Knee Surgery, Sports Traumatology, Arthroscopy
https://doi.org/10.1007/s00167-018-5283-x

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The significant effect of the medial hamstrings on dynamic knee stability

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Received: 27 March 2018 / Accepted: 7 November 2018

Abstract

Purpose While hamstring autograft is a popular option for the general population, BTB autograft is still significantly more popular among professional athletes due to concerns of altering knee kinematics with hamstring harvest. This study seeks to quantify the contribution of the medial hamstrings to knee stability.

Methods Valgus knee laxity, anterior tibial translation, and rotational motion were measured in eight fresh-frozen cadaveric knees after forces were applied on the tibia in each plane (coronal, sagittal, and axial). Four muscle loading conditions were tested: (1) physiologic fully loaded pes anserinus, (2) semitendinosus only loaded, (3) gracilis only loaded, and (4) unloaded pes anserinus. The protocol was then repeated with the ACL transected.

Results In the ACL intact knee, the neutral position of the tibia with an unloaded pes anserinus was significantly more externally rotated ($p < 0.01$) and anteriorly translated ($p < 0.05$) at all knee flexion angles than a tibia with a physiologic loaded pes anserinus. Applying an external rotation torque significantly increased external rotation for the fully unloaded ($p < 0.001$), gracilis only loaded ($p < 0.001$), and semitendinosus only loaded ($p < 0.01$) conditions at all flexion angles. Applying a valgus torque resulted in a significant increase in laxity for the fully unloaded condition only at 30° of flexion ($p < 0.05$). Applying an anterior tibial force resulted in significant increase in anterior translation for the fully unloaded condition at all flexion angles ($p < 0.01$), and for the gracilis only loaded condition in 30° and 60° of flexion ($p < 0.05$). Similar results were seen in the ACL deficient model.

Conclusion The medial hamstrings are involved in rotational, translational, and varus/valgus control of the knee. Applying anterior, external rotation, and valgus forces on the hamstring deficient knee significantly increases motion in those planes. Harvesting the gracilis and semitendinosus tendons alters native knee kinematics and stability. This is clinically relevant and should be a consideration when choosing graft source for ACL reconstruction, especially in the elite athlete population.

Keywords Hamstring autograft · Pes anserinus · ACL · Knee stability · Semitendinosus · Gracilis

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Introduction

Both static and dynamic structures contribute to the stability of the knee joint. The important medial structures include the medial collateral ligament (MCL), capsule, posterior oblique ligament (POL), semimembranosus, and the medial hamstrings. The medial hamstrings encompass the pes anserinus, and include the sartorius, gracilis, and semitendinosus tendons.

Dynamic function of the hamstrings has long been documented as being important in neuromuscular control of the knee with or without an intact anterior cruciate ligament (ACL). Hamstring contraction reduces anterior tibial shear force and translation [15, 18]. Additionally, this reduces ACL strain and loading in the cadaveric knee and in vivo [5, 18, 22].

Current trends show an increase in the use of hamstring autograft for ACL reconstruction in the general population. Magnussen et al. [19] reported in 2010 that hamstring autograft in the US was utilized in 44% of cases, as compared to bone-tendon-bone (BTB) autograft being utilized in 42% cases. There was even a bigger margin in Norway, where 63% of cases utilized hamstring autograft. Furthermore, Kvist et al. [14] reported that according to the Swedish national anterior cruciate ligament register, 95% of primary ACL reconstructions utilized hamstring autograft in 2012. Duquin et al. [8] reported survey results in 2009 demonstrating the declining popularity for BTB in regards to graft choice.

However, the literature shows contrasting results when analyzing graft choice in the elite athlete population. Erickson et al. [10] reported ACL practice patterns among pro and college football team physicians. 86% utilized BTB autograft compared to 11% utilizing hamstring autograft. Mall et al. [20] reported trends among NBA team physicians. 81% utilized BTB autograft compared to 16% utilizing hamstring autograft.

The question arises as to whether the outcomes in the elite athlete population are different when comparing BTB and hamstring autograft. There is an abundance of literature to show that there are no differences in subjective or functional outcomes between the two graft choices in the general population [11, 25, 27, 28]. However, athletes place a greater demand and stress on their knees. In an effort to achieve stronger initial fixation and to achieve bone to bone healing, BTB autograft is often utilized. The rationale against hamstring use is largely due to the thinking that there is a potential loss of the stabilizing effect of the hamstrings.

