal (6–10Nm) force increments. Initial and terminal IR_K and ER_K were calculated from 0–2Nm and 3–5Nm, respectfully.

Results: Once accounting for an individual's sex, less LELM consistently predicted greater VV_{LAX} (R^2=.57) and IER_{LAX} (R^2=.21), and lower initial VAR_K (R^2=.53), VAL_K (R^2=.53), IR_K (R^2=.18) and ER_K (R^2=.27) and lower terminal VAR_K (R^2=0.42), VAL_K (R^2=0.21), IR_K (R^2=.14) and ER_K (R^2=.30) (all $p<.001$). The regression equations revealed that for every 1kg decrease in LELM, VV_{LAX} and IER_{LAX} increased by 1.32 and 1.66 degrees, respectively. Once accounting for both sex and LELM, sex was not a significant predictor in any of the models.

Conclusions: Lower LELM (rather than sex) appears to largely explain greater knee laxity and reduced stiffness in the frontal and transverse planes. The fact that LELM accounted for such a larger percentage of the variance in these measures suggest that frontal and transverse plane knee laxity and stiffness, thus associated high risk biomechanics, may be modifiable through training designed to increase muscle mass about the knee.

This project was funded by NFL Charities.

Abstract #3

Identification of Genetic Loci Underlying Predisposition to Anterior Cruciate Ligament Injuries

Posthumus M,* Rahim M,* Mannion S,* O'Cuinneagain D,† van der Merwe W,*† Collins M,*‡; September AV*: *Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africa; †Sports Science Orthopaedic Clinic, Cape Town, South Africa; ‡South African Medical Research Council, Cape Town, South Africa

Context: Both a familial predisposition and more recently specific genetic sequence variants, have been associated with risk of ACL ruptures. Genes such as *COL5A1*, *COL1A1*, *COL12A1* and *MMP12* have been implicated. Moreover, additional genes, which are involved in ligament remodelling and repair, may also influence the risk of ACL ruptures. Interleukin-6 (*IL6*), Interleukin-1B (*IL1B*), prostaglandin E receptor 4 (*PTGER4*), transforming growth factor B2 (*TGFB2*) genes, which code for proteins involved in the extracellular matrix degradation and repair signalling (inflammatory) pathway may be considered as candidate genes.

Objective: To determine if the selected functional *IL6* rs1800795, *IL1B* rs16944, *PTGER4* rs4495224 and TGFB2 rs7550232 gene variants are associated with risk of ACL ruptures. Design: A pathway-based genetic association study

Setting: A laboratory based study.

Patients or Other Participants: One hundred and twenty six (74 male and 52 female) participants with ACL ruptures (ACL group) and 382 asymptomatic controls (CON group) were recruited. Participants within the ACL groups, which had ruptured their ACL through non-contact mechanisms (NON sub-group) were also separately analysed.

Intervention(s): All participants were genotyped for the selected gene variants. Differences in genotype frequency between groups were analysed using Pearson's chi-squared test. Significance was accepted when $P<0.05$.

Main Outcome Measure(s): The mean genotype frequency of each of the selected gene variants within the ACL group (or NON sub-group) and the CON group. Inferred allele combinations frequencies were also calculated within each group.

Results: There were no significant genotype differences between the ACL group (including the NON sub-group) and the CON group. However, the *IL6* rs1800795 genotype frequency was significantly different (P=0.030) between the female NON sub-group (2 GG, 11%; 13 GC, 72%; 3 CC, 17%) and the female CON group (40 GG, 37%; 46 GC, 42%; 23 CC, 21%). In addition, the inferred allele combination A-C-A (for the *IL1B* rs16944, *PTGER4* rs4495224 and TGFB2 rs7550232 gene variants, respectively) was significantly over-represented (P=0.033) among the female CON group, when compared to the female ACL group. No similar associations were found among the male participants.

Conclusions: This preliminary study indicates that the *IL6*, *IL1B*, *PTGER4* and TGFB2 genes may be implicated in the aetiology of ACL ruptures among females. These genes code for proteins involved in extracellular matrix degradation and repair. It remains unknown why the associations were only observed within females. Further research is required to confirm these findings within a larger population of females.

Abstract #4

Females Increase Knee Laxity More Than Males During a 90-Minute Intermittent Exercise Protocol

Shultz SJ, Tritsch AJ, Schmitz RJ: The University of North Carolina at Greensboro

Context: Greater knee joint laxity is associated with high risk knee joint biomechanics and injury. Joint laxity increases during exercise, and injury risk increases near the end of the first and into the second half of practice and competition. Whether exercise-induced increases in knee laxity (with corresponding susceptibility to high risk movements and injury) differ in males and females has received little attention.

Objective: To compare males and females on exercise-induced increases in anterior knee laxity (AKL) before and after a dynamic warm up, and every 15 minutes during and following a 90-minute intermittent exercise protocol (IEP). We expected that females would demonstrate earlier and greater magnitudes of exercise-induced increases in AKL compared to males.

Design: Descriptive cohort.

Setting: Controlled laboratory.

Patients or Other Participants: 25 female (1.7±0.1m, 61.5±9.6kg, 20.8±2.5yrs) and 28 male (1.8±0.1m, 75.1±7.1kg, 20.3±2.0yrs) intercollegiate and club athletes (3+ years competitive sport experience; currently active 6 hrs/week).

Intervention(s): AKL was measured intermittently before, during and after a 90-minute IEP designed to mimic the running intensities and duration of a competitive soccer match. Running intensities were individualized to each participant's fitness level as determined by a graded exercise test.

Main Outcome Measure(s): AKL was measured as the anterior displacement of the tibia relative to the femur (mm) during a 133N anterior directed load. One investigator with established measurement reliability [ICC(SEM) = 0.93(0.45mm)] measured all subjects before (PreWm) and after (PostWm) a dynamic warm up, and every 15 minutes during (15Min, 30Min, 45Min, Half, 60Min, 75Min, 90Min) and for one hour following (Post_15, Post_30, Post_45, Post_60) the IEP. A 2 (sex) by 13 (time) repeated measures ANOVA compared males and females on AKL over time. Post-hoc testing consisted of simple within-subjects contrasts comparing AKL at each time point relative to PreWm within each sex (Bonferroni corrected, P=.004).

Results: PreWm (baseline) AKL was 6.8±1.6mm in females and 6.6 ± 1.7mm in males. AKL increases over time relative to PreWm ranged from 0.34 ± 0.77 to 0.91 ± 0.82mm in females and –0.04 ± 0.83 to 0.41 ± 0.78mm in males. These AKL increases over time differed by sex (P=.031). AKL increased in females at 30Min (7.5 ± 1.9mm), 45Min (7.7±1.8mm), 60Min (7.4±1.9mm) and 90Min (7.6 ± 1.9) relative to PreWm (P<.003); no AKL increases were observed in males (P>.105).

Conclusions: Females experience significant increases in AKL during prolonged intermittent exercise. However, the magnitude of these changes varied considerably among females (range 0.9 to 4.4mm). These changes are of similar magnitude and variability as the cyclic AKL changes observed in females across their menstrual cycle, which have been found to be sufficient to alter knee joint biomechanics. The extent to which exercise-induced increases in AKL influence a female's susceptibility to knee injury later in a game or practice warrants further study.

This project was funded by NFL Charities.

Abstract #5

Exploratory Analysis of Joint Laxity and Genotypes Associated With ACL Injury

Bell R, Wideman L, Henrich VC, Shultz SJ: University of North Carolina at Greensboro

Context: Increased magnitudes of anterior knee laxity (AKL), genu recurvatum (GR) and general joint laxity (GJL) are associated with higher risk landing biomechanics and a greater risk of ACL injury. Recently, familial and genetic association studies show a relationship between genetics and ACL injury. There is also substantial evidence that joint laxity is a heritable trait. Thus, joint laxity may represent an intermediate phenotype for the genetic association with ACL injury that can be measured clinically.

Objective: To determine if genetic variants within the *COL1A1* (rs1800012), *COL5A1* (rs12722) and *COL12A1* (rs970547) genes previously associated with ACL injury were also associated with greater magnitudes of AKL, GR and GJL.

Design: Candidate gene association study.

Setting: Controlled, laboratory setting.

Patients or Other Participants: One hundred and twenty four (50 male; 22.2 ± 2.8 yrs, 177.9 ± 9.3 cm, 80.9 ± 13.3 kg and 74 female; 21.4 ± 2.6 yrs, 163.9 ± 6.7 cm, 61.1 ± 8.8 kg) healthy, recreationally active subjects with no history of connective tissue disorders or knee injury.

Intervention(s): Serum blood samples and joint laxity were obtained from each subject using established laboratory techniques. AKL was measured as the anterior displacement of the tibia relative to the femur with a 133N posterior-to-anterior directed load. GR was measured as the amount of knee hyperextension (positive value) during active knee extension with the distal shank on a 4 in. bolster. GJL was measured with the Beighton and Horan Joint Mobility Index. Female laxity values represent the minimum (baseline) values obtained when measured over multiple days of the menstrual cycle.

Main Outcome Measures: Genomic DNA was extracted from the blood samples and genotyped for 3 single nucleotide polymorphisms (SNPs). Univariate ANOVAs compared AKL (mm), GR (°) and GJL (score 0–9) across the 3 genotypes for each SNP in both sex combined and sex specific models.

Results: Data reported as means and SD. For rs1800012, GR was higher in the combined TT+GT (4.8°±3.3°) genotypes compared to the GG (2.9°±3.6°) in all subjects (p=0.02). For rs12722, GR was higher in the CT genotype (4.5°±4.2°) than either the CC (2.2°±3.1°) or TT (1.7°±2.8°) (p=0.03), and GJL was higher in CT (2.5±1.8) than the CC (0.9±1.3) (P<0.001) in females only. Also only in females, the AA genotype had greater AKL (6.7±1.9mm) than the combined AG+GG (5.8±2.07mm) (p=0.03) for rs970547.

Conclusions: Gene variants that were previously associated with ACL injury risk were also associated with greater magnitudes of joint laxity. Sex specific genetic associations with joint laxity were consistent with sex specific genetic associations reported for ACL injury. Joint Laxity may represent an intermediate phenotype for explaining the genetic association with ACL injury risk.

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Abstract #6

Jump Landing Biomechanics Change Across the Menstrual Cycle in Females With a History of ACL Injury

Bell DR,* Blackburn JT,† Hackney AC,† Marshall SW,† Beutler AI,‡ Padua DA†: *University of Wisconsin-Madison; †University of North Carolina at Chapel Hill; ‡Uniformed Services University, Bethesda, MD

Context: Previous research examining biomechanical characteristics across the menstrual cycle (MC) has concluded that these variables do not change across the MC. However, these studies utilized healthy, uninjured females. After primary ACL rupture and reconstruction, up to 25% of individuals will go on to suffer a second ACL injury to either the contralateral or ipsilateral limb. If reproductive hormones influence ACL injury risk by altering the properties of tissue, then females with a history of non-contact ACL injury may be more sensitive to hormonal fluctuations than females from the general, uninjured population.

Objective: To determine if three dimensional hip and knee kinematics and kinetics and peak vertical ground reaction force (VGRF) change across the menstrual cycle in females with unilateral non-contact ACL rupture during a jump landing.

Design: Repeated measures.

Setting: Laboratory.

Patients or Other Participants: Twenty females (168.6±5.3cm, 66.2±9.1kg, 19.6±1.31yrs) with noncontact, unilateral ACL rupture completed the study. This sample was approximately two years from rupture (25.7±12.6 months).

Intervention(s): All individuals completed 5 trials of a jump landing off a 12 inch high box placed 50% of their height from force plates. Participants jumped forward off the box, landed on the plates, and immediately jumped for height. An electromagnetic motion analysis system interfaced with non-conductive force plates recorded lower extremity kinematics and kinetics. Each subject was tested twice across the MC at periods associated with low (3–5 days post menses) and high (within 3 days post ovulation) estrogen concentrations. MC phase testing order was randomized and the PI was blind to MC phase at the time of testing. The uninjured limb was used for testing.

Main Outcome Measure(s): Dependent variables included peak vertical ground reaction force (VGRF), three dimensional hip and knee kinematics and kinetics at initial contact, and blood hormone levels (Estradiol-B-17 [E], progesterone [P], and free testosterone [FT]) assessed via radioimmunoassay procedures. Separate paired t-tests were performed with MC phase as the within subject factor ($\alpha < .05$).

