# The Effect of Lateral Extra-articular Tenodesis in an ACL-Reconstructed Knee With Partial Medial Meniscectomy

## A Biomechanical Study

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**Background:** Knee laxity increases with medial meniscectomy in anterior cruciate ligament (ACL)–reconstructed knees; however, the biomechanical effect of an additional lateral extra-articular tenodesis (LET) is unknown.

**Purpose/Hypothesis:** The purpose of this study was to determine the kinematic effect of a LET in knees that underwent combined ACL reconstruction (ACL-R) and partial medial meniscus posterior horn (MMPH) meniscectomy. It was hypothesized that the addition of LET would reduce laxity in the ACL-reconstructed knee.

**Study Design:** Controlled laboratory study.

**Methods:** Ten fresh-frozen human cadaveric knees (mean age, 41.5 years) were tested using a robotic system under 3 loads: (1) 89.0 N of anterior tibial (AT) load, (2) 5 N·m of internal rotation (IR) tibial torque, and (3) a simulated pivot shift—a combined valgus of 7 N·m and IR torque of 5 N·m—at 0°, 15°, 30°, 45°, 60°, and 90° of knee flexion. Kinematic data were acquired in 4 states: (1) intact, (2) ACL-R, (3) ACL-R + partial MMPH meniscectomy (MMPH), and (4) ACL-R + partial MMPH meniscectomy + LET (MMPH + LET).

**Results:** In response to AT loading, there was a significant increase seen in AT translation (ATT) in the MMPH state at all knee flexion angles compared with the ACL-R state, with the highest increase at 90° of knee flexion (mean difference, 3.1 mm) ($P < .001$). Although there was a significant decrease in ATT at 15° of knee flexion with MMPH + LET ($P = .022$), no significant differences were found at other knee flexion angles ($P > .05$). In MMPH with IR torque, a significant increase was observed in IR at all knee flexion angles except 90° compared with the ACL-R state (range, 2.8°-4.9°), and this increase was significantly decreased at all flexion angles with the addition of LET (range, 0.7°-1.6°) ($P < .05$).

**Conclusion:** Performing a partial MMPH meniscectomy increased ATT and IR in response to AT and IR loads compared with the isolated ACL-R state in a cadaveric model. However, when the LET procedure was performed after partial MMPH meniscectomy, a significant decrease was seen at all knee flexion angles except 90° in response to IR and torque, and a significant decrease was seen at 15° of knee flexion in response to AT load.

**Clinical Relevance:** LET may be a useful adjunct procedure after ACL-R with partial MMPH meniscectomy to reduce knee laxity.

**Keywords:** ACL-R; meniscectomy; lateral extra-articular tenodesis; LET; biomechanical analysis; BTB

Meniscal pathology is detected in almost half of the patients who undergo anterior cruciate ligament (ACL) reconstruction (ACL-R), and this rate increases if surgery is delayed for >6 months.[6,22] Although meniscal preservation is the goal for surgical treatment of the meniscus, meniscectomy is still used for irreparable meniscal tears accompanying ACL injury and in revision surgeries of nonhealing meniscal repairs.[4,12,18,33]

The menisci play a major role in providing load transfer and knee stability.[19,26,12,37,42] The medial meniscus is a secondary stabilizer of anteroposterior laxity of the tibia.[16,26] It has been reported that the medial meniscus is a restraint to anteroposterior translation, especially near 90° of knee flexion.[12] Longitudinal tears located in the medial

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meniscus posterior horn (MMPH), one of the most common meniscal tear patterns accompanying ACL injuries, increase anterior tibial (AT) translation (ATT).[1,20] An increase in ATT has been reported after meniscectomy involving ≥46% of the MMPH.[3] Furthermore, it has been reported that ACL strain and ATT increase with total medial meniscectomy.[34] This finding serves as one of the more common indications for meniscal allograft transplantation, as ACL strain reduction and anteroposterior stability can occur after meniscal transplantation.[34] While an increase in internal rotatory instability was reported after MMPH meniscectomy,[8] no significant effect of medial meniscectomy on AT displacement was shown in the ACL-deficient knee during pivot-shift examination in another biomechanical study.[26]

