Quantitative and Qualitative Assessment of the Posterior Medial Meniscus Anatomy

Defining Meniscal Ramp Lesions

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Background: Meniscal ramp lesions have been defined as 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 anatomic 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 nonpaired fresh-frozen cadavers were used. The locations of the posteromedial meniscocapsular and meniscotibial attachments were identified. Measurements to surgically relevant landmarks were performed with 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 nonpaired specimens.

Results: The posterior meniscocapsular attachment had a mean ± SD length of 20.2 ± 6.0 mm and attached posteroinferiorly to the PHMM at a mean depth of 36.4% of the total posterior meniscal 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 meniscal root attachment. The meniscotibial ligament tibial attachment was 5.9 ± 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 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 2 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 anatomic 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

Ramp lesions have been described as tears at the posterior meniscocapsular junction and/or tears of the posterior meniscotibial ligament,[19,20,24] and they have a reported incidence of 16% to 24% for all anterior cruciate ligament (ACL) tears.[8,15,18] Recent biomechanical studies reported discrepancies on the effect of untreated meniscal ramp lesions on knee kinematics of ACL-deficient and ACL-reconstructed knees.[10,17,21] Some authors advocate for the surgical repair of all meniscal ramp lesions at the time of ACL reconstruction, based on an increased risk of persistent instability and reconstruction graft failure when not treated.[2,9,23] However, given the vascularization of the capsule and the red-red zone of the meniscus,[3,4] some clinical studies reported the potential for these tears to heal without surgical treatment.[11,16]

There are limited data on the surgically relevant anatomy of the posterior horn of the medial meniscus (PHMM), and there is no consensus on the definition of ramp lesions. Thus, an improved understanding of the

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anatomy of the PHMM may improve (1) the understanding of its importance in tears localized at the PHMM and (2) the anatomic 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 anatomic attachments and consistent relationships to one another, as well as pertinent, surgically relevant landmarks with correlative histologic findings.

METHODS

Specimen Preparation

Fourteen nonpaired fresh-frozen male cadaveric knee specimens (mean age, 61.0 years; range, 54-66 years) with no evidence of prior injury, previous surgery, osteoarthritis, meniscal 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 before preparation. Before testing, each specimen underwent arthrotomy to confirm the absence of intra-articular 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; 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 meniscal anatomy and corresponding tibial attachments while preserving the femoral attachments. The tibia and fibula were potted in a cylindrical mold filled with PMMA (Fricke Dental International Inc).

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) was used to record points in 3-dimensional space with Rhino 5 software (McNeel North America). Point coordinates were imported into Python software (Python Software Foundation), and measurements were calculated with a custom software script. The 3-dimensional anatomic distances and lengths were calculated and broken down into directional components with the knee's main axes: anterior-posterior, medial-lateral, and proximal-distal. The proximal-distal direction was defined with the tibial axis. The medial-lateral direction was defined with 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 earlier. The same investigator (N.N.D.) performed all measurements to decrease interobserver variability. A board-certified orthopaedic surgeon (G.M.) was present during all testing for landmark confirmation.

Landmarks and Measurements. Total meniscal length was calculated by summing the distance between discrete points along the entire periphery of the curved medial meniscus, from the posterior root attachment to the anterior. Based on 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 curved meniscal length (posterior to anterior).

The length of the PHMM was measured along the central portion of the meniscus with 5 data points. Parallel to these measurements, the corresponding length of the posterior medial capsular attachment was measured with 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 with 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 following: 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, the center of the ACL tibial attachment, the center of the posterior cruciate ligament tibial attachment, the 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, midbody, posterior horn), meniscal height (posterior