Results: At ovulation, VGRF decreased (1968.3 ± 623.8 vs 1775.8 ± 642.9N, *P*=.04), the tibia was externally rotated (1.6 ± 7.3 vs –3.31 ± 8.12°, *P*=

.01), and internal varus moment decreased (.01 ± .01 vs .003 ± .01, $P = .01$). [E] and [P] were higher at ovulation ([E]: 31.1 ± 13.7 vs 70.3 ± 54.7pg/mL, $P = .009$), [P] (0.51 ± 0.3 vs 3.92 ± 4.27 ng/mL, $P = .003$). No other significant findings were observed ($P > .05$).

Conclusions: Jump landing kinematics and kinetics change across the MC in females with a history of noncontact ACL rupture. The landing posture observed at the menses test session (rather than the ovulation session) is associated with increased ACL loading. Females with noncontact ACL rupture may be sensitive to hormonal fluctuations and utilizing this population in research may provide insight into hormonal influences on tissue and primary ACL rupture.

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Abstract #7

Pubertal and Sex Differences in Lower Extremity Kinematics During a Cutting Task

DiStefano LJ,* Trojian TH,* Nguyen A,† Boling MC‡: *University of Connecticut, Storrs; †College of Charleston, SC; ‡University of North Florida, Jacksonville

Context: Previous research suggests that lower extremity biomechanics during a jump landing task change as children mature. Many ACL injuries occur during a sidestep cutting task, but knowledge on biomechanical changes related to maturation during this task is limited.

Objective: To compare lower extremity kinematics during a sidestep cutting task between prepubertal, pubertal and postpubertal male and female athletes.

Design: Cross-sectional.

Setting: Field laboratory.

Patients or Other Participants: 123 healthy youth athletes volunteered to participate. Participants were classified as prepubertal (16 males: mass=34.2±5.4 kg, height=140.1±5.8 cm, age=10±1 years; 15 females: mass=33.8±5.4 kg, height=134.9±9.2 cm, age=9±1 years), pubertal (13 males: mass=43.3±12.8 kg, height=155.6±18.5 cm, age=12±3 years; 12 females: mass=36.7±11.2 kg, height=144.3±15.0 cm, age=11±3 years), or postpubertal (30 males: mass=70.6±11.0 kg, height=176.3±7.9 cm, age=17±1 years; 27 females: mass=56.9±6.7 kg, height=163.4±6.1 cm, age=15±2 years) based on their Pubertal Maturation Observational Score (Prepubertal: ≤1, Pubertal: 2–5, Postpubertal: >5).

Intervention(s): Participants completed three trials of a standardized sidestep cutting task that required them to jump forward from a 30-cm high box a distance of half their height, land on their dominant foot, and perform a 60° cut toward their non-dominant side. An electromagnetic motion analysis system and force plate collected three-dimensional lower extremity kinematics and vertical ground reaction forces (VGRF) during the cutting task.

Main Outcome Measure(s): Three-dimensional hip and knee kinematics at initial contact (IC)(VGRF>10N), the peak values during the stance phase of the cutting task (between IC and VGRF<10N), and joint displacements (Peak-IC) were calculated from the average of the three trials. Separate two-way (sex x pubertal group) analyses of variance were performed to evaluate sex and maturation group differences ($\alpha \leq .05$). Separation of confidence intervals was evaluated for post hoc analyses.

Results: There was a significant interaction for hip displacement in the frontal plane ($F_{(2,107)}$=3.94, P=0.02). Prepubertal males (18.84±7.47°) performed the cutting task with more hip motion in the frontal plane than postpubertal males (12.31±5.98°). Regardless of sex, postpubertal participants (12.42±6.51°) had less hip rotation displacement than prepubertal (11.96±5.11°) and pubertal participants (13.65±5.54°)($F_{(1,107)}$=13.17, P<0.001). Regardless of pubertal group, females had less peak knee internal rotation ($F_{(1,107)}$=7.92, P=0.006; Females: 4.69±9.31°, Males: 11.08±12.12°), hip abduction ($F_{(1,107)}$=4.88, P=0.03; Females: 17.38±5.76°, Males: 20.85±8.84°), hip flexion ($F_{(1,107)}$=4.69, P=0.03; Females: 27.33±11.50°, Males: 34.40±11.38°)

Conclusions: Following puberty, athletes appear to perform a cutting task with less hip rotation and frontal plane motion than their less mature counterparts. Females consistently moved with a relatively more adducted and extended hip and externally rotated knee. These sex differences do not appear to change with maturation, which is in contrast to previous research evaluating maturation differences during a jump landing task.

Abstract #8

Sex Differences in Lower Extremity Stiffness During a Single Limb Drop Jump Maneuver: Evidence for Heightened Feedforward Control in Females

Lyle MA, Stearns KM, Powers CM: University of Southern California, Los Angeles

Context: ACL injuries occur soon after ground contact during tasks such as landing from a jump and cutting. Increased leg stiffness immediately following impact with the ground is one factor thought to be related to ACL injury risk in females.

Objective: To compare lower extremity stiffness between sexes and to identify factors that influence lower extremity stiffness during landing.

Design: Between subjects cohort study.

Setting: Research laboratory.

Patients or Other Participants: 14 female and 13 male soccer athletes between the ages of 15 and 18. All subjects played in the same competitive division (soccer experience: 10.9±1.8 vs 10.3± 2.1 yrs) and reported no previous knee surgery or injury that prevented participation in soccer for ≥3 weeks within the previous 6 months.

Intervention(s): Kinematics (Qualisys motion system, 250 Hz), kinetics (AMTI forceplate, 1500 Hz), and electromyography (1500 Hz) obtained from the medial gastrocnemius (MG), tibialis anterior (TA), medial hamstrings, lateral hamstrings and rectus femoris (RF) were recorded during a single limb drop-jump from a 30 cm box.

Main Outcome Measure(s): Leg stiffness was calculated by dividing the peak vertical ground reaction force (pVGRF) by the center of mass displacement (COMd). Other variable of interest included pVGRF and COMd, as well as COM velocity and sagittal plane joint angles at initial contact and both angle and angular velocity at pVGRF. Co-contraction indexes for MG/TA and RF/hamstrings muscle pairs over the 80 ms period prior to foot contact were used to represent feedforward muscle activation. Independent samples t-tests were used to compare dependent variables between sexes. Stepwise multiple regression (controlling for gender) was used to identify the extent to which the co-contraction indexes and angular velocities at pVGRF were predictive of leg stiffness.

Results: Females exhibited significantly greater vertical stiffness when compared to males (395.7±101.6 and 304.8±54.9 N/m*kg, P= 0.01). COMd was significantly less (P= 0.01) and pVGRF higher (P= 0.03) in females when compared to males. Knee angle and angular velocity at pVGRF were significantly greater in males (P= 0.002 & P= 0.02). Co-contraction of the ankle and knee muscle pairs were both significantly greater in females (P< 0.002 & P< 0.02). Regression analysis revealed that 83% of the variance in stiffness was accounted for by ankle co-contraction (41%), ankle angular velocity at pVGRF (30%), and gender (12%) (P= 0.001).

Conclusions: Our findings suggest that a heightened feedforward control strategy in female soccer players contributed to a less compliant limb during the early period after landing (i.e. 50 ms). The results indicate that ankle and knee dynamics account for the sex difference and support the notion that technique instruction should focus on increasing distal limb compliance at impact (i.e. ankle and knee angular velocity).

Abstract #9

Adult Female Athletes Display Different Hip and Knee Biomechanics During Sidestep Cutting Compared to Adolescent and Prepubescent Female Athletes

Pfile KR,* Hertel J,† Hart JM,† Kerrigan DC,† Ingersoll CD‡: *University of Toledo, OH; †University of Virginia, Charlottesville; †Central Michigan University, Mt Pleasant

Context: The anterior cruciate ligament (ACL) gender bias emerges after age 12 and may be associated with physical changes resulting from maturation. Information comparing biomechanical patterns of females from varying maturational stages during dynamic tasks is limited. It is important to understand the role of physical development in ACL injury risk.

Objective: To identify kinematic and kinetic differences between adult, adolescent and prepubescent females during sidestep cutting (SSC).

Design: Cohort.

Setting: Research laboratory.

Patients or Other Participants: Twenty-nine females with no history of lower extremity injury in the previous 6 months volunteered (adult: n=12, 21.4+4.1yrs, 168.4+8.2cm, 57.3+7.5kg; adolescent: n=9, 12.0 ± 1.1yrs, 162.7 ± 8.2cm, 49.9+12.6kg; prepubescent: n=8, 9.4+1.2yrs, 144.4+8.5cm, 35.7+3.1kg). All were involved in sports requiring running, jumping and SSC. Participants were classified into maturation groups according to the Pubertal Maturation Observation Scale.

Intervention(s): The independent variable was group (prepubescent, adolescent, adult). A three-dimensional motion analysis system captured participants as they ran (3.5–4.5 m/s) and performed a SSC. Participants were told to plant their right foot on the force plate and change direction to the left between a 40–60° angle. Five trials were normalized to 100% of the stance phase. The mean peak value of 0–25% of stance was used for analysis. Data were collected for the right limb and external joint moments were quantified.

Main Outcome Measure(s): Dependent variables were mean peak 3-dimensional hip and knee kinematics and kinetics. Two separate one-way MANOVAs comparing maturation group on hip and knee kinematic variables were run. The kinetic data were not normally distributed therefore Kruskal-Wallis tests were used for comparisons. Descriptive kinetic data is reported as the median (interquartile range [IQR]: 25th, 75th). A one-way ANOVA was performed to identify differences in the knee flexion: hip flexion moment ratio (Knee:Hip ratio) where >1 represents greater knee flexion moments. Standardized effect sizes (Cohen's d) with 95% confidence intervals (CI) were calculated for each group comparison when a significant p-value (P<0.05) was identified.

Results: There were no statistically significant kinematic differences, P>0.05. The adult group had a significantly greater hip external rotation moment, P=0.013, (–0.31[–0.34, –0.21]Nm/kgm) compared to prepubescent (–0.18[–0.24, –0.12]Nm/kgm; d = –0.95(–1.89, –0.01)). The knee flexion moment was also significantly different between groups, P = .008. The adult value (2.22[1.89,2.42]Nm/kgm) was greater than adolescent (1.54[1.32,1.94]Nm/kgm; *d* = 1.08(0.15,2.00)) and prepubescent (1.65[1.30,1.91]Nm/kgm; *d* = 1.13(0.17,2.09)). Knee:Hip ratio was statistically significant, P = 0.035, the adult group (1.15 ± 0.40) had a ratio >1 compared to the adolescent (0.73 ± .27; *d* = 1.20(0.26,2.13)) and prepubescent (0.83 ± .40; *d* = 0.80(–0.13,1.73) groups.

Conclusions: Adult females showed different biomechanical measures in all three planes during SSC compared to adolescent and prepubescent participants. More research is needed to determine whether these differences are associated with ACL injury risk.

Abstract #10

The Influence of Hip Abductor Muscle Performance on the Knee Valgus Moment During Landing: A Gender Comparison

Stearns KM, Powers CM: University of Southern California, Los Angeles

Context: A high knee valgus moment during the deceleration phase of landing has been identified as a risk factor for ACL injury in females. Diminished hip abductor muscle performance has been hypothesized as being a primary contributor to elevated knee valgus moments.

Objective: To assess gender differences in hip abductor muscle performance, and determine the relationship between hip abductor muscle performance and frontal plane loading at the knee joint during a double limb landing task.

Design: Controlled descriptive study.

Setting: Research laboratory.

Patients or Other Participants: 20 males (23.2 ± 1.3 years of age, height: 1.8 ± 0.1m, mass: 81.5 ± 6.7kg) and 21 females (23.7 ± 1.2 years of age, height: 1.7 ± 0.1m, mass: 64.0 ± 10.7kg) participated. All subjects were recreationally active (≥30 minutes of exercise, twice a week), and free from lower extremity injury or pathology.

Intervention(s): Hip abductor muscle torque production was measured using a force transducer (Omega Engineering, Inc., 1500 Hz) and a custom testing set-up. Subjects were tested in supported standing (neutral hip abduction, 10° hip extension) and performed 2 types of contractions: 1) sustained isometric contraction (2 trials, 5 sec duration), and 2) rapid isometric contraction (12 trials, <1 sec duration). Lower extremity kinematics (10-camera Qualisys Motion Capture System, 250 HZ) and kinetics (AMTI force plates, 1500 Hz) were collected during a double-leg drop jump from a 36cm platform.

Main Outcome Measure(s): The peak knee valgus moment was identified during the deceleration phase of landing. Peak isometric strength (ISOMax) was calculated from the sustained isometric contraction, and peak rate of force development (RFDMax) and time to peak rate of force development (TTP) were calculated from the rapid isometric contractions. All variables were normalized by body mass. Differences between males and females were assessed using independent samples t-tests (one-tailed, p≤ 0.05). Pearson's partial correlation, controlling for gender, was used to assess the relationship between each variable and the peak knee valgus moment.

