Original Research

Lateral Compartment Contact Pressures Do Not Increase After Lateral Extra-articular Tenodesis and Subsequent Subtotal Meniscectomy

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Background: Modified Lemaire lateral extra-articular tenodesis (LET) has been proposed as a method of addressing persistent anterolateral rotatory laxity after anterior cruciate ligament (ACL) reconstruction (ACLR). However, concerns remain regarding the potential for increasing lateral compartment contact pressures.

Purpose: To investigate changes in tibiofemoral joint contact pressures after isolated ACLR and combined ACLR plus LET with varying states of a lateral meniscal injury.

Study Design: Controlled laboratory study.

Methods: Eight fresh-frozen cadaveric knee specimens (mean age, 60.0 ± 3.4 years) were utilized for this study, with specimens potted and loaded on a materials testing machine. A pressure sensor was inserted into the lateral compartment of the tibiofemoral joint, and specimens were loaded at 0°, 30°, 60°, and 90° of flexion in the following states: (1) baseline (ACL- and anterolateral ligament–deficient), (2) ACLR, (3) ACLR with LET, (4) partial meniscectomy (removal of 50% of the posterior third of the lateral meniscus), (5) subtotal meniscectomy (removal of 100% of the posterior third of the lateral meniscus), and (6) LET release (LETR). Mean contact pressure, peak pressure, and center of pressure were analyzed using 1-way repeated-measures analysis of variance.

Results: Across all flexion angles, there was no statistically significant increase in the mean contact pressure or peak pressure after ACLR plus LET with and without lateral meniscectomy compared with isolated ACLR. There was a significant reduction in the mean contact pressure, from baseline, after subtotal meniscectomy (69.72% ± 19.27% baseline; $P = .04$) and LETR (65.81% ± 13.40% baseline; $P = .003$) at 0° and after the addition of LET to ACLR at 30° (61.20% ± 23.08% baseline; $P = .031$). The center of pressure was observed to be more anterior after partial (0°, 30°) and subtotal (0°, 60°) meniscectomy and LETR (0°, 30°, 60°).

Conclusion: Under the loading conditions of this study, LET did not significantly alter lateral compartment contact pressures when performed in conjunction with ACLR in the setting of an intact or posterior horn–deficient lateral meniscus.

Clinical Relevance: This study should provide surgeons with the confidence that it is safe to perform LET in this manner in conjunction with ACLR without altering lateral compartment pressures, regardless of the status of the lateral meniscus.

Keywords: contact pressure; meniscectomy; ACL reconstruction; lateral extra-articular tenodesis; lateral meniscectomy

Although anterior cruciate ligament (ACL) reconstruction (ACLR) has been shown to be an effective treatment for patients with an ACL-deficient knee,[14] recent studies have demonstrated an alarmingly high failure rate in young patients, with return-to-sport rates often shown to be suboptimal.[34] Concern exists over persistent anterolateral rotatory laxity,[11,20,28,33] with the pivot-shift examination having been shown to correlate with functional outcomes postoperatively.[2] This residual laxity may contribute to subjective failure, with patients being unable to return to athletic activities, or objective failure, as observed with graft reruptures.[9,18,19] Consequently, there has been a resurgence of interest in lateral extra-articular procedures that may confer improved rotational stability.

Recently, 2 meta-analyses reported significantly improved control of rotational laxity with ACLR combined with lateral extra-articular tenodesis (LET), compared with isolated single-bundle ACLR.[14,27] However, there are ongoing concerns over LET and its potential to overconstrain physiological tibiofemoral rotation,[5-8,10,22,29] with early

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studies suggesting no added clinical benefit of extra-articular procedures.[1,25] As a result of these criticisms, the adoption of this procedure has been relatively slow.[12]

A number of recent biomechanical studies have been performed, using either combined ACLR with LET (both the ACL and anterolateral structures were sectioned first)[13,16,17] or LET in combination with an intact ACL,[15] and have generally corroborated previous findings; isolated ACLR was inadequate in restoring native knee joint kinematics and rotational stability.[13,16,17] Furthermore, Inderhaug et al[16] identified that the addition of LET to ACLR restored native joint kinematics, with no evidence of rotational overconstraint. Importantly, in a separate study, Inderhaug et al[15] only found evidence of overconstraint when LET was tensioned to 80 N of force.

Despite these preclinical kinematic data, there is still clinical concern about the impact of LET on lateral joint contact pressures,[23] heightened by the presence of concomitant lateral meniscal deficiency. To our knowledge, however, there are no studies evaluating the effect of LET on lateral compartment tibiofemoral contact pressure parameters after ACLR in an ACL- and lateral meniscus–deficient model.

Therefore, the purpose of this study was to investigate changes in tibiofemoral joint contact pressures between isolated ACLR and combined ACLR plus LET in various lateral meniscal injury states. The hypothesis was that lateral tibiofemoral contact pressures would not increase after combined ACLR plus LET with and without a lateral meniscal injury, compared with the isolated ACL-reconstructed knee, under physiological loading conditions.