The purpose of this study is to perform a biomechanical cadaveric study to analyze the contribution of the medial hamstrings to rotational motion, valgus knee motion, and anterior tibial translation. The authors hypothesize that the medial hamstrings do play a significant role in the three planes of motion, and that the degree of contribution would be greater in the ACL deficient knee. The goal is to provide further insight into the role of hamstring function in ACL injury prevention and rehabilitation, and additionally insight into the question of ACL graft selection, especially for the elite athlete population. The study is useful because graft selection is still controversial for the elite, professional athlete.

Materials and methods

Specimen preparation and mounting

Eight fresh-frozen cadaveric knees (three left, five right; one male, seven female) obtained from the University of California, Irvine willed body program were prepared and tested. The knees were disarticulated after testing and any specimen with signs of gross knee pathology, such as obvious ligament incompetence, were excluded. Each specimen was dissected free of skin, subcutaneous tissue, and muscle tissue, while preserving the knee capsule, lateral collateral ligament, medial collateral ligament, vastus lateralis, vastus medialis, rectus femoris, biceps femoris, and pes anserine muscles. Krakow locking running stitch using No. 2 FiberWire suture (Arthrex, Naples, FL) were placed on the tendinous insertions of each of these muscles for muscle loading during testing.

The femur and tibia of each specimen were potted in polyvinyl chloride pipes using plaster of Paris. Each specimen was potted a standardized distance from the joint line (i.e. 8 cm on the tibia and 9 cm on the femur). A single bicortical, diaphyseal screw was placed through both femoral and tibial pipes and into the specimen for rigid fixation. For mounting into custom knee testing system, the femoral and tibial pipes were centered and then secured in their respective aluminum cylinders using eight fixation pins so that the cylinder's long axis would be representative of the bone's long axis. The custom jig was assembled on a material testing system (Instron model 1122, Instron Coproration, Canton, MA). It allowed for 6 degrees of freedom for both the femur and tibia (Fig. 1).

Muscle loads were applied based on the ratio of the cross-sectional area of each muscle as reported in literature [30]. A total of 100 N was applied using a cable and pulley system. The muscle load for each muscle was: Sartorius—2.0 N, semitendinosus—6.0 N, gracilis—2.0 N, vastus lateralis—36.0 N, rectus femoris—15.0 N, vastus medialis—25.0 N, and biceps femoris—15.0 N.

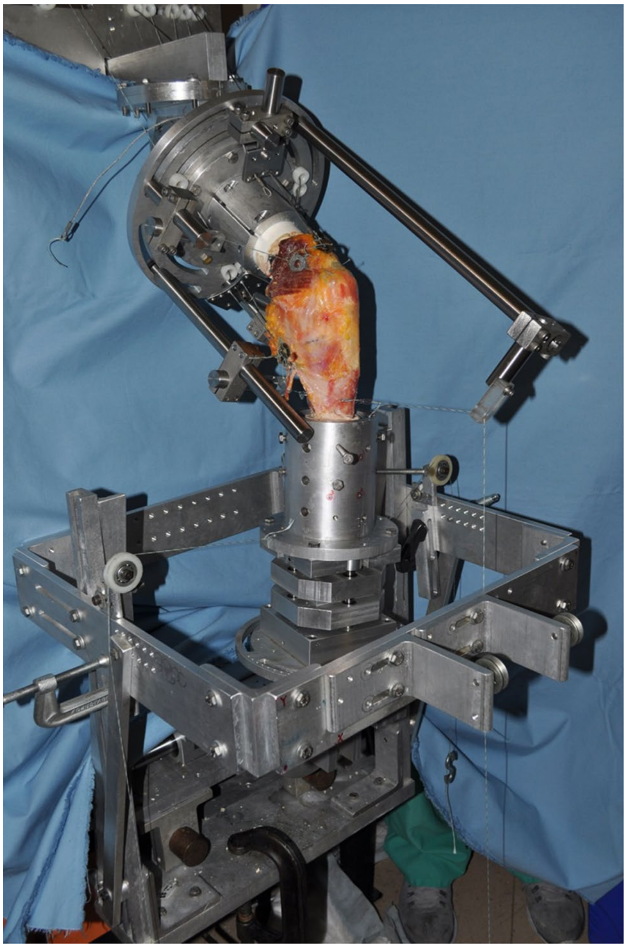


Fig. 1 This custom knee apparatus was used for data collection. This jig allowed for 6 degrees of freedom for both the femur and tibia. Using a cable and pulley system, muscle loads and tibial force/torque were applied