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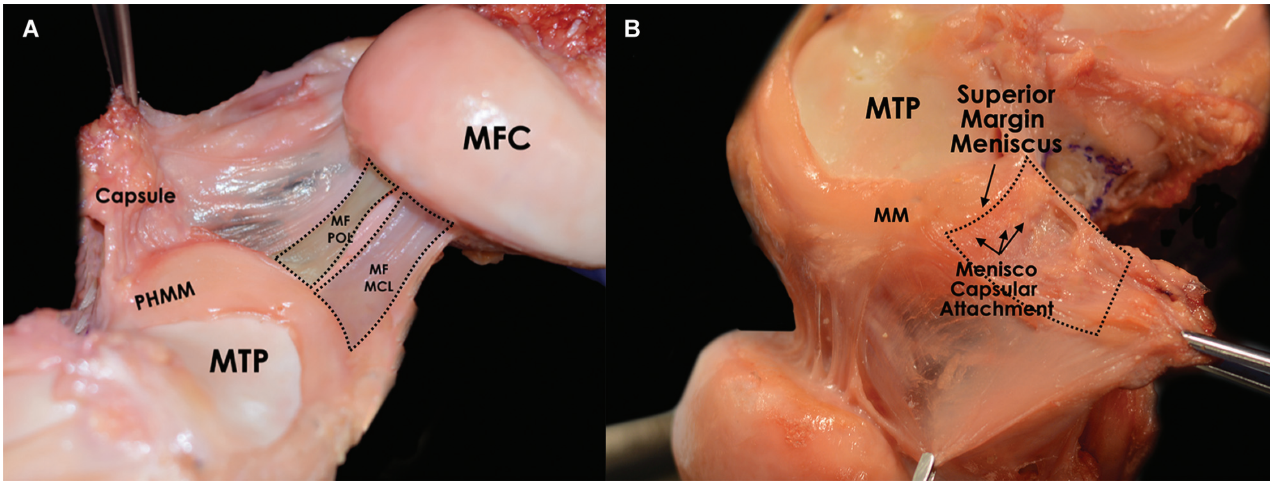

Figure 1. Right knee cadaveric dissection demonstrating (A) the relationship of the posterior medial capsule and meniscofemoral (MF) attachments of the POL and deep MCL to the posterior horn of the medial meniscus (PHMM) and (B) the posterior medial capsule attaching just below the superior margin of the medial meniscus (MM). MCL, medial collateral ligament; MFC, medial femoral condyle; MTP, medial tibial plateau; POL, posterior oblique ligament.

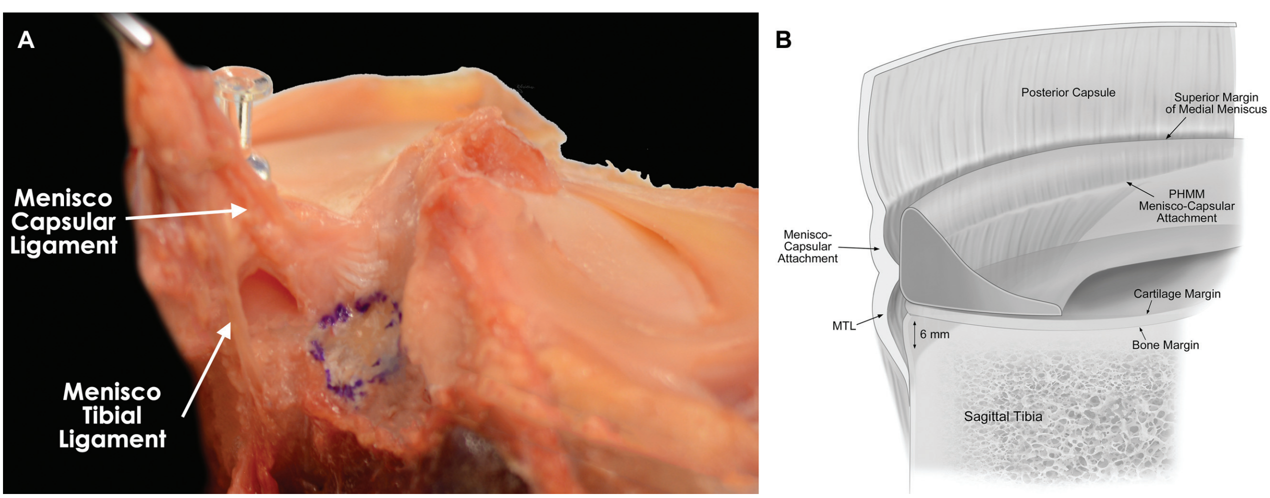

Figure 2. (A) Sagittal view of a cadaveric dissection of the posterior horn medial meniscus (PHMM) anatomy, showcasing the meniscocapsular and meniscotibial ligament (MTL) attachments as they merge to form a common attachment. The posterior cruciate ligament facet is outlined in methylene blue to illustrate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

horn), and the length and width of the medial tibial plateau. Standard descriptive statistics for all quantified measurements were performed and included the calculation of mean scores and SDs.