METHODS

Specimen Preparation

Eight fresh-frozen (–20°) cadaveric knee specimens (midfemur to midtibia) (mean age, 60.0 ± 3.4 years; mean height, 1.76 ± 0.17 m; mean weight, 84.37 ± 15.66 kg) were procured for use in this study (Science Care). The study protocol was approved by our institutional review board (approval No. MW 030217). The specimens were free of any bone and soft tissue disorders, assessed through visual and manual inspection as well as arthroscopic inspection for degenerative changes to the joint. The specimens were thawed, and the soft tissues from the proximal femur and distal tibia were dissected for potting; all soft tissues surrounding the knee joint were left intact. The tibia was potted into a 3 cm–long section of 9 cm–diameter ABS piping using dental cement (Denstone Dental Cement; Heraeus). Once set, the specimen was inverted and held in extension while the proximal femur was potted into a section of 6 cm–diameter ABS piping. A 10-N compressive load was applied through the tibia during this process to maintain the knee's native alignment.

Lateral Compartment Pressure Measurements

The mean contact pressure (ie, mean pressure over the surface of the tibial plateau), peak pressure, and location of the center of pressure were selected as outcome measures, as evidence suggests that alterations in the knee joint loading environment are a strong contributor to the onset and propagation of knee osteoarthritis (OA).[30] Once the specimens were potted, a pressure sensor was inserted into the joint (K-Scan System model 4011; Tekscan) through an anterolateral parapatellar arthrotomy site (Figure 1A). Tekscan sensors have previously been utilized in similar studies, demonstrating that they provide a valid and reliable measurement of in vitro joint loading.[15] The sensor matrix was 24.8 × 40.0 mm, resulting in 273 sensels at a resolution of 27.6 sensels/cm^2. The sensor had a maximum capacity of 3448 kPa and was calibrated and equilibrated before insertion following the manufacturer's guidelines. Two sutures were attached to the edge of the sensor and passed in a submeniscal fashion using an inside-out suture-shuttling technique. This allowed the sensor to be pulled along the lateral tibial surface, under the lateral meniscus, until it was in the intended position. The placement of the sensor was confirmed arthroscopically before sutures were tied over the posterolateral joint capsule (Figure 1B).

Experimental Conditions

The lateral compartment contact parameters were measured in response to the following conditions.

(1) Baseline. This was an ACL-deficient and anterolateral ligament (ALL)/anterolateral capsule (ALC)–deficient condition. The ACL was sectioned arthroscopically, while the inframeniscal fibers of the ALL/ALC were sectioned through a 2-cm iliotibial band (ITB) arthrotomy site. The ALL/ALC fibers were identified as starting just anterior to the lateral collateral ligament to a position adjacent to the posterior margin of the Gerdy tubercle. Using these anatomic landmarks would ensure that the inframeniscal portion of the ALL was sectioned.[3] Care was taken to avoid

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Ethical approval for this study was obtained from the Western University Institutional Review Board (approval No. MW030217).

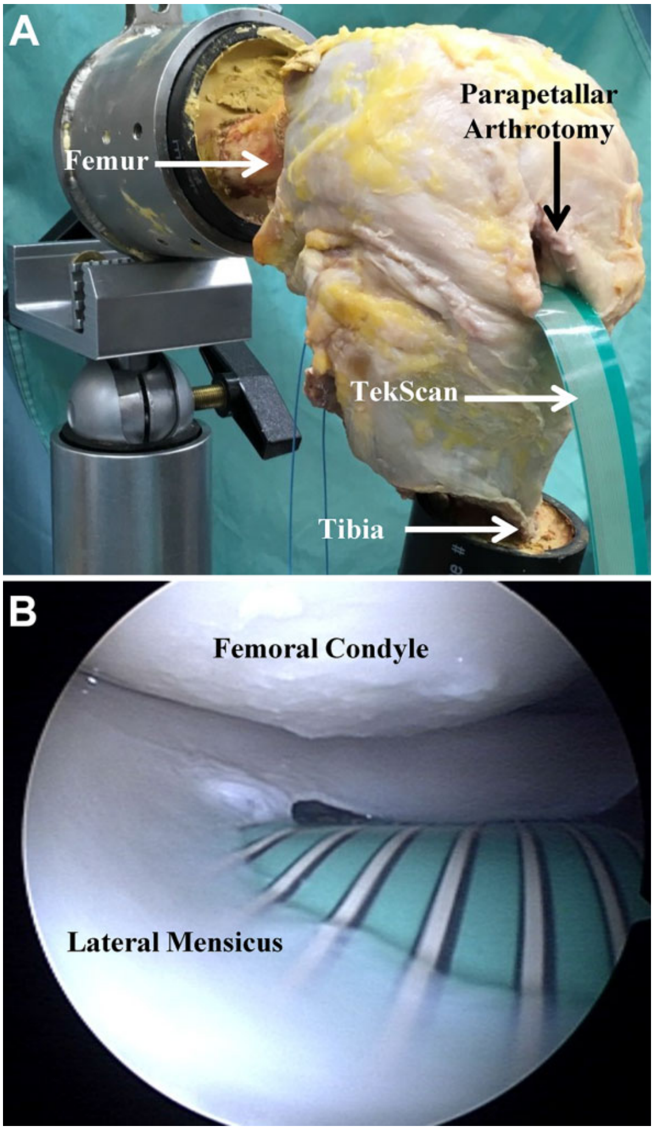

Figure 1. Experimental setup showing (A) the insertion of the Tekscan pressure sensor through the anterior lateral parapatellar arthrotomy site and (B) an image from the arthroscope showing the sensor secured on the tibial joint surface under the lateral meniscus.

posterior extension into the deep ITB. All arthrotomy sites and the ITB were sutured before testing.

