Effect of Anterior Horn Tears of the Lateral Meniscus on Knee Stability

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Background: Investigations on the biomechanical characteristics of the anterior horn of the lateral meniscus (AHLM) related to anterior cruciate ligament (ACL) tibial tunnel reaming have revealed increased contact pressure between the femur and tibia, decreased attachment area, and decreased ultimate failure strength.

Purpose/Hypothesis: The purpose of this study was to investigate the influence of a complete radial tear of the AHLM on force distribution in response to applied anterior and posterior drawer forces and internal and external rotation torques. We hypothesized that the AHLM plays an important role in knee stability, primarily at lower knee flexion angles.

Study Design: Controlled laboratory study.

Methods: A total of 9 fresh-frozen cadaveric knee specimens and a robotic testing system were used. Anterior and posterior drawer forces up to 89 N and internal and external rotation torques up to 4 N·m were applied at 0°, 30°, 60°, and 90° of knee flexion. A complete AHLM tear was then made 10 mm from the lateral border of the tibial attachment of the ACL, and the same tests performed in the intact state were repeated. Next, the recorded intact knee motion was reproduced in the AHLM-torn knee, and the change in the resultant force after an AHLM tear was determined by calculating the difference between the 2 states.

Results: In the torn AHLM, the reduction in the resultant force at 0° for external rotation torque (34.8 N) was larger than that at 60° (5.2 N; $P < .01$) and 90° (6.7 N; $P < .01$).

Conclusion: The AHLM played a role in facilitating knee stability against an applied posterior drawer force of 89 N and external rotation torque of 4 N·m, especially at lower knee flexion angles.

Clinical Relevance: This study provides information about the effects of AHLM injuries that may occur during single-bundle ACL reconstruction using a round tunnel.

Keywords: lateral meniscus; anterior horn; robotic system; fresh-frozen cadaveric specimen

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The lateral meniscus (LM) is important to combined loads, including rotational loads.[11] LM posterior root tears in anterior cruciate ligament (ACL)–deficient knees led to increased anterior tibial translation during simulated pivot-shift tests.[2,5,16] Furthermore, a radial tear of the middle segment of the LM decreased LM force and caused a medial shift and valgus rotation of the tibia in response to valgus torque and axial loading.[19] Similarly, biomechanical tests have revealed that the LM plays an important role in knee stability and force sharing in response to rotational, valgus, or axial loading.[9,11-13,16,20]

Tears of the anterior horn of the LM (AHLM) can occur in football players.[1] Because of the close anatomic relationship between the ACL and the AHLM attachment site,[4,8,17,18,21] AHLM injuries also reportedly occur when making a round tibial tunnel during single-bundle ACL reconstruction (ACLR). In a cadaveric model, the AHLM was injured during single-bundle ACLR using the round tunnel technique.[7,10,22,23] In clinical cases, the lateral location of the tibial tunnel increased the rate of lateral meniscal extrusion after single-bundle ACLR.[14] Further, several authors have investigated the biomechanical effects of an AHLM tear and reported increased contact pressure between the femur and tibia,[15] decreased attachment area, and decreased ultimate failure strength.[10]

In this study, we aimed to investigate the effect of a complete radial tear of the AHLM on force distribution in response to applied anterior and posterior drawer forces and internal and external rotation torques. We hypothesized that an AHLM tear would influence the knee's rotational and posterior stability, primarily at decreased knee flexion angles.

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METHODS

Specimen Preparation

A total of 9 fresh-frozen, cadaveric nonpaired knee specimens from 6 men with a mean age at death of 87.0 years (range, 78-101 years) were used. The study protocol to obtain, use, and dispose of fresh-frozen human cadaveric knees was approved by a university ethics committee. Physical examinations were performed to confirm ligamentous stability and range of motion from full extension to 130° of flexion. Specimens with ligamentous instability or insufficient range of motion were excluded. Each specimen was thawed at room temperature for at least 12 hours before the experiment. After that, we kept all specimens wet to avoid tissue deterioration during the experiment.

