DePhillipo, N., Moatshe, G., Chahla, J., Aman, Z. S., Storaci, H. W., Morris, E. R. ... LaPrade, R. F. (2018). Quantitative and qualitative assessment of the posterior medial meniscus anatomy: Defining meniscal ramp lesions. *American Journal of Sports Medicine,* under utgivelse. doi: 10.1177/0363546518814258

Quantitative and Qualitative Assessment of the Posterior Medial Meniscus Anatomy: Defining Meniscal Ramp Lesions

ABSTRACT

Background: Meniscal ramp lesions have been defined as both a tear of the peripheral attachment of the posterior horn of the medial meniscus (PHMM) at the meniscocapsular junction or an injury to the meniscotibial attachment. Precise anatomical descriptions of these structures are limited in the current literature.

Purpose: To quantitatively and qualitatively describe the PHMM and posteromedial capsule anatomy pertaining to the location of a meniscal ramp lesion with reference to surgically relevant landmarks.

Study Design: Descriptive laboratory study.

Methods: Fourteen male, non-paired, fresh-frozen cadavers were used. The locations of the posteromedial meniscocapsular and meniscotibial attachments were identified. Measurements to surgically relevant landmarks were performed using a coordinate measuring system. To further analyze the posteromedial meniscocapsular and meniscotibial attachments, hematoxylin and eosin and Alcian blue staining were conducted on a separate sample of 10 non-paired specimens.

Results: The posterior meniscocapsular attachment had an average length of 20.2 $\pm$ 6.0 mm and attached posteroinferiorly to the PHMM at an average depth of 36.4% of the total posterior meniscus height. The posterior meniscotibial ligament attached on the PHMM 16.5 mm posterior and 7.7 mm medial to the center of the posterior medial meniscus root attachment. The meniscotibial ligament tibial attachment was 5.9 $\pm$ 1.3 mm inferior to the articular cartilage margin of the posterior medial tibial plateau. The posterior meniscocapsular attachment converged with the meniscotibial ligament at the most posterior point of the meniscocapsular junction in all specimens. Histological staining of the meniscocapsular and meniscotibial ligament PHMM attachments showed very similar structure, cell density, and fiber directionality with no qualitative difference in the makeup of their collagen matrices across all specimens.

Conclusion: The anatomy of the area where a medial meniscal ramp tear occurs revealed that the two posterior meniscal attachments merged at a common attachment on the PHMM. Histological analysis validated a shared attachment point of the meniscocapsular and meniscotibial attachments of the PHMM.

Clinical Relevance: The findings of this study provide the anatomical foundation for an improved understanding of the meniscocapsular and meniscotibial attachments of the PHMM, which may help provide a more precise definition of a meniscal ramp lesion.

Keywords: knee, ramp lesion, medial meniscus, quantitative anatomy

For Peer Review Only:

What is known about the subject?

There is no consensus regarding the definition of a ramp lesion because different anatomical locations have been proposed as the site of injury. Originally, a ramp lesion was defined as a longitudinal tear of the peripheral attachment of the PHMM at the meniscocapsular junction of less than 2.5 cm in length. However, a ramp lesion has also been reported as an injury to the meniscotibial ligament attachment of the PHMM.

What this study adds to the existing literature?

This study strengthens the current anatomic knowledge of the posteromedial aspect of the knee. Specifically, the meniscocapsular and meniscotibial attachments of the posteromedial aspect of the medial meniscus merge at a common attachment site, which helps to explain the ambiguity of different meniscal ramp tear classifications.

INTRODUCTION

The medial meniscus is an important secondary restraint to anterior tibial translation (ATT).[6, 21] Previous studies have reported that peripheral tears of the posterior horn of the medial meniscus (PHMM), or deficiency of the PHMM, are important factors correlated with an increased risk of anterior cruciate ligament (ACL) reconstruction graft failure.[22, 31, 32] Furthermore, injuries at the meniscocapsular attachment of the PHMM, termed ramp lesions, may cause increased knee ATT and rotation in an ACL injured knee.[1, 20]

Ramp lesions, which have been described as tears at the posterior meniscocapsular junction and/or tears of the posterior meniscotibial ligament[25, 26, 30], have a reported incidence of 16 to 24% for all ACL tears[9, 18, 24]. Recent biomechanical studies report discrepancies on the effect of untreated meniscal ramp lesions on knee kinematics of ACL deficient and ACL reconstructed knees.[11, 23, 27] Some authors advocate for the surgical repair of all meniscal ramp lesions at the time of ACL reconstruction due to an increased risk of persistent instability and reconstruction graft failure when not treated.[2, 10, 29] However, due to the vascularization of the capsule and the red-red zone of the meniscus[3, 4], some clinical studies have reported the potential for these tears to heal without surgical treatment[12, 19].

There is limited data on the surgically relevant anatomy of the PHMM, and there is no consensus on the definition of ramp lesions. Thus, an improved understanding of the anatomy of the PHMM may improve the understanding of its importance in tears localized at the PHMM, and also improve the anatomical approach to their treatment.

Therefore, the purpose of this study was to quantitatively and qualitatively describe the posterior medial meniscus and posteromedial capsule anatomy pertaining to the location of a meniscal ramp lesion with reference to surgically relevant landmarks. It was hypothesized that the meniscocapsular and meniscotibial attachments would have definable parameters concerning their anatomical attachments and consistent relationships to one another, as well as pertinent, surgically-relevant landmarks with correlative histologic findings.

MATERIALS AND METHODS

Specimen Preparation

Fourteen non-paired, fresh-frozen male cadaveric knee specimens (mean age: 61.0 years; range: 54-66 years) with no evidence of prior injury, previous surgery, osteoarthritis, meniscus pathology, or ligament pathology were used for this study. The cadaveric specimens utilized in this study were donated to a tissue bank for the purpose of medical research and then purchased by our institution. All specimens were stored at -20˚ C and thawed at room temperature 24 hours prior to preparation. Before testing, each specimen underwent arthrotomy to confirm the absence of intraarticular pathology.

In preparation for potting, the tibial, fibular, and femoral diaphyses were cut 20 cm from the joint line. Sharp dissection to bone was performed, and all soft tissues were removed 10 cm distal and proximal to the joint line and the fibula was fixed to the tibia in its anatomic position. The superficial medial collateral ligament, posterior capsule, semimembranosus tendon, and entire posteromedial corner structures were left intact. The femurs were then sectioned down the midline, in the sagittal plane to allow for direct visualization of the meniscus anatomy and corresponding tibial attachments while preserving the femoral attachments. The tibia and fibula were potted in a cylindrical mold filled with poly methyl methacrylate (PMMA; Fricke Dental International Inc., Streamwood, IL).

Anatomic Measurements

Setup and measuring device

The tibia was rigidly clamped to prevent any movement during testing. A coordinate measuring device with a manufacturer reported repeatability of 0.025 mm (Romer Absolute Arm, Hexagon Metrology, North Kingstown, RI) was used to record points in 3-dimensional space using Rhino 5 software (McNeel North America, Seattle, WA). Point coordinates were imported into Python software (The Python Software Foundation, https://www.python.org) and measurements were calculated using a custom software script. The 3-dimensional anatomic distances and lengths were calculated and broken down into directional components using the knee's main axes: anterior-posterior, medial-lateral, and proximal-distal. The proximal-distal direction was defined using the tibial axis. The medial-lateral direction was defined using the most medial and lateral points of the tibial plateaus. The anterior-posterior axis was defined as being perpendicular to the coronal plane, calculated from the proximal-distal and medial-lateral axes defined above. The same investigator (*initials blinded for review*) performed all measurements to decrease interobserver variability. A second board-certified orthopaedic surgeon (*initials blinded for review*) was present during all testing for landmark confirmation.

