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Qualitative and Quantitative Anatomic Analysis of the Posterior Root Attachments of the Medial and Lateral Menisci

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Background: The clinical importance of the meniscal posterior root attachments has been recently reported by both biomechanical and clinical studies. Although several studies have been performed to evaluate surgical techniques, there have been few studies on the quantitative arthroscopically pertinent anatomy of the posterior meniscal root attachments.

Hypothesis: The posterior root attachments of the medial and lateral menisci are consistent among specimens, and repeatable quantitative measurements using arthroscopically pertinent landmarks are achievable.

Study Design: Descriptive laboratory study.

Methods: Twelve nonpaired, fresh-frozen cadaveric knees were used. The positions of the posterior root attachments of the medial and lateral menisci were identified, and 3-dimensional measurements to arthroscopically pertinent landmarks were performed using a coordinate measuring system.

Results: The direct distance (±standard error of the mean) between the medial tibial eminence apex and the medial meniscus posterior root attachment center was 11.5 (±0.9) mm. When split into directional components along the knee's main axes, the medial meniscus posterior root attachment center was 9.6 (±0.8) mm posterior and 0.7 (±0.4) mm lateral along the bony surface from the medial tibial eminence apex. It was located 3.5 (±0.4) mm lateral from the medial articular cartilage inflection point and directly 8.2 (±0.7) mm from the nearest tibial attachment margin of the posterior cruciate ligament. The direct distance between the lateral tibial eminence apex and the lateral meniscus posterior root attachment center was 5.3 (±0.3) mm. When it was split into directional components using the knee's main axes, the lateral meniscus posterior root attachment center was 4.2 (±0.4) mm medial and 1.5 (±0.7) mm posterior from the lateral tibial eminence apex. The lateral meniscus posterior root attachment center was located 4.3 (±0.5) mm medial from the nearest articular cartilage margin and directly 12.7 (±1.1) mm from the nearest margin of the tibial attachment of the posterior cruciate ligament.

Conclusion: This quantitative study reproducibly identified the posterior root attachment centers of the medial and lateral menisci in relation to arthroscopically pertinent landmarks and guidelines.

Clinical Relevance: These data can be directly applied to assist in anatomic meniscal root repairs.

Keywords: meniscal posterior horn root attachments; medial meniscus; lateral meniscus; posterior cruciate ligament

Evidence supporting the importance of the posterior meniscal root attachments on maintenance of articular cartilage health has been well documented in the past few years,[1,8,11,16,20] yet few studies have reported their quantitative anatomic positions. It has been reported that a medial meniscal posterior root tear, which is the most likely meniscal attachment to sustain injury,[10,16] is functionally equivalent to a total medial meniscectomy.[1] Clinically, it has been reported that rapid progression of arthritis often accompanies a medial meniscal root tear because of the loss of its ability to resist hoop stresses and the significant alteration in its load-sharing ability as a result of medial meniscal extrusion.[3,16] Although it has been reported that the proper selection of anchoring sites for the posterior horns is likely of greater importance than the surgical technique of reinsertion of the

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attachments,[19] much of the new studies about meniscal root tears have focused on varying surgical techniques,[5,7,12,15,16] and there are few reports beyond the initial qualitative studies defining the anatomy of the posterior root attachments of the menisci.[9,13,16]

Studies have quantitatively described the locations of the anterior root attachments of the medial and lateral menisci in relation to bony and soft tissue landmarks,[4,9,13,18] but little research has quantitatively described the locations for the posterior root attachments. A detailed quantitative understanding of the arthroscopically pertinent anatomy of the posterior meniscal root attachments could ensure proper anatomic placement during root repair surgeries.

The purpose of this study was to further describe the qualitative, but more importantly to define the quantitative, anatomic locations of the posterior root attachments of the medial and lateral menisci with reference to arthroscopically pertinent landmarks. It was hypothesized that definable and consistent identification of the posterior root attachments of the medial and lateral menisci in relation to arthroscopically pertinent landmarks was possible. This information should result in more anatomic placement during meniscal root repairs.

MATERIALS AND METHODS

Specimen Preparation

Twelve nonpaired, fresh-frozen cadaveric specimens with an average age of 44.5 years (ranges 21-59 y; 4 female and 8 male) and no history of injury were used in the study. Institutional Review Board approval was not needed for this cadaveric study. All soft tissue, ligaments, and tendons were removed with the exception of both menisci. In addition, the attachments of the posterior meniscofemoral ligaments of Humphrey and Wrisberg, as well as the lateral meniscal attachments to the posterior aspect of the anterior cruciate ligament,[21] were excised from the lateral meniscus and were not measured in this study. The posterior root attachment centers were identified and the peripheries of the central fibers were marked with a permanent-ink pen by varying tension and positioning on the posterior horns of the menisci and outlining only the densest areas of the individual menisci's fiber bundles. The inferior portion of the transverse shiny white fibers of the posterior horn of the medial meniscus[2] were not measured concurrently with the densest fibers of the medial meniscal root attachment because our surgical technique and those of others have focused on root fixation of the main medial meniscal fiber bundle,[5,7,12,14,16] and their attachment is further distal and medial to the main posterior horn medial meniscal root attachment. After measuring 20 data points along the margins of the transverse shiny white fibers of the posterior horn of the medial meniscus, the menisci were sharply dissected from their bony attachments and removed. The margins of the attachment points were labeled in preparation for data collection.