Lateral extra-articular tenodesis (LET) is recommended as an adjunct procedure to ACL-R in patients with high-grade pivot shift.[15] While anterolateral complex injury accompanying ACL injury can increase rotatory instability, a LET has been shown to reduce residual laxity after ACL-R.[14,23] Additionally biomechanical studies have shown that the combination of anterolateral complex injury and MMPH meniscectomy increases AT laxity,[2] whereas the combination of ACL-R and LET reduces AT laxity.[9] Further, a recent biomechanical study reported that while there was no significant increase in ATT at 30° of knee flexion during AT loading, a significant decrease was reported at 90° of knee flexion after adding a LET to ACL-R when compared with isolated ACL-reconstructed knees.[24] Finally, it has been shown that adding lateral extra-articular augmentation to single-bundle ACL-R performed with over-the-top technique reduces AT laxity, which increases due to MMPH meniscectomy being performed during ACL-R surgery.[12] However, the biomechanical effect of a LET on an anatomic ACL-R with partial medial meniscectomy is unknown.

The purpose of this study was to determine the kinematic effect of a LET in knees that underwent combined ACL-R and partial medial meniscectomy. We hypothesized that the LET would reduce ATT and internal knee rotation caused by MMPH meniscectomy in the ACL-R setting.

## METHODS

Institutional approval was obtained from the University of Pittsburgh, and the cadaveric knee specimens were procured from our institution-approved tissue suppliers. Ten fresh-frozen human cadaveric knee specimens were tested (1 female and 9 male; mean age, 41.5 years). The knees were kept frozen at −20°C and thawed at room temperature for ≥24 hours before testing. All soft tissues 15 cm proximal and distal to the knee joint were removed, and the femur and tibia were potted in cylindrical molds with an epoxy compound for fixation in custom clamps for robotic testing. An intra-articular evaluation of the menisci, cartilage, and cruciate ligaments was performed arthroscopically to rule out any preexisting knee joint injuries. Varus and valgus stress tests were also performed to rule out collateral ligament injuries. Each knee was tested at 4 different states in the following order: (1) intact knee, (2) ACL-R with bone–patellar tendon–bone graft (ACL-R), (3) ACL-R with partial MMPH meniscectomy (MMPH), and (4) ACL-R + partial MMPH meniscectomy + LET (MMPH + LET).

### Robotic Testing

All knee specimens were tested using a robotic testing system (CASPAR Stäubli RX90; Orto Maquet), with a robotic arm that has ±0.02 mm of motion repeatability at each joint and an end effector that has a universal force-moment sensor (Model 4015; JR3) with a force and moment accuracy of ±0.2 N and ±0.1 N·m, respectively, per the manufacturer.[10,27,43] The tibia and femur of each specimen were placed in custom cylinder fixtures, with the tibia connected to the robotic end effector cylinder and the femoral fixture secured to a fixed base. A Cartesian coordinate system, with defined axes in the anteroposterior, mediolateral, and proximodistal directions of the tibia, was used as described by Fujie et al[13] and Grassi et al.[16] Also used was a tibial coordinate system centered with 1 axis directed along the long axis of the tibia, the medial axis between the medial and lateral tibial plateau prominences, and the anterior axis perpendicular to these 2 axes. Tibial translations were measured midpoint between the medial and lateral tibial prominences.[17] Data acquisition was performed using a custom software with a multitask operating system (MATLAB; MathWorks) to perform the controlled translations and rotations and measure the force/moments in all 6 degrees of freedom. The robotic system determined the passive path of the cadaveric knee by minimizing forces (<0.5 N) and moments (<0.25 N·m) in all remaining degrees of freedom and throughout the flexion range from full extension to 90° in increments of 0.5°.[39,40]

All specimens were tested under the following loading conditions: (1) an 89.0-N AT load (simulated Lachman test) to assess ATT,[11,21] (2) a 5-N·m internal rotation (IR)

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tibial torque, and (3) a combined valgus of 7 N·m and IR tibial torque (simulated pivot-shift test) of 5 N·m.[29] ATT and IR were measured at full extension and 0°, 15°, 30°, 45°, 60°, and 90° of knee flexion. The simulated pivot-shift loads were applied at 0°, 15°, and 30° of knee flexion. Kinematic data obtained from the different knee conditions were compared.