Results: Females had a significantly higher peak knee valgus moment compared to males (male: 0.16 ± 0.1 Nm/kg, female: 0.25 ± 0.1 Nm/kg; *P*=.01). Females also had a significantly lower ISOMax (2.2 ± 0.5 vs. 2.4 ± 0.3 Nm/kg; *P*=.03), RFDMax (11.8 ± 2.1 vs. 13.7 ± 2.9 Nm/ms; *P*=.01), and a slower TTP (186.6 ± 16.1 vs. 169.0 ± 22.6 msec; *P*=.004). There was a significant negative correlation between the peak knee valgus moment and TTP (r=0.422, *P*=.004). No other significant associations were observed.

Conclusions: While females exhibited weaker hip abductors compared to males, deficits in the ability to rapidly generate force were predictive of the knee valgus moment. Therefore, interventions aimed at increasing hip abductor contraction speed may be important in reducing the knee valgus moment and ACL injury risk.

Abstract #11

Effects of Stiff and Soft Landing Techniques on Knee Loading During a Single-Leg Cross-Over Hop

Benjaminse A,*† Gokeler A,‡ Cortes N,§ Otten E*: *Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, The Netherlands; †School of Sports Studies, Hanze University Groningen, University of Applied Sciences, The Netherlands; ‡Center for Rehabilitation, University Medical Center Groningen, University of Groningen, The Netherlands; §George Mason University, Fairfax, VA

Context: Landing technique is a factor to anterior cruciate ligament (ACL) injuries.

Objective: To investigate the influence of stiff and soft landing technique (LT) on knee loading.

Design: Quasi-experimental

Setting: Controlled laboratory.

Patients or Other Participants: Sixteen healthy athletes (8 males (M); 23±2.2yrs, 1.85±0.09m, 74.6±8.8kg; 8 females (F); 21±0.9yrs, 1.76±0.12m, 66.1±8.8kg).

Intervention(s): Subjects completed four single-leg cross-over hops over a 900cmx20cm course. Five normal (preferred-technique) trials followed by ten soft and ten stiff trials (instructed with 'land as soft' or 'as hard as you can'). The third landing of each trial was captured on the force plate. LTs were counterbalanced between subjects. Multivariate ANOVA and post-hoc were calculated.

Main Outcome Measure(s): Lower extremity moments (Nm/kg) and angles (°) at peak vertical ground reaction force (PvGRF), vGRF (N/kg) and knee and ankle range of motion (ROM) from initial contact to PvGRF were evaluated.

Results: Stiff landing resulted in higher PvGRF (M=46.55±10.95, F=42.47±11.10) followed by normal (M = 25.38 ± 11.62, F = 29.65 ± 4.36) and soft LT (M=14.13±8.13, F=15.42±8.47) (P<0.001). Males had more knee flexion during natural (M=15.10±11.83, F=18.75±14.09) and stiff LT (M = 12.84 ± 12.21, F = 9.85 ± 7.09) (P = 0.004). Females had greater knee valgus during normal landing (M = –0.18 ± 5.56, F = –4.70 ± 10.98, P=0.019). Stiff landings caused increased knee valgus (P<0.001) for both genders (M = –4.50 ± 10.14, F = –4.51 ± 7.97) and knee ROM decreased (M = 4.82 ± 3.71, F = 5.52 ± 4.26) over normal (M=28.39±16.19, F = 11.93 ± 10.06) landings (P < 0.001). Ankle ROM decreased for stiff (M = 1.64 ± 1.48, F=0.47±0.43) compared to normal (M = 3.41 ± 1.25, F = 1.24 ± 1.37) landings (P = 0.001). Ankle dorsiflexion differences were found between the natural (M= –0.07±13.09, F=5.20±8.15) and soft (M=–9.63±31.96, F=0.53±10.18) (P=0.017) and between soft and stiff (M=–0.05±21.85, F=4.49±11.19) (P=0.004) landings. Females used greater dorsiflexion than males regardless of technique (P=0.003).

Conclusions: Females executed normal landing with a more extended knee than males and utilized less ankle shock absorption strategy. This study shows that females performed landings with less ROM compared to males. It indicates increased ACL injury risk by a 'ligament dominant' landing profile.

Abstract #12

Using Ground Reaction Forces to Predict Knee Kinetic Asymmetries in Adolescent Patients Post ACL Reconstructions

Dai B, Butler RJ, Garrett WE, Queen RM: Duke University, Durham, NC

Context: The anterior cruciate ligament (ACL) re-injury rate is extremely high in adolescent patients. One risk factor for ACL re-injuries could be the noticeable limb asymmetries in neuromuscular control. One goal of rehabilitation is to restore knee kinetic symmetries during dynamic movements. However, an inverse dynamic approach with motion analysis and ground reaction force (GRF) measurements is usually needed to assess knee kinetics and might not be available in many medical settings.

Objective: To determine if asymmetries in knee moments and knee work can be predicted from asymmetries in GRF during a cutting task in adolescent patients post ACL reconstruction.

Design: Descriptive cohort study design.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Twenty-three (9M, 14F) adolescent patients (16.0 ± 0.6 yrs, 1.7 ± 0.1 m, 72.2 ± 15.6 kg) 6 month (6.2 ± 0.2 mo.) post ACL reconstruction participated in the study. All patients were high school or collegiate athletes with no history of other lower extremity surgeries. Intervention(s): Three-dimensional kinematic and GRF data were collected bilaterally during a 35° side-cutting task. Inverse dynamics were performed to calculate sagittal plane knee moments and total knee work during the stance phase of the cutting activity. Asymmetry indices between surgical and non-surgical limbs were calculated for peak impact vertical GRF, peak propulsion vertical GRF, peak posterior GRF, loading rate to peak impact vertical GRF, vertical GRF impulse, and anterior-posterior GRF impulse. Asymmetry indices were also calculated for peak knee moments, averaged knee moments, and total knee work. Asymmetry index for each variable was calculated as: (non-surgical side - surgical side) / non-surgical side. Pearson correlation analysis was performed between GRF asymmetry indices and knee kinetic asymmetry indices. Step-wise multiple linear regressions determined which GRF asymmetry indices could predict knee kinetic asymmetries.

Main Outcome Measure(s): Asymmetries in GRF and knee kinetics.

Results: Asymmetries in vertical GRF impulse (9% ± 9%) and peak propulsion vertical GRF (6% ± 9%) were significantly correlated with asymmetries in peak knee moments (24% ± 21%), averaged knee moments (24% ± 24%), and total knee work (34% ± 26%, P<0.05). No other GRF asymmetry was significantly correlated with knee kinetics asymmetries. Step-wise regression demonstrated that asymmetry in vertical GRF impulse significantly predicted asymmetries in peak knee moments (R^2=0.55, P<0.01, mean absolute error (MAE) =16%), averaged knee moments (R^2=0.58, P<0.01, MAE=17%), and total knee work (R^2=0.70, P<0.01, MAE=19%).

Conclusions: Knee kinetic asymmetries were correlated with asymmetries in certain GRF parameters. Vertical GRF impulse significantly predicted knee kinetic asymmetries with approximately 17% prediction error. The current study demonstrates the feasibility of using force plates or sensors with a single vertical axis as clinically applicable tools to monitor limb asymmetries during the rehabilitation progress.

Abstract #13

The Triple Hop for Distance is Associated to Frontal Plane Hip Peak Torque and Rate of Torque Development

Kollock RO,*† Van Lunen B,* Ringleb S,* Onate JA‡: *Old Dominion University, Norfolk, VA; †Gardner-Webb University, Boiling Springs, NC; ‡The Ohio State University, Columbus

Context: Insufficient frontal plane hip strength may increase an athlete's susceptibility to noncontact anterior cruciate ligament ruptures. However, screening for strength deficits using computer-based instrumentation may not be practical in all clinical settings.

Objective: To determine the relationship of the triple hop for distance (THD) to frontal plane hip peak torque (PT) and rate of torque development (RTD).

Design: Correlational design.

Setting: Research laboratory.

Patients or Other Participants: Sixty-two (30M, 32F) recreational athletes (21.05±2.82 yrs, 171.23±10.72 cm, 74.63±14.79 kg).

Intervention(s): Two sessions, separated by seven days were required. Session 1 isometric PT and RTD, sampled at 1000 Hz using a data acquisition module, were collected for hip abduction (AB) and adduction (AD) using a portable fixed-dynamometer. 3 test trials each lasting 5 seconds each separated by a 60 second rest-period were obtained for each measure. Participants' were informed to contract as hard and as fast as possible. The maximum of the 3 trials was used to determine the PT and RTD. The initial 200 ms after the onset of the contraction (i.e. time-point at which the torque was 7.5 Nm greater than the baseline value) were used to calculate the RTD from 0–30,0–50,0–100, and 0–200 ms. Session 2, 3 test trials of the THD were performed. Participants stood on one leg and perform 3 consecutive hops as far as possible landing on the same leg. The total distance of the hops was recorded. The highest trial was selected. Pearson correlations were used to evaluate the association between THD and strength. Alpha level was $p \leq 0.05$. R-values were squared to calculate the coefficient of determinations.

Main Outcome Measure(s): PT in Nm, RTD in Nm/s from 0–30,0–50,0–100, and 0–200 ms, THD distance in centimeters (cm), and THD work in joules (J): work [J]=participant's mass [kg] x (9.81 m/s^2) x distance hopped [m].

Results: *M+SDs* for THD cm and J were 477.49±106.49 cm and 3529.26±1124.50 J, respectively. *M+SDs* for AB PT in Nm was 137.61±42.11and RTD in Nm/s from 0–30,0–50,0–100, and 0–200 were 3756.46±1257.71, 2290.26±775.21, 1146.47±386.62, and 571.76±197.98, respectively. *M+SDs* for AD PT in Nm was 138.50±47.91 and RTD in Nm/s from 0–30,0–50,0–100, and 0–200 were 3657.48±1371.44, 2237.69±845.86, 1125.37±418.77, and 565.99±213.34, respectively. THD cm accounted for a significant portion of the variance for AB PT and RTD (r^2=.29 – .32, p<.01) and AD PT and RTD (r^2=.33 – .43, p<.01). THD J accounted for a significant portion of the variance for AB PT and RTD (r^2=.55 – .63, p<.01) and AD PT and RTD (r^2=.49 – .61, p<.01).

Conclusions: The findings suggest that THD J may be a strong indicator of frontal plane hip PT and RTD, potentially adding to the clinical usefulness of the task in determining lower limb strength. Future studies are needed using predictive models to validate these findings.

Abstract #14

Mechanism of Action of an Unloading Brace With Regards to the Reduction of ACL Injury Risk

Nicholls M, Briem K: University of Iceland, Reykjavík

Context: Frontal plane knee biomechanics play an important role in ACL injury. Peak and initial contact knee abduction angles during a drop jump have been shown to predict future risk of ACL injury. Braces designed to change forces and angles in the frontal plane may therefore offer some protection against ACL injury. Originally designed for unicompartmental knee osteoarthritis, the Unloader One® brace (Ossur, Reykjavik) applies a specific frontal plane force via two dynamic force straps during the last 20 degrees of extension to unload the compartment. In contrast, a functional knee brace is designed to restrict forward tibial translation and prevent hyperextension as well as offering generalized frontal plane stability.

Objective: To investigate the potential for a lateral Unloader brace to reduce the risk of ACL injury.

Design: Randomized cross-over design.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Eight healthy male participants (18 to 40 yrs) with no history of significant injury to the lower extremity.

Intervention(s): Lower limb kinetics and kinematics were obtained for each subject over a series of drop jumps (DVJs) during a single session. Subjects stood ontop of a 31cm high box and were instructed to drop directly down off the box, land on both feet and immediately jump as high as they could. Subjects performed three successful DVJs for the no brace and braced condition. Data were captured using two force plates sampling at 1200Hz and eight digital cameras at 125 Hz. Retroreflective markers were placed in a standard manner around the pelvis and lower limbs. Wireless force sensors were placed in the hinge and dynamic force straps of the brace. Visual3D was used to process marker data and calculate angles and moments at each joint.

Main Outcome Measure(s): Frontal plane knee angles at initial contact and peak value. Forces from brace sensors (Newtons).

Results: No significant difference was observed in mean+SD knee abduction angles at initial contact between the no brace and brace conditions (–7.4±4.7 and –8.3±4.7 degrees, respectively (P=0.18)). However, a significant difference was found in mean+SD peak knee abduction angles for the no brace and brace conditions (6.5±5.3 3.9±5.8, respectively (P=0.02)). The strap sensors showed very little activity until knee extension approached zero just prior to take off following landing. The hinge sensor peaks coincided with peaks in knee abduction.