Experimental conditions and measurements

Four pes anserine muscle loading conditions were tested at each knee flexion angle (0°, 30°, 60°): physiologic loading of pes anserinus, only semitendinosus loaded, only gracilis loaded, and fully unloaded pes anserinus. The following tibial kinematic parameters were measured: valgus laxity, external rotation, and anterior translation. These parameters were measured before (to obtain neutral position) and after a torque or force was applied. Specifically, a valgus torque of 6 Nm, external rotation torque of 3 Nm, and an anterior force of 30 N were applied using weights and pulley systems.

To measure tibial kinematics, three markers were placed in an orthogonal manner on the anterior aspect of tibial aluminum cylinder to be digitized. These digitization markers were used for each specimen using a Microscribe 3DLX (Revware Inc, Raleigh, NC). Each specimen underwent ten cycles of preconditioning prior to measurement of every kinematic parameter.

Each knee was tested using the above protocol with the ACL intact and cut. A tear was made using a sharp scalpel with the specimen in 60° of flexion. A 3–5 cm longitudinal, medial parapatellar incision was made to gain access to the ACL. Synovium and other surrounding tissues were carefully dissected to visualize the ligament. After visualization, a sharp scalpel was used to make an incision on the tibial insertion of the ACL. The tear was confirmed via palpation and by placing an anterior drawer force on the tibia.

This study was waived by our institution for IRB approval since it was a cadaveric biomechanical study.

Statistical analysis

Statistical analysis of muscle loading was performed using repeated measures analysis of variance with a Tukey post hoc test (muscle loading) and paired Student's *t* test (comparing intact versus ACL tear) with significance level set at $p < 0.05$.

Results

Data are organized based on the three planes of motion (i.e. external rotation, valgus, and anterior translation). Within each plane of motion, changes in neutral position and changes after a force or torque is applied are reported. The following results pertain to the ACL intact knee.

External rotation increased sequentially as the pes anserinus (pes) was unloaded before any torque was applied. The statistically significant increases in external rotation (ER) for the fully unloaded pes as compared to the control (physiologic fully loaded pes) are as follows: +0.55° at 0° ($p < 0.01$); +1.74° at 30° ($p < 0.001$); +2.58° at 60° ($p < 0.001$). Significant increases for the gracilis loaded condition were also found at all three flexion angles (Fig. 2a). Furthermore, after an ER torque of 3 Nm was applied, ER again increased as the pes was unloaded. Significant increases were found for the fully unloaded (+0.66°, +1.43°, +0.8°) ($p < 0.001$), gracilis only loaded (+0.55°, +1.1°, +0.66°) ($p < 0.001$), and semitendinosus only loaded conditions (+0.34°, +0.98°, +0.47°) ($p < 0.01$) (Fig. 2b).

When analyzing the neutral varus/valgus position, there were no significant differences among the muscle conditions in the neutral position at all three flexion angles (Fig. 3a). After a 6 Nm valgus tibial torque was applied, no significant changes were seen in varus/valgus motion among the four muscle conditions at 0° and 60° of flexion. However, at 30° of flexion, there was a quantitatively small but significant increase in valgus for the fully unloaded pes muscle condition [+0.28° ($p < 0.05$)] (Fig. 3b).