## Surgical Procedures

The standard arthroscopic anterolateral and anteromedial portals of the knee were created, and diagnostic arthroscopy was performed to evaluate the cartilage, medial and lateral menisci, and ACL. After ensuring that all intra-articular structures were intact, an ACL resection and anatomic single-bundle ACL-R were performed arthroscopically.[10,27,30,43] The ACL was transected using a punch and motorized shaver. The femoral tunnel was drilled in the center of the ACL footprint using a 10-mm cannulated femoral drill (Acufex; Smith & Nephew Inc) via the transportal technique. A tibial tunnel sized to 10 mm was drilled in the center of the tibial ACL insertion sites through the anteromedial portal using a tibial aiming guide (Acufex; Smith & Nephew Inc) set to 55°. A 10 mm–diameter bone–patellar tendon–bone autograft was then harvested from each cadaveric specimen.[30] The autograft was fixed using 9 × 20–mm bioabsorbable screws (Biosure; Smith & Nephew Inc) on the femur and tibia. Tibial fixation was performed at 20° of knee flexion and tensioned at 80 N using a ligament tension meter (Meira Corp).[7,10,28]

To provide standardization for the meniscectomy, 2 classification systems were used for the medial meniscus.[20,32] The MMPH was defined as the region from the posterior border of the superficial medial collateral ligament to the medial meniscus posterior root.[32] The Cooper system further divides each meniscus into thirds

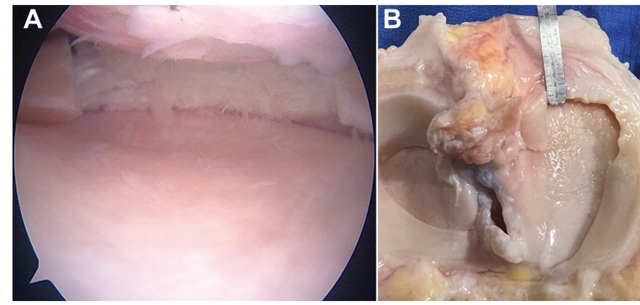


**Figure 1.** (A) Arthroscopic view of the medial meniscus after a medial meniscus posterior horn (MMPH) partial meniscectomy using a 30° arthroscope placed in the anterolateral knee portal of the right knee. (B) Superior view of the right proximal tibial articular surface and menisci after an MMPH partial meniscectomy. The ruler shows that 2 mm of the meniscus remained after the MMPH partial meniscectomy.

circumferentially.[20] After arthroscopic identification of the MMPH, Cooper zones 2 and 3 were resected for a partial meniscectomy, which equates to ≥66% of the original meniscal width.[3,32] During the meniscectomy, the meniscocapsular junction was not approached closer than 2 mm to ensure that the meniscotibial ligaments remained intact[32] and the posterior root of the medial meniscus was preserved. A 2.7-mm biter (Acufex; Smith & Nephew Inc) and 4.5-mm motorized shaver (Dyonics; Smith & Nephew Inc) were used to complete the meniscectomy. The linear width along the MMPH was measured and recorded at 1-cm intervals using an arthroscopic ruler (Acufex; Smith & Nephew Inc) (Figure 1).

The LET procedure was performed with the modified Lemaire technique previously described in the literature.[35] An oblique 5-cm lateral skin incision was created just behind the lateral epicondyle through the Gerdy tubercule.