Conclusions: As the straps apply an adduction force only as the knee reaches full extension, the results are contrary to expectations. The hinge, although not intended to be an active part of the alignment process, appears to be applying an opposing force at knee abduction angle peaks. Further investigation is warranted with an at risk population.

Abstract #15

A Simple Clinical Screening Test Can Identify Elite Female Football Players With Increased Knee Valgus Angles

Nilstad A, Kristianslund E, Krosshaug T, Steffen K, Myklebust G, Bahr R, Andersen TE: Oslo Sports Trauma Research Center, Norwegian School of Sports Sciences

Context: A link has been suggested between increased dynamic knee valgus and the risk of anterior cruciate ligament (ACL) injuries in female athletes. However, these findings are based on complex time-consuming 3D motion analysis. There is a need for simple screening tools to identify athletes at increased risk of an ACL rupture.

Objective: To assess whether an experienced clinician can identify athletes with increased valgus angles and abduction moments during a vertical drop jump using a simple screening test.

Design: Cross-sectional study.

Patients or Other Participants: Elite female football players.

Intervention(s): Players in the Norwegian elite league (12 teams; 14 players) were screened for potential risk factors for ACL injuries prior to the 2009 football season. Knee kinematics and kinetics in the landing phase of a 30 cm vertical drop jump (VDJ) were calculated using 3D motion analysis. Using a similar jump task, a physiotherapist assessed how well players stabilized their knees, and scored their knee control as being "good", "reduced" or "poor".

Main Outcome Measure(s): Maximal knee valgus angles and abduction moments in the landing phase of a VDJ.

Results: Of the 156 players included, 41% were classified as being "good", 33% had "reduced" control, and 26% were scored as "poor". Players with good control had significantly lower maximal valgus angles compared to players with poor control (4.7° vs. 12.6°, p≤0.001). These players also displayed lower abduction moments compared to players with poor control (0.32 Nm/kg vs. 0.40 Nm/kg, p=0.013). ROC analyses showed that high valgus angles were easier to identify with the screening test than high abduction moments (0.83 vs. 0.62).

Conclusions: The clinical screening test identified female athletes with high knee valgus angles. There was moderate correlation between clinical test scores and knee abduction moments. Further investigations are needed to determine the cut-off value for defining high versus low risk groups, as well as the predictive value of the screening test.

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Abstract #16

The Influence of Lower Extremity Muscle Activation and Flexibility on Single Leg Squat Performance in Those With and Without Medial Knee Displacement

Begalle RL, Mauntel TC, Cram TR, Frank BS, Hirth CJ, Blackburn JT, Padua DA: The University of North Carolina at Chapel Hill

Context: Medial knee displacement (MKD) is a potential risk factor for non-contact ACL and other lower extremity (LE) injuries. Clinical movement screenings and flexibility measurements may help identify neuromuscular characteristics contributing to MKD.

Objective: To compare LE muscle activation and flexibility between participants who display MKD during a single leg squat (SLS) and those who do not (CON). We hypothesized that differences in flexibility and muscle activation would exist between the groups.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Forty, physically active adults participated in this study. Those with MKD (MKD; n=20, male=10,female=10, age=20.2±1.8 years, height=173.8±8.8cm, mass=71.8±14.7kg) and those without MKD (CON; n=20,male=10,female=10, age=20.2±1.5 years, height=173.1±10.1cm, mass=71.0±14.6kg) were identified during screening. Potential participants performed five SLS trials on their dominant leg (chosen to kick a ball). MKD was defined as the midline of the patella moving medial to the great toe in at least three squats.

Intervention(s): Lower extremity passive range of motion (flexibility) was assessed prior to SLS testing; hip internal/external rotators, iliopsoas, iliotibial band, adductors, hamstrings, ankle plantarflexors, femoral anteversion, and posterior talar glide were measured. Participants performed five consecutive SLS trials with surface electromyography (EMG) for data collection.

Main Outcome Measure(s): Surface EMG was used to quantify the activity level of the gluteus medius (GMed), gluteus maximus (GMax), and hip adductors (Hip Add) during the descent phase of each SLS, defined as the initiation of movement to the time point of peak knee flexion. Normalized mean signal amplitudes (%MVIC) for the descent phase were used to calculate co-activation ratios for GMed/Hip Add and GMax/Hip Add, where values greater than 1.0 indicate greater activation of the gluteal muscle in comparison to the hip adductors. Three separate MANOVA tests with post-hoc one-way ANOVA were utilized to identify group differences in range of motion, EMG data, and muscle co-activation.

Results: Significant differences were identified between the MKD and CON groups in passive range of motion and hip muscle co-activation. Specifically, the MKD group displayed significantly less passive ankle dorsiflexion with the knee straight (MKD=5.5±5.4; CON=8.8±4.7; p=.047) and flexed (MKD=9.5±6.2; CON=14.2±7.3; p=.034), and greater posterior talar glide motion (MKD=29.8±4.8; CON=25.7±.50; p=.012). During the SLS, the MKD group had smaller hip co-activation ratios for GMed:Hip Add (MKD=2.4±1.1; CON=4.5±1.8; p=.028) and GMax:Hip Add (MKD=1.1±.62; CON=2.4±1.8; p=.007) compared to the control group indicating greater activation of the hip adductors. No between group differences were revealed for the other variables ($p>0.05$).

Conclusions: MKD during a single leg squat appears to be associated with decreased passive ankle dorsiflexion and decreased co-activation of the gluteal muscles in comparison to the hip adductors. Therefore, improving ankle dorsiflexion range of motion and balancing hip muscle activation may decrease MKD and warrant consideration when designing injury prevention programs.

Abstract #17

Immediate Decreases in Peak Vertical Ground Reaction Force Following Real-Time Feedback During Jump Landing

Ericksen HM, Lepley AS, Doebel SC, Armstrong CW, Pfile KR, Gribble PA, Pietrosimone BG: University of Toledo, OH

Context: Individuals landing with increased peak vertical ground reaction (VGRF) force and asymmetry during landing could be at increased risk for ACL injury. Clinician provided feedback has been used previously to reduce VGRF during landing, yet the use of technology in an effort to allow for the participant to make real time adjustments during landing has not been evaluated.

Objective: Determine the immediate effects of real-time feedback (RTF) and traditional feedback (TF) on peak vertical ground reaction force (VGRF) and inter-limb VGRF symmetry during landing compared to a jumping only and control condition.

Design: Single blinded, randomized controlled trial.

Setting: Research laboratory.

Patients or Other Participants: Thirty physically active females with no history of lower extremity injury were randomized into 4 groups (RTF:n=7, 21.1±1.5yrs, 164.0±5.5cm, 63.4±7.1kg; TF:n=8, 20.8±2.1yrs, 165.4±5.2cm, 61.6±3.4kg; Control:n=8, 21.3±1.2yrs, 162.6±6.8cm, 66.0±18.5kg; Jumping:n=7, 22.7±3.5yrs, 166.6±6.2cm, 68.6±14.22kg).

Intervention(s): RTF and TF participants completed three sets of six jump-landing trials (18 total) off a 30cm box. Both Intervention(s)(s) groups were provided standardized feedback, using verbal cues and visual representation of correct landing biomechanics, from a single clinician pertaining to each set of jumps. Additionally, for participants in the RTF group, retroreflective markers were positioned on the patella and dorsum of the great toe and tracked in real-time with a motion capture system. As they performed the trials, these subjects viewed the display on a 107cm monitor, enabling them to observe the alignment of their lower extremity. They were instructed to attempt to align the highlighted knee-foot segment with a stationary vertical reference line in the frontal plane during the landing. Control participants sat quietly for 10 minutes. Jumping participants received no feedback while performing the 18 jumps.

Main Outcome Measure(s): Participants performed three pre-intervention jumps and three post-intervention jumps consisting of a forward jump off a 30cm box transitioning into a maximal vertical jump. Peak VGRF was calculated for each limb and normalized to mass. A repeated measures ANOVA and Tukey post hoc comparisons were used to assess changes in VGRF, and inter-limb symmetry ((dominant VGRF/non-dominant VGRF)*100) upon landing. Pre-intervention VGRF values were used as a covariate to account for baseline group differences in the right VGRF analysis. Alpha was set a priori at $P<0.05$.

Results: Post-intervention right RTF VGRF was lower than control (RTF vs. control: 1.47±0.29, 2.27±0.36; P=0.001) and jumping (RTF vs. jumping: 1.47±0.29, 2.03±0.23, P=0.018). Left RTF (1.24±0.16) VGRF was lower compared to the control (1.82±0.24, P=0.006). There was no significant group by time interaction for inter-limb symmetry on landing (P=0.448).

Conclusions: A bilateral reduction in VGRF was observed following unilateral RTF treatment without a change in inter-limb symmetry. Further study should determine the effect of RTF on decreasing ACL injury risk.

Abstract #18

Sagittal Plane Trunk Stability Modulate Lower Extremity Sagittal Plane Kinetics and Kinematics During Single-Leg Landings

Shimokochi Y,* Igawa T,* Oishi A,* Kato N,* Ambegaonkar JP†: *Osaka University of Health and Sport Sciences, Kumatori-cho, Japan; †George Mason University, Fairfax, VA

Context: Sagittal plane trunk positions are suggested to influence non-contact ACL injury risk by modifying lower extremity kinetics and kinematics during landing activities. Still little is known about how increased trunk stability influences lower extremity kinetics and kinematics during single-leg landings.

Objective: To investigate effects of increased trunk stability on sagittal plane lower extremity kinetics and kinematics during single-leg landings.

Design: Repeated measures design.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Eighteen recreationally active females (20.2±1.2 yrs, 52.7±7.1 kg, 1.580±0.064 m) with no current pain in any part of the body or previous history of knee ligamentous injuries or surgeries.

Intervention(s): Participants performed single-leg landings from a 30 cm box in three different conditions; 1) Self-Selected Landings (SSL), 2) Valsalva Landings (VLL), and 3) enhanced Trunk Stability Landings (TSL). In VLL, participants had a mouthpiece with a small hole in their mouth and forcefully exhaled and hollowed their abdomen (valsalva maneuver) throughout the landing. In TSL, participants had a straight cardboard bar attached externally from their sacrum to thorax using an elastic bandage while performing the aforementioned valsalva maneuver during landing. Biomechanical data were obtained using an electromagnetic tracking system and force plate. Repeated-measure ANOVAs and post-hoc Bonferroni corrections compared landing conditions.

Main Outcome Measure(s): Thigh-thorax (TFE_{GRFpk} and TFE_{KEMpk}) and thigh-sacrum flexion excursions (SFE_{GRFpk} and SFE_{KEMpk}) (°) and sagittal plane joint work done by the hip, knee, and ankle joints from the foot contact to peak vertical ground reaction force (HW_{GRFpk}, KW_{GRFpk}, and AW_{GRFpk}, respectively) and peak knee extensor moment (HW_{KEMpk}, KW_{KEMpk}, and AW_{KEMpk}, respectively) ($J \cdot N^{-1} \cdot m^{-1}$) were calculated in each condition.

Results: Significant main effects ($p \leq 0.01$) were observed in SFE_{GRFpk} (SSL:2.9±3.1, VLL:4.4±2.9, TSL:5.2±3.1), SFE_{KEMpk} (SSL:5.9±3.4, VLL:9.1±3.6, TSL:11.8±5.5), HW_{GRFpk} (SSL: –0.001±0.002, VLL: –0.003±0.003, TSL: –0.007±0.004), KW_{GRFpk} (SSL: –0.012±0.008, VLL: –0.008±0.008, TSL: –0.007±0.004), and HW_{KEMpk} (SSL:–0.003±0.004, VLL:–0.007±0.006, TSL:–0.012±0.009). SFE_{GRFpk} and SFE_{KEMpk} in VLL (p=0.05 and $p<0.01$, respectively) and TSL ($p<0.05$ and $p<0.01$, respectively) were significantly greater than those in SSL. HW_{GRFpk} ($p<0.01$ for all pairs) and HW_{KEMpk} ($p<0.05$ for between VLL and TSL and $p<0.01$ for other pairs) were different across three conditions. KW_{GRFpk} in SSL were significantly larger than those in VLL and TSL (both $p<0.05$). No significant differences existed in TFE_{GRFpk} (SSL:8.9±3.2, VLL:8.5±3.3, TSL:8.5±2.9), TFE_{KEMpk} (SSL:16.6±4.2, VLL:18.5±5.5, TSL:17.8±5.3), AW_{GRFpk} (SSL:–0.043±0.016, VLL:–0.040±0.013, TSL:–0.041±0.014), KW_{KEMpk} (SSL:–0.037±0.014, VLL:–0.035±0.011, TSL:–0.037±0.013), and AW_{KEMpk} (SSL:–0.051±0.018, VLL:–0.051±0.016, TSL:–0.053±0.014).