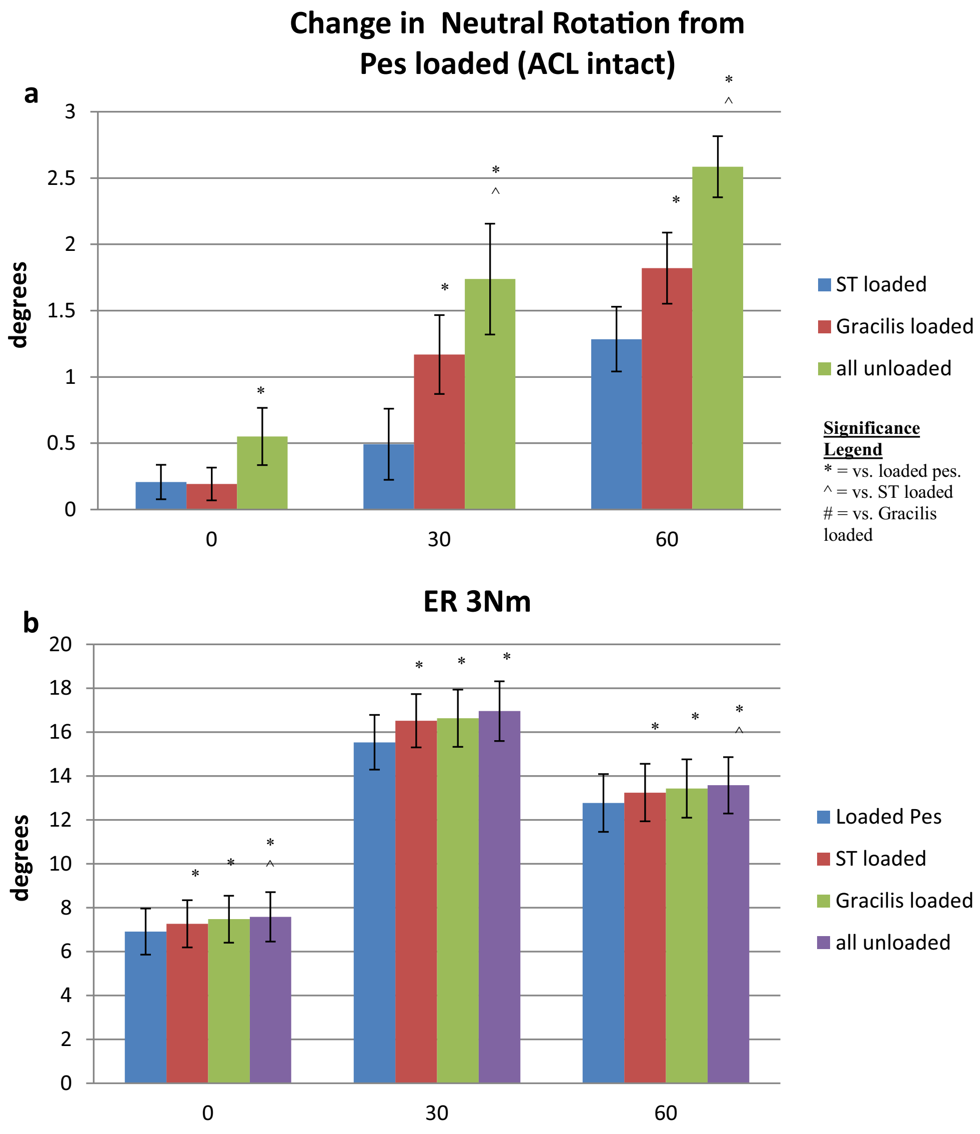


Fig. 2 **a** The graph illustrates the increase in external rotation as the pes is unloaded. This is significant at all three flexion angles. **b** After an ER torque is applied, there is again significant increases in ER as the pes is unloaded

In regards to the neutral position in the sagittal plane (i.e. anterior-posterior), increasing anterior translation was seen as the pes was unloaded. The significant increases in anterior translation occur for the fully unloaded pes at all three flexion angles, and are as follows: +0.18 mm at 0° ($p < 0.05$); +1.16 mm at 30° ($p < 0.01$); +0.91 mm at 60° ($p < 0.001$) (Fig. 4a). After a 30 N anterior tibial force was applied, significant increases in anterior translation were seen for the fully unloaded pes at all three flexion angles. The quantitative increases are as follows: +0.29 mm (0°), +0.85 mm (30°), +1.87 mm (60°) ($p < 0.01$). Significant increases were also seen for the gracilis loaded condition at 30° and 60° of flexion (Fig. 4b).

Finally, this protocol was repeated with the ACL transected. Similar significant results were found for all three flexion angles. These values in the ACL deficient knee were then compared with the values in the ACL intact knee. No significant differences were found when comparing external rotation or valgus motion. However, when comparing anterior tibial translation, there were statistically significant increases in anterior translation for ACL deficient knee at 30° of flexion (Fig. 5).