Landmarks and measurements

The total meniscus length was calculated by summing the distance between discrete points taken along the periphery of the entire length of the curved medial meniscus from the posterior root to the anterior root attachments. Utilizing the geometric data and 3-dimensional points, curved distances and percentages of meniscal attachments were calculated and referenced according to where they attached along the total curved meniscus length (from posterior to anterior).

The length of the PHMM was measured along the central portion of the meniscus using 5 data points. Parallel to these measurements, the corresponding length of the posterior medial capsular attachment was measured using 5 data points along the periphery of the posterior medial meniscus between its lateral extent and the posterolateral aspect of the posterior oblique ligament (POL). For the meniscotibial attachment to the medial meniscus, the length of the entire structure was measured using 3 data points. Surgically relevant arthroscopic and open landmarks were identified and measured in relation to their attachments on the medial meniscus. Surgically relevant landmarks included the meniscofemoral and meniscotibial attachments of the POL, the meniscofemoral and meniscotibial attachments of the deep medial collateral ligament (dMCL), the anteromedial meniscocapsular attachment, the centers of the anterior and posterior meniscal root attachments, center of the ACL tibial attachment, center of the posterior cruciate ligament (PCL) tibial attachment, center of the shiny white fibers of the posterior meniscal root tibial attachment, and the capsular attachment of the direct arm of the semimembranosus tendon. In addition, digital calipers were used to measure meniscal width (anterior horn, mid-body, posterior horn), meniscal height (posterior horn), and the length and width of the medial tibial plateau.

Histological Analysis

A sample of 10 non-paired, fresh-frozen male cadaveric knee specimens (mean age 58.3 years; range, 45-70 years), separate from the specimens used for anatomical measurements, were used for the histological analysis. Tissue specific to the meniscocapsular and the meniscotibial attachments of the PHMM was gathered via open dissection of the posterior medial meniscus anatomy. All tissues were fixed in 10% neutral buffered formalin at room temperature for 72 hours, rinsed in phosphate buffered saline (PBS), and stored in PBS at 4˚C before paraffin processing. The tissues were then paraffin processed by hand. Specifically, samples were dehydrated from 75% ethanol (EtOH), through 100% EtOH, cleared with three changes of xylene, and paraffin infiltrated with three changes of paraffin wax at 60˚C while shaking. Tissues were embedded in paraffin, solidified in cassettes on ice, and sectioned at 6 µm widths. Prior to staining, slides were dried in a 60˚C oven for two hours, deparaffinized with two changes of xylene, and rehydrated to water. Hematoxylin and eosin (H&E) staining was then conducted to determine the orientation of the meniscocapsular and meniscotibial attachments of the posterior medial meniscus. All images were taken using a Nikon Eclipse Ni-U upright microscope (Nikon, Edgewood, New York, USA).

RESULTS

Posterior Meniscocapsular Attachment of the Medial Meniscus

The posterior meniscocapsular attachment had an average length of 20.2 ± 6.0 mm (range, 11.3 to 33.2 mm) and did not attach directly to the superior margin of the PHMM. In all specimens, the posterior medial capsule attached inferior to the superior margin of the posterior medial meniscus at an average depth of 36.4% of the total posterior meniscus height (Figure 1). The PHMM had an average length of 21.3 ± 2.0 mm (range, 17.6 to 24.5 mm), essentially confluent with the entire length of the posterior capsule. The dimensions of the medial meniscus and medial tibial plateau are presented in Table 1.

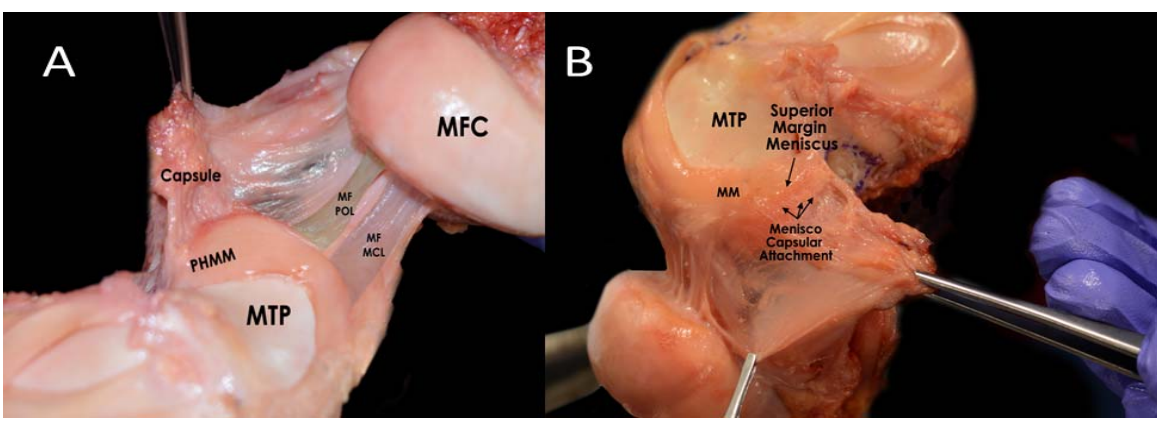


Figure 1. Right knee cadaveric dissection demonstrating the A) relationship of the posterior medial capsule and meniscofemoral attachments of the POL and deep MCL to the posterior horn of the medial meniscus; B) posterior medial capsule attaching just

below the superior margin of the medial meniscus. PHMM: posterior horn medial meniscus; MTP: medial tibial plateau; MF: meniscofemoral attachment; POL: posterior oblique ligament; MCL: medial collateral ligament; MFC: medial femoral condyle; MM: medial meniscus.

Structure	Distance (mean ± SD)
Anterior Horn MM Width	7.6 ± 1.7 mm
Mid-Body MM Width	9.3 ± 2.6 mm
Posterior Horn MM Width	12.6 ±3.3 mm
Height of Posterior MM	4.6 ± 1.5 mm
Length of Medial Tibial Plateau	49.1 ± 3.1 mm
Width of Medial Tibial Plateau	35.1 ± 3.0 mm

Table 1. Average dimensions of the medial meniscus and medial tibial plateau (n=14). The height of the medial meniscus was measured at the most posterior point along the posterior horn. The length and width of the medial tibial plateau were measured to include the articular cartilage margins. MM: medial meniscus; SD= standard deviation.

Posterior Meniscotibial Ligament Attachment of the Medial Meniscus

The posterior meniscotibial ligament attachment to the PHMM had an average length of 14.0 ± 5.4 mm (range, 6.4 to 27.4 mm) at its insertion on the posterior tibia. This structure was identified in all specimens and coursed at an oblique angle from the posterior tibia to its insertion proximal to the inferior edge of the posterior medial meniscus. On average, the most lateral point of the meniscotibial ligament attachment on the posterior medial meniscus was 16.5 mm (range, 12.9 to 25.6 mm) posterior and 7.7 mm (range, 1.7 to 19.8 mm) medial to the center of the posterior medial meniscus root attachment. The meniscotibial tibial ligament attachment was located 5.9 ± 1.3 mm (range, 3.7 to 8.0 mm) inferior to the articular cartilage margin of the posterior medial tibial plateau. The meniscotibial ligament attachment merged with the posterior meniscocapsular attachment to form a common PHMM attachment at the most posterior point of the meniscocapsular junction in all specimens (Figure 2).