Histological Analysis

A sample of 10 nonpaired fresh-frozen male cadaveric knee specimens (mean age, 58.3 years; range, 45-70 years), separate from the specimens used for anatomic measurements, were used for the histological analysis. Tissue specific to the meniscocapsular and meniscotibial attachments of the PHMM was gathered via open dissection of the posterior medial meniscal anatomy by the same board-certified orthopaedic surgeon who confirmed the anatomic landmarks for the descriptive data analysis. All tissues were fixed in 10% neutral-buffered formalin at room temperature for 72 hours, rinsed in phosphate-buffered saline, and stored in phosphate-buffered saline at 4°C before paraffin processing. The tissues were then paraffin processed by hand. Specifically, samples were dehydrated from 75% ethanol, through 100% ethanol, cleared with 3 changes of xylene, and paraffin infiltrated with 3 changes of paraffin wax at 60°C while shaking. Tissues were embedded in

TABLE 1
Mean Dimensions of the Medial Meniscus and Medial Tibial Plateau (n = 14)[a]

Structure	Mean ± SD, mm
Medial meniscal width	
Anterior horn	7.6 ± 1.7
Midbody	9.3 ± 2.6
Posterior horn	12.6 ± 3.3
Height of posterior meniscal width	4.6 ± 1.5
Medial tibial plateau	
Length	49.1 ± 3.1
Width	35.1 ± 3.0

[a]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.

TABLE 2
Mean Length of the Meniscocapsular and Meniscotibial Attachments and the PHMM[a]

Structure	Mean ± SD, mm
Meniscocapsular attachment length	20.2 ± 6.0
Meniscotibial attachment length	14.0 ± 5.4
PHMM length	21.3 ± 2.0

[a]PHMM, posterior horn of the medial meniscus.

paraffin, solidified in cassettes on ice, and sectioned at 6-μm widths. Before staining, slides were dried in a 60°C oven for 2 hours, deparaffinized with 2 changes of xylene, and rehydrated to water. Hematoxylin and eosin staining was then conducted to determine the orientation of the meniscocapsular and meniscotibial attachments of the posterior medial meniscus. All images were taken with a Nikon Eclipse Ni-U upright microscope. A histologist reviewed all histological specimens and directly interpreted the results regarding qualitative findings.

RESULTS

Posterior Meniscocapsular Attachment of the Medial Meniscus

The posterior meniscocapsular attachment had a mean ± SD length of 20.2 ± 6.0 mm (range, 11.3-33.2 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 a mean depth of 36.4% of the total posterior meniscal height (Figure 1). The PHMM had a mean length of 21.3 ± 2.0 mm (range, 17.6-24.5 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.

Posterior Meniscotibial Ligament Attachment of the Medial Meniscus

The posterior meniscotibial ligament attachment to the PHMM had a mean length of 14.0 ± 5.4 mm (range, 6.4-27.4 mm) at its insertion on the posterior tibia (Table 2). 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 posterior (range, 12.9-25.6 mm) and 7.7 mm medial (range, 1.7-19.8 mm) to the center of the posterior medial meniscal root attachment. The meniscotibial tibial ligament attachment was located 5.9 ± 1.3 mm inferior (range, 3.7-8.0 mm) 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).

POL Attachment to the Medial Meniscus

The meniscal attachment of the POL was a direct expansion of the posteromedial capsule (ie, the POL capsular arm[14]) and was located directly between the posterior meniscocapsular attachment and the meniscofemoral dMCL attachment. There were 2 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, 6.0-13.0 mm). The center of the meniscofemoral POL attachment was located 34.1 ± 6.7 mm medial (range, 26.6-48.7 mm) to the posterior medial meniscal root center, corresponding with a mean curved distance of 38.7% of the total meniscal length, from the posterior meniscal root to the anterior meniscal root. The POL meniscotibial attachment length was 9.0 ± 2.3 mm (range, 4.0-13.6 mm), and it inserted 6.7 ± 1.7 mm inferior (range, 3.4-10.1 mm) 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).

dMCL Attachment to Medial Meniscus

The dMCL had a broad, firm attachment to the midbody 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 mean length of the dMCL attachment on the medial meniscus was 14.8 ± 3.2 mm (range, 10.0-21.1 mm). The center of the meniscofemoral dMCL attachment was located 45.9 ± 7.0 mm medial to the posterior medial meniscal root center, corresponding with a mean curved distance of 50.5% of the total meniscal length. The meniscotibial attachment of the dMCL was a distinct and separate structure and had a mean length of 17.7 ± 3.4 mm (range, 12.8-24.4 mm), and it inserted 6.4 ± 1.9 mm inferior (range,