(2) ACLR. Transportal (8 mm–diameter tunnel) anatomic single-bundle reconstruction was performed arthroscopically using a tibialis posterior allograft (RegenMed) with fixed-loop suspensory fixation on the femoral side (Endobutton; Smith & Nephew), tensioned to 80 N and fixed at 15° of flexion with a 9 × 25–mm interference screw on the tibial side (Biosure PK; Smith & Nephew).

(3) ACLR with LET (ACLR/LET). After ACLR, modified Lemaire LET was performed. A 1 cm–wide × 8 cm–long central strip of the ITB was harvested, leaving the distal attachment to the Gerdy tubercle intact. The proximal end was whip-stitched and passed under the fibular collateral ligament and secured with a Richards staple (Smith & Nephew) proximal and posterior to the lateral femoral epicondyle, with 20 N of tension applied to the graft and the knee in neutral rotation and 70° of flexion.[10,15] The free end of the ITB was then sutured back onto itself.

(4) Partial meniscectomy with ACLR and LET (ACL/LET/Partial). Partial meniscectomy was performed by removing 50% of the posterior third of the lateral meniscus arthroscopically.

(5) Subtotal meniscectomy with ACLR and LET (ACLR/LET/Total). Meniscectomy was performed by removing 100% of the posterior third of the lateral meniscus. For both meniscus-sectioning instances, the meniscus was sectioned via meniscal biters, and all debris was removed via suction. Also, the surgeon had full visualization of the Tekscan sensor during these processes, and care was taken not to damage the sensors.

(6) LET release (LETR) with ACLR and subtotal menisectomy (ACLR/Total/LETR). The LET procedure that was performed in condition 3 was released by removing the staple from the femur and pulling the LET construct out from under the fibular collateral ligament.

Loading Protocol

Once the specimen was appropriately prepared for each experimental condition, it was rigidly attached to a materials testing machine (model 8874; Instron). The tibia was secured to the actuator of the Instron machine via a 6 degrees of freedom load cell (MC3A-1000; Advanced Mechanical Technologies), while the femur was attached to a flexion/extension jig (Figure 2). When the desired flexion angle was set, as measured with a goniometer (Baseline; Fabrication Enterprises), the Instron machine was programmed to load the joint to 735 N (body weight [75 kg] force of the average human, thus simulating single-leg standing) and hold this load for 10 seconds. During this time, the lateral compartment pressures were recorded by the Tekscan software at 4 frames per second (I-Scan System; Tekscan). Care was taken to ensure that the specimen was secured in the Instron machine in the position that it acquired immediately after each of the experimental conditions. This loading setup constrained the joint, such that it only allowed motion to occur in the axial direction once the flexion angle was set; no accommodating translation or rotation could occur in this system, such that it was simulating a closed chain loading protocol. The loading protocol was applied for all conditions at knee flexion angles between 0° and 90° in 30° increments.

Statistical Analysis

The data collected from the pressure sensors, including mean contact pressure, peak pressure, and location of the center of pressure, were averaged over the middle third of the 10-second data collection period. With the exception of the location of the center of pressure, all data were normalized to the baseline condition (presented as percentage baseline) and analyzed as such. For each independent variable, 1-way repeated-measures analysis of variance was conducted for each knee angle to determine differences between the

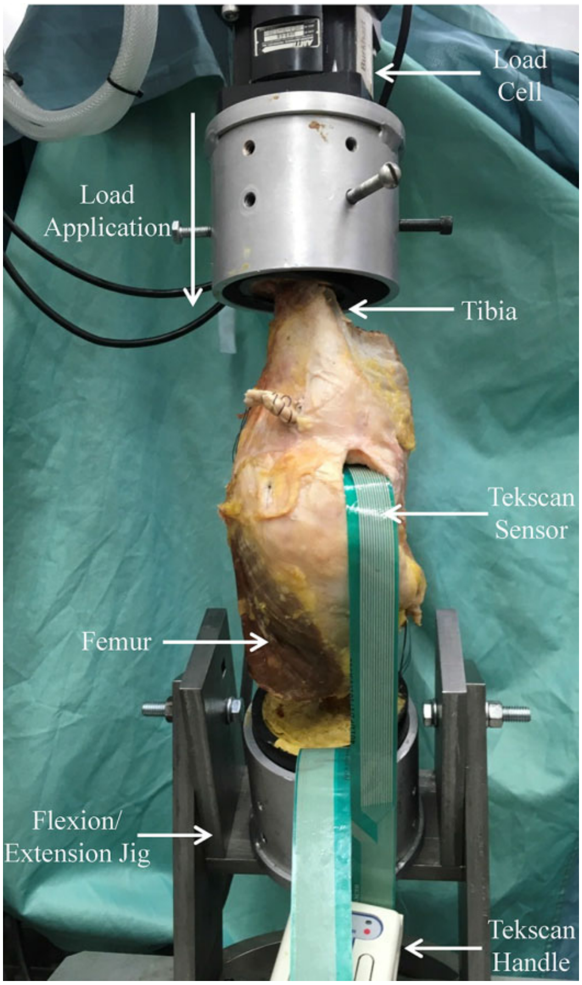

Figure 2. Experimental setup showing the specimen rigidly secured within the Instron materials testing machine. The knee is in 30° of flexion.

conditions. For the location of the center of pressure, the medial-lateral (x-coordinate) and anterior-posterior (y-coordinate) coordinates were analyzed independently. The coordinates for the location of the center of pressure are presented in the sensor frame of reference, where the origin is located in the top left corner. Therefore, larger x-axis values represent translation medially, and smaller y-axis coordinates are located more posteriorly; the coordinates of 6.5 mm and 10.5 mm represent the center of the sensor/joint. Post hoc power and the eta-squared effect size (ES) were calculated, and the ES was interpreted according to Sullivan and Feinn.[32] All statistical analyses were performed using SPSS software (version 23; IBM), post hoc analysis was conducted with a Bonferroni adjustment, and alpha was set at 0.05.