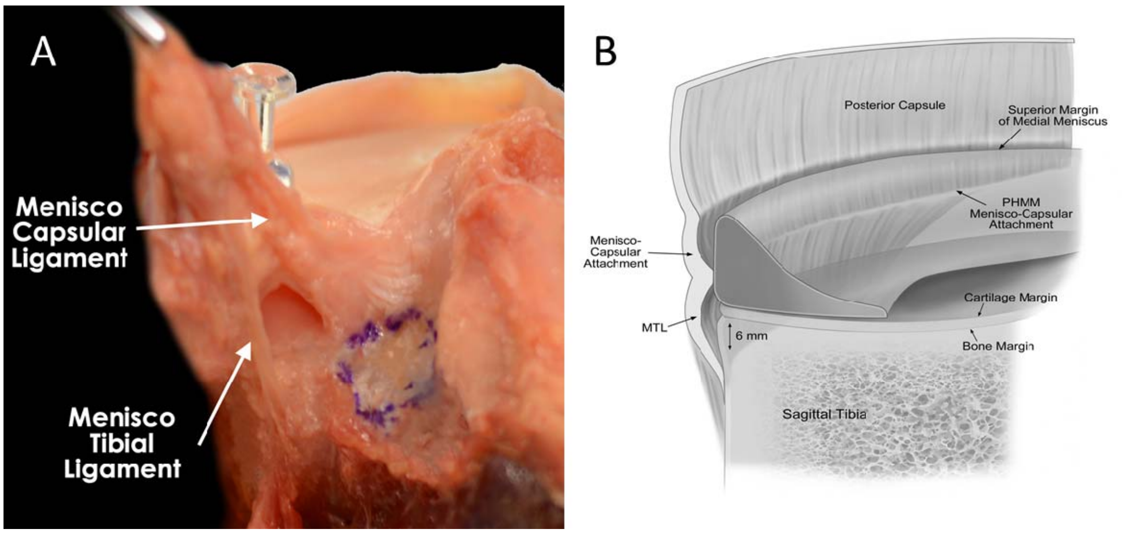


Figure 2. A) Sagittal view of a cadaveric dissection of the posterior horn medial meniscus (PHMM) anatomy, showcasing the meniscocapsular and meniscotibial ligament (MTL) attachments as they merged to form a common attachment. The posterior cruciate ligament (PCL) facet is outlined in methylene blue to illustrate the proximity of the PCL tibial attachment. B) Illustration of the PHMM and shared common attachment of both the meniscocapsular and MTL. The MTL attached 5.9 mm distal to the articular cartilage margin of the posterior medial tibial plateau.

Posterior Oblique Ligament (POL) Attachment to the Medial Meniscus

The meniscal attachment of the POL was a direct expansion of the posteromedial capsule (i.e., the POL capsular arm[16]) and was located directly between the posterior meniscocapsular attachment and the meniscofemoral dMCL attachment. There were two distinct POL structures; one attaching the meniscus to the femur and another attaching it to the tibia. The POL meniscofemoral attachment length was 8.2 ± 2.1 mm (range, 6.0 to 13.0 mm). The center of the meniscofemoral POL attachment was located 34.1 ± 6.7 mm (range, 26.6 to 48.7 mm) medial to the posterior medial meniscus root center; corresponding with an average curved distance of 38.7% of the total meniscus length, from the posterior meniscus root to the anterior meniscus root. The POL meniscotibial attachment length was 9.0 ± 2.3 mm (range, 4.0 to 13.6 mm) and it inserted 6.7 ± 1.7 mm (range, 3.4 to 10.1 mm) inferior to the articular cartilage margin of the medial tibial plateau. On a curved distance, the POL meniscotibial attachment was 6.0 ± 3.6 mm anterior and 16.5 ± 4.5 mm medial to the center of the posterior meniscotibial ligament attachment (Figure 3).

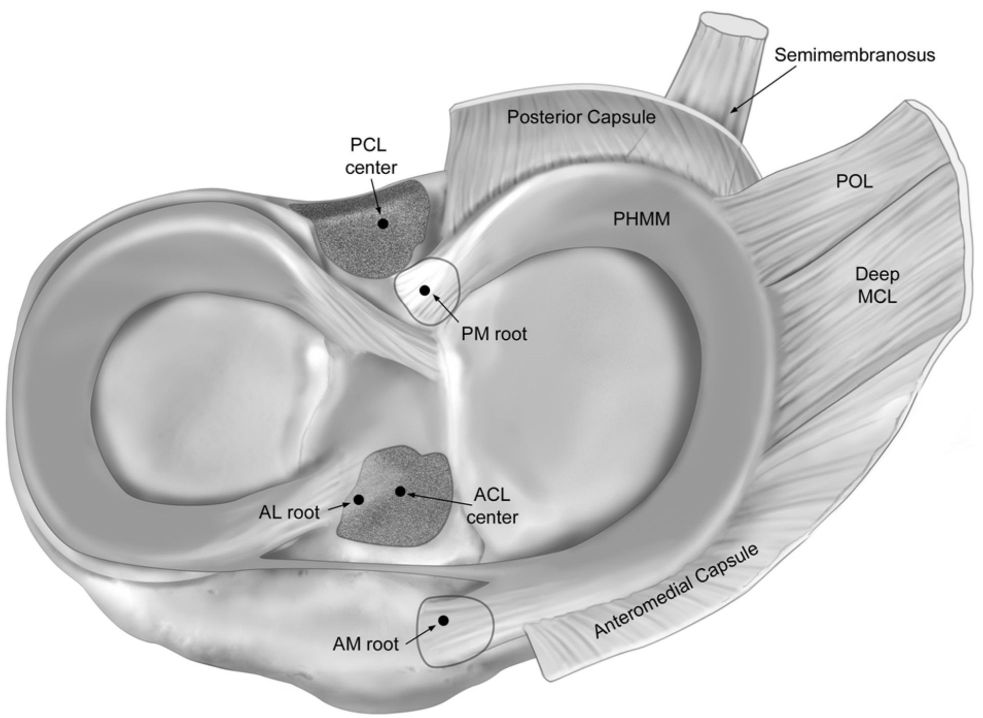


Figure 3. Axial view illustration of the anatomic relationships of the posterior horn of the medial meniscus (PHMM), posterior capsule, posterior oblique ligament (POL), deep medial collateral ligament (MCL), and semimembranosus tendon. The posterior meniscocapsular attachment spanned the entire length of the PHMM and attached at an average depth of 36.4% of the total posterior meniscus height, supporting the potential for a "hidden" space for meniscal ramp lesions when the knee is near full extension.

Deep Medial Collateral Ligament (dMCL) Attachment to Medial Meniscus

The dMCL had a broad, firm attachment to the mid-body of the medial meniscus in all specimens. The dMCL meniscofemoral attachment blended with the POL meniscofemoral attachment posteriorly and with the anteromedial capsule anteriorly. The average length of the dMCL attachment on the medial meniscus was 14.8 $\pm$ 3.2 mm (range, 10.0 to 21.1 mm). The center of the meniscofemoral dMCL attachment was located 45.9 $\pm$ 7.0 mm medial to the posterior medial meniscus root center; corresponding with an average curved distance of 50.5% of the total meniscus length. The meniscotibial attachment of the dMCL was a distinct and separate structure and had an average length of 17.7 $\pm$ 3.4 mm (range, 12.8 to 24.4 mm) and it inserted 6.4 $\pm$ 1.9 mm (range, 3.6 to 11.1 mm) inferior to the articular cartilage margin of the medial tibial plateau.