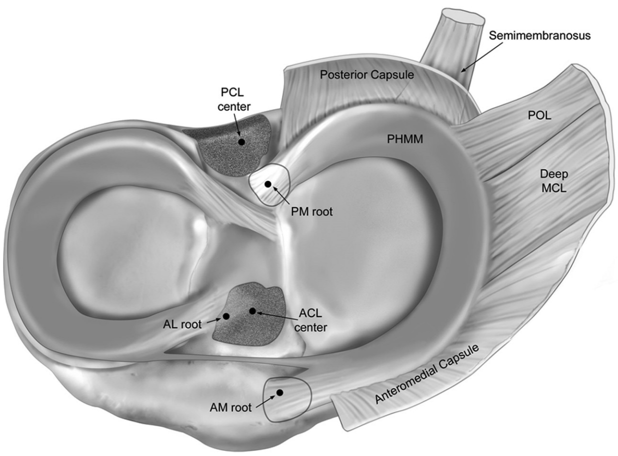

Figure 3. Axial view illustration of the anatomic relationships of the posterior horn of the medial meniscus (PHMM), posterior capsule, posterior oblique ligament (POL), deep medial collateral ligament (MCL), and semimembranosus tendon. The posterior meniscocapsular attachment spanned the entire length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

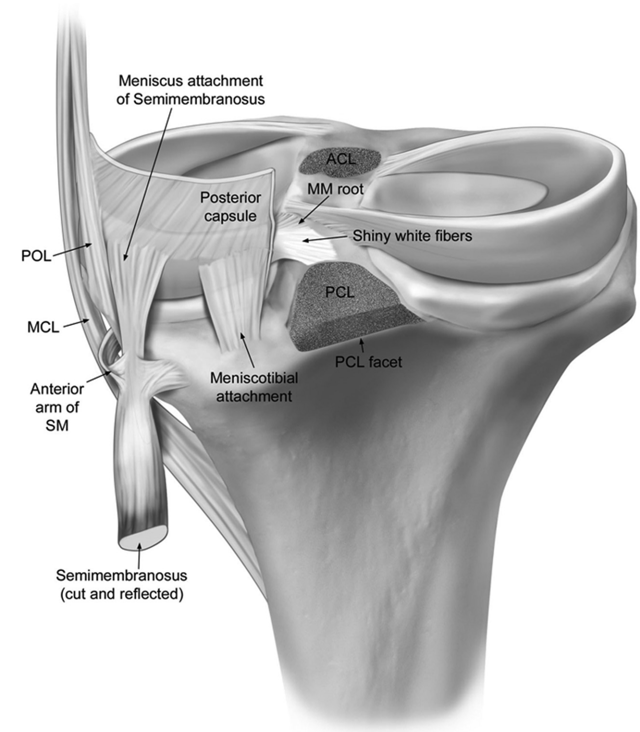

Figure 4. Posterior medial anatomy with the posterior capsule reflected. This figure illustrates the intimate relationship of the static and dynamic structures of the posteromedial corner, including the semimembranosus tendon fascial expansion that attached directly to the posterior horn of the medial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

3.6-11.1 mm) to the articular cartilage margin of the medial tibial plateau.

Semimembranosus Tendon

The semimembranosus tendon consisted of 2 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 mean length of the fascial attachment of the semimembranosus to the meniscus was 9.2 ± 2.1 mm (range, 5.1-12.5 mm). The mean curved distance of the semimembranosus attachment was located at 34.0% of the total meniscal length from the posterior medial meniscal root center.

Histology

Hematoxylin and eosin staining of the PHMM demonstrated a well-defined collagen structure and cell distribution that was typical of meniscal structure. Conversely, the meniscocapsular and meniscotibial attachments both demonstrated long fibers organized linearly, which is characteristic of collagen type I–expressing fibroblasts that compose ligaments. Across all specimens, these attachments showed similar structure, cell density, and fiber directionality. No histological differences were observed, and the 2 attachments merged at a common attachment site on the PHMM (Figure 5).

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

DISCUSSION

The main findings of the present study were that (1) there was a shared common attachment of the meniscocapsular and meniscotibial ligament attachments that merged into the PHMM and (2) 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

