Healthy Males and Females Have Similar Hop Landing Kinematics and Ground Reaction Force Kinetics During a 1-Leg Hop-for-Distance Landing

John D. Holtgrewe[1], Crystal J. Murray[1], Dominique A. Barnes,[1] Janine Molino,[1] Braden C. Fleming[1], Jillian E. Beveridge[1]
[1]Brown University and Rhode Island Hospital, Providence, RI
Email of presenting author: john_holtgrewe@brown.edu

Disclosures: Braden C. Fleming (Miach Orthopaedics, American Journal of Sports Medicine); Other authors (N)

INTRODUCTION: Our previous work has shown that during the landing of a jump-cut maneuver, healthy females reached peak ground reaction force sooner than healthy males and had a more rapid rate of anterior tibial translation during the same period.[3] While these differences may help explain the higher ACL injury rate in females,[9] it is possible that they could be have been mediated by the effects of ACL reconstruction, as the work investigated interactions between these kinematic and kinetic outcomes, sex, and ACL status. Here, we extend the investigation of the effect of sex on single leg hop landing kinematics and kinetics in persons who have never sustained a knee injury requiring surgery. Contrary to earlier work, we hypothesized that there would be no difference in the relationship between anterior tibial translation and flexion angle (i.e., regression model slope & intercept) between sexes; however, we hypothesized that healthy females would continue to reach peak GRF sooner than males as the stiffened landing strategy in females has been repeatedly described.[1,2]

METHODS: **Subjects.** Data from 28 subjects (15 female, 32.7 ± 10.4 years; 13 male, 33.1 ± 9.5 years) with healthy knees were pooled from two cohorts: 18 (10 female, 8 male) subjects were recruited for an ongoing randomized controlled trial (RCT) (NCT03776162),[5] and 10 (5 female, 5 male) were part of a recently completed RCT (NCT00434837).[4] Inclusion and exclusion criteria between studies were similar. Subjects were randomly assigned an index limb at the time of enrollment. All procedures were reviewed and approved by our Institutional IRB. **Kinematic recording.** Each subject performed a single-leg hop-for-distance, which was reduced to 65% of the average distance to ensure reproducibly. Hop landings were recorded using biplane videoradiography at 250 frames/second with a source-to-image distance of ~185cm and a separation angle of ~55°.[7] Ground reaction forces were recorded simultaneously at 3000Hz. **Kinematic reconstruction.** Subject-specific bone models of the femur and tibia were built from computed tomography scans using SlicerAutoscoperM (SAM) (https://www.slicer.org/, accessed April 2024). These models were used for model-based tracking and to construct anatomical coordinate systems.[6] Rigid body motions of the femur and tibia were obtained from ground contact to 0.2s after contact. The peak anterior tibial position and the corresponding flexion angle at which it occurred were extracted for each subject and modelled using a generalized linear model (GLM). Model intercepts and slopes were primary kinematic outcomes. The time from ground contact to peak GRF was a secondary outcome. Additional kinematic measures described in Table 1 were explored. **Statistical analysis.** To test our primary hypothesis, the GLM employed a Gaussian distribution and identity link function to test main effects for Sex and Flexion angle and the interaction term Sex X Flexion angle. Two one-sided t-tests (TOST) were used to compare the intercept and slope between sexes to determine whether the intercepts were equivalent within 4.0mm and the slopes were equivalent within 0.16°/mm. Values of equivalencies were set *a priori* using existing data.[8] Time to peak GRF and all other exploratory outcomes employed standard superiority testing.

RESULTS: Anterior position and flexion angle did not differ by biological sex (Slope: Female -0.48mm/° vs Male -0.38mm/° [CI diff: -0.42 to 0.20], p = 0.51; Intercept: Female 6.80mm vs Male 4.1mm [CI diff: -2.07 to 7.48], p = 0.99) (Figure 1). There was also no difference in time to peak GRF (p = 0.97, Figure 2), or in any of the exploratory measures; however, females tended to have less knee adduction at peak GRF than males (Table 1).