Semimembranosus Tendon

The semimembranosus tendon consisted of two main portions, the anterior arm and the direct arm. The semimembranosus tendon had a fascial attachment to the posterior inferior margin of the medial meniscus in 12 of 14 (86%) specimens (Figure 4). This semimembranosus-meniscal attachment branched from the anterior arm of the semimembranosus and was located between the posterior meniscotibial ligament and the meniscotibial POL attachments. The average length of the fascial attachment of the semimembranosus to the meniscus was 9.2 $\pm$ 2.1 mm (range, 5.1 to 12.5 mm). The average curved distance of the semimembranosus attachment was located at 34.0% of the total meniscus length, from the posterior medial meniscus root center.

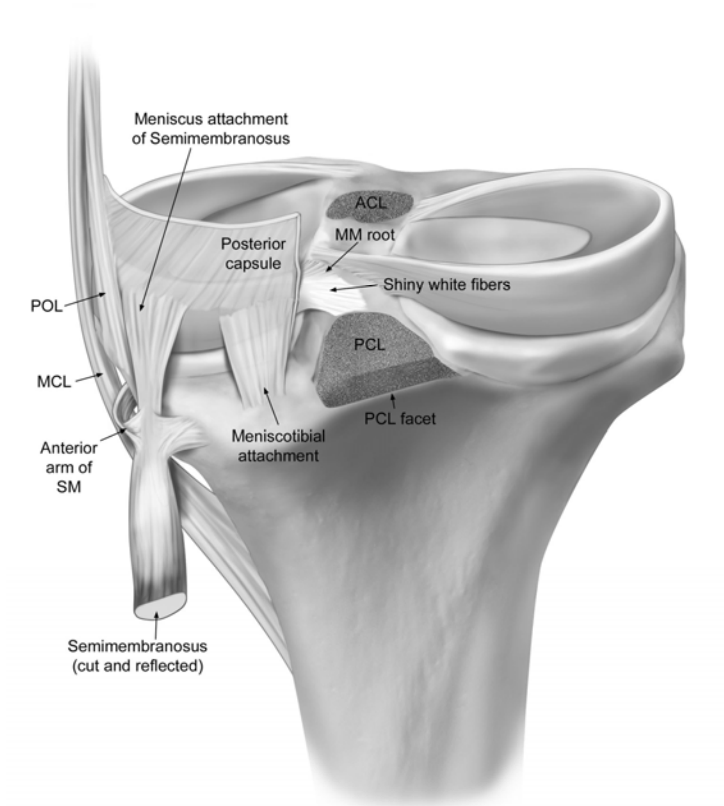


Figure 4. Illustration of posterior medial anatomy with the posterior capsule reflected. This figure illustrates the intimate relationship of the static and dynamic structures of the posteromedial corner including the semimembranosus tendon fascial expansion that attached directly to the PHMM. SM: semimembranosus; MCL: medial collateral ligament; POL: posterior oblique ligament; ACL: anterior cruciate ligament; MM: medial meniscus; PCL: posterior cruciate ligament.

Histology

Hematoxylin and eosin (H&E) staining of the posterior horn of the medial meniscus demonstrated a well-defined collagen structure and cell distribution that was typical of meniscal structure. Conversely, both the meniscocapsular and the meniscotibial attachments demonstrated long fibers organized linearly, which is characteristic of collagen type I-expressing fibroblasts that comprise ligaments. Across all specimens, these attachments showed very similar structure, cell density, and fiber directionality. No histological differences were observed and the two attachments merged together at a common attachment site on the PHMM (Figure 5).

Alcian blue staining of the specimens demonstrated a clear gradient of Glycosaminoglycan (GAG) presence, with high expression in the posterior medial meniscus and decreasing expression moving toward its meniscocapsular and meniscotibial attachments. GAG expression in both meniscocapsular and meniscotibial attachments were similar and suggested no qualitative difference in the composition of their collagen matrices.

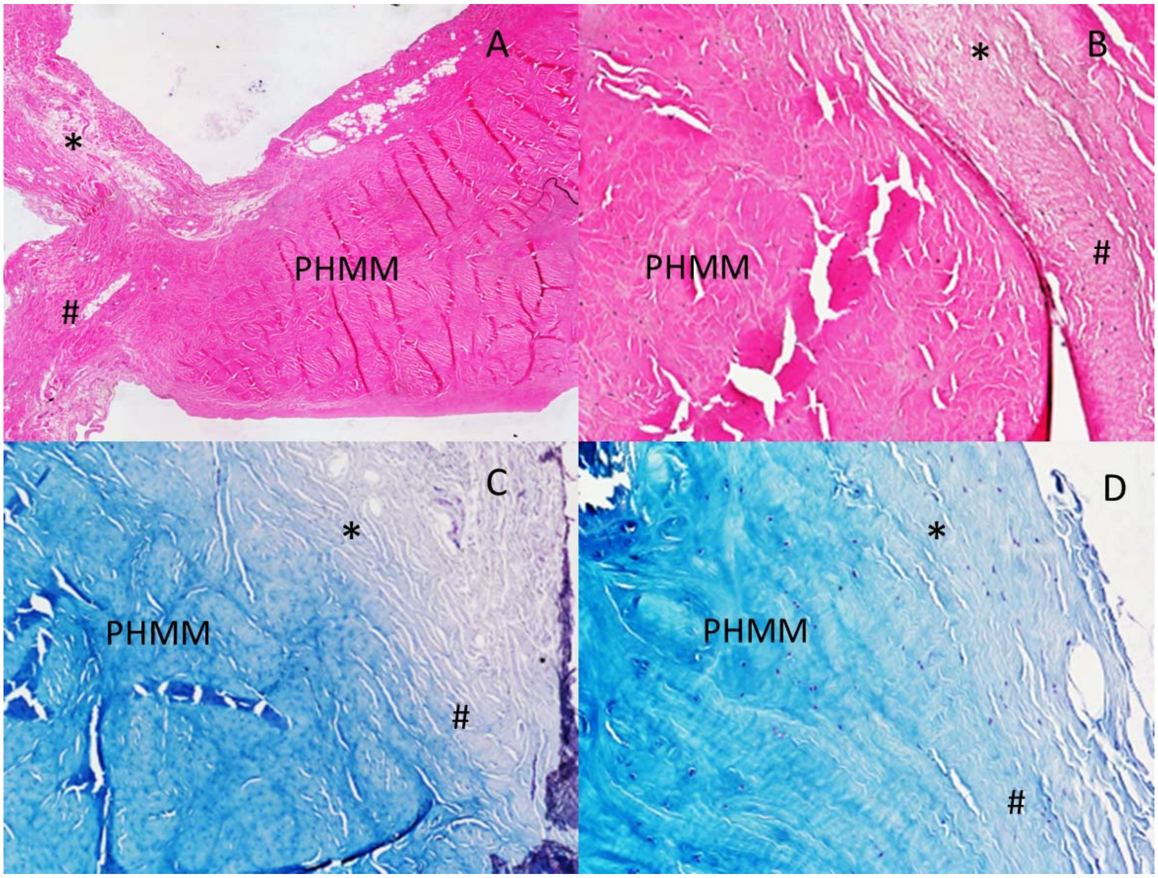


Figure 5. *A/B*: H&E staining of the capsular and tibial attachments of the PHMM, demonstrating similar appearance of collagen type-I and cell density with no observed differences between the two attachments. *C/D*: GAG expression in both meniscocapsular and meniscotibial attachments were visually similar, with a clear decrease in GAG expression from high to low as the meniscus transitioned towards to the capsular and tibial attachments (anterior to posterior). Figures A/B show no difference in the fiber orientation between the meniscocapsular and meniscotibial attachments of the PHMM, while figures C/D show these two structures are indistinguishable regarding their collagen composition as they converge and attach to the PHMM. Image A was taken at 2x magnification while all other images (B, C, and D) were taken at 4x magnification. *: Meniscocapsular attachment; #: Meniscotibial attachment; H&E: Hematoxylin and eosin; PHMM: posterior horn medial meniscus; GAG: Glycosaminoglycan.

