THE RELATIONSHIP BETWEEN HAMSTRING MUSCULO-ARTICULAR STIFFNESS AND LOWER-EXTREMITY BODY COMPOSITION

Justin P Waxman, Randy J Schmitz, Sandra J Shultz

Applied Neuromechanics Research Laboratory, Department of Kinesiology, University of North Carolina at Greensboro, Greensboro, NC, United States

The purpose of this study was to compare hamstring musculo-articular stiffness (MAS) and lower extremity (LE) body composition in the dominant (D) and non-dominant (ND) legs of men and women, and then to examine relationships between MAS and LE body composition while controlling for sex. No differences in MAS or LE body composition were found between D and ND legs in either sex. Males demonstrated greater MAS and LE % lean mass (%LM) than females, while females had greater LE % fat mass (%FM) than males. The combination of sex and %FM explained ~60% of the variance in MAS, while ~31% of the variance could be attributed to sex alone. Findings suggest that between-sex differences may potentially mask relationships between MAS and the factors influencing this measure, highlighting the need for future sex-stratified designs.

KEYWORDS: Leg lean mass or fat mass, ACL, Muscle, Neuromechanics

INTRODUCTION: Anterior cruciate ligament (ACL) injuries are one of the most prevalent injuries in athletic populations, and it has been reported that approximately 72% of all ACL injuries occur in non-contact situations (Boden, Dean, Feagin, & Garrett, 2000). Non-contact ACL injuries typically occur upon initial foot contact with the ground during cutting and landing tasks (Krosshaug et al., 2007). While the precise mechanism(s) of injury remain unclear, it has been established that the ACL is loaded via anterior tibial translation (ATT) and knee valgus, and that the ACL is the primary restraint to ATT (Shimokochi & Shultz, 2008). Therefore, any factors that are able to reduce ACL loading may potentially reduce ACL injury risk.

Hamstring musculo-articular stiffness (MAS) is a neuromechanical property that quantifies the resistance of the hamstring musculo-articular unit lengthening in response to an applied load. Individuals with greater MAS have been reported to display characteristics associated with reduced ACL loading during controlled perturbations (Blackburn, Norcross, & Padua, 2011) and dynamic landing tasks (Blackburn, Norcross, Cannon, & Zinder, 2013). Additionally, females display less MAS (Blackburn, Bell, Norcross, Hudson, & Kimsey, 2009; Blackburn, Riemann, Padua, & Guskiewicz, 2004) and are at a substantially greater risk for ACL injury than males (Agel, Arendt, & Bershadsky, 2005), which suggests that MAS may contribute to ACL injury risk. However, little is known about the underlying structural factors that influence MAS. Recently, MAS has been reported to be positively related to strength and negatively related to posterior thigh fat thickness (Blackburn & Pamukoff, 2014). Because strength and fat thickness are correlated with body composition (Leahy, Toomey, McCreesh, O'Neill, & Jakeman, 2012), further examination of the relationship between lower-extremity (LE) body composition and MAS is warranted. Therefore, the purpose of this study was to compare hamstring MAS and LE body composition in the dominant (D) and non-dominant (ND) legs of men and women, and then to examine relationships between hamstring MAS and LE body composition while controlling for sex.

METHODS: Measures of hamstring MAS and LE body composition were obtained from 16 healthy individuals (8 Male, 8 Female; Age = 22.4 ± 2.8 yrs, height = 1.7 ± 0.1 m, body mass = 70.7 ± 15.3 kg) who volunteered to participate in the current study. All participants were: (1) recreationally active, participating in a minimum of 90 minutes of physical activity per week, (2) free from any injury to the lower extremity for a minimum of 6 months prior to participation, (3) free from any history of surgery on the lower extremity, (4) without any known medical conditions that would affect connective tissue, and (5) without any cardiovascular or pulmonary problems. MAS and LE body composition assessments were conducted during separate testing sessions occurring within 7 days of each other.