Discussion

The study has shown that the medial hamstrings play a significant role in all planes of knee stability both with and without the ACL intact. Numerous comparison trials and systematic reviews have shown that comparable results are achieved after ACL reconstruction with either hamstring or BTB autograft [11, 25, 27–29]. However, limited studies are available specifically looking at elite athletes as the primary patient population. Because these high-level athletes

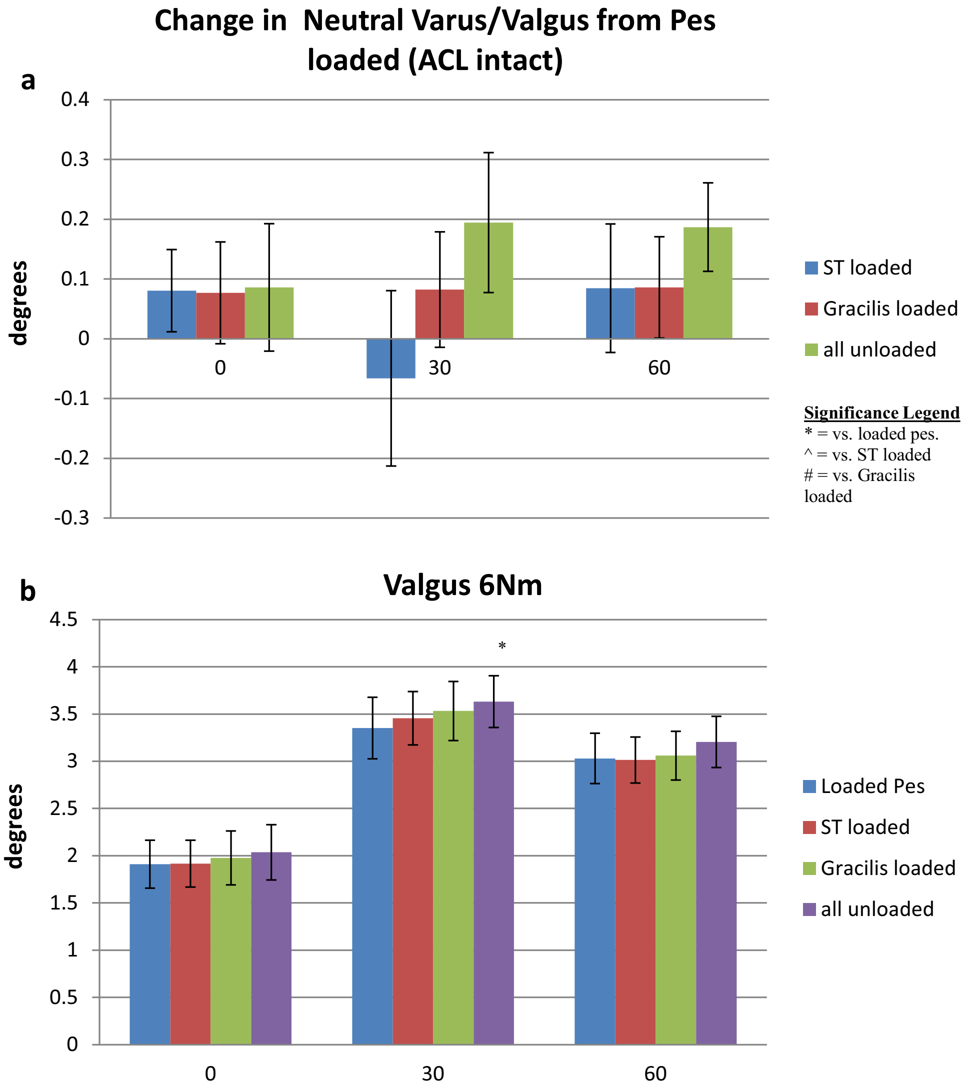


Fig. 3 **a** The graph illustrates the change in neutral varus/valgus as the pes is unloaded. There were no significant differences. **b** After a 6 Nm valgus tibial torque is applied, there were no differences except at one condition. There was a small increase in valgus at 30° of flexion for the unloaded pes muscle condition

place the greatest impact and stress on their knee joints, they demand the greatest stability. This is especially important as the trends in the United States and other countries have shown an increasing popularity for hamstring autograft. This trend has not yet been seen to that level in professional or collegiate athlete populations. Thus, the question must be posed. Do hamstring autograft ACL reconstructions result in similar comparable outcomes in this population of athletes. Because the literature lacks data specific to this, we performed this biomechanical study to analyze the contribution of the medial hamstrings to knee stability.