Conclusions: Our Intervention(s)s to increase trunk stability increased thigh-sacrum flexion excursions, leading to better sacrum-thorax flexion synchronization in the early phase of single-leg landings. Increased thigh-sacrum flexion excursions may increase eccentric hip extensor muscle actions and decrease eccentric knee extensor muscle actions in very early phase of single-leg landings. Our results indicate a possible mechanism for how increased trunk stability increases knee stability and decreases ACL injury risk, especially immediately post-impact during single-leg landings.

Abstract #19

Lumbopelvic Hip Complex Neuromuscular Control Is Associated With Triplanar Knee Loading

Frank BS,* Bell DR,† Norcross MF,‡ Goerger BM,* Blackburn JT,* Padua DA*: *University of North Carolina at Chapel Hill; †University of Wisconsin-Madison; ‡Oregon State University, Corvallis

Context: Triplanar knee loading induces stress in the anterior cruciate ligament (ACL). Recent findings suggest neuromuscular control (NMC) of the lumbopelvic hip complex (LPHC) influences lower extremity biomechanics during landing. However, the relationship between LPHC NMC and triplanar knee loads during an athletic cutting task (ACUT) has not been examined.

Objective: Assess the relationship between LPHC kinematics and stability between knee moments during an ACUT.

Design: Cross-Sectional.

Setting: Research laboratory.

Patients or Other Participants: 30 healthy, physically active volunteer subjects (15 males, 15 females, age: 20.5±2.5 yrs, mass: 67.50±11.39 Kg, height: 173.78±9.28 cm).

Intervention(s): ACUT Task: Triplanar trunk and lower extremity kinematics and kinetics were collected using an optical motion capture system and force plate during the first 50% of the stance-phase of the ACUT on the subject's dominant limb. The ACUT required 3 running approach steps, jumping over a 17 cm hurdle before cutting 60° in the opposite direction of the dominant plant limb. Trunk stability was captured during an unstable sitting task (UST) as individuals sat atop a 30 cm polyresin hemisphere atop a force plate for 30 seconds.

Main Outcome Measure(s): Average angular triplanar trunk displacements (degrees) and peak external knee moments (normalized to the body mass (Kg) by body height (m) product) were calculated during the first 50% of the stance-phase of the ACUT. The 95% center-of-pressure (CoP) sway area (cm^2) quantified trunk stability during the UST. Pearson product-moment correlation coefficients were calculated between trunk angular displacements, 95% CoP, and peak knee moments.

Results: Trunk stability (50.30±18.50cm^2) was positively ($r=0.478$, $p=0.018$) associated with lateral trunk displacement (3.56±2.46°) and knee flexion moment (1.10±0.20Nm/(Kg*m)) ($r=0.407$, $p=0.049$). A larger CoP sway area was associated with more lateral displacement of the trunk toward the stance limb and a larger knee flexion moment magnitude. Trunk forward flexion (7.62±5.28°) was positively ($r=0.424$, $p=0.002$) associated with knee internal rotation moment (0.11±0.08Nm/(Kg*m)). More forward trunk flexion was associated with higher magnitude knee internal rotation moment. Trunk rotation (20.25±4.42°) was negatively (–0.460, $p=0.011$) associated with knee valgus moment (0.11±0.12Nm/(Kg*m)). More trunk rotation away from the stance limb was associated with a lower knee valgus moment magnitude.

Conclusions: Individuals with lesser trunk stability (larger 95% CoP area) demonstrated higher knee loading in the sagittal plane and greater frontal plane trunk displacements compared to those with greater trunk stability. Additionally, more trunk motion in the sagittal plane and less trunk motion in the transverse plane was associated with greater knee loading in the transverse and frontal planes. The results of this study exhibit a relationship between LPHC stability and motion and triplanar knee loads during an ACUT. This study may provide insight into previous research demonstrating that trunk NMC was associated with prospective ACL injury risk.

Abstract #20

Hamstring Muscle-Tendon Unit Function During Drop and Hop Landings: Implications for ACL Strain

Oh YK, Ashton-Miller JA, Palmieri-Smith RM, Wojtys EM: University of Michigan, Ann Arbor

Context: Non-contact anterior cruciate ligament (ACL) ruptures frequently occur when landing from a jump. Increases in hamstring tension can reduce peak ACL strain by as much as 70% during a simulated jump landing (Withrow et al., 2006), depending upon hip and knee flexion angles at ground contact, and the contractile states of the quadriceps and hamstrings muscles. The latter tension will depend on the level of pre-activation as well as whether the hamstrings shorten, remain isometric or lengthen during a landing.

Objective: To determine how the lengths of the hamstring muscle-tendon unit (MTU) change during the first 100 msec of a landing. We hypothesized that certain combinations of hip and knee flexion can cause a lengthening of the hamstring MTU during a jump landing.

Design: An *in vitro* experimental study combined with a secondary *in silico* analysis of *in vivo* jump landing kinematics.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Three cadavers (2F, 1M; 81.0±9.6 yrs) without musculoskeletal abnormalities in the hips and knees were tested. A secondary analysis of *in vivo* data from post-impact knee and hip angle changes measured in 48 young adults performing 60-cm drop (Russell et al., 2006) and 1-m forward hop (Palmieri-Smith et al., unpublished) landings on one leg was performed.

Intervention(s): The origins and insertions of the biceps femoris (BF), semimembranosus (SM) and semitendinosus (ST) MTU were exposed and their 3-D positions were tracked using an Optotrak Certus system while the knee was slowly flexed through 90° in the parasagittal plane with the fixed hip angles. The lengths of the hamstring MTUs were then calculated as the straight-line distance between origin and insertion at each time interval. The best-fit quadratic polynomials were found to model the relationship between the measured MTU length and knee angle for each hip angle.

Main Outcome Measure(s): The changes in hamstring MTU lengths were mathematically predicted based on the premise that a representative cadaver could employ the same changes in hip and knee angles as those measured in each of the *in vivo* 215 drop and 102 hop landings.

Results: The BF MTU monotonically shortened in 64% and 52% of the hop and drop landing trials (–6.7±2.8 mm and –3.7±1.4 mm, respectively). For the rest of the landing trials, the changes in length of the BF MTU were less than ±1.5 mm.

Conclusions: The hamstring MTUs were predicted to shorten or remain isometric during the first 100 msec of these hop and drop landings. But, there was evidence for a lengthening state in some trials. It may be possible to enhance this lengthening effect, and therefore ACL injury prevention, by teaching an individual to increase hip flexion during the landing phase.

Abstract #21

The Influences of Knee Flexion Angle at Initial Contact and Sex on Knee Kinetics

Norcross MF,* Lewek MD,† Padua DA,† Shultz SJ,‡ Weinhold PS,† Blackburn JT†: *Oregon State University, Corvallis, OR; †University of North Carolina at Chapel Hill; ‡University of North Carolina at Greensboro

Context: Increasing initial contact (IC) knee flexion angle during landing is a common component of ACL-injury prevention programs, and is suggested to decrease ACL-injury risk. However, it is unknown how altering IC knee flexion angle influences knee kinetics related to ACL-injury, and whether these changes differ by sex.

Objective: To compare knee kinetics between males and females performing drop landings using different IC knee flexion angles.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Seventy-nine healthy, recreationally active volunteers (38M, 41F; Age = 20.9±2.5 years, Height = 173.2±9.1 cm, Mass = 68.1±11.3 kg).

Intervention(s): Subjects hung from an adjustable overhead bar and performed 60-cm terminal drop landings using flexed (F) and erect (E) IC knee postures in a counterbalanced order. Real-time visual and auditory biofeedback was provided to achieve F and E postures, with successful trials requiring subjects' knee flexion angle at IC to be 35±5° and 20±5°, respectively. Dominant leg three-dimensional kinematics and kinetics were assessed using an electromagnetic motion capture system and a force plate.

Main Outcome Measure(s): Knee flexion at IC; peak vertical ground reaction force (pVGRF), and internal knee extension (pKEM) and varus (pKVM) moments during the 100 ms immediately after IC; and knee flexion angles at the time of pKEM (_pKEM) and pKVM (_pKVM) were calculated. Twenty-nine participants (13M, 16F) failed to complete 5 successful trials of each condition and were excluded from the analyses. Separate 2 (Sex) x 2 (Posture) repeated-measures ANOVAs were used to evaluate the influences of sex and knee posture on the dependent variables.

Results: IC knee flexion angle was significantly different between conditions ($F_{1,48}=1162.312$, $P<0.001$; F:33.82±2.10° vs. E:19.61±2.12°), and the magnitude of this change was similar between sex ($P>0.05$). Significant Posture main effects were identified indicating that, compared to the E condition, F landings resulted in lesser pVGRF ($F_{1,48}=14.416$, $P<0.001$; F:2.68±0.77 vs. E:2.98±0.77 [xBW^{-1}]) and pKVM ($F_{1,48}=6.038$, $P=0.018$; F:0.067±.063 vs. E:0.079±0.054 [$x(BW*Ht)^{-1}$]); and greater pKEM ($F_{1,48}=12.337$, $P=0.001$; F:–0.203±0.052 vs. E:–0.188±0.047 [$x(BW*Ht)^{-1}$]), _pKEM ($F_{1,48}=79.242$, $P<0.001$; F:40.74±8.04° vs. E:30.33±10.50°) and _pKVM ($F_{1,48}=6.038$, $P<0.001$; F:41.06±4.70° vs. E:29.90±4.89°). Females demonstrated lesser _pKEM than males across conditions ($F_{1,48}=8.136$, $P=0.006$; Females:33.29±11.24° vs. Males:43.41±8.97°), but no other significant Sex or Sex*Posture interaction effects were identified ($P>0.05$).

Conclusions: Landing with greater IC knee flexion produced lesser pVGRF and pKVM, and greater _pKVM; factors generally associated with lesser ACL loading. The greater pKEM requirement when landing with greater knee flexion suggests that some individuals might employ a more erect landing posture due to limited moment production capability (i.e. weakness or fatigue). However, while a larger pKEM is generally associated with greater anterior tibial shear force and ACL loading, these effects during F were likely offset by the concomitant increase in _pKEM.

Abstract #22

Landing Technique Affects Knee Position During a Pivot Task

Cortes N,* Greska E,† Ambegaonkar JP,* Benjaminse A,‡ Onate JA§: *George Mason University, Fairfax VA; †Old Dominion University, Norfolk VA; ‡Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, The Netherlands, and Hanze University Groningen, School of Sport Studies, The Netherlands; §The Ohio State University, Columbus

Context: Noncontact anterior cruciate ligament injuries (ACL) are reported to occur during rapid deceleration, and particularly when a change in direction occurs. Recent observational studies have reported that the ankle is in a dorsiflexion (rearfoot (RF)) position when ACL injury occurs. However, few studies have investigated the contribution of foot landing technique to the biomechanical aspects during landing.

Objective: The purpose of this study was to quantify lower extremity biomechanical differences between two landing techniques (forefoot (FF) and RF) while performing a pivot task.

Design: Quasi-experimental.

Setting: Controlled laboratory.

Patients or Other Participants: Nineteen female collegiate soccer athletes (20±0.9years; 1.67±0.1m; 63.2±10.1kg) with no previous history of ACL injury, or lower extremity injury within the past 2 years participated in the study.

Intervention(s): Lower extremity biomechanics of the dominant leg were obtained while performing a pivot task with FF and RF landing techniques. An 8-camera VICON system, and 2 Bertec force plates collected kinematic and ground reaction force data at 500 Hz. Five valid trials, verified by video, of each task were collected. Landing techniques were counterbalanced between participants. For the FF, participants were instructed to land on their toes at initial contact (IC), whereas for the RF they were instructed to land on their heels. Repeated measures ANOVAs were conducted to assess differences between landing techniques on the various outcome measures. Alpha level set *a priori* at $p \leq .05$.

Main Outcome Measure(s): Hip flexion, knee flexion and abduction angles, and ankle flexion moment were evaluated at IC and peak stance (PS). Angles were measured in degrees, and moments normalized to Nm/kgm.