DISCUSSION

The main findings of the present study were that there was a shared common attachment of the meniscocapsular and meniscotibial ligament attachments that merged into the PHMM, and there were no histological differences observed between the meniscocapsular and meniscotibial attachments. Additionally, the posterior capsule did not attach directly to the superior portion of the PHMM, providing evidence for the potential location of "hidden" meniscal ramp lesions when the knee is near full extension. Specifically, this hidden area may be responsible for missed diagnoses of ramp tears during preoperative MRI scans and it further supports the utility of viewing the PHMM posteromedially during arthroscopy to confirm or deny the presence of a ramp lesion at the time of ACL surgery.

To date, there is no consensus regarding the definition of a ramp lesion because different anatomical locations have been proposed as the site of injury. Originally, a ramp lesion was defined as a longitudinal tear at the meniscocapsular junction 2.5 cm in length.[28] In the current study, the posteromedial meniscocapsular junction was 2.0 cm in length; thus a tear 2.5 cm in length may not be an accurate definition for a ramp lesion. Similarly, Ahn et al.[2] performed a clinical follow-up with second-look arthroscopy and recommended that peripheral tears of the PHMM > 1 cm in length should be repaired during concomitant ACL reconstruction. In contrast, Liu et al.[19] evaluated clinical outcomes at a mean follow-up of 2 years in patients with ACL reconstruction and concomitant stable ramp lesions < 1.5 cm and reported no significant difference in outcomes between trephination and meniscal repair. These authors theorized that all meniscal ramp lesions < 1.5 cm in length were stable and thus may not require surgical repair with a concomitant ACL reconstruction.[19]

The anatomic and histologic analysis of the current study demonstrates a shared attachment of the meniscocapsular and meniscotibial structures on the PHMM. Thaunat et al.[29] described a classification system for meniscal ramp lesions with five different types—involving both meniscocapsular separation and meniscotibial ligament disruption, with or without partial tearing at their attachments to the PHMM, as well as tears at the red-red and red-white aspects of the posterior horn of the medial meniscus. Considering the findings of the current study, the previously described classification system may not be appropriate for surgical planning, because a tear in either the meniscocapsular or meniscotibial attachment of the PHMM could dictate the same treatment (i.e. repair).[29]

The intuitive theories behind inherent knee instability and meniscal ramp lesions are becoming more recognized. If the superior meniscocapsular joint capsule or the inferior meniscotibial ligament is torn, this may create further instability with anterior tibial translation and knee rotation.[1, 11, 23, 27] However, from our anatomic and histologic analysis, we found that these two structures share a common PHMM attachment and thus we theorize that both the meniscocapsular and meniscotibial attachments may function together as an anatomical unit. A recent biomechanical study supports the above-mentioned findings, because there were no significant differences in knee kinematics between a meniscocapsular-based tear and a meniscotibial-based tear in ACL-deficient and ACL-reconstructed knees.[11] This suggests that although ramp lesions may occur in two separate locations outside of the meniscal substance of the PHMM instead of only at the meniscocapsular junction of the PHMM as previously described, an inside-out repair of the PHMM may be adequate to address lesions of both structures and restore knee stability.

The POL meniscofemoral attachment was found to be a direct expansion of the posteromedial capsule, located directly between the posterior meniscocapsular attachment and the dMCL meniscofemoral attachment. The POL consists of three main fascial attachments that course from the distal semimembranosus tendon and have been previously termed the superficial, central, and capsular arms.[13] The central arm forms the main portion of the POL and together with the capsular arm merges directly with the posteromedial capsule and attaches firmly to the PHMM.[14, 16] These quantified anatomic descriptions may be useful for intraoperative planning during anatomic-based repair of POL tears in medial-sided knee injuries.

The dMCL had a broad, firm meniscofemoral and meniscotibial attachment to the mid-body of the medial meniscus, located between the meniscofemoral attachment of the POL and the anteromedial capsule.[8, 16] The center of the dMCL meniscofemoral attachment was located at the mid-portion of the medial meniscus, with an average curved distance of 50.5% of the total meniscus length. The dMCL meniscotibial attachment inserted an average 6.4 mm inferior to the articular cartilage margin of the medial tibial plateau, which may serve as an anatomic landmark for tibial suture anchor placement during dMCL repairs.

The semimembranosus muscle-tendon complex had a firm attachment to the PHMM in the majority of specimens (86%). This attachment may have a dynamic role in posteromedial corner and medial meniscus stability. However further biomechanical studies are needed to evaluate this anatomic relationship.

The present study has some limitations inherent to a cadaveric study design. In order to visualize the medial meniscus for measurements, the femur had to be sectioned sagitally. Although a detailed dissection was performed to clearly visualize the anatomic attachments and fiber orientations, distances were calculated as absolute 3-dimensional vector norms, which do not provide directional information.

CONCLUSION

The anatomy of the area where a medial meniscal ramp tear occurs revealed that the two posterior meniscal attachments merged at a common attachment on the PHMM. Histologic analysis validated a shared attachment point of the meniscocapsular and meniscotibial attachments of the PHMM. The findings of this study provide the anatomical foundation for an improved understanding of the role of the meniscocapsular and meniscotibial attachments of the PHMM and the anatomic basis of ramp tears. This will help to further refine injury classification and allow for a more precise definition of a meniscal ramp lesion.

References

1. Ahn JH, Bae TS, Kang KS, Kang SY, Lee SH. Longitudinal tear of the medial meniscus posterior horn in the anterior cruciate ligament-deficient knee significantly influences anterior stability. *Am J Sports Med.* 2011;39(10):2187-2193.

2. Ahn JH, Wang JH, Yoo JC. Arthroscopic all-inside suture repair of medial meniscus lesion in anterior cruciate ligament--deficient knees: results of second-look arthroscopies in 39 cases. *Arthroscopy.* 2004;20(9):936-945.

3. Arnoczky SP, Warren RF. Microvasculature of the human meniscus. *Am J Sports Med.* 1982;10(2):90-95.

4. Barber-Westin SD, Noyes FR. Clinical healing rates of meniscus repairs of tears in the central-third (red-white) zone. *Arthroscopy.* 2014;30(1):134-146.

5. Cinque ME, Chahla J, Kruckeberg BM, DePhillipo NN, Moatshe G, LaPrade RF. Posteromedial Corner Knee Injuries: Diagnosis, Management, and Outcomes: A Critical Analysis Review. *JBJS Rev.* 2017;5(11):e4.