The results show that unloading of the medial hamstrings, which simulates a gracilis and semitendinosus tendon harvest, changes native knee kinematics and stability. Looking at the changes in neutral position first, we find that the tibia sits externally rotated and anteriorly translated from its native position at all three flexion angles once the hamstrings are unloaded. Although quantitative differences are small, the literature has shown that even small changes in native kinematics can lead to cartilage degeneration and osteoarthritis [1, 33]. Andriacchi et al. proposed that this change in kinematics leads to a degenerative cascade whereby the cartilage is unable to accommodate this shift in loading [2].

The results have confirmed this change in knee kinematics. However, the primary focus of the study is to analyze differences in knee stability after a force or torque is applied. The results demonstrate increased external rotation and anterior translation at all three flexion angles once the medial hamstrings are unloaded. At most, the increase in external rotation approaches 2° (i.e. at 30° of flexion) and the increase in anterior translation approaches 2 mm (i.e. at 60° of flexion). Again, these differences may not seem large, but that does not suggest it is not clinically significant, especially when looking at high demand patient populations.

Side-to-side differences in anterior-posterior (AP) knee laxity is one factor used to determine surgical success.

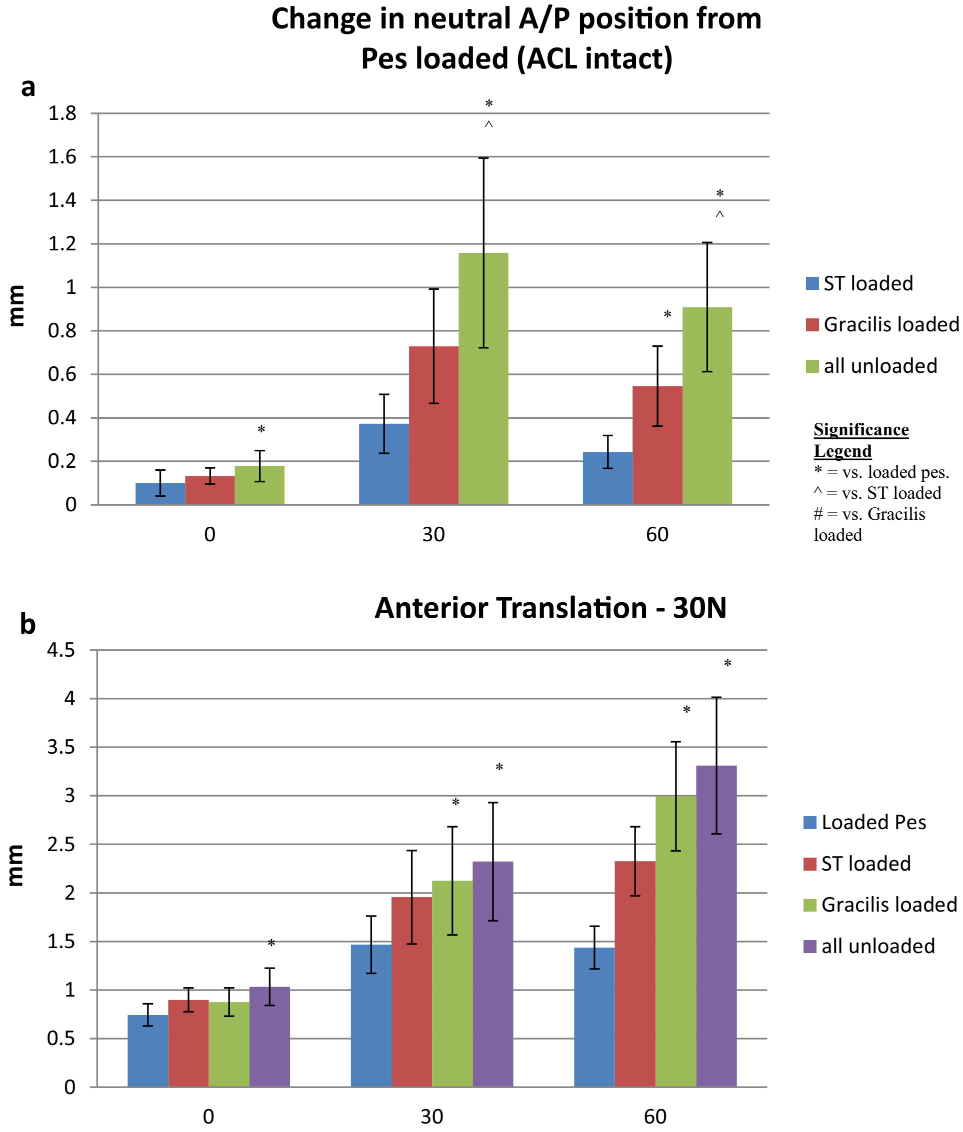


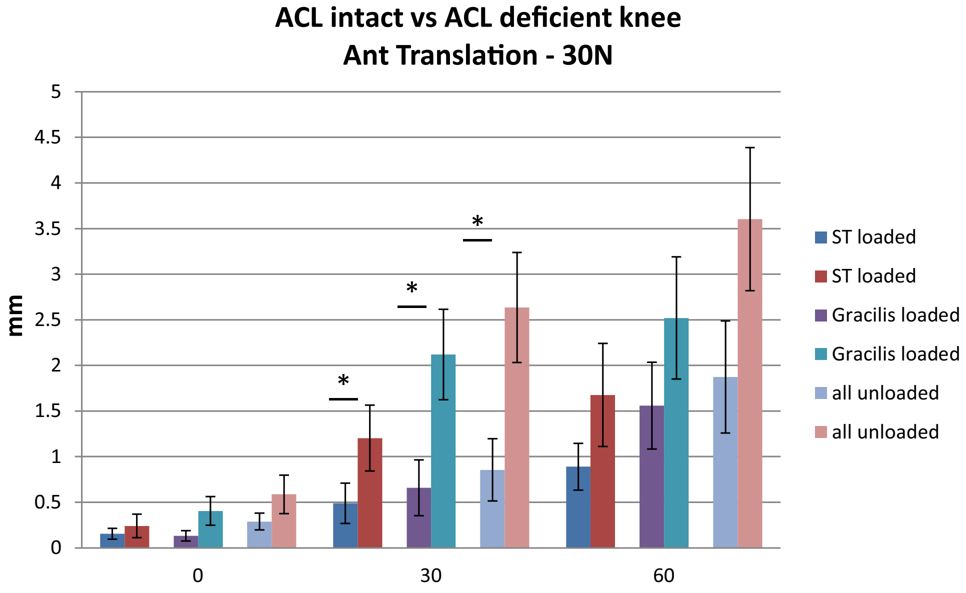
Fig. 4 **a** The graph illustrates the increase in neutral anterior tibial translation as the pes is unloaded. The significant increases occur for the fully unloaded pes in all three flexion angles. **b** After a 30 N anterior tibial force is applied, there are significant increases in anterior translation for the fully unloaded pes as well as the gracilis only loaded muscle conditions