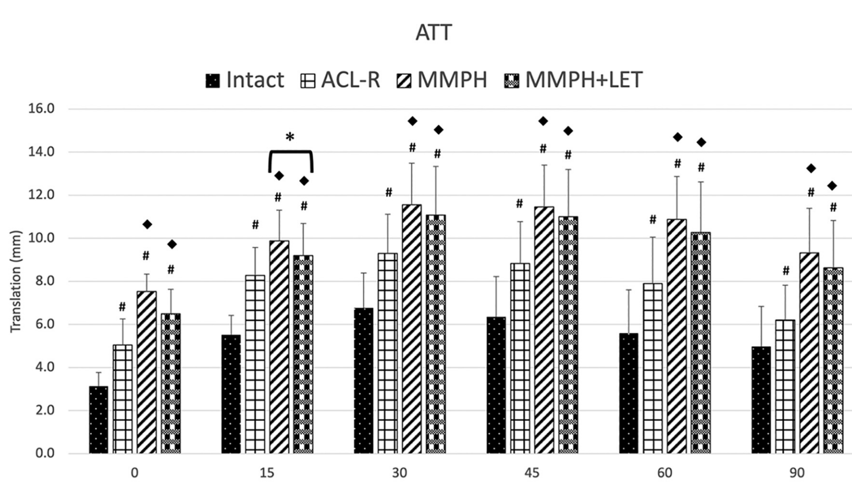


**Figure 2.** Anterior tibial translation (ATT; mm) under 89 N of anterior tibial loading at different flexion angles. #$P < .05$ versus intact; ♦$P < .05$ versus anterior cruciate ligament reconstruction (ACL-R); *$P < .05$ between medial meniscus posterior horn (MMPH) and MMPH + lateral extra-articular tenodesis (LET) groups.

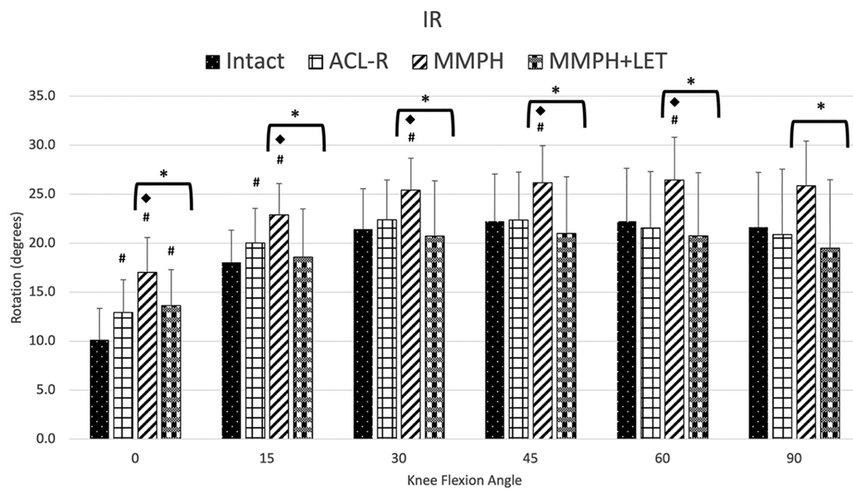


**Figure 3.** Internal rotation (IR; degrees) under 5 N·m of IR tibial torque at different flexion angles. #$P < .05$ versus intact; ♦$P < .05$ versus anterior cruciate ligament reconstruction (ACL-R); *$P < .05$ between medial meniscus posterior horn (MMPH) and MMPH + lateral extra-articular tenodesis (LET) groups.

An iliotibial band autograft (1 cm wide × 8 cm long) was harvested 1 cm anterior to the posterior border of the iliotibial band. The distal end was left attached to the Gerdy tubercle. The iliotibial band graft was sutured to be tubularized at a length of 2 cm with a No. 2 nonabsorbable suture (Ultrabraid; Smith & Nephew Inc) from its proximal end. The iliotibial band graft was then passed deep to the lateral collateral ligament. The femoral attachment site was positioned 5 mm posterior to the lateral epicondyle.[41] The femoral tunnel of the LET was drilled using a 6-mm cannulated femoral reamer aimed 20° proximal and 20° anterior.[14] Taking the specimen out of the robot but retaining the potting fixtures, the LET graft was tensioned 20 N using a ligament tension meter (Meira Corp) and fixed at neutral rotation and 70° of knee flexion via a bioabsorbable screw (7 × 25 mm).[41]

## Statistical Analysis

The intact state was used to measure the normality and sphericity of the data. All data were reported as mean ± SD. One-way repeated-measures analyses of variance were performed at each knee flexion angle to compare the differences in ATT, IR, and simulated pivot shift between the intact, ACL-R, MMPH, and MMPH + LET states. To account for multiple comparisons, a Bonferroni correction was applied within the software program (SPSS Version 26.0; IBM Corp). Then 95% CIs were obtained and the significance of pairwise comparisons was set at $P < .05$.

## RESULTS

The performance of an MMPH partial meniscectomy in ACL-reconstructed knees showed significant increases in ATT (89 N of AT loading) at all angles of knee flexion ($P < .001$). Although a significant decrease in ATT (89 N of AT loading) was found after the addition of LET at 15° ($P = .022$) of knee flexion, no significant decreases were found at any other angle of knee flexion compared with the MMPH state ($P > .05$) (Figure 2).