6. Cristiani R, Ronnblad E, Engstrom B, Forssblad M, Stalman A. Medial Meniscus Resection Increases and Medial Meniscus Repair Preserves Anterior Knee Laxity: A Cohort Study of 4497 Patients With Primary Anterior Cruciate Ligament Reconstruction. *Am J Sports Med.* 2018;46(2):357-362.

7. De Maeseneer M, Marcelis S, Boulet C, et al. Ultrasound of the knee with emphasis on the detailed anatomy of anterior, medial, and lateral structures. *Skeletal Radiol.* 2014;43(8):1025-1039.

8. De Maeseneer M, Van Roy F, Lenchik L, Barbaix E, De Ridder F, Osteaux M. Three layers of the medial capsular and supporting structures of the knee: MR imaging-anatomic correlation. *Radiographics.* 2000;20 Spec No:S83-89.

9. DePhillipo NN, Cinque ME, Chahla J, Geeslin AG, Engebretsen L, LaPrade RF. Incidence and Detection of Meniscal Ramp Lesions on Magnetic Resonance Imaging in Patients With Anterior Cruciate Ligament Reconstruction. *Am J Sports Med.* 2017:363546517704426.

10. DePhillipo NN, Cinque ME, Kennedy NI, et al. Inside-Out Repair of Meniscal Ramp Lesions. *Arthrosc Tech.* Aug 2017;6(4):e1315-e1320.

11. DePhillipo NN, Moatshe G, Brady A, et al. Effect of Meniscocapsular and Meniscotibial Lesions in ACL-Deficient and ACL-Reconstructed Knees: A Biomechanical Study. *Am J Sports Med.* 2018:363546518774315.

12. Duchman KR, Westermann RW, Spindler KP, et al. The Fate of Meniscus Tears Left In Situ at the Time of Anterior Cruciate Ligament Reconstruction: A 6-Year Follow-up Study From the MOON Cohort. *Am J Sports Med.* 2015;43(11):2688-2695.

13. Hughston JC. The importance of the posterior oblique ligament in repairs of acute tears of the medial ligaments in knees with and without an associated rupture of the anterior cruciate ligament. Results of long-term follow-up. *J Bone Joint Surg Am.* 1994;76(9):1328-1344.

14. Hughston JC, Eilers AF. The role of the posterior oblique ligament in repairs of acute medial (collateral) ligament tears of the knee. *J Bone Joint Surg Am.* 1973;55(5):923-940.

15. Kumar NS, Edgar C, Spencer T, et al. Anatomic Repair of Posteromedial Meniscocapsular Separation Using an All-Inside Technique. *Arthrosc Tech.* 2017;6(4):e921-e926.

16. LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. *J Bone Joint Surg Am.* 2007;89(9):2000-2010.

17. Li WP, Chen Z, Song B, Yang R, Tan W. The FasT-Fix Repair Technique for Ramp Lesion of the Medial Meniscus. *Knee Surg Relat Res.* 2015;27(1):56-60.

18. Liu X, Feng H, Zhang H, Hong L, Wang XS, Zhang J. Arthroscopic prevalence of ramp lesion in 868 patients with anterior cruciate ligament injury. *Am J Sports Med.* 2011;39(4):832-837.

19. Liu X, Zhang H, Feng H, Hong L, Wang XS, Song GY. Is It Necessary to Repair Stable Ramp Lesions of the Medial Meniscus During Anterior Cruciate Ligament Reconstruction? A Prospective Randomized Controlled Trial. *Am J Sports Med.* 2017;45(5):1004-1011.

20. Mariani PP. Posterior horn instability of the medial meniscus a sign of posterior meniscotibial ligament insufficiency. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(7):1148-1153.

21. Papageorgiou CD, Gil JE, Kanamori A, Fenwick JA, Woo SL, Fu FH. The biomechanical interdependence between the anterior cruciate ligament replacement graft and the medial meniscus. *Am J Sports Med.* 2001;29(2):226-231.

22. Parkinson B, Robb C, Thomas M, Thompson P, Spalding T. Factors That Predict Failure in Anatomic Single-Bundle Anterior Cruciate Ligament Reconstruction. *Am J Sports Med.* 2017;45(7):1529-1536.

23. Peltier A, Lording T, Maubisson L, Ballis R, Neyret P, Lustig S. The role of the meniscotibial ligament in posteromedial rotational knee stability. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(10):2967-2973.

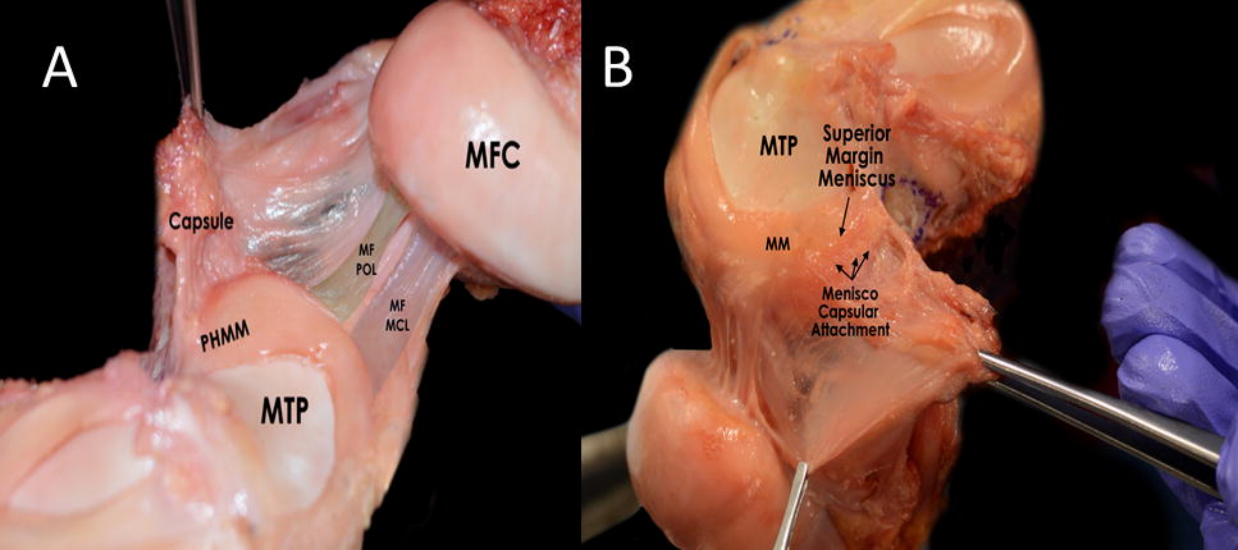
24. Seil R, Mouton C, Coquay J, et al. Ramp lesions associated with ACL injuries are more likely to be present in contact injuries and complete ACL tears. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(4):1080-1085.