Daniel et al. assessed AP knee laxity in healthy and ACL deficient patients, and determined that roughly 90% of healthy patients have a < 2 mm side-to-side difference [7]. Other authors have published more conservative data showing that < 5 mm differences exist in healthy individuals [16, 21]. Thus, a 2–5 mm side-to-side difference is used today as one factor to define success and failure of an ACL reconstruction. It is important to note that as previous clinical studies in the literature have shown no differences in AP laxity between BTB and hamstring [32], lachman testing and instrumented laxity measures do not take into account the increase in anterior translation of the native tibial position. Ultimately, the literature does not show agreement on this issue of AP laxity between the two techniques, as a systematic review [27] in 2004 and Cochrane review in 2011 [23] reported increased anterior laxity in the hamstring groups.

When it comes to external rotatory laxity, there is no consensus on quantitative values that may suggest failure. However, Armour et al. did show that patients who underwent hamstring autograft ACL reconstructions did have weaker internal tibial rotation postoperatively at 2 years [3]. The increase in ER seen in this study is explained by the unloading of the internal rotatory force provided by the medial hamstrings. Meta-analysis in 2015 comparing hamstring and BTB did conclude that outcomes after pivot shift tests were significantly in favor of BTB [32].

Finally, in regards to varus/valgus motion, the study did show significantly increase valgus after 6 Nm applied torque in the fully unloaded muscle condition at the 30° flexion angle. However, this is likely not clinically significant as the average increase valgus was very minimal at + 0.28°. Additionally, no other statistically significant differences were found in the other flexion angles or muscle conditions.

Fig. 5 Data from the ACL intact knee were compared with data from the ACL deficient knee. When comparing anterior translation, the graph illustrates that at 30° of flexion, there was significantly more translation for the ACL deficient knee



Thus, this plane of motion is likely predominately determined by the stabilizing effects of the collateral ligaments and the native or reconstructed ACL.