DISCUSSION: Hop landing kinematics and kinetics did not differ by biological sex in our cohort of healthy men and women, which contrasts from our earlier work[3] and that of others.[1,2] Differences in the nature of the hop-for-distance versus jump cut maneuver that we investigated previously may be one possible explanation for the contrasting time to peak GRF findings, although this is speculative and would require additional data to test. Given the subjects investigated were age- and activity-matched to ACL-injured persons enrolled in the two RCTs but never sustained an injury, we hypothesized that there would be no sex-specific differences. Our results support this hypothesis which could imply that the healthy control cohorts in our study represent athletes who were at low risk of injury to begin with. In this regard, males and females who do not sustain an ACL injury could be expected to exhibit similar (low risk) biomechanical landing strategies. Lastly, more stringent agreement criteria may lead to different conclusions from the non-inferiority testing. However, the exploratory measures that did not rely on agreement criteria also support the finding that kinematic and kinetic GRF were not sex-dependent in the subjects investigated here.

SIGNIFICANCE/CLINICAL RELEVANCE: The kinematic and kinetic similarities between healthy male and female controls provide important baseline information to interpret differences that may be present in our future work that investigates kinematics in competing ACL surgeries.

REFERENCES: 1. Lyle, M.A. et al. J Biomech (47), 2014. 2. Lephart, S.M. et al. Clin Orthop Relat Res (401), 2004. 3. Miranda, D.L. et al. Med Sci Sports Exerc. (45), 2013. 4. Costa, M.Q. et al. Am J Sports Med (13), 2022 5. Spindler, K.P. et al. Orthop J Sports Med (10), 2022. 6. Miranda, D.L. et al J Biomech (43), 2010. 7. Holtgrewe, J.D. et al. Bioengineering *(In Press*). 8. Holtgrewe, J.D. et al. Trans ORS, 2025. 9. Prodromos, C.C. et al. Athroscopy (23), 2007

ACKNOWLEDGEMENTS: NIH NIAMS (K99/R00-AR069004, R01-AR083168, R01-AR047910, R01-AR074973); NIGMS (P30-GM122732, P20-GM139664); and the Lucy Lippitt Endowment.

IMAGES AND TABLES:

Table 1. Exploratory kinematic measures investigated. GRF = Ground Reaction Force.

Exploratory Outcome Measure	Female N=15 (53.6%) Mean (95% CI)	Male N=13 (46.4%) Mean (95% CI)	P-value
Flexion Excursion (°)	12.99 (9.92, 16.05)	13.56 (11.30, 15.83)	0.76
Flexion Excursion Rate (°/s)	0.33 (0.27, 0.40)	0.37 (0.28, 0.46)	0.48
Anterior Excursion (mm)	3.75 (2.54, 4.95)	4.36 (3.31, 5.42)	0.44
Anterior Excursion Rate (mm/s)	0.09 (0.07, 0.11)	0.12 (0.09, 0.15)	0.15
Adduction at Peak GRF (°)	0.43 (0.26, 0.60)	0.89 (0.41, 1.38)	0.07
Flexion Angle at Contact (°)	15.99 (11.57, 20.40)	11.58 (7.81, 15.34)	0.13

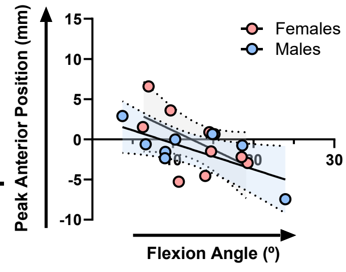

Figure 1. Peak anterior position as a function of flexion angle. There was no difference in intercepts or slopes between female and male kinematics. Shaded areas denote 95% CIs.

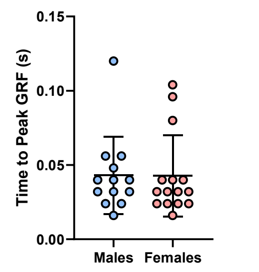

Figure 2. Time to peak ground reaction force (GRF). Error bars denote ± 95% CIs. There was no difference between female and male mean time to peak GRF.