Results: At IC, the RF landing technique resulted in lower knee flexion (RF: –17.7±4.9° vs. FF: –25.8±7.8°, $p<0.001$), decreased knee abduction (RF: –7.4±6.6° vs. FF: –12.8±7.8°, $p<0.001$), but increased hip flexion (RF: 50.7±6.8° vs. 46.5±7.9°, $p<0.001$). At PS, the RF landing resulted in significantly decreased knee flexion (RF: –54.6±8.4° vs. FF: –58.6±9.3°, $p=0.002$), less knee abduction angle (RF: –8.4±7.3° vs. –14.4±8.1°, $p<0.001$), although the hip was more flexed (RF: 66.3±10.4° vs. FF: 58.2±12.4°, $p<0.001$). Ankle moments were not different at either time instant, IC and PS, $p>0.05$.

Conclusions: There are inherent dissimilarities between the RF and FF landing techniques while performing a pivot task. RF landings presented a more straight posture at the knee, but with less knee abduction when compared to FF landings. This more extended knee position is thought to be an at-risk position for ACL injury, as it may not allow for proper hamstring activation to protect the tibia from anterior displacement. Further, increased knee abduction has been shown as a strong predictor of ACL injuries. Intervention programs should consider the potential effects of landing technique being performed on knee abduction and flexion angles.

Abstract #23

Risk of Knee Sprain Following the Implementation of an Injury Prevention Program is Associated With Level of Supervision

Carow SD, Haniuk EM, Cameron KL, DiStefano LJ, Padua DA, Marshall SW, Beutler AI, Gerber JP: United States Military Academy, West Point, NY

Context: Recently, movement patterns have been identified that are associated with increased risk of Anterior Cruciate Ligament (ACL) injury. The Dynamic Integrated Movement Enhancement (DIME) exercises were developed specifically to address these harmful movement patterns based on prospective data from the JUMP-ACL study.

Objective: The primary purpose was to determine if the DIME program was effective for preventing knee sprains in United States Military Academy (USMA) Cadets.

Design: Cluster randomized controlled trial.

Setting: Cadet Basic Training (CBT) at USMA. Following a six week intervention, injury data was collected from the electronic military medical record system. All cadet injuries are recorded in these databases with diagnosis information. Injury data was collected for a period of 11 months, beginning with CBT and extending through the cadets' first academic year. Risk ratios and 95%confidence intervals were calculated to compare groups.

Patients or Other Participants: 1313 incoming cadets (1070 males, 243 females) consented to participate in this study.

Intervention(s): Subjects were cluster randomized based on their CBT company to different warm-up groups. All groups performed warm-up exercises for approximately 15 minutes prior to engaging in physical training three times per week for six weeks. Four companies of cadets (659 subjects) performed the traditional Army warm-up (AWU) and served as the active-control group. The other four companies (654 subjects) performed the DIME warm-up exercises. The DIME companies were further separated into two groups; the DIME with Cadre Supervision (DCS) and the DIME with Expert Supervision (DES). In the DCS group, cadets led and supervised the DIME program. In the DES group, cadets led the DIME program with additional supervision provided by a physical therapist or athletic trainer. The DIME consists of 10 exercises focused on improving biomechanics through unilateral and bilateral jumping and squatting exercises.

Main Outcome Measure(s): The cumulative risk of acute traumatic knee joint injury was the primary outcome of interest.

Results: There were 3 knee sprains (0 ACL) in the DES group, 11 (2 ACL) in the DCS group, and 15 (5 ACL) in the AWU group. The risk of knee sprain was 0.9% in the DES group, compared to 2.1% and 3.9% in the AWU and DCS groups, respectively. The risk of knee sprain in the DES group was 76% lower (RR=0.24, 95%CI:0.07, 0.82) when compared to the DCS group and 57% lower (RR=0.43, 95%CI:0.13,1.50) when compared to the AWU group; however, the observed risk reduction was only statistically significant when comparing DES group to the DCS group.

Conclusions: Subjects who performed the DIME with expert supervision had a reduced risk of knee sprain following six weeks of training with the DIME. These preliminary data suggest that supervision is associated with the effectiveness of knee injury prevention programs.

Abstract #24

A Prospective Evaluation of Knee Flexion and Valgus Mechanics as Predictors for Anterior Cruciate Ligament Injury Risk

Padua DA,* Boling MC,† Goerger BM,* DiStefano LJ,‡ Cameron K,§ Beutler AI,¶ Marshall SW*: *University of North Carolina, Chapel Hill; †University of North Florida, Jacksonville; ‡University of Connecticut, Storrs; §United States Military Academy, West Point, NY; ¶Uniformed Services University of the Health Sciences, Bethesda, MD

Context: Knee flexion and valgus mechanics are hypothesized prospective risk factors for ACL injury. However, there is limited prospective research investigating the risk of ACL injury between individuals with different profiles of knee flexion and valgus mechanics.

Objective: To determine if knee flexion and valgus mechanics during a jump-landing task are prospective risk factors for ACL injury.

Design: Prospective cohort.

Setting: Research laboratory.

Patients or Other Participants: 5,689 healthy, physically active participants (males=3,496; females=2,193; age=18.6±0.6 yrs, ht=173.5±9.2 cm, wt=71.9±12.9 kg) were baseline tested. 107 of the original participants later suffered an ACL injury after baseline testing.

Intervention(s): Three-dimensional knee joint kinematics and kinetics were quantified using an electromagnetic motion analysis system and force plate while participants performed a jump-landing task (3 trials).

Main Outcome Measure(s): Knee flexion and valgus angles and internal knee flexion and valgus-varus moments (normalized to body weight x height) were calculated at the following time points during the stance-phase of the jump-landing task: initial-contact and 50%. Poisson regression was performed to model ACL injury rate per 1,000 person-years at risk (adjusted for gender, testing site, and year of enrollment). These variables are continuous in nature. We report the rate ratio comparing the upper tertile to the lower tertile.

Results: Poisson regression models for knee flexion mechanics demonstrated that knee flexion angle at initial-contact (RR=1.35, 95%CI= 0.82,2.23, CLR=2.7, $p=0.23$), knee flexion angle at 50% of stance (RR=1.23, 95%CI= 0.76,1.98, CLR=2.6, $p=0.39$), knee flexion moment at initial-contact (RR=1.16, 95%CI= 0.73,1.86, CLR=2.6, $p=0.52$), knee flexion moment at 50% of stance (RR=1.23, 95%CI= 0.76,1.98, CLR=2.6, $p=0.39$) were not risk factors for ACL injury. Poisson regression models for knee valgus mechanics demonstrated that knee valgus angle at initial-contact (RR=1.17, 95%CI= 0.73,1.88, CLR=2.6, $p=0.52$), knee valgus angle at 50% of stance (RR=1.42, 95%CI= 0.88,2.29, CLR=2.6, $p=0.15$), knee valgus moment at (RR=0.89, 95%CI= 0.55,1.45, CLR=2.6, $p=0.64$), and knee valgus moment at 50% of stance (RR=0.63, 95%CI= 0.38,1.04, CLR=2.7, $p=0.06$) were not risk factors for ACL injury.

Conclusions: Knee flexion and valgus mechanics (angle and moment) at initial-contact and 50% of the stance-phase during a jump-landing task are not prospective risk factors for ACL injury. These findings are in contrast to previous research in high school athletes indicating that external knee valgus moment was a prospective risk factor. Differences in populations studied may partially explain these discrepancies. Knee flexion and valgus mechanics are believed to play a role during the mechanism of ACL injury and altering these variables may be an important component of ACL injury prevention programs; however, these variables do not appear to be useful for identifying individuals at risk for future ACL injury.

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Abstract #25

The Effects of Isometric and Isotonic Training on Hamstring Musculotendinous Stiffness: Implications for ACL Loading

Blackburn JT,* Norcross MF†: *University of North Carolina at Chapel Hill; †Oregon State University, Corvallis

Context: Individuals with greater hamstring musculotendinous stiffness (MTS) display lesser anterior tibial translation during controlled perturbations and smaller anterior tibial shear forces and frontal plane knee angles and moments during landing compared to those with more compliant hamstrings. MTS can be modified via isometric and isotonic training, but the majority of previous investigations have evaluated tendon stiffness rather than that of the musculotendinous unit, and none have involved the hamstrings.

Objective: To evaluate the effects of isometric and isotonic training on hamstring MTS.

Design: Randomized controlled trial.

Setting: Research laboratory.

Patients or Other Participants: Thirty-six healthy, physically active volunteers (18M, 18F; age=23±3 years; height=1.8±0.1m; mass=73.1±16.6kg).

Intervention(s): Subjects were assigned to Isometric Training (IsoM; n=12), Isotonic Training (IsoT; n=12), or Control (CON; n=12) groups in a stratified random manner to produce equal sex distributions. Training groups completed 6 weeks of training designed to increase hamstring MTS, while the CON group continued their normal physical activity habits throughout the intervention period. Hamstring characteristics were measured within 1 week immediately prior to and following the intervention. Hamstring strength and maximal EMG amplitude were assessed during maximal voluntary isometric contractions (MVIC). Hamstring MTS was measured by quantifying the damping effect imposed by the hamstrings on oscillatory knee flexion/extension following perturbation with the hamstrings active to 45%MVIC. Hamstring EMG was sampled during MTS assessments to verify similar relative effort between groups.

Main Outcome Measure(s): Hamstring MTS was normalized to body mass. Mean hamstring EMG amplitude was measured prior to and following perturbation during MTS assessments and normalized as %MVIC. Hamstring strength was calculated as peak force during MVIC normalized to body weight. Separate 3(Group) x 2(Test) repeated-measures ANOVA were used to evaluate changes in hamstring characteristics across the intervention.

Results: Changes in hamstring MTS did not differ between groups ($p > 0.05$). However, the Test main effect was significant ($p = 0.028$) indicating a 10.2% increase at post-test. Mean Pre-test vs. Post-test MTS was (IsoM:19.4±4.6 vs. 22.5±5.8 N/m·kg^{-1}; Δ=15.7%), (IsoT:21.3±6.2 vs. 24.1±10.6 N/m·kg^{-1}; Δ=13.5%), and (CON:18.5±6.0 vs. 18.5±3.8 N/m·kg^{-1}; Δ=0.4%). Exploratory dependent t-tests indicated that MTS increased significantly in the IsoM group ($p = 0.006$), and that the change in MTS in the IsoT group approached significance ($p = 0.089$), but not in the CON group ($p = 0.942$). Similar exploratory analyses indicated that hamstring strength and EMG amplitude did not change across the intervention ($p > 0.05$).

Conclusions: Isometric training increases hamstring MTS. The lack of changes in hamstring strength and EMG suggest an influence on viscoelastic properties. As greater hamstring stiffness is associated with a more stable joint and a landing biomechanics profile consistent with lesser ACL loading, isometric hamstring training may be an important addition to future ACL injury prevention programs.

Abstract #26

Predictive Value of the Jump Task for Injury Among Division-I Female Soccer Athletes

Whale C,* Oliver G,* Tripp PM†: University of Arkansas, Fayetteville; †University of Florida, Gainesville

Context: Proper landing mechanics, adequate strength, and coordinated movement patterns may reduce incidence of lower-extremity injury among athletes participating in sports such as volleyball, basketball and soccer. Unfortunately, limited evidence exists assessing the effectiveness of injury prediction screening based on identified mechanical faults. One proposed tool quantifies errors while athletes perform a tuck jump task in hopes of identifying those athletes who are at-risk for suffering a lower-extremity injury.

Objective: To evaluate the ability of the tuck jump assessment to predict lower-extremity injury among Division-I collegiate female soccer athletes.

Design: Prospective cohort study design.

Setting: Clinical setting.

Patients or other Participants: Thirty-two female Division-I soccer athletes (20+2yrs, 64.5+16.5kg, 1.66+0.14m) with no current participation-restrictions.

Intervention(s): Before the start of soccer preseason, functional performance for each participant was evaluated using the tuck jump assessment. Participants performed consecutive tuck jumps in a 10 second time frame following the protocol previously published. Following the published standards, we recorded and used video to quantify error scores for each participant's tuck jumps; Intra-rater reliability was considered good (.83).

Main Outcome Measure(s): Error scores can range from 0 to 10, with 10 representing poor performance (more errors). Following published guidelines, we considered participants with error scores ≥6 "high risk". The team's athletic trainer recorded all lower-extremity injuries, defined as an injury resulting in a missed practice, during the season. We calculated the sensitivity, specificity, and likelihood ratios based on the identification of "high risk" participants and the actual injury incidence. True positives were those participants scored as >6 ("high risk") that sustained a lower-extremity injury; false positives were those scored as "high risk" that remained uninjured true negatives were those scored as <6 that remained uninjured; and false negatives were those scoring <6 that sustained a lower-extremity injury.