This study also analyzed other muscle conditions simulating single tendon harvest. Simulation of the semitendinosus harvest (i.e. gracilis only loaded condition) still resulted in an increase in external rotation and anterior translation, although to a lesser extent when comparing it with the fully unloaded condition. This is clinically important when considering single tendon harvest for ACL reconstruction. It suggests that the benefits may not be significant when trying to preserve the gracilis. Recent systematic review concluded that although there were differences in hamstring strength, it was not likely clinically relevant [26]. Additionally, anterior knee laxity was not different between semitendinosus harvest and combined semitendinosus-gracilis harvest [26]. On the other hand, simulation of the gracilis harvest (i.e. semitendinosus only loaded condition) did not show any differences with anterior translation but did show a small increase in external rotation. This is clinically important when considering gracilis harvest for procedures such as ulnar collateral ligament reconstruction. Here, the data suggests that native knee kinematics is relatively preserved if only the gracilis is harvested.

The last part of the study focused on the role of the medial hamstrings in the ACL deficient knee. Expectedly, unloading of medial hamstrings showed similar significant results specifically in anterior translation and external rotation. When the results were compared with the ACL competent knee, the degree of change was not different in regards to rotation. However, in regards to anterior translation at 30°, unloading of the hamstrings resulted in significantly greater anterior translation. This speaks to the importance of rehabilitation of the medial hamstrings in the preoperative setting before ACL reconstruction, as well as, in any setting where nonoperative measures are pursued for ACL insufficiency. Furthermore, the importance of rehabilitation of the medial hamstrings is further elevated during the immediate postoperative period after ACL reconstruction. As there is an abundance of literature to show that hamstring activity is decreased and altered postoperatively [4, 6, 9, 13, 24], it is also a period where the newly reconstructed ACL demands minimal strain for successful graft incorporation and healing.

The authors acknowledge that there are few limitations to the study. First, this is a cadaveric study, and thus it is unknown how such findings might be translated in the clinical setting. Clinical studies comparing hamstring autograft and BTB autograft in the elite athlete population would be paramount in helping to answer this question. Nevertheless, the study does quantify the role of the medial hamstrings in each plane of motion. Second, muscle loading in this protocol was based on physiologic cross-sectional areas. This makes it difficult for the biomechanical models to account for the dynamic changes in loads that occur with the type of physical activity being performed. However, the muscle loads used in this study for the medial hamstrings were dramatically lower when compared with the other major muscles. Moreover, if different loads were studied to represent specific activities such as jumping or squatting, hamstring loads would likely be higher increasing the degree of significant differences demonstrated in this study. Finally, the study could not take into account the potential of muscle compensation and hypertrophy. Multiple studies have reported increased activity [12] and hypertrophy [17, 31] of the semimembranosus muscle after hamstring ACL reconstruction. It is unknown if this impacts stability.

Nevertheless, the clinical relevance of this study is significant. Loss of the medial hamstrings alters knee kinematics and leads to a decrease in knee stability in all planes both with and without the ACL. Although quantitatively small, this should be a consideration when determining graft source for high level athletes with an ACL rupture.

Conclusion

The medial hamstrings are involved in rotational, translational, and valgus stability of the knee. Simulation of semitendinosus and gracilis harvest resulted in altered native knee kinematics. Specifically, the hamstring deficient knee experienced increased external rotation and anterior translation before and after an applied force or torque. Simulation of semitendinosus only harvest also resulted in increased external rotation and anterior translation. The medial hamstrings contribute to a greater degree in limiting anterior translation in an ACL deficient knee demonstrating the importance of hamstring rehabilitation in the preoperative and postoperative setting. The results of this study should be taken into consideration when choosing graft source for ACL reconstruction, specifically in the elite athlete population.

Author contributions AT conceived idea of study, carried out the cadaveric studies in the laboratory, and wrote significant portion of the manuscript. OL made substantial contributions in conception, design, and helped revise manuscript. HI was heavily involved in conducting the cadaveric studies and writing the methods portion of manuscript. MM was involved in conducting the cadaveric studies and assembling/organizing the lab setting for experimentation. MB helped with study conception, revision of manuscript, and conducting studies. TL supervised the entire cadaveric study, made substantial contribution to design, and edited final manuscript.

Funding The authors of this study have no relevant financial relationships to disclose.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval The article does not contain any studies with human participants performed by any of the authors.

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