RESULTS

Mean Contact Pressure

At all flexion angles, across all conditions, the mean contact pressure did not significantly increase from the baseline condition (Figure 3). The only significant differences between groups appeared at 0° (power = 0.92; ES = 0.37) and 30° of flexion (power = 0.83; ES = 0.31). At 0°, there was a statistically significant reduction in contact pressure after subtotal meniscectomy (ACLR/LET/Total) and LETR (ACLR/Total/LETR) to 69.72% ± 19.27% (P = .04) and 65.81% ± 13.40% (P = .003) compared with baseline, respectively. At 30°, a statistically significant reduction in the mean contact pressure was observed with the addition of LET to ACLR (61.20% ± 23.08%) compared to the baseline condition (P = .031). Otherwise, at both 60° and 90° of flexion, there were no statistically significant differences in the mean contact pressure between groups (Figure 3).

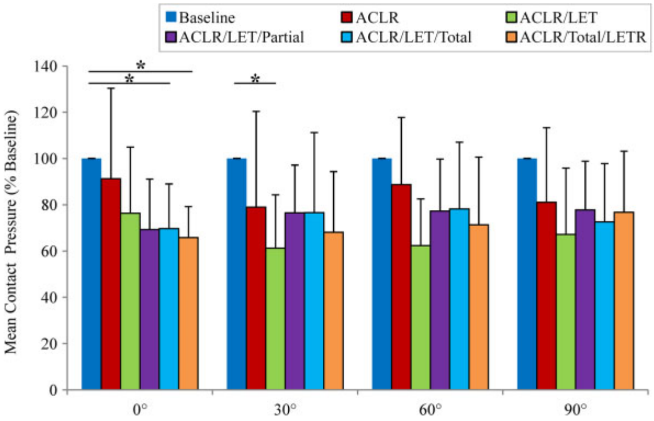

Figure 3. Comparison of the mean contact pressure between the 6 different tissue states across the different knee flexion angles (*$P < .05$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis; LETR, lateral extra-articular tenodesis release; Partial, partial meniscectomy; Total, subtotal meniscectomy.

Peak Pressure

Similar to the mean contact pressures, there was no significant increase in peak pressure after LET, with and without lateral meniscectomy, when compared with the baseline condition. At 0° of knee flexion, there was a significant reduction in peak pressure in the ACLR/Total/LETR group (68.44% ± 19.60%) (P = .04; power = 0.91; ES = 0.36) compared with the baseline condition (Figure 4). There were no significant differences in peak pressure between groups at 30°, 60°, or 90° of knee flexion (Figure 4).

Location of Center of Pressure

At 0° of knee flexion (power = 1.00; ES = 0.63), partial meniscectomy (P = .012), subtotal meniscectomy (P = .021), and LETR (P = .007) all significantly altered the location of the center of pressure, such that it translated anteriorly by 3.84 mm, 3.44 mm, and 4.22 mm, respectively. In addition, the mean center of pressure after subtotal meniscectomy (8.34 ± 1.64 mm) was positioned significantly more anterior when compared with the ACLR condition (11.06 ± 1.54 mm) (P = .008) (Figure 5A and Table 1).

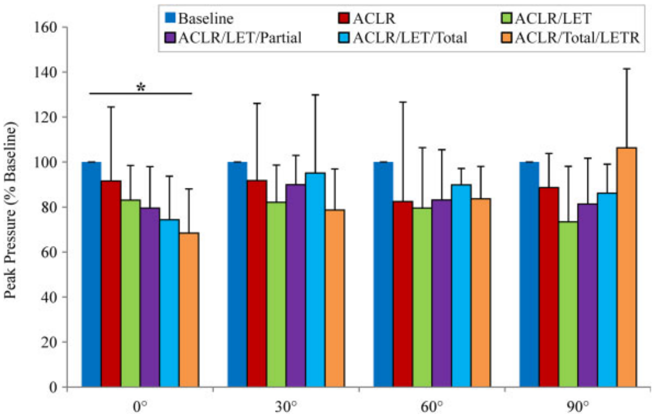

Figure 4. Comparison of the mean peak pressure between the 6 different tissue states across the different knee flexion angles (*$P < .05$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis; LETR, lateral extra-articular tenodesis release; Partial, partial meniscectomy; Total, subtotal meniscectomy.

When the knee was flexed to 30°, there was significant anterior translation of the center of pressure (power = 0.99; ES = 0.64), from 12.21 ± 2.52 mm at baseline to 7.52 ± 2.22 mm and 6.94 ± 1.24 mm after partial meniscectomy ($P = .047$) and LETR ($P = .02$), respectively. Furthermore, LETR resulted in the center of pressure being positioned significantly more anterior when compared with the ACLR/LET condition (6.94 ± 1.24 mm vs 10.11 ± 1.47 mm, respectively; $P = .017$) (Figure 5B and Table 1).