Results: Eighteen lower-extremity injuries occurred during the season. Mean pre-season tuck jump error scores were 5.38+1.50. Those suffering a lower-extremity injury had fewer errors compared with those that remained uninjured (5.12+1.41 to 5.67+1.59 respectively). The tuck jump assessment displayed poor sensitivity (53%) and specificity (47%) and poor positive (1.01) and negative (0.99) likelihood ratios.

Conclusions: Previous authors suggest a score ≥6 on the tuck jump assessment identifies "high risk" individuals who would benefit from an intervention aimed to correct faulty landing mechanics. However, our data suggest this benchmark score is neither sensitive nor specific to identify "high risk" individuals competing in Division I collegiate soccer. Although the tuck jump assessment is considered a clinician friendly tool, there is limited evidence to support clinical usefulness for identifying at-risk athletes in this population. Further research should consider a larger sample, and a diversity of sports and participation levels.

Abstract #27

Non-Contact ACL Injury and Prevention Awareness of Pennsylvania Coaches at the DII and the High School Level

Fetchen-DiCesaro S, Traber A, Zuchelkowski E, Miller L: California University of Pennsylvania

Context: Female athletes have a 4 to 6 times higher rate of ACL injury than their male counterparts. Coaches have a unique ability to implement injury prevention strategies into daily practices and conditioning sessions, however they may not have the knowledge needed to effectively incorporate these strategies.

Objective: The purpose of this study was to survey coaches of different levels and genders regarding their awareness of risk factors and injury prevention of ACL injuries in female athletes.

Design: Descriptive survey study design.

Setting: Controlled laboratory setting.

Patients or Other Participants: Seventy-six surveys out of 204 sent were completed and returned at a return rate of 37.4%. The sample consisted of 76 total coaches (33 males and 43 females) from the Collegiate Pennsylvania State Athletic Conference (N=49) and the High School Western Pennsylvania Interscholastic Athletic League (N=27). The respondents coached 12 different sports at the high school and collegiate level.

Intervention(s): The independent variables were coaching level (collegiate or high school) and gender. A survey constructed by the researcher based on published literature examined the awareness of NC-ACL injury risk factors via 33 questions pertaining to known risk factors, injury prevention and demographic questions and was distributed electronically via Survey Monkey. Prior to distribution of the survey preliminary research was conducted through a panel of experts who were asked to examine the validity of the content and the comprehension of the questions.

Main Outcome Measure(s): The dependent variable was the coach's awareness of the risk factors of injury. A 2X2 factorial ANOVA was used to determine if there was a difference between gender of coach, coaching level and overall awareness.

Results: Overall, participants averaged an awareness score of 21.87 ±6.321 out of 33 question or 51 percent of the questions answered correctly. Awareness scores for coaching level (Col = 22.59 ±6.00, HS = 20.56 ±6.784 were found not significant ($F_{(1,72)}$= 1.136, P=.290), indicating that coaching level does not significantly affect awareness of proposed risk factors for injury. However, scores were found to be significant between gender of coaches ($F_{(1,72)}$= 6.894, P=.011), with females having a higher awareness score (23.58 ± 5.569) than males (19.64 ±6.623).

Conclusions: Coaches should be knowledgeable of injury prevention strategies that can be implemented during practices and conditioning to potentially decrease the risk of a NC-ACL injury. This survey demonstrates that despite the barrage of NC-ACL information in the media, there is disparity of coaches' overall knowledge as well as between genders. Further research including a more detailed survey and increased sample size should be conducted to assess the current level of coaches NC-ACL injury prevention knowledge.

Abstract #28

Lower Extremity Strength Ratios and ACL Injury in NCAA Division I Soccer Players

Onate J,* Miller M,* Schroeder M,* Hertel J,† Van Lunen B,‡ Cortes N,§ Grooms D*: *The Ohio State University, Columbus; †University of Virginia, Charlottesville; ‡Old Dominion University, Norfolk, VA; §George Mason University, Fairfax, VA

Context: Weak lower extremity musculature has been theorized as a factor contributing to increased anterior cruciate ligament (ACL) and generalized lower extremity injury occurrence.

Objective: The purpose of this study was to examine strength ratios of the lower extremity musculature between college soccer players who did and did not suffer ACL and lower extremity injuries.

Design: Cohort study.

Setting: Movement analysis laboratory.

Patients or Other Participants: 382 NCAA Division I collegiate soccer players; 200 male (179.6 ± 6.7 cm, 76.6 ± 7.8 kg, 19.5 ± 1.3 years) and 182 female (167.4 ± 6.0 cm, 62.7 ± 7.1 kg, 19.3 ± 1.1 years) screened over a 2-yr period.

Intervention(s): Peak isometric hip and knee strength was measured prospectively using a portable load cell (BTE Technologies, Hanover, MD). Frontal and sagittal plane motions were measured in the standing position;

transverse plane rotations were measured in the seated position. Peak isometric knee strength was measured in the seated position. Peak strength values were arranged into four strength ratios: hip flexion:extension (FLX:EXT), abduction:adduction (ABD:ADD), external:internal rotation (ER:IR), knee extension:flexion (EXT:FLX). Ratio values were obtained by dividing peak strength of the agonist muscle by peak strength of the antagonist.

Main Outcome Measure(s): Athletes were prospectively followed for two consecutive seasons. Each team's athletic trainer recorded all injuries. Athletes were classified as "ACL injured" (n=9) or "non-injured" (n=373). Athletes were also classified as either "lower extremity injured" (n=136) or "non-injured" (n=178), with lower extremity injury defined as any event affecting the lower limb, originating at the hip and extending distally, that caused participation time loss for one or more days. Independent samples *t*-tests were conducted, with an *a priori* alpha level of 0.05, in order to determine if differences in strength ratio asymmetries were present between athletes who did and did not sustain an ACL or lower extremity injury.

Results: No significant differences in ACL-injured groups were found for any of the recorded lower extremity strength ratios. A significant difference in strength ratios, with respect to lower extremity injury, was reported for one of the four calculated strength ratios: (Hip FLX:EXT $p=.026$). Average (mean $\pm$ sd) strength ratios were for Hip FLX:EXT injured (117.9 $\pm$ 43.9%) and non-injured (108.8 $\pm$ 28.2%) showed a nearly 10% stronger hip flexor ratio occurred in the group that sustained a lower extremity injury.

Conclusions: The results of this study show that lower extremity strength ratios did not differ in college soccer athletes who did/did not sustain an ACL injury, yet a significant difference existed between hip flexion: extension ratios for overall lower extremity injury between groups. Future lower extremity injury studies in college soccer athletes may benefit from focusing on hip musculature imbalances during the pre-season, rather than singularly focusing on knee strength.

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Abstract #29

The Effects of Fatigue and Leg Dominance on Hip and Knee Neuromechanics

Greska E,* Cortes N,† Samaan M,* Onate JA,‡ Ringleb S,* Van Lunen B*: *Old Dominion University, Norfolk, VA; †George Mason University, Fairfax VA; ‡The Ohio State University, Columbus

Context: Previous studies have demonstrated that noncontact anterior cruciate ligament (ACL) injury rates differ between dominant and non-dominant legs, as well as during different states of fatigue; but have not examined the two variables concurrently.

Objective: The purpose of this study was to evaluate the effect of fatigue and leg dominance on lower extremity neuromechanical factors during an unanticipated sidestep task (SST).

Design: Quasi-experimental.

Setting: Controlled laboratory.

Patients or Other Participants: Twenty female collegiate soccer athletes (19.2$\pm$1.0years; 1.67$\pm$0.1m; 53.2$\pm$6.17kg) free of lower extremity injuries at the time of participation.

Intervention(s): Participants completed three valid trials for both the dominant and non-dominant legs, of the SST at pre-fatigue and post-fatigue. The dominant leg was defined as the leg the subject would use to kick a soccer ball furthest. Fatigue was determined using heart rate and a rating of perceived exertion, while performing dynamic anaerobic tasks. An 8-camera motion capture system, and two force plates, captured data at rates of 250Hz and 2000Hz, respectively. Repeated measures ANOVA's were used to determine the main and interaction effects for fatigue and leg dominance on hip and knee mechanics. An alpha level of 0.05 was set *a priori*.

Main Outcome Measure(s): Knee flexion (KF), knee abduction (KAB), hip flexion (HF), and hip abduction (HAB) joint angles, and knee abduction moment (KABM) were measured at initial contact (IC) and peak knee abduction moment (PKABM). Angles were measured in degrees, and moments normalized to Nm/kgm.

Results: At IC, the main effect of fatigue demonstrated significant angular decreases for KF ($p=0.005$), for dominant (–28.2$\pm$6.4° to –23.7$\pm$8.5°) and non-dominant legs (–30.0$\pm$8.0° to –26.1$\pm$8.5°), HF ($p<0.001$), for dominant (52.9$\pm$9.7° to 46.4$\pm$10.3°) and non-dominant (53.6$\pm$7.9° to 48.8$\pm$10.7°), and HAB ($p=0.030$), for dominant (–11.5$\pm$6.7° to –8.2$\pm$7.0°) and non-dominant (–10.7$\pm$6.0° to –9.4$\pm$6.0°). Fatigue also demonstrated a main effect at PKABM, with significant differences for KF ($p=0.026$), for dominant (–43.4$\pm$7.8° to –41.4$\pm$10.3°) and non-dominant legs (–44.4$\pm$5.0° to –41.4$\pm$7.5°), HF ($p<0.001$), for dominant (52.4$\pm$8.7° to 43.5$\pm$12.0°) and non-dominant (50.1$\pm$7.7° to 44.3$\pm$11.1°), and KABM ($p<0.001$), for dominant (–0.2$\pm$0.2 Nm/Kgm to –0.3$\pm$0.2 Nm/Kgm) and non-dominant (–0.2$\pm$0.2 Nm/Kgm to –0.3$\pm$0.1 Nm/Kgm). A significant difference was noted post-fatigue for the main effect of leg dominance at PKABM for KAB ($p=0.027$), for dominant (0.1$\pm$4.4°) and non-dominant legs (–2.4$\pm$4.6°). No interaction effects for fatigue and leg dominance were observed ($p>0.05$).

Conclusions: Lower extremity neuromechanics, in the absence of fatigue, do not appear to differ between dominant and non-dominant legs during an SST. During fatigue, both legs demonstrated alterations in lower extremity neuromechanics that have been implicated as non-contact ACL injury risk factors, with the non-dominant leg showing a pronounced abducted position at PKABM as well. Prevention programs should focus on maintaining similar movement patterns between legs at pre-fatigue and post-fatigue states.

Abstract #30

Correlation of Frontal Plane Knee Moments and Angles Between Drop Vertical Jump and Run-to-Cut Maneuvers

Jamison ST, McNally MP, Schmitt LC, Chaudhari AMW: The Ohio State University, Columbus

Context: High knee valgus moments and angles have been implicated in the ACL injury mechanism and suggested to be predictors of injury. However, different research groups use different activities to explore these moments and angles, and it remains unknown how comparable the results of studies testing different activities are to one another.

Objective: To determine the correlations between frontal plane knee moments and angles measured during unanticipated cut (CUT) and drop vertical jump (DVJ) maneuvers.

Design: Descriptive cohort study design.

Setting: Controlled, laboratory setting.

Patients or Other Participants: Seventy-four (36M, 38F) healthy participants (23.9$\pm$5.1yrs, 174.0$\pm$9.6cm, 69.5$\pm$12.0kg) with no current history of injury to the lower extremity. An a priori sample size estimation determined that the minimum number needed for a significant (alpha=0.05) correlation coefficient of 0.4 with a power of 80% was 47.

Intervention(s): Drop vertical jumps (41cm box) and unanticipated run-to-cut maneuvers (45° side-step cut at self-selected speed) were performed by each subject during the same visit. Run-to-cut maneuvers were always performed with a three-step run-up before planting the dominant foot on one or two force plates side by side. During drop vertical jumps, subjects were asked to land with both feet, each foot striking an individual force plate, and then to immediately jump as high as possible. Peak knee valgus moment (pKVM) and peak knee valgus angle (pKVA) were found for the dominant limb (foot used to kick a ball) during the weight acceptance portion of stance (foot strike to peak knee flexion), as well as knee valgus angle at initial contact (icKVA). The average value from 3 to 4 trials for each activity was used for analysis. Pearson's linear correlation coefficients were used to determine the association of frontal plane knee variables between the two activities.

Main Outcome Measure(s): The point-cluster technique was used to estimate lower extremity kinematics. pKVM was normalized by body weight times height (%BW*Ht). KVA was measured based on anatomic coordinate systems embedded in the femur and tibia (i.e. not relative to a standing reference).