The femur and tibia were cut at least 15 cm above and below the joint line, while the fibula was cut 5 cm below the proximal tibiofibular joint. Soft tissues (including the quadriceps and hamstring) and the patella were removed. The ligaments, meniscus, and capsule were retained intact. Both ends of the tibia and femur were fixed by pouring acrylic resin (Ostron II; GC) into a cylindrical mold. The fibula was fixed with resin in its original position. The femoral and tibial cylinders were secured with aluminum clamps and connected to the end effector of the robotic testing system developed by Fujie et al[3] (Figure 1).

For all 9 specimens, anterior and posterior drawer forces and internal and external rotation torques were applied at various degrees of knee flexion. A complete AHLM tear was then created 10 mm from the lateral border of the tibial attachment of the ACL using a scalpel, and the same tests performed in the intact state were repeated.

Testing Apparatus

We utilized a robotic testing system (FRS-2010; Technology Services), consisting of a custom-made manipulator with 6 degrees of freedom (DOFs) equipped with a universal force-torque sensor (Delta IP65 SI-660-60; ATI Industrial Automation) (Figure 1). The robotic testing system made it possible to simulate physiological knee joint motion, incorporating the joint coordinate system developed by Grood and Suntay[6] in vitro. This system was managed in real time using a LabView-based control program (Version 12.0.1; National Instruments) running on a Windows personal computer (Microsoft) to control the displacement of and force/torque applied to knee joints.

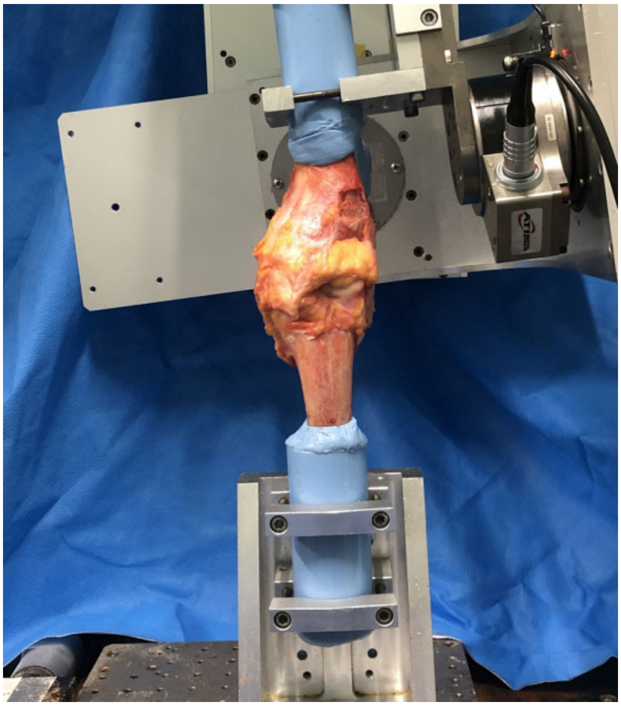

Figure 1. The biomechanical robotic testing system with a right knee. The femur was positioned at the bottom and the tibia to the upper end effector to calculate knee motion, as in previous studies using this system. The universal force-moment sensor for calculating knee kinetic data was placed on the upper end effector.

Testing Protocol for Intact State

Full knee joint extension (0° of extension) was attained by applying 0.5 N·m of torque to the knee while keeping the force/torque of the other DOFs at zero using force control. Zero degrees and zero displacements of the DOFs except the flexion-extension DOF were also defined at that position. Passive flexion-extension from hyperextension (applying 5 N·m of torque) to 120° at a rate of 0.5 deg/s was applied to the knee 3 times to reduce the viscoelastic effects of creep before the main test.

Anterior and posterior drawer forces up to 89 N were applied at 0°, 30°, 60°, and 90° of knee flexion while maintaining the force/torque of 4 DOFs (except for the flexion-extension and anterior-posterior DOFs) at zero using force

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Ethical approval for this study was obtained from Sapporo Medical University (No. 1-2-68).

