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Relationships of hamstring muscle volumes to lateral tibial slope☆

Randy J. Schmitz [a,*], Anthony S. Kulas [b], Sandra J. Shultz [a], Justin P. Waxman [e], Hsin-Min Wang [c], Robert A. Kraft [d]

[a] The University of North Carolina at Greensboro, Greensboro, NC, United States
[b] East Carolina University, Greenville, NC, United States
[c] China Medical University, Taichung, Taiwan
[d] Wake Forest University, Winston-Salem, NC, United States
[e] High Point University, High Point, NC United States

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ABSTRACT

Background: Greater posterior–inferior directed slope of the lateral tibial plateau (LTS) has been demonstrated to be a prospective ACL injury risk factor. Trainable measures to overcome a greater LTS need to be identified for optimizing injury prevention protocols.

It was hypothesized that Healthy individuals with greater LTS who have not sustained an ACL injury would have a larger lateral hamstring volume.

Methods: Eleven healthy females (mean +/- standard deviation) (1.63 ± 0.07 m, 62.0 ± 8.9 kg, 22.6 ± 2.9 years) & 10 healthy males (1.80 ± 0.08 m, 82.3 ± 12.0 kg, 23.2 ± 3.4 years) underwent magnetic resonance imaging of the left knee and thigh. LTS, semitendinosus muscle volume, and biceps femoris long head muscle volume were obtained from imaging data.

Results: After controlling for potential sex confounds ($R^2 = .00$; $P = .862$), lesser semitendinosus volume and greater biceps femoris-long head volume were indicative of greater LTS ($R^2\Delta = .30$, $P = .008$).

Conclusions: Healthy individuals with greater LTS have a muscular morphologic profile that includes a larger biceps femoris-long head volume. This may be indicative of a biomechanical strategy that relies more heavily on force generation of the lateral hamstring and is less reliant on force generation of the medial hamstring.

Level of evidence: Level IV.

1. Introduction

Biomechanical and neuromuscular factors have dominated the anterior cruciate ligament (ACL) injury risk-factor literature, as these risk factors seemingly have a relative ease of identification and potential for direct intervention and prevention. However, outcomes are mixed with regard to the effectiveness of screening movement biomechanics to predict injury risk [1–3]. A number of anatomical risk factors for ACL injury have been identified [4], but are often dismissed in prevention programming due to the perceived difficulty in modifying anatomical structure. As such, the development of interventions aimed to moderate injury risk in

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* Corresponding author at: Dept. of Kinesiology, 256 Coleman, The University of North Carolina at Greensboro, Greensboro, NC 27402, United States.
E-mail address: rjschmit@uncg.edu (R.J. Schmitz).

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individuals with high-risk non-modifiable anatomical factors is of clinical importance for preventing knee injury and subsequent risk of early degenerative joint disease.

The articular geometry of the knee is important in the transmission of joint loads and resultant movement biomechanics [5]. In this regard, posterior–inferior directed slope of lateral tibial plateau (LTS) has been increasingly studied as a potential risk factor [6]. A larger LTS has been associated with increasing ACL force during axial loading activities [7,8]. While both posterior medial and posterior lateral tibial plateau slopes can be obtained from magnetic resonance imaging (MRI) data, a larger LTS in combination with axial load is theorized to contribute to greater anterior tibial translation as well as greater internal tibial rotations [5], both of which are known to increase ACL strain [9]. Both retrospective [10] and prospective studies have identified a greater LTS as a risk factor for ACL injury [5] as well as a risk factor for re-injury to the ACL reconstructed knee [11]. While the structural nature of this risk factor cannot be easily modified, there is a need to consider ways that the surrounding musculature can be trained to either counteract or compensate for these structural variants. Thus, investigations of modifiable factors that may be related to such established anatomical risk factors are warranted.