Results: pKVM was not significantly correlated between the two activities ($r = –0.0370$, $p = 0.7540$; average $\pm$ standard deviation: CUT = 6.37$\pm$5.47 %BW*Ht, DVJ = 2.05$\pm$1.28 %BW*Ht). Significant correlations were found for pKVA ($r = 0.7054$, $p<0.001$; CUT = 5.28$\pm$5.75°, DVJ = 0.14$\pm$6.8°) and icKVA ($r = 0.6561$, $p<0.001$; CUT = 0.30$\pm$4.09°, DVJ = –4.81$\pm$4.75°).

Conclusions: Significant positive correlations in frontal knee angles (icKVA and pKVA) suggest that one may reasonably compare findings based on these angles during cutting and drop jump maneuvers to each other directly. However, the non-significant correlation between pKVM for the two activities suggests that caution should be taken when attempting to apply categorizations based on pKVM during one maneuver to the other.

Abstract #31

Investigation of Non-Contact ACL Injury Mechanism Through Estimating Knee Joint Moment Using a Model-Based Image-Matching Technique

Koga H,* Ogasawara I†: *Tokyo Medical and Dental University, Tokyo, Japan; †Mukogawa Women's University, Hyogo, Japan

Context: Video analysis of injury tapes is the only method available to extract kinematical information from real injury situations. Although knee joint kinematics in actual ACL injury situations has been described in the recent studies, knee joint moment during ACL injuries has not yet been clarified.

Objective: Describe the three-dimensional knee joint moment based on a static-based calculation in actual ACL injury situations using a model-based image-matching (MBIM) technique.

Design: Case series.

Setting: Video analysis.

Patients or Other Participants: Two video sequences with at least three views of ACL injuries from women's handball (Case 1, one-leg landing) and basketball (Case 2, stop after passing). The videos were analyzed using the MBIM method, providing an estimate of the time course of knee joint kinematics and moments for the injury sequence. To calculate the knee joint moment, the ground reaction force applied at the foot of the injured athlete was estimated using two different types of the mathematical models, i.e., a mass-spring-damper

model and a rigid model, and then the external knee joint moment was calculated.

Main Outcome Measure(s): Three-dimensional knee joint moments, as well as knee flexion, valgus and rotation angles were measured.

Results: In case 1, initial peak of the knee flexion moment and the knee abduction moment (1175 Nm and 840 Nm, respectively), which was induced by the impact force, occurred at 5 ms after initial foot contact (IC). Sudden increases of the knee flexion angle and the knee abduction angle were also observed during the first 20ms after IC (16° and 8°, respectively). In case 2, initial peak of the knee flexion moment (364 Nm) occurred at 4 ms after IC; however, the peak of the knee abduction moment (354 Nm) occurred thereafter, at 36 ms after IC, which was induced by the inertia force of the upper body. Knee abduction angle was increased only by 6° during the first 40ms after IC; however, it was increased by another 8° during the next 20 ms. Peak internal rotation angle (9°) was also observed at 60 ms after IC. Furthermore, in both cases, the knee was kept dislocated more than 200 ms after IC due to the inertia force of the upper body.

Conclusions: Based on when the sudden changes in joint angular motion and the peak knee abduction moment occurred, we assumed that the ACL injury occurred within 20 ms after IC in case 1, and approximately 60 ms after IC in case 2. The force leading to the injury seemed to be a sudden impact force immediately after IC in case 1, whereas ground reaction force caused by sudden deceleration after passing in case 2.

Abstract #32

The Effect of Previous ACL Injury on Linear and Non-Linear Measures of Single Limb Postural Control

Goerger BM,* Padua DA,* Frank BS,* Begalle RL,* Beutler AI,† Marshall SW*: *Sports Medicine Research Laboratory, University of North Carolina, Chapel Hill; †Uniformed Services University of the Health Sciences, Bethesda, MD

Context: Individuals with a previous history of ACL injury are at an increased risk for subsequent ACL injury, regardless of limb, as compared to those with no injury. Postural control differs between limbs for those with previous ACL injury and reconstruction (ACLR), and differs as compared to those with no injury. Non-linear measures are suggested to be more sensitive, and may provide a better understanding of the role of postural control on the prospective risk for ACL injury.

Objective: To determine if individuals with ACLR display differences in linear and nonlinear measures of postural control as compared to healthy controls.

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Fifty-two physically active persons participated in this study: ACLR Group (n = 18): Males = 11, Females = 7; Height = 171.56±8.68 cm, Mass = 74.66±10.34 kg; CON Group (n = 34): Males = 16, Females = 18; Height = 171.11±10.09 cm, Mass = 73.22±14.23 kg.

Intervention(s): Center of pressure (CoP) was measured as participants performed single-leg balance (20 seconds) atop a nonconductive force plate. Testing was performed bilaterally under both eyes open (EO) and eyes closed (EC) conditions (2 trials per leg, per condition).

Main Outcome Measure(s): Postural control was assessed using linear and nonlinear measures. Linear measures included Ellipse Area, Sway Path, and Sway Speed. Nonlinear measures consisted of using approximate entropy (ApEn) to assess variability of the CoP trajectory in the anterior-posterior (ApEn_AP) and medial-lateral (ApEn_ML) direction. ApEn quantifies the variability of a time series and may be more sensitive to differences in postural control than linear measures. A value closer to 0 indicates a more regular time series, and a value closer to 2 indicates a more random time series. Between group and within group differences for each dependent variable were assessed using five 2x2x2 (Group, Leg, Condition) Mixed Model ANOVAs ($\alpha \leq 0.05$). T-tests were used to assess significant GroupxLeg and GroupxCondition interaction effects.

Results: Significant main effects for Condition were observed for ApEn_AP ($P<0.001$) (EO: 0.90±0.16; EC: 1.04±0.13), Ellipse Area ($P<0.001$) (EO: 5.37±2.22 cm^2; EC: 23.11±11.30 cm^2, Sway Path ($P<0.001$) (EO: 85.30±17.79 cm; EC: 166.15±38.45 cm), and Sway Speed ($P<0.001$) (EO: 4.27±0.89; EC: 8.31±1.92 cm/s). There were no significant main effects or interaction effects for Group ($P>0.05$).

Conclusions: Differences in linear and non-linear postural control measures were not present between groups in this sample of participants, and both groups responded similarly to elimination of visual input. This indicates that previous ACL injury does not affect the ability to maintain postural stability on a stable surface. Future research focusing on challenging vestibular and proprioceptive inputs of postural control may provide a better understanding as to the reason for increased risk for subsequent injury in those with previous ACL injury.

Abstract #33

Relationship Between Lower Extremity Kinematics and Kinetics and Loss of Vertical Jump Height Due to Fatigue

McGrath ML,* Stergiou N,* Blackburn JT,† Lewek MD,† Giuliani C,† Padua DA†: *University of Nebraska at Omaha; †University of North Carolina, Chapel Hill

Context: Neuromuscular fatigue has been proposed as a potential risk factor for non-contact Anterior Cruciate Ligament (ACL) injury. However, each athlete may respond differently to activities that cause fatigue. It is unknown whether athletes who show significant negative performance changes, like a loss of vertical jump height (VJ_{ht}), after fatiguing exercise may also demonstrate biomechanical changes during landing or cutting that are associated with non-contact ACL injury.

Objective: To determine whether fatigue-related loss of VJ_{ht} is associated with kinetic and kinematic changes in the lower extremity during an unanticipated sidestep-cut task (CUT).

Design: Cross-sectional.

Setting: Research laboratory.

Patients or Other Participants: Twenty-one healthy club-sport athletes (10M, 11F) volunteered for the study. Participants were grouped based upon their post-fatigue VJ_{ht} change: 12 participants (age:19.5±2.2years, mass:69.9±11.1kg, height:1.8±0.1m) that had no change, or an increase in, VJ_{ht} post-fatigue (NC_{VJ}); and 9 participants (age:19.1±1.3years, mass:71.4±8.9kg, height:1.8±0.1m) whose VJ_{ht} decreased at least 2.54cm post-fatigue (C_{VJ}).

Intervention(s): Participants had their pre-fatigue VJ_{ht} measured, then performed the CUT. The CUT involved a jump over a hurdle, triggering a randomized directional cue. The subject landed with the dominant foot on a force platform and cut 60° in the indicated direction. Participants then performed an intense, intermittent fatigue protocol involving multi-directional sprints and broad jumps. CUT testing procedures and VJ_{ht} were repeated post-fatigue.

Main Outcomes Measures: Three-dimensional ankle, knee, hip, and trunk kinematics were calculated at two points: initial contact with the force platform (IC), and peak angle during the CUT stance phase (IC – toe off). Vertical ground reaction force (GRF), posterior GRF, medial GRF, lateral GRF, and anterior tibial shear force (all normalized to body mass), plus knee extension moment and knee valgus moment (normalized to body mass*body height), were calculated during the first 40% of the stance phase. Change scores in the above variables were calculated (post-fatigue – pre-fatigue). Independent t-tests comparing kinematic and kinetic change scores between the two groups were performed ($\alpha \leq 0.05$).

Results: VJ_{ht} increased 1.1±1.7cm in the NC_{VJ}, while VJ_{ht} decreased 5.4±3.6cm in the C_{VJ} (t_{19}=–5.478, $P<0.001$). Ankle inversion angle at IC increased 0.2±3.3° in the NC_{VJ}, but decreased 3.7±3.9° in the C_{VJ} (t_{19}=2.437, P=0.25). Peak knee flexion angle decreased 4.6±3.6° in the NC_{VJ}, but only decreased 1.2±3.2° in the C_{VJ} (t_{19}=–2.203, P=0.40). There were no other differences between groups.

Conclusions: There appear to be few significant biomechanical differences between these two groups, despite significant differences in post-fatigue VJ_{ht} performance. Athletes that display a significant drop in VJ_{ht} post-fatigue do not appear to have biomechanical changes in the lower extremity that may increase risk of non-contact ACL injury. Therefore, there is no evidence yet that certain athletic performance measurements, like VJ_{ht}, can be used to indicate increased risk of non-contact ACL injury when fatigued.

Abstract #34

A Combined In-Vivo /In-Vitro Method to Study the Biomechanics of ACL Injury

Chandrashekar N, Cassidy K, Sabharwal P: University of Waterloo, Waterloo, Ontario, Canada

Context: The mechanism of non-contact anterior cruciate ligament (ACL) injury is not well understood. It is partly because previous studies have been unable to relate dynamic knee muscle forces during sports activities such as landing from a jump to the strain in the ACL.

Objective: The objective of this research was to develop and validate a unique combined in-vivo/in-vitro method to relate the muscle group forces to ACL strain during jump-landing using a newly developed dynamic knee simulator.

Design: Controlled laboratory study.

Setting: Research laboratory.

Patients or Other Participants: One 26 year old male amateur athlete and three fresh frozen healthy cadaver knees (all male, average age 44 years).

Intervention(s): A novel dynamic knee simulator system was designed and developed to study sagittal plane biomechanics of knee. The simulator is computer controlled and uses six powerful electromechanical actuators to move a cadaver knee in the sagittal plane and to apply dynamic muscle forces at the insertion sites of the quadriceps, hamstring and gastrocnemius muscle groups and the net moment at the hip joint. To validate the equipment, motion capture of a live subject landing from a jump on a force plate, was performed. The kinematics and ground reaction force data obtained from the motion capture was input into a computer based musculoskeletal lower extremity model. From the model, the force-time profile of each specific muscle groups across the knee during the movement was extracted, along with the kinematics of the hip and ankle joints. This data was then programmed into the dynamic knee simulator system. Jump-landing was simulated on a cadaver knees.

Main Outcome Measure(s): The programmed and actual muscle forces applied to the cadaver knees were compared. The net moment applied at the knee and calculated from inverse dynamics were compared. The ACL strain during jump-landing simulation was measured.

Results: Our results show that the simulator has the capability to accurately simulate the dynamic sagittal plane motion and the dynamic muscle forces during jump-landing. The average difference between calculated and applied maximum muscle forces were 1.5±12%. The applied muscle forces resulted in similar net knee moment profiles calculated through inverse dynamics (5% difference in maximum moment). The ACL strain values (3±2% strain) were repeatable and agreed with the values reported in the literature.

Conclusions: This combined in-vivo/in-vitro approach can be effectively used to study the relationship between sagittal plane muscle forces and ACL strain during dynamic activities. The information gained through such kind of research can give valuable insight into the neuromuscular factors that affect ACL injury. This approach could also be used to find the effects of neuromuscular training for ACL protection by performing the simulation based on motion capture on high risk athletes before and after training.