TABLE 1
Changes in the Resultant Force of the Tear to the Anterior Horn of the Lateral Meniscus in Response to Each Load[a]

	Flexion Angle			
	0°	30°	60°	90°
Anterior drawer force	15.0 ± 12.6	9.0 ± 5.3	5.6 ± 3.3	7.0 ± 4.1
Posterior drawer force	27.0 ± 18.1	16.8 ± 8.5	16.1 ± 10.4	14.5 ± 9.8
Internal rotation torque	9.0 ± 5.1	5.8 ± 3.9	8.4 ± 7.2	7.0 ± 6.6
External rotation torque	34.8 ± 16.9	16.0 ± 10.9	5.2 ± 2.7	6.7 ± 3.7

[a] Data are reported as mean ± SD (in N).

control. Similar to the anterior-posterior drawer test, both internal rotation torque and external rotation torque up to 4 N·m were applied at 0°, 30°, 60°, and 90° of knee flexion. During the test, the intact 6-DOF knee motion and force/torque were recorded.

Testing Protocol for AHLM Tear State

The recorded intact knee motion was reproduced in the AHLM-torn knees, and the force/torque of the knee detected by the end effector of the force-torque sensor was recorded. By applying the principle of superposition as previously described,[3] the resultant AHLM force was determined using the 6-DOF force/torque data of the intact and AHLM-torn states.

Statistical Analysis

The decrease in the resultant force after an AHLM tear was analyzed using 2-factor repeated-measures analysis of variance with post hoc pairwise comparisons using the Bonferroni correction. The 2 factors assessed were the applied load and the knee flexion angle. All analyses were performed using Statistical Package for the Social Sciences (Version 28.0; IBM). The threshold for statistical significance was set at $P < .05$.

A post hoc power analysis confirmed that with 9 specimens, the power of our study to detect differences in the knee flexion angle and the interaction between the knee flexion angle and the applied load was >0.927 when comparing intact and AHLM-torn knees.

RESULTS

The changes in the resultant force after an AHLM tear are shown in Table 1. The 2-factor repeated-measures analysis of variance showed significant differences in the knee flexion angle factor ($P < .01$) and interaction effects ($P < .01$). Our analyses also revealed that the decrease in the resultant force after the development of an AHLM tear was significantly more pronounced when a posterior drawer force was applied than when an anterior drawer force ($P = .03$) or internal rotation torque ($P = .01$) was applied. Comparisons of the change in the resultant force after the development of an AHLM tear at each knee flexion angle in response to the same applied load (Figure 2) showed that for external rotation torque, the reduction in force at 0° was larger than that at 60° ($P < .01$) and 90° ($P < .01$). No significant differences were observed in any other comparisons.

DISCUSSION

We investigated the effect of a complete radial tear of the AHLM on force distribution in response to applied drawer forces and rotation torques. Our most important finding was that the decrease in the resultant force after an AHLM tear was larger when a posterior drawer force was applied than when an anterior drawer force ($P = .03$) or internal rotation torque ($P = .01$) was administered. Further, in knees with an AHLM tear, the decrease in the resultant force in response to external rotation torque was also larger, particularly in the extended knee position than at deep knee flexion angles.

Previous biomechanical studies using fresh-frozen cadaveric specimens have shown that a posterior root tear of the LM leads to increased anterior tibial translation in response to a simulated pivot-shift load.[16] In contrast, in our study, posterior tibial translation increased when a posterior drawer force was applied.

Similarly, Novaretti et al[12] performed biomechanical cadaveric tests and found that partial meniscectomy of the posterior root of the LM led to a decrease in the resultant force when combined valgus and internal tibial torque or combined valgus and external tibial torque was applied. Although statistical comparisons between each knee flexion angle were not performed in that study, the decrease in the resultant force tended to be larger at deeper knee flexion angles. On the contrary, in the current study, the decrease in the resultant force secondary to an AHLM tear was larger at 0° of knee flexion than at 60° and 90° of knee flexion. Considering these results, we believe that the LM is associated with force distribution against rotation torque. Further, the knee flexion angle by which the force distribution is influenced varies depending on the LM segment that is torn.