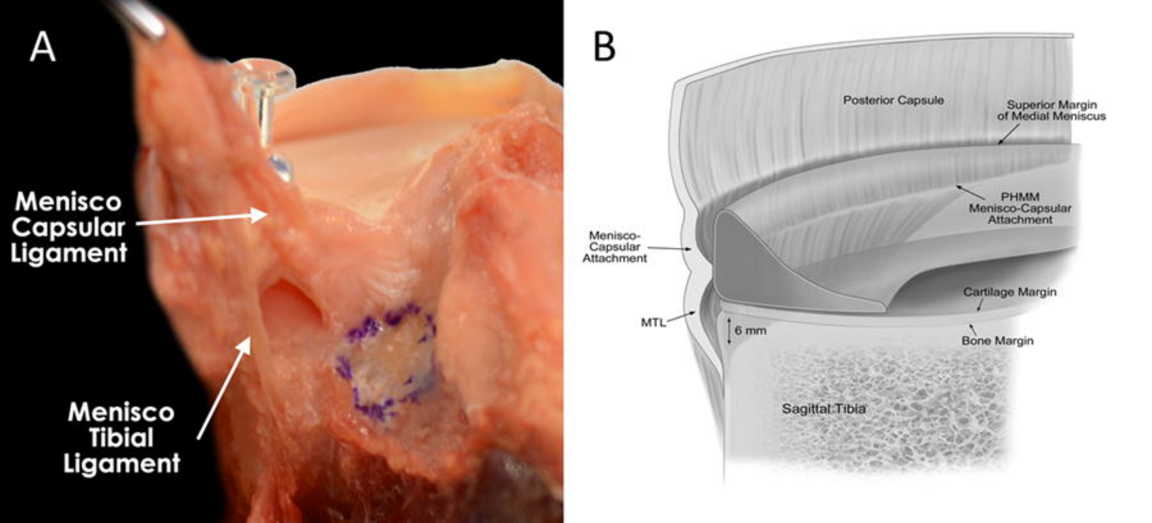
25. Smigielski R, Becker R, Zdanowicz U, Ciszek B. Medial meniscus anatomy-from basic science to treatment. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(1):8-14.

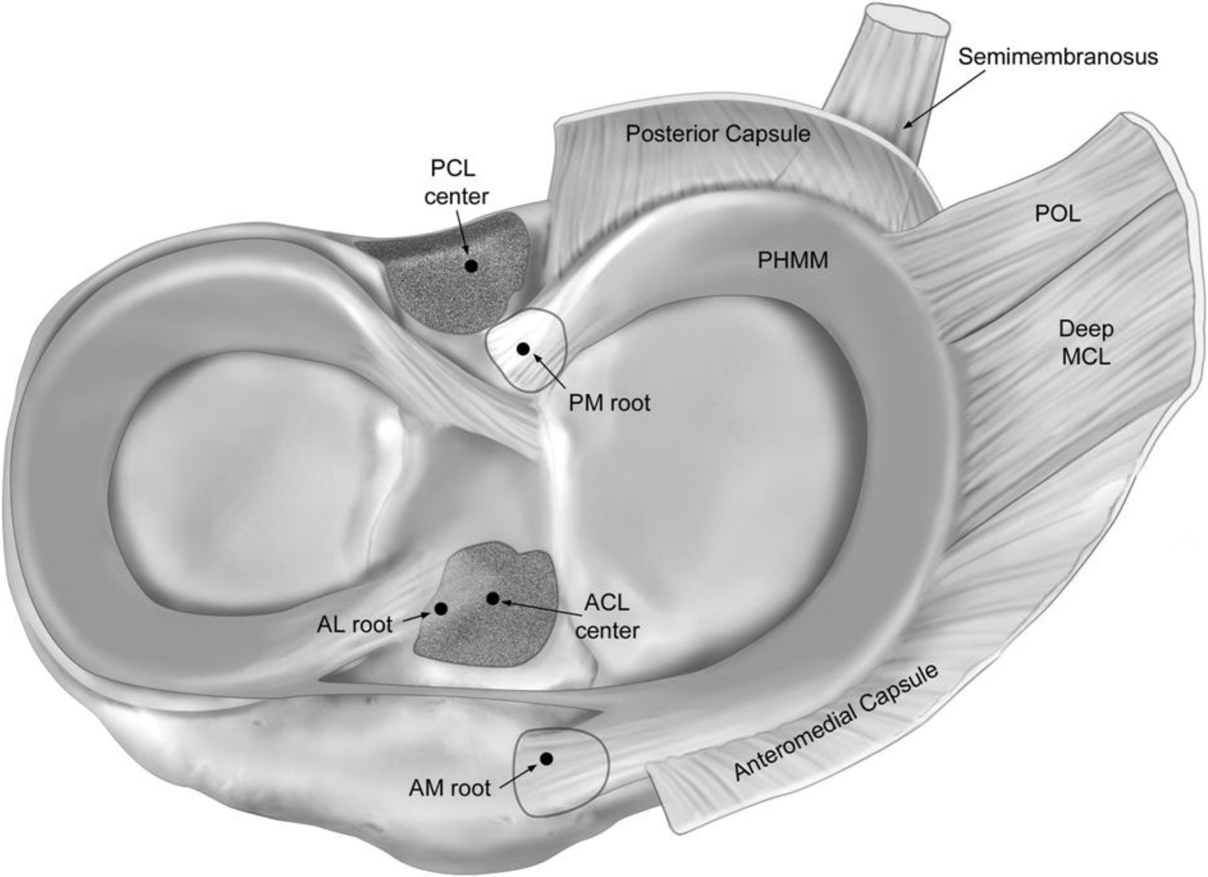
26. Sonnery-Cottet B, Conteduca J, Thaunat M, Gunepin FX, Seil R. Hidden lesions of the posterior horn of the medial meniscus: a systematic arthroscopic exploration of the concealed portion of the knee. *Am J Sports Med.* 2014;42(4):921-926.

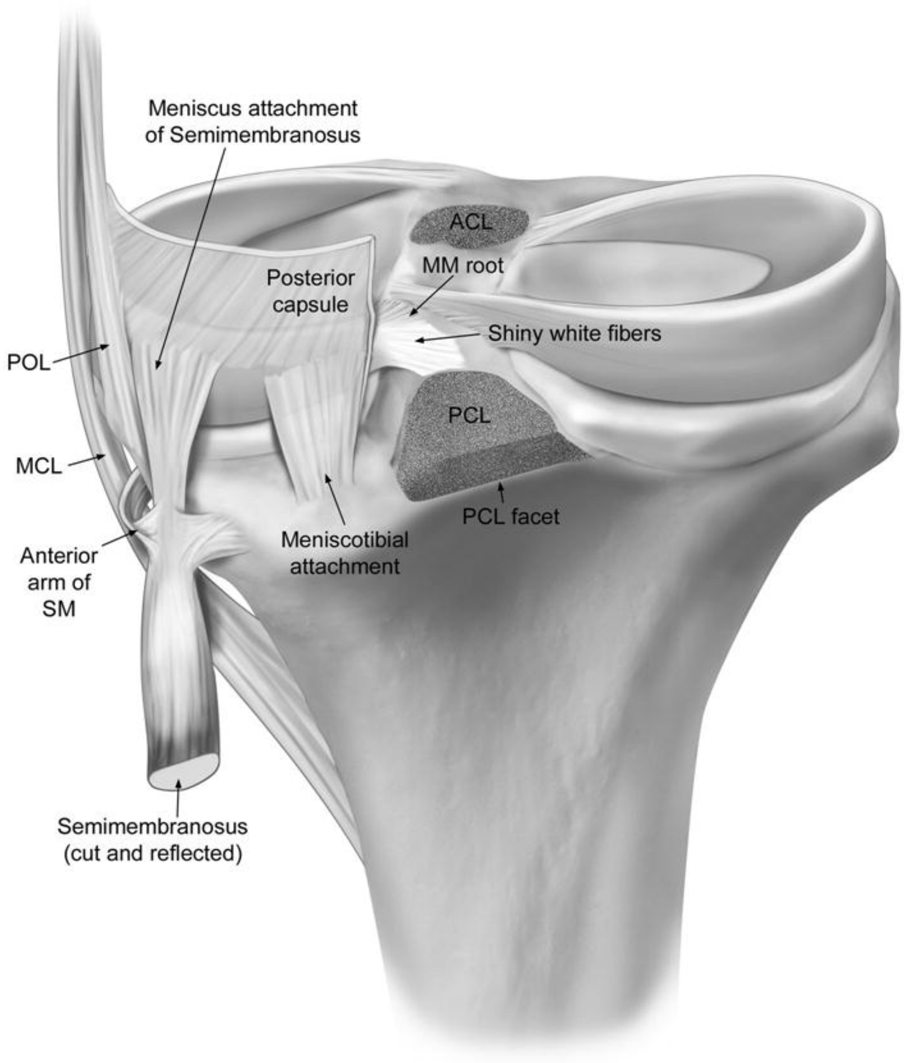
27. Stephen JM, Halewood C, Kittl C, Bollen SR, Williams A, Amis AA. Posteromedial Meniscocapsular Lesions Increase Tibiofemoral Joint Laxity With Anterior Cruciate Ligament Deficiency, and Their Repair Reduces Laxity. *Am J Sports Med.* 2016;44(2):400-408.