At 60°, both the ACLR/LET and ACLR/Total/LETR conditions produced a center of pressure that was located significantly more anterior (power = 1.00; ES = 0.64) compared with the baseline condition, by approximately 2.27 mm ($P = .032$) and 5.41 mm ($P = .031$), respectively. The center of pressure was not significantly affected in the medial-lateral direction (Figure 5C and Table 1).

At 90°, there was a significant main effect of condition on anterior-posterior translation, which would suggest a trend of anteriorization ($P = .005$; power = 0.913; ES = 0.584), with the partial meniscectomy, subtotal meniscectomy, and LETR conditions (Figure 5D and Table 1); however, the post hoc test did not identify any statistically significant pairwise comparisons.

DISCUSSION

The most important finding of this study was that under axial loading conditions, the addition of LET after ACLR did not significantly increase contact pressures in the lateral compartment. There was a trend of increasing pressure after the inclusion of meniscal lesions, although these were not statistically significant and did not rise above the baseline condition. LET also did not appear to overconstrain or “capture” the knee, as there was no significant anteriorization of the center of pressure after the addition of LET. Finally, a progressive lateral meniscal injury appeared to alter the location of the center of pressure with axial loading, resulting in an anterior shift in the center of pressure.

Prior studies have also evaluated the impact of LET on tibiofemoral contact pressures and joint kinematics in an attempt to quell fears of overconstraint and the theoretical risk of lateral compartment OA. Inderhaug et al[15] evaluated tibiofemoral contact pressures after MacIntosh tenodesis at 2 different tensioning loads (20 N and 80 N). They reported decreased lateral compartment contact pressures, with the subsequent restoration of normal contact pressures after lateral tenodesis tensioned at 20 N. MacIntosh tenodesis at 80 N of graft tension produced overconstraint of internal tibial rotation. They also identified relative external rotation of the tibia with 80 N of LET graft tensioning, yielding a more anterior contact point on the tibia. Geeslin et al[10] evaluated the kinematic effects of combined ACLR and LET while also assessing the impact of graft fixation angle. One of the more interesting findings of their study was that LET produced less overconstraint when secured at 70° of flexion, rather than 30° of flexion, suggesting that graft fixation may be safer at this angle. This is in slight contrast to another study by Inderhaug et al[16] evaluating the impact of LET graft fixation on knee kinematics, suggesting that normal joint kinematics are restored when fixation occurs between 0° and 60°.

The contact pressure results presented in the current investigation were comparable with the data reported by Inderhaug et al,[16] with no significant increase in lateral compartment pressure after LET tensioned at 20 N. This is likely because of the similarities in LET with the graft secured at 70° of flexion, as suggested by Geeslin et al.[10] However, in contrast to Inderhaug et al,[15] we did not notice the tibiofemoral contact point moving to a more (statistically significant) anterior location with relative tibial external rotation, as identified in their study, after the inclusion of LET. This was likely because our graft tension was kept to a maximum of 20 N, avoiding this overconstraint, observed primarily with an 80-N tensioning force.

The results of our study are supported by the long-term outcomes of LET reported by Zaffagnini et al[35] and Devitt et al.[4] Zaffagnini et al[35] reported on the 20-year outcomes after combined hamstring ACLR and LET, noting no association between LET and lateral or patellofemoral compartment OA. Similarly, Devitt et al[4] performed a systematic review evaluating long-term follow-up studies after ACLR and LET, noting no association between LET and lateral compartment OA. Both studies, however, indicated a correlation between meniscectomy and OA but showed a higher rate of medial compartment OA in response to medial meniscal damage compared with lateral compartment OA.

A novel aspect of the current study was the inclusion of a lateral meniscal injury to evaluate the resultant change in contact pressures and pressure point location after isolated ACLR or ACLR with LET. In our experimental testing of an ACL-reconstructed knee, contact pressures increased in the lateral compartment with both partial and subtotal lateral meniscectomy. The pressures in the lateral compartment were unaffected by the addition of LET. There was no significant difference in pressure between the ACLR/Total/