Hamstring Stiffness: Hamstring MAS was measured on both the D and ND leg using the free-oscillation technique, whereby the leg is modeled as a single-degree-of-freedom mass-spring system and the damping effect that the hamstring muscles impose on oscillatory flexion/extension of the knee joint, following a perturbation, is quantified. Participants were positioned prone on a padded table with the left thigh supported in 30° of flexion below the horizontal, and the lower leg (shank) and foot free to move. A Orthoplast™ splint was secured to the plantar aspect of the foot and posterior shank to standardize ankle position and gastrocnemius length, and a standardized load representing 10% of the participant's body mass was then secured to the distal shank at the level of the malleoli using cuff-style ankle weights. Next, the investigator passively positioned the shank parallel to the floor, and the participant was required to maintain this position via isometric hamstring contraction. With the left hip flexed 30° below the horizontal, the orientation of the shank parallel to the floor placed the knee in 30° of flexion. Within 5 s of the participant's isometric hamstring contraction, the investigator manually applied a brief downward perturbation to the posterior aspect of the participant's heel, slightly extending the knee and initiating damped oscillatory knee flexion and extension. This damped oscillatory motion was characterized by the tangential acceleration of the shank, captured via a triaxial linear accelerometer (NeuwGhent Technology, USA) attached to the Orthoplast™ splint. Accelerometer data were sampled at 1000 Hz and then low pass filtered at 10 Hz with a fourth-order Butterworth filter. The time interval between the first two oscillatory peaks (t_1 and t_2) was used to calculate the damped frequency of oscillation and hamstring MAS using the equation $MAS = 4\pi^2 mf^2$, where m is the summed mass of the shank and foot segment (6.1% body mass) and the applied load (10% body mass), and f is the damped frequency of oscillation. Participants were instructed to try not to intervene with or voluntarily produce the oscillations following the perturbation, and attempt the keep the hamstrings active only to the level necessary to support the shank in the testing position. A total of 3 to 5 practice trials were provided prior to data collection for each limb in order to familiarize the participant to the task. After familiarization, 5 trials were recorded and subsequently averaged for statistical analyses. In order to reduce the likelihood of fatigue, approximately 30 s to 1 min of rest was provided between trials.

Body Composition: LE body composition was assessed via dual-energy X-ray absorptiometry (DXA; Lunar iDXA Prodigy Advance, GE Healthcare, Madison, WI). Because body composition testing via DXA is contraindicated during pregnancy, urinary pregnancy tests (Midstream Pregnancy Test; Early-Pregnancy-Tests.com, Bellingham, WA) were administered prior to testing to ensure the safety of our female participants. Body mass and height were measured with a digital scale and stadiometer, respectively, and entered into a patient's database (enCORE™ 2011 software, version 13.6, GE Healthcare); this information was then used in the software's calculations of total body composition. Participants were placed in the standard supine position, as suggested by the manufacturer for a total body scan. Manual traction was then applied to the distal tibias, arms, and head, to ensure neutral alignment of the spine and equal bilateral positioning of the upper and lower extremities. Total body scans were later reduced using GE enCORE™ 2011 software. Standard regions of interest (ROI) were used to partition total body composition into regional bone, lean, and fat mass for the trunk and left and right upper and lower extremities. The lower extremity ROI was defined superiorly by an inferior-lateral line bisecting the neck of the femur and encapsulated the lateral hip as well as the entire thigh, shank, and foot of the D and ND legs individually. LE percent fat mass (%FM) and percent lean mass (%LM) were then calculated by dividing LE fat mass and LE lean mass by LE total mass, respectively.

Statistical Analyses: Paired-samples *t* tests and separate one-way analyses of variance (ANOVA) were used to examine differences in %FM, %LM, and MAS between D and ND legs and between sexes, respectively. Relationships between %FM, %LM, and hamstring MAS were evaluated via hierarchical multiple regression, controlling for sex. A two-block model was used for the regression analysis, using hamstring MAS as the dependent variable. In the first block, sex was entered as the lone predictor variable. %FM and %LM were then entered into the second block using a stepwise method. The a priori alpha level was set at 0.05 for all analyses.

RESULTS: Paired-samples t tests revealed that hamstring MAS, %FM, and %LM did not differ between D and ND legs for either sex. Therefore, MAS, %FM, and %LM values for the D and ND legs were averaged and used for subsequent analyses. Results of the one-way ANOVAs demonstrated that hamstring MAS (Males: 1197.6 ±164. 6 N/m; Females: 994.7 ± 184.9 N/m) and %LM (Males: 76.4 ± 6.7%; Females: 61.2 ± 6.2%) were significantly greater in males than females ($p < .05$). Females had greater %FM than males (Males: 19.0 ± 7.1%; Females: 35.1 ± 6.5%; $p < .05$). The hierarchical multiple regression analysis revealed that the linear combination of sex and %FM explained ~60% of the variance in hamstring MAS ($p < .01$). Once differences in hamstring MAS due to sex were controlled for ($R^2 = .31$, $p = .03$), the addition of %FM to the model explained an additional ~29% of the variance in MAS (R^2 change = .29, P = .01; overall $R^2 = .60$, $p < .01$). %LM did not enter into the model due to it being perfectly negatively correlated with %FM (r = -1.00, $p < .01$). Of interest, once differences due to the individual's sex were accounted for, the partial correlation between hamstring MAS and %FM increased from r = -.09 ($p = .37$) to r = .64 ($p = .01$).