After MMPH partial meniscectomy in ACL-reconstructed knees, a significant increase in IR (5 N·m of IR tibial torque) was found at 0° ($P < .001$), 15° ($P = .005$), 30° ($P = .006$), 45° ($P = .007$), and 60° ($P = .046$) of knee flexion. However, no significant difference in IR (5 N·m of IR tibial torque) was found between the ACL-R and MMPH states at 90° of knee flexion ($P > .05$). Significant decreases in IR (5 N·m of IR tibial torque) were found after the addition of a LET at 0° ($P = .002$), 15° ($P = .022$), 30° ($P = .045$), 45° ($P = .045$), 60° ($P = .043$), and 90° ($P = .025$) of knee flexion compared with MMPH state. Further, there were no significant differences in IR (5 N·m of IR tibial torque) at any angle of knee flexion between the ACL-R and MMPH + LET states ($P > .05$) (Figure 3).

In response to the pivot-shift simulation (7 N·m of valgus, moment, and 5 N·m of IR torque), no significant differences were found between the ACL-R states and MMPH + LET states in tibial displacement at any angle of knee flexion ($P > .05$). However, with the addition of a LET to the MMPH state, a significant 1.4 ± 0.3–mm decrease was detected between the MMPH and MMPH + LET states in response to the pivot-shift simulation (7 N·m of valgus, moment, and 5 N·m of IR torque) at full knee extension ($P = .008$) (Figure 4).

## DISCUSSION

The most important finding of this study was that MMPH partial meniscectomy performed after ACL-R increased IR (5 N·m of IR tibial torque) at all knee flexion angles except

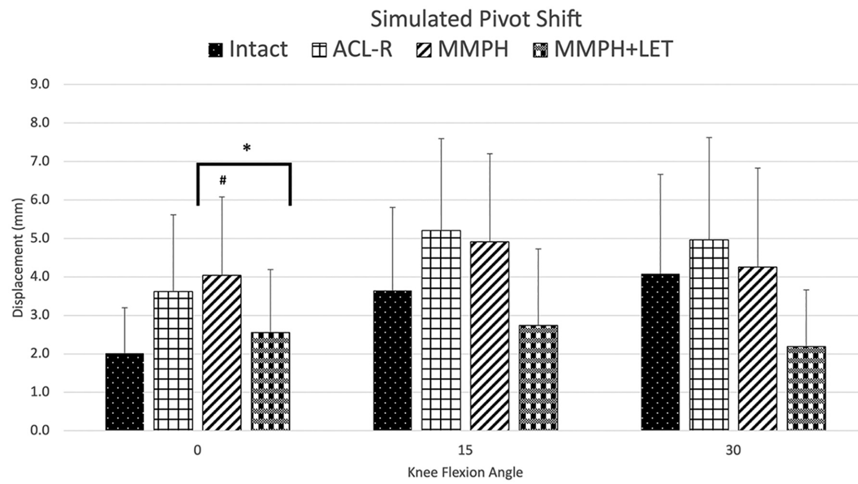


**Figure 4.** Anterior tibial displacement (mm) under a combined valgus of 7 N·m, moment, and internal rotation torque (simulated pivot shift) loading of 5 N·m at different knee flexion angles. #$P < .05$ versus intact; *$P < .05$ between medial meniscus posterior horn (MMPH) and MMPH + lateral extra-articular tenodesis (LET) groups. ACL-R, anterior cruciate ligament reconstruction.

90° of knee flexion compared with the ACL-R and intact states, and that LET had a significant effect on decreasing the IR laxity. The second most important finding of this study was that the LET did not reduce ATT induced by MMPH partial meniscectomy under 89 N of anterior loading.

In a study performed on cadavers with intact ACLs, MMPH meniscectomy involving ≥46% of the meniscus resulted in a decrease in the rotational stability of the knee.[3] Also, increases in IR at 30° and 60° of knee flexion were reported after MMPH meniscectomy in knees with an intact ACL, while increases in IR at 0° and 30° of knee flexion were reported after medial meniscectomy in knees that had undergone ACL-R.[8,31] In addition, it has been reported that the anterolateral complex has a role in providing internal rotatory stability of the knee similar to the medial meniscus.[2,23] In a recent biomechanical study, an increase in knee IR stability was observed after modified Lemaire LET surgery.[42] In our study, which is in line with current literature,[42] an increase in IR (5 N·m of IR tibial torque) was observed at all knee flexion angles except 90° after MMPH partial meniscectomy, while a significant decrease was found in IR (5 N·m of IR tibial torque) after the addition of a LET.