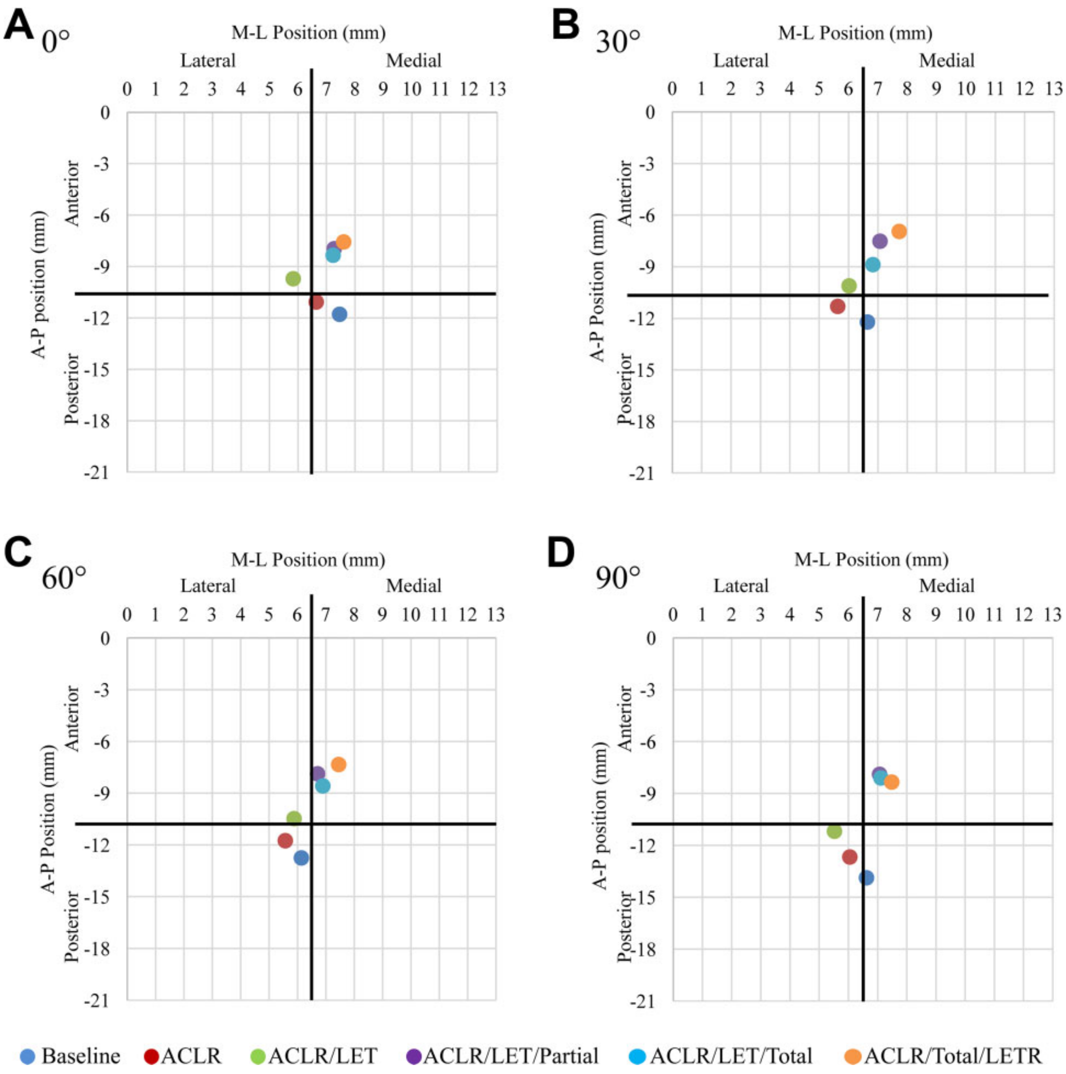

Figure 5. Comparison of the mean anterior-posterior (A-P) (*y*-axis) and medial-lateral (M-L) (*x*-axis) positions of the center of pressure between the 6 different tissue states with the knee in (A) 0°, (B) 30°, (C) 60°, and (D) 90° of flexion. The coordinates are presented in the sensor coordinate system, which positions the origin in the top left corner. The solid black lines represent the center of the sensor/joint. ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis; LETR, lateral extra-articular tenodesis release; Partial, partial meniscectomy; Total, subtotal meniscectomy.

LETR and ACLR/LET/Total conditions. This suggests that combined ACLR plus LET is safe to perform when the graft is secured at 70° of flexion with 20-N tension and will not cause an increase in lateral compartment pressures with concomitant ACL and lateral meniscal deficiency.

Interestingly, it was also noted that the location of the center of pressure changed with a meniscal injury with and without LET. At all flexion angles, the position of the center of pressure shifted anteriorly after the ACLR/LET/Partial, ACLR/LET/Total, and ACLR/Total/LETR conditions, suggesting that the tibia is either translating posteriorly or moving into slight external rotation. If this were true only with LET, then this might cause concern of overconstraint, but the effect was slightly more pronounced without LET. This is in contrast to the findings of previous studies that have identified the lateral meniscal posterior root as a secondary stabilizer in an ACL-deficient knee, limiting anterior translation.[21,24,31] In these studies, resection of the lateral meniscal root led to increased anterior tibial translation, which would create a more posterior contact point on the tibia. One potential explanation for this discrepancy is that most of these studies evaluated joint translation in response to applied anteroposterior loads or simulated pivot-shift maneuvers, while only axial loading was tested here. Additionally, our experimental setup may have introduced some constraint, yielding lower anterior translation in the injury model. As a result, meniscectomy in our study likely accentuated the relative incongruency of the lateral compartment, focusing contact pressures on the anterior horn of the meniscus and anterior portion of the

TABLE 1
Anterior-Posterior and Medial-Lateral Coordinates of the Location of the Center of Pressure Across Conditions for Each Knee Angle[a]

Knee Angle	Baseline	ACLR	ACLR/LET	ACLR/LET/Partial	ACLR/LET/Total	ACLR/Total/LETR
Anterior-posterior						
0°	11.8 ± 1.5	11.1 ± 1.5	9.7 ± 2.2	8.0 ± 1.6[b]	8.3 ± 1.6[b,c]	7.6 ± 1.2[b]
30°	12.2 ± 2.5	11.3 ± 2.7	10.1 ± 1.5	7.5 ± 2.2[b]	8.9 ± 2.0	6.9 ± 1.2[b,d]
60°	12.7 ± 2.7	11.7 ± 2.6	10.4 ± 2.4[b]	7.9 ± 2.4	8.6 ± 1.9	7.3 ± 1.6[b]
90°	13.9 ± 3.7	12.7 ± 3.1	11.2 ± 3.0	7.9 ± 2.9	8.1 ± 2.5	8.4 ± 2.5
Medial-lateral						
0°	7.5 ± 2.2	6.6 ± 2.0	5.8 ± 2.1	7.3 ± 1.5	7.2 ± 1.6	7.6 ± 1.8
30°	6.6 ± 2.1	5.6 ± 2.2	6.0 ± 1.2	7.1 ± 1.4	6.8 ± 1.3	7.7 ± 1.6
60°	6.1 ± 1.8	5.6 ± 2.1	5.9 ± 1.4	6.7 ± 1.4	7.0 ± 1.2	7.4 ± 1.5
90°	6.6 ± 2.2	6.0 ± 2.2	5.5 ± 1.3	7.1 ± 1.5	7.1 ± 1.5	7.5 ± 1.5

[a] Data are shown as mean ± SD in mm. ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis; LETR, lateral extra-articular tenodesis release; Partial, partial meniscectomy; Total, subtotal meniscectomy.