DISCUSSION & CONCLUSIONS: The primary aim of this study was to examine the relationship between hamstring MAS and measures of LE body composition. However, before examining such relationships, we felt it necessary to first determine whether these measures differed between dominant and non-dominant legs for either sex. Findings revealed that hamstring MAS and LE body composition did not differ between legs for either sex; therefore, these data were pooled and the bilateral means of the dominant and non-dominant legs were used for further analyses. Our findings that hamstring MAS did not differ between legs in healthy uninjured individuals, and that males displayed significantly greater hamstring MAS than females, are in agreement with prior work by Jennings and Seedhom (1998) and Blackburn et al (2004). Perhaps the most significant finding of the current investigation was that after accounting for sex differences in hamstring MAS, greater %FM was associated with greater hamstring MAS. In contrast to this finding, hamstring MAS has previously been reported to be positively correlated with strength and negatively correlated with posterior thigh fat thickness assessed via ultrasound (Blackburn & Pamukoff, 2014). Subcutaneous fat thickness is positively correlated with total body fat composition (Leahy et al., 2012), which is positively correlated with intramuscular fat content (Brumbaugh, Crume, Nadeau, Scherzinger, & Dabelea, 2012). Additionally, intramuscular fat content is negatively correlated with strength (Fukumoto et al., 2012). Together, this suggests that relatively stronger and leaner individuals would be expected to display greater MAS than those that are relatively weaker and less lean (i.e., greater body fat).
The conflicting findings between the current investigation and those of Blackburn and Pamukoff (2014) may be in part explained by differences in data normalization procedures and the type of statistical analyses used. Blackburn and Pamukoff (2014) performed correlational analyses to assess the relationships between hamstring MAS and strength and posterior thigh fat thickness first on un-normalized data and then repeated these analyses after normalizing these data to body mass. Although males were found to have significantly greater strength and less posterior thigh fat mass than females following normalization, these between-sex differences were not controlled for in the analyses performed. In the current study, we chose to leave the data un-normalized, but to control for sex in our analyses. Because the applied load for the hamstring MAS assessment was standardized as 10% of the participant's body mass and because the equation used to calculate MAS includes the mass of the shank and foot segment, which is calculated as a percentage of total body mass, we chose to not additionally normalize to total body mass. The current

findings suggest that between-sex differences may be masking the relationships between MAS and other factors that potentially influence MAS and highlights the need for sex-stratified designs in future studies.

REFERENCES:

Agel, J., Arendt, E. a, & Bershadsky, B. (2005). Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *The American Journal of Sports Medicine*, *33*(4), 524–30.

Blackburn, J. T., Bell, D. R., Norcross, M. F., Hudson, J. D., & Kimsey, M. H. (2009). Sex comparison of hamstring structural and material properties. *Clinical Biomechanics*, *24*(1), 65–70.

Blackburn, J. T., Norcross, M. F., Cannon, L. N., & Zinder, S. M. (2013). Hamstring Stiffness and Landing Biomechanics Linked to Anterior Cruciate Ligament Loading. *Journal of Athletic Training*, *48*(6), 764–772.

Blackburn, J. T., Norcross, M. F., & Padua, D. A. (2011). Influences of hamstring stiffness and strength on anterior knee joint stability. *Clinical Biomechanics (Bristol, Avon)*, *26*(3), 278–83.

Blackburn, J. T., & Pamukoff, D. N. (2014). Geometric and architectural contributions to hamstring musculotendinous stiffness. *Clinical Biomechanics*, *29*, 105–110.

Blackburn, J. T., Riemann, B. L., Padua, D. A., & Guskiewicz, K. M. (2004). Sex comparison of extensibility, passive, and active stiffness of the knee flexors. *Clinical Biomechanics*, *19*(6), 36–43.

Boden, B. P., Dean, G. S., Feagin, J. A., & Garrett, W. E. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics*, *23*(6), 573–578.

Brumbaugh, D. E., Crume, T. L., Nadeau, K., Scherzinger, A., & Dabelea, D. (2012). Intramyocellular lipid is associated with visceral adiposity, markers of insulin resistance, and cardiovascular risk in prepubertal children: the EPOCH study. *Journal of Clinical Endocrinology and Metabolism*, *97*(7), 1099–1105.

Fukumoto, Y., Ikezoe, T., Yamada, Y., Tsukagoshi, R., Nakamura, M., Mori, N., … Ichihashi, N. (2012). Skeletal muscle quality assessed from echo intensity is associated with muscle strength of middle-aged and elderly persons. *European Journal of Applied Physiology*, *112*(4), 1519–1525.

Krosshaug, T., Nakamae, A., Boden, B. P., Engebretsen, L., Smith, G., Slauterbeck, J. R., … Bahr, R. (2007). Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *The American Journal of Sports Medicine*, *35*(3), 359–67.

Leahy, S., Toomey, C., McCreesh, K., O'Neill, C., & Jakeman, P. (2012). Ultrasound measurement of subcutaneous adipose tissue thickness accurately predicts total and segmental body fat of young adults. *Ultrasound in Medicine & Biology*, *38*(1), 28–34.

Shimokochi, Y., & Shultz, S. J. (2008). Mechanisms of noncontact anterior cruciate ligament injury. *Journal of Athletic Training*, *43*(4), 396–408.