Another finding of this study was that MMPH partial meniscectomy performed after ACL-R increased ATT (89 N of AT loading) at all knee flexion angles when compared with the ACL-R and intact states. It has been reported that longitudinal tears located in the MMPH increase anterior knee laxity equally with total meniscectomy.[1] In an in vivo study, no significant difference in ATT was found between patients who underwent medial meniscal repair + ACL-R and those who underwent isolated ACL-R; however, an increase in ATT was reported in patients who underwent meniscectomy + ACL-R.[38] Total medial meniscectomy has been shown to increase ATT and ACL strain at all knee flexion angles, and it has been reported that meniscectomy involving ≥46% of the MMPH also increases ATT.[3,26,34] In vivo studies have reported that ATT increased at 30° of knee flexion, but no statically significant increase was seen at 90° of knee flexion after medial meniscectomy in ACL-R patients.[12,16] A biomechanical study reported that performing subtotal meniscectomy after ACL-R increased ATT at full knee extension and 30° of knee flexion compared with the isolated ACL-R state.[31] In another recent biomechanical study, it was reported that ATT increased at 30°, 60°, and 90° of knee flexion after the implementation of MMPH meniscectomy.[2] In this study, similar to the literature, an increase in ATT (89 N of AT loading) was seen after MMPH partial meniscectomy at all knee flexion angles in the ACL-reconstructed knee.

Contrary to our hypothesis, the addition of the LET did not reduce the knee anterior laxity induced by MMPH partial meniscectomy other than at 15° of knee flexion. In a biomechanical study, the addition of LET to ACL-R resulted in a decrease in ACL graft force and ATT at 90° of knee flexion when compared with the isolated ACL-R state, while no significant difference was found at 30° of knee flexion.[24] In vivo studies have reported that ATT decreases with the addition of lateral extra-articular augmentation procedures to ACL-R surgery.[5,9,16,25] Di Paolo et al[12] reported an increase in ATT at 90° of knee flexion after ACL-R with medial meniscectomy, which was significantly decreased with the addition of lateral extra-articular augmentation. In our study, a slight decrease in ATT was only detected at 15° of knee flexion after LET was added to ACL-R + MMPH knee. This was contrary to the hypothesis that LET would have a significant effect on knee anterior laxity induced by MMPH partial meniscectomy.

It has been reported that the contribution of the lateral meniscus to rotational stability during pivot-shift loading is greater than that of the medial meniscus.[26] Although it was shown that no increase in knee instability was observed during pivot-shift loading after total medial meniscectomy in knees with ACL deficiency, another study reported that lateral meniscectomy increased knee instability.[1,23] In a biomechanical study reporting that the anterolateral complex plays an important role in rotational stability, like the lateral meniscus, it was reported that the lateral meniscus plays an important role especially during full extension and early knee flexion.[23] In our study, with the addition of MMPH partial meniscectomy, an increase in anterior translation at full knee extension was observed during pivot-shift simulation (7 N·m of valgus moment and 5 N·m of IR torque) loading, which was reduced with the addition of the LET.

This study has several limitations. This is a time-zero study and is not able to account for the effects of healing. The majority of specimens were male (90%), which may limit generalizability. Also, in this study, the LET was only performed using the modified Lemaire technique. Therefore, these results may not be generalizable for anterolateral ligament reconstruction and other lateral extra-articular procedures. Finally, bioabsorbable screw fixation was used for LET in our study, and these results may not be generalizable for other fixation methods such as staple and suture anchor.[42]

## CONCLUSION

This cadaveric study found that an MMPH partial meniscectomy performed after ACL-R increased ATT at all knee flexion angles and IR at 0°, 15°, 30°, 45°, and 60° of knee flexion when compared with the ACL-R and intact states. However, when the LET procedure was performed after MMPH partial meniscectomy, a significant decrease was seen at all knee flexion angles in response to IR load, and a significant decrease was seen at 15° of knee flexion in response to AT load.

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