[b] Significantly different compared with baseline ($P < .05$).

[c] Significantly different compared with ACLR ($P < .05$).

[d] Signficantly different compared with ACLR/LET ($P < .05$).

compartment. These results are similar to a previous finite element analysis that simulated posterior horn lateral meniscectomy, noting a significant increase in anterior horn peak contact stress in response to an axial load.[26] Future studies should focus on lateral compartment pressures after ACLR and lateral meniscectomy with a kinematic evaluation, including anterior-posterior translation or pivot-shift testing. However, more importantly, the current study highlights the ability to address high-grade anterolateral rotatory laxity, which may occur as a result of meniscal loss, with LET without the increased concern of elevating lateral compartment contact pressures.

While this study presents several clinically useful results, there are associated limitations. First, we did not test specimens in the intact state before the creation of the injury model. This prevented us from validating our experimental setup, as we are unable to demonstrate the anticipated kinematic changes after ACL and ALL sectioning. However, we were most interested in the ACL-deficient knee as being the most clinically relevant baseline state from which all experimental variables would be compared. Furthermore, the resultant lower number of sectioning states improved our statistical analysis. Second, kinematic testing was not included with either anterior-posterior translation or simulated pivot-shift testing. The intent was not to evaluate the kinematics of LET, as this has previously been assessed in multiple similar cadaveric studies, but rather to focus on the impact of LET with and without lateral meniscectomy on lateral compartment pressures in an ACLR model. In addition, pressure was only measured in the lateral compartment, and therefore, it is unclear how the medial compartment was responding to the different conditions tested, especially given the relatively constrained loading setup that was used here.

Although care was taken to maintain the acquired position of the knee after each experimental condition, our setup did not allow for accommodating translation or rotation. While this experimental setup was designed to simulate a closed chain loading protocol, different from the open chain loading previously used, it is possible that constraining motion along these axes could have affected the measured compartment pressures, and these results should be interpreted with that in mind. Future work from our laboratory is aimed at measuring compartment pressures within a novel joint motion simulator that does allow for manipulation of additional translation and rotation. Last, the results are prone to the inherent limitations of cadaveric studies, with time-zero kinematics in elderly specimens that may limit clinical applicability.

CONCLUSION

The findings of this study demonstrated that under axial loads, LET does not appear to increase lateral compartment contact pressures or produce relative external tibial rotation (ie, overconstraint) when performed in conjunction with ACLR in the setting of an intact or posterior horn–deficient lateral meniscus. This would suggest that in combination with previously published clinical studies and systematic reviews, it is safe to perform LET in conjunction with ACLR with graft fixation at 70° of flexion and 20-N tension without altering lateral compartment pressures.

REFERENCES

1. Anderson AF, Snyder RB, Lipscomb AB. Anterior cruciate ligament reconstruction: a prospective randomized study of three surgical methods. *Am J Sports Med*. 2001;29(3):272-279.
2. Ayeni OR, Chahal M, Tran MN, Sprague S. Pivot shift as an outcome measure for ACL reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(4):767-777.
3. Burkhart TA, Mathew M, McGuffin S, Blokker A, Holdsworth DW, Getgood A. There are no kinematic differences between intrameniscal and suprameniscal anterolateral ligament injury in the anterior cruciate ligament-deficient knee. *Am J Sports Med*. 2018;46(14): 3391-3399.

4. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA. Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(4):1149-1160.
5. Draganich LF, Reider B, Ling M, Samuelson M. An in vitro study of an intraarticular and extraarticular reconstruction in the anterior cruciate ligament deficient knee. *Am J Sports Med*. 1990;18(3):262-266.
6. Draganich LF, Reider B, Miller PR. An in vitro study of the Müller anterolateral femorotibial ligament tenodesis in the anterior cruciate ligament deficient knee. *Am J Sports Med*. 1989;17(3):357-362.
7. Engebretsen L, Lew WD, Lewis JL, Hunter RE. The effect of an iliotibial tenodesis on intraarticular graft forces and knee joint motion. *Am J Sports Med*. 1990;18(2):169-176.
8. Engebretsen L, Lew WD, Lewis JL, Hunter RE, Benum P. Anterolateral rotatory instability of the knee: cadaver study of extraarticular patellar-tendon transposition. *Acta Orthop Scand*. 1990;61(3):225-230.
9. Ferretti A. Extra-articular reconstruction in the anterior cruciate ligament deficient knee: a commentary. *Joints*. 2014;2(1):41-47.
10. Geeslin AG, Moatshe G, Chahla J, et al. Anterolateral knee extra-articular stabilizers: a robotic study comparing anterolateral ligament reconstruction and modified Lemaire lateral extra-articular tenodesis. *Am J Sports Med*. 2018;46(3):607-616.
11. Georgoulis AD, Ristanis S, Chouliaras V, Moraiti C, Stergiou N. Tibial rotation is not restored after ACL reconstruction with a hamstring graft. *Clin Orthop Relat Res*. 2007;454:89-94.
12. Getgood A, Brown C, Lording T, et al. The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(1):166-176.
13. Guenther D, Irarrázaval S, Bell KM, et al. The role of extra-articular tenodesis in combined ACL and anterolateral capsular injury. *J Bone Joint Surg Am*. 2017;99(19):1654-1660.
14. Hewison CE, Tran MN, Kaniki N, Remtulla A, Bryant D, Getgood AM. Lateral extra-articular tenodesis reduces rotational laxity when combined with anterior cruciate ligament reconstruction: a systematic review of the literature. *Arthroscopy*. 2015;31(10):2022-2034.
15. Inderhaug E, Stephen JM, El-Daou H, Williams A, Amis AA. The effects of anterolateral tenodesis on tibiofemoral contact pressures and kinematics. *Am J Sports Med*. 2017;45(13):3081-3088.
16. Inderhaug E, Stephen JM, Williams A, Amis AA. Anterolateral tenodesis or anterolateral ligament complex reconstruction: effect of flexion angle at graft fixation when combined with ACL reconstruction. *Am J Sports Med*. 2017;45(13):3089-3097.
17. Inderhaug E, Stephen JM, Williams A, Amis AA. Biomechanical comparison of anterolateral procedures combined with anterior cruciate ligament reconstruction. *Am J Sports Med*. 2017;45(2):347-354.
18. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. Relationships between objective assessment of ligament stability and subjective assessment of symptoms and function after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2004;32(3):629-634.
19. Lee MC, Seong SC, Lee S, et al. Vertical femoral tunnel placement results in rotational knee laxity after anterior cruciate ligament reconstruction. *Arthroscopy*. 2007;23(7):771-778.
20. Lie DTT, Bull AMJ, Amis AA. Persistence of the mini pivot shift after anatomically placed anterior cruciate ligament reconstruction. *Clin Orthop Relat Res*. 2007;457:203-209.
21. Lording T, Corbo G, Bryant D, Burkhart TA, Getgood A. Rotational laxity control by the anterolateral ligament and the lateral meniscus is dependent on knee flexion angle: a cadaveric biomechanical study. *Clin Orthop Relat Res*. 2017;475(10):2401-2408.
22. Matsumoto H, Seedhom BB. Treatment of the pivot-shift intraarticular versus extraarticular or combined reconstruction procedures: a biomechanical study. *Clin Orthop Relat Res*. 1994;299:298-304.
23. Musahl V, Getgood A, Neyret P, et al. Contributions of the anterolateral complex and the anterolateral ligament to rotatory knee stability in the setting of ACL injury: a roundtable discussion. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(4):997-1008.
24. Musahl V, Rahnemai-Azar AA, Costello J, et al. The influence of meniscal and anterolateral capsular injury on knee laxity in patients with anterior cruciate ligament injuries. *Am J Sports Med*. 2016; 44(12):3126-3131.
25. O'Brien SJ, Warren RF, Wickiewicz TL, et al. The iliotibial band lateral sling procedure and its effect on the results of anterior cruciate ligament reconstruction. *Am J Sports Med*. 1991;19(1):21-24.
26. Peña E, Calvo B, Martinez MA, Palanca D, Doblaré M. Why lateral meniscectomy is more dangerous than medial meniscectomy: a finite element study. *J Orthop Res*. 2006;24(5):1001-1010.
27. Rezende FC, de Moraes VY, Martimbianco ALC, Luzo MV, da Silveira Franciozi CE, Belloti JC. Does combined intra- and extraarticular ACL reconstruction improve function and stability? A meta-analysis. *Clin Orthop Relat Res*. 2015;473(8):2609-2618.
28. Ristanis S, Giakas G, Papageorgiou CD, Moraiti T, Stergiou N, Georgoulis AD. The effects of anterior cruciate ligament reconstruction on tibial rotation during pivoting after descending stairs. *Knee Surg Sports Traumatol Arthrosc*. 2003;11(6):360-365.
29. Samuelson M, Draganich LF, Zhou X, Krumins P, Reider B. The effects of knee reconstruction on combined anterior cruciate ligament and anterolateral capsular deficiencies. *Am J Sports Med*. 1996;24(4): 492-497.
30. Sanchez-Adams J, Leddy HA, McNulty AL, O'Conor CJ, Guilak F. The mechanobiology of articular cartilage: bearing the burden of osteoarthritis. *Curr Rheumatol Rep*. 2014;16(10):451.
31. Shybut TB, Vega CE, Haddad J, et al. Effect of lateral meniscal root tear on the stability of the anterior cruciate ligament-deficient knee. *Am J Sports Med*. 2015;43(4):905-911.
32. Sullivan GM, Feinn R. Using effect size: or why the *P* value is not enough. *J Grad Med Educ*. 2012;4(3):279-282.
33. Tashman S, Collon D, Anderson K, Kolowich P, Anderst W. Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2004;32(4):975-983.
34. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med*. 2016;44(11):2827-2832.
35. Zaffagnini S, Marcheggiani Muccioli GM, Grassi A, et al. Over-the-top ACL reconstruction plus extra-articular lateral tenodesis with hamstring tendon grafts: prospective evaluation with 20-year minimum follow-up. *Am J Sports Med*. 2017;45(14):3233-3242.