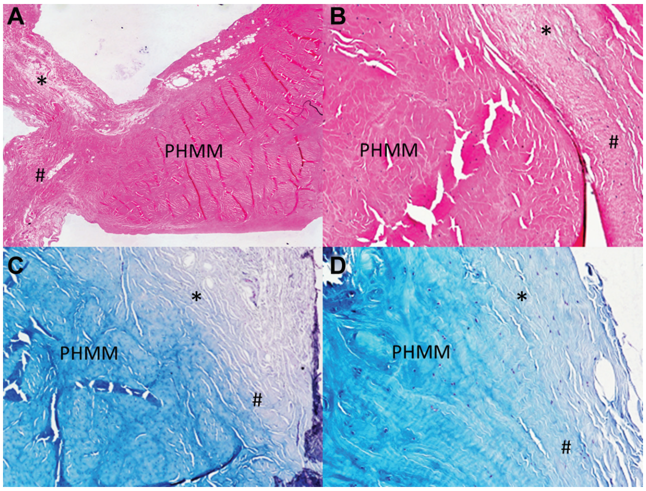

Figure 5. (A, B) Hematoxylin and eosin staining of the capsular and tibial attachments of the PHMM, demonstrating similar appearance of collagen type I and cell density with no observed differences between the attachments. (C, D) Glycosaminoglycan expression in meniscocapsular and meniscotibial attachments was visually similar, with a clear decrease in expression from high to low as the meniscus transitioned toward to the capsular and tibial attachments (anterior to posterior). (A, B) There is no difference in the fiber orientation between the meniscocapsular and meniscotibial attachments of the PHMM, while (C, D) these 2 structures are indistinguishable regarding their collagen composition as they converge and attach to the PHMM. (A) 2× magnification, (B-D) 4× magnification. *Meniscocapsular attachment. #Meniscotibial attachment. PHMM, posterior horn medial meniscus.

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 disprove 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 anatomic locations have been proposed as the site of injury. Originally, a ramp lesion was defined as a longitudinal tear 2.5 cm in length at the meniscocapsular junction.[22] In the current study, the posteromedial meniscocapsular junction was 2.0 cm long; thus, a 2.5-cm tear may not be an accurate definition for a ramp lesion. Similarly, Ahn et al[2] performed clinical follow-up with second-look arthroscopy and recommended that peripheral tears of the PHMM >1 cm be repaired during concomitant ACL reconstruction. In contrast, Liu et al[16] evaluated clinical outcomes at a mean follow-up of 2 years among patients with ACL reconstruction and concomitant stable ramp lesions <1.5 cm and reported no significant difference in outcomes between trephination and meniscal repair. The 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.

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[23] described a classification system for meniscal ramp lesions with 5 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 PHMM. Based on the findings of the current study, the previously described classification system may not be appropriate for surgical planning, because a tear in the meniscocapsular or meniscotibial attachment of the PHMM could dictate the same treatment (ie, repair).

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.[1,6,10,17,21] However, from our anatomic and histologic analysis, we found that these 2 structures share a common PHMM attachment; thus, we theorize that the meniscocapsular and meniscotibial attachments may function together as an anatomic unit. A recent biomechanical study supports the aforementioned 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.[10] This suggests that although ramp lesions may occur in 2 separate locations outside the meniscal substance of the PHMM, instead of at only 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 3 main fascial attachments that course from the distal semimembranosus tendon, previously termed the *superficial, central*, and *capsular arms*.[12] The central arm forms the main portion of the POL and, with the capsular arm, merges directly with the posteromedial capsule and attaches firmly to the PHMM.[13,14] These quantified anatomic descriptions may be useful for intraoperative planning during anatomic-based repair of POL tears in medial-sided knee injuries.[5]

The dMCL had a broad, firm meniscofemoral and meniscotibial attachment to the midbody of the medial meniscus, located between the meniscofemoral attachment of the POL and the anteromedial capsule.[7,14] The center of the dMCL meniscofemoral attachment was located at the midportion of the medial meniscus, with a mean curved distance of 50.5% of the total meniscal length. The dMCL meniscotibial attachment inserted a mean 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 meniscal stability. However, further biomechanical studies are needed to evaluate this anatomic relationship.

The present study has some limitations inherent to a cadaveric study design. To visualize the medial meniscus for measurements, the femur had to be sectioned sagittally. 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 2 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 anatomic 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 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, 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(suppl 1):S83-S89.
8. 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;45(10):2233-2237.
9. DePhillipo NN, Cinque ME, Kennedy NI, et al. Inside-out repair of meniscal ramp lesions. *Arthrosc Tech*. 2017;6(4):e1315-e1320.
10. 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;46(10):2422-2431.
11. 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.
12. 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.
13. 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.
14. 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.
15. 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.
16. 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.
17. 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.
18. 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.
19. 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.
20. 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.
21. 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.
22. Strobel MJ. Menisci. In: Fett HM, Flechtner P, eds. *Manual of Arthroscopic Surgery*. New York, NY: Springer; 1988:171-178.
23. 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.
24. 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;32(11):2269-2277.