This study had several limitations. First, the experiments were performed on specimens from elderly donors. Therefore, there are potential biases, given that at least some of our specimens probably had meniscal degeneration. Second, neither axial loading nor valgus torque was applied. With that said, the purpose of this study was to investigate the influence of an AHLM tear on the response

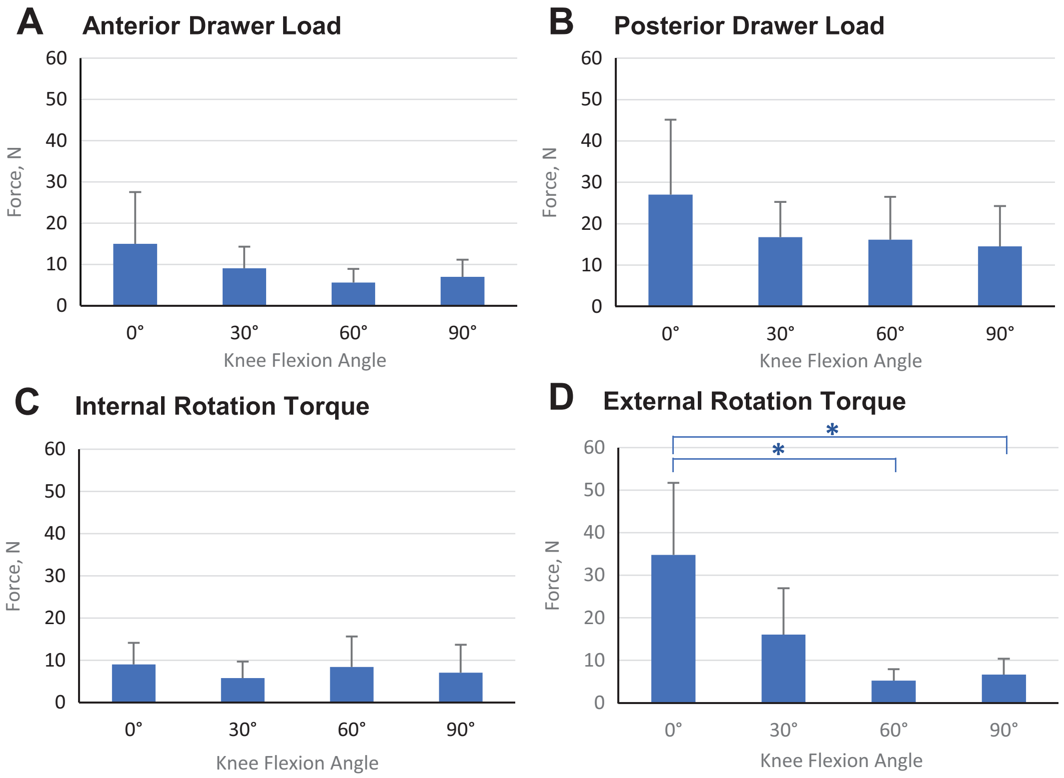

Figure 2. Changes in the resultant force in knees with a torn anterior horn of the lateral meniscus at each knee flexion angle in response to the same applied load: (A) anterior drawer force, (B) posterior drawer force, (C) internal rotation torque, and (D) external rotation torque. Error bars indicate SDs. *Statistically significant difference between knee flexion angles ($P < .05$).

to applied anterior and posterior drawer forces and internal and external rotation torques. Third, no anterior capsule, quadriceps, or hamstring loads were applied. In conclusion, the AHLM played a role in facilitating knee stability against an applied posterior drawer force and external rotation torque to some extent, especially in the extended knee position.

CONCLUSION

The findings of this study indicated that the AHLM played a role in facilitating knee stability against an applied posterior drawer force of 89 N and external rotation torque of 4 N·m, especially at lower knee flexion angles.

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