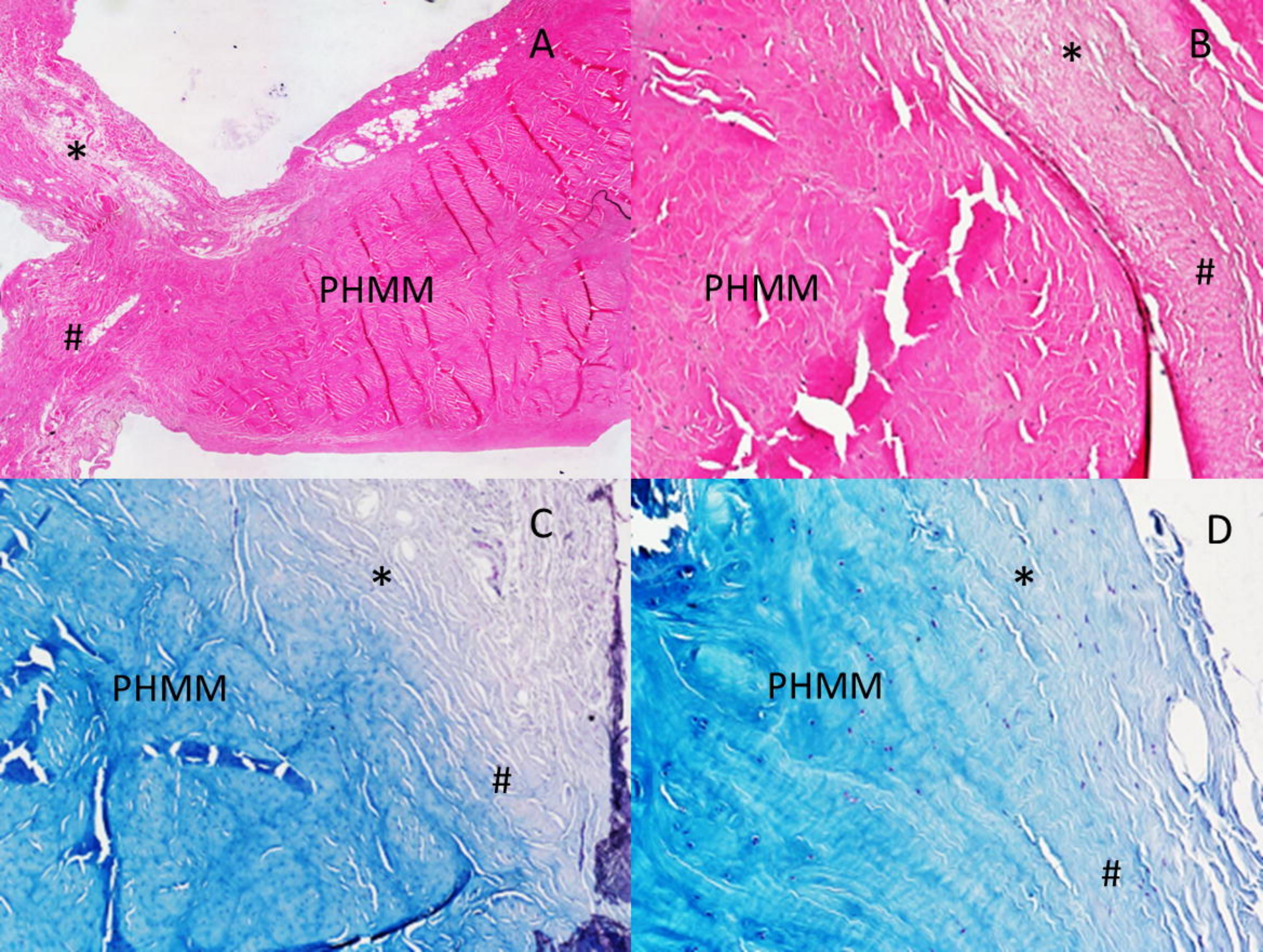
28. Strobel MJ. Menisci. In: Fett HM, Flechtner P, eds. *Manual of Arthroscopic Surgery.* 1988;. New York, NY: Springer:171-178.
29. Thaunat M, Fayard JM, Guimaraes TM, Jan N, Murphy CG, Sonnery-Cottet B. Classification and Surgical Repair of Ramp Lesions of the Medial Meniscus. *Arthrosc Tech.* 2016;5(4):e871-e875.
30. Thaunat M, Jan N, Fayard JM, et al. Repair of Meniscal Ramp Lesions Through a Posteromedial Portal During Anterior Cruciate Ligament Reconstruction: Outcome Study With a Minimum 2-Year Follow-up. *Arthroscopy.* 2016.
31. Trojani C, Sbihi A, Djian P, et al. Causes for failure of ACL reconstruction and influence of meniscectomies after revision. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(2):196-201.
32. Webster KE, Feller JA, Kimp AJ, Whitehead TS. Revision Anterior Cruciate Ligament Reconstruction Outcomes in Younger Patients: Medial Meniscal Pathology and High Rates of Return to Sport Are Associated With Third ACL Injuries. *Am J Sports Med.* 2018;46(5):1137-1142.


A
MFC
Capsule
MF
POL
MF
MCL
PHMM
MTP
B
MTP
Superior
Margin
Meniscus
MM
Menisco
Capsular
Attachment


A
Menisco Capsular Ligament
Menisco Tibial Ligament
B
Posterior Capsule
Superior Margin of Medial Meniscus
PHMM Menisco-Capsular Attachment
Menisco-Capsular Attachment
Cartilage Margin
MTL
6 mm
Bone Margin
Sagittal Tibia


Semimembranosus
Posterior Capsule
PCL
center
POL
PHMM
Deep
MCL
PM root
ACL
center
AL root
Anteromedial Capsule
AM root


Meniscus attachment of Semimembranosus
ACL
MM root
Posterior capsule
Shiny white fibers
POL
PCL
MCL
PCL facet
Meniscotibial attachment
Anterior arm of SM
Semimembranosus (cut and reflected)


A
*
#
PHMM
B
*
#
PHMM
C
*
#
PHMM
D
*
#
PHMM