Given the agonistic relationship of the hamstrings to ACL function, available hamstring muscle volume (and subsequent force production capability) may be one means to counteract the mechanism by which LTS increases ACL strain and corresponding injury risk. Cadaver studies have demonstrated that the hamstrings' distal attachments on the proximal tibia and fibula allow this muscle group the ability to influence anterior–posterior displacement and internal–external rotation of the tibia relative to the femur [12–15]. In addition, adequate co-contraction of the hamstrings has been shown to effectively reduce anterior translation and internal rotation of the tibia, thereby enhancing knee joint stability and reducing ACL strain [16–19]. As such, current ACL injury prevention and rehabilitation efforts often attempt to strengthen the hamstring muscle group as a whole in order to increase the net force applied by the hamstrings and thus enhance knee joint stability. However, given differential hamstring muscle function in the transverse plane [20], it may be of greater benefit to focus on the effects of individual hamstring muscle forces to reduce ACL loading.

Although co-contraction of the hamstrings has been shown to effectively reduce anterior tibial displacement and internal tibial rotation [14,15], these findings have been established via symmetrical loading of the medial (i.e. semitendinosus and semimembranosus) and lateral hamstrings (i.e. biceps femoris short head and long head). Differences in morphological features that influence muscle force production such as muscle volume, pennation angle, physiological cross-sectional area, and muscle fiber length have been identified among different hamstring muscles [21,22]. In addition, it has been demonstrated that the lateral hamstring action is more influential on knee joint kinematics compared to medial hamstring action due a larger moment arm in the transverse plane [12,23]. It is possible that individuals with a steeper LTS may require a greater capacity for force production in the lateral hamstring musculature in order to better resist anterior tibial displacement and internal rotation. This in turn may protect the ACL from deleterious multi-planar loads. Thus the purpose of this study was to determine the relationship of individual medial and lateral hamstring muscle volumes to LTS. It was hypothesized that healthy individuals with greater LTS who have not sustained an ACL injury would have a larger lateral hamstring volume. Testing of the healthy individuals allows us to better determine muscular targets for future training/intervention work.

2. Materials and methods

2.1. Experimental protocol

Eleven healthy females (mean +/- standard deviation) (1.63 ± 0.07 m, 62.0 ± 8.8 kg, 23.6 ± 2.7 years) and 10 healthy males (1.80 ± 0.08 m, 82.3 ± 12.0 kg, 23.5 ± 3.8 years) attended one session in which they underwent MRI examination. Healthy was defined as no current orthopedic injury or history of significant injury or surgery in left limb. Height, weight, and age were obtained along with an MRI assessment of muscle volume and tibial geometry. All measures were obtained on the left limb (preferred stance limb in 18/21 participants).

MRI examination of the left limb was performed with a three tesla MRI system (Trio, Siemens, Erlangen, Germany) using a 15 channel transmit/receive high resolution knee coil and a combined spine and body coil for the hamstring muscle volume measures. Tibial geometry measurements were acquired with T1-weighted fat suppressed sagittal MRI scans of the tibiofemoral joint (Slice Thickness = 0.6 mm, In-Plane Resolution = 0.5 mm × 0.5 mm, Number of Slices = 176, FoV = 320 × 320 mm, TR = 1200 ms, TE = 33 ms, Flip Angle mode = PdVar, Bandwidth (Hz/pixel) = 539 Hz. Fat Suppression = SPAIR. Acquisition time = 8:29). Muscle volume measurements were obtained with T1-weighted fat suppressed frontal MRI scans of the thigh (Slice Thickness = 1.0 mm, In-Plane Resolution = 3.0 mm × 3.0 mm, Number of Slices = 256, FoV = 480 × 480 mm, TR = 1200 ms, TE = 33 ms, Flip Angle mode = PdVar, Bandwidth (Hz/pixel) = 539 Hz. Fat Suppression = SPAIR. Acquisition time = 8:29). The resulting images allowed visualization of both the hip joint and knee joint.

2.2. Tibial slope measurement

Using MIPAV software (http://mipav.cit.nih.gov), LTS was measured by a single examiner as described by Hudek et al. [24]. First, the central sagittal image was selected on which the tibial attachment of the posterior cruciate ligament (PCL), the intercondylar eminence, and the anterior and posterior tibial cortices appeared in a concave shape. Next, two circles (proximal and distal) were drawn in the proximal tibia. The proximal circle touched the anterior, posterior, and superior tibial cortex bone and the distal circle had to touch the anterior and posterior cortex border. A standardized relative distance between the proximal and distal circles was established as the center of the distal circle was placed on proximal circle circumference

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