System Validation

A coordinate measuring device was used to measure anatomic locations in 3-dimensional space using a calibrated stylus. To assess the accuracy of our device, a single-point articulation performance test (SPAT) was performed based on the B89.4 22 American Society of Mechanical Engineers (ASME) standard and the manufacturer's recommendations. At 10 locations, 10 points were recorded while the tip was placed in a kinematic seat, and the mechanical arm of the device rotated through its axis of motion. The average SPAT result was found to be 0.113 mm. The SPAT reflects both the repeatability and reproducibility of measurements using this device in our laboratory testing environment. Therefore, values under 0.113 mm may be attributed to error within the measurement system, and values greater than 0.113 mm may be considered significant.

Anatomic Measurements

Three-dimensional positional data were collected using a calibrated stylus that measured interspatial relationships between reference points. After secure fixation of the tibia, the pertinent landmarks were individually labeled and measured. The periphery of each root attachment was measured, and these values were used to calculate a footprint area using the Heron formula.[17] The following data points were also collected: root attachment centers, apexes of the tibial eminences, the articular cartilage inflection point as defined along the posterolateral edge of the medial tibial plateau and at the base of the medial tibial eminence, the posteromedial articular cartilage edge of the lateral tibial plateau, and the nearest tibial attachment of the posterior cruciate ligament (PCL) to each posterior meniscal root attachment center. All reported measurements were performed by the same individual (R.F.L.) to avoid interobserver variability.

Standard system software (MicroScribe Utility Software, version 6.0; Revware Inc, Raleigh, North Carolina) ran the MicroScribe system and exported the 3-dimensional coordinates of the measured data points to Microsoft Excel (Microsoft Corp; Redmond, Washington). For each specimen, the most medial, lateral, anterior, and posterior points of the tibial plateau were used to define a local coordinate system based on the specimen's anatomic directions. All measurements were made in these local coordinate systems. Pertinent 3-dimensional distances and areas were calculated, and some measurements were broken down into components using the knee's main axes: anterior/posterior, medial/lateral, and superior/inferior according to previously reported standard knee nomenclature.[6,21]

RESULTS

Measurements are reported in Tables 1 and 2, with visual interspatial relationships demonstrated in Figures 1 and 2. The most arthroscopically pertinent findings are reported.

TABLE 1
Reported Measurements Between the Medial and Lateral Meniscal Posterior Root Attachments and Arthroscopically Pertinent Landmarks[a]

	Average Distance ± SEM, mm	Direction
To medial meniscus posterior root attachment center from:		
Medial tibial eminence apex	11.5 ± 0.9	Posterior/inferior/lateral
Medial tibial eminence apex (medial-lateral distance)	0.7 ± 0.4	Lateral
Medial tibial eminence apex (anterior-posterior distance)	9.6 ± 0.8	Posterior
Medial tibial eminence apex (inferior-superior distance)	6.0 ± 0.6	Inferior
Medial articular edge inflection point (medial-lateral distance)	3.5 ± 0.4	Lateral
Nearest PCL edge	8.2 ± 0.7	Superior/anterior/medial
To lateral posterior root attachment center from:		
Lateral tibial eminence apex	5.3 ± 0.3	Medial/posterior/inferior
Lateral tibial eminence apex (medial-lateral distance)	4.2 ± 0.4	Medial
Lateral tibial eminence apex (anterior-posterior distance)	1.5 ± 0.7	Posterior
Lateral tibial eminence apex (inferior-superior distance)	1.4 ± 0.2	Inferior
Nearest lateral articular cartilage edge (medial-lateral distance)	4.3 ± 0.5	Medial
Nearest posterior cruciate ligament edge	12.7 ± 1.1	Anterior/superior/medial
Posterior edge of the anterior root attachment of lateral meniscus	10.1 ± 0.8	Posterior/superior/medial

[a]SEM, standard error of the mean.

TABLE 2
Area and Calculated Repair Tunnel Diameter Size for the Central Fibers for the Medial and Lateral Meniscal Posterior Root Attachments[a]

	Average Area ± SEM, mm^2	Tunnel Size, mm
Medial meniscus posterior root attachment	30.4 ± 2.9	6
Lateral meniscus posterior root attachment	39.2 ± 2.4	7
Shiny white fibers of medial meniscus	47.3 ± 4.4	Not applicable

[a]SEM, standard error of the mean.

All variations are reported as the standard error of the mean (SEM) among specimens. All vector measurements are reported, with component directions listed immediately afterward. Three-dimensional measurements between landmarks will be referred to as "direct" measurements.

Medial Meniscus Posterior Root Attachment

The posterior root attachment of the medial meniscus was qualitatively found to be posterior from the medial tibial eminence apex, lateral from the articular cartilage inflection point of the medial tibial plateau, and anteromedial from the PCL tibial attachment point. It was posteromedial from the lateral meniscus posterior root attachment (Figures 1 and 2).

Using quantitative descriptions, the direct distance between the medial tibial eminence apex and the medial meniscus posterior root attachment center was 11.5 (±0.9) mm. When it was split into directional components along the knee's main axes, the medial meniscus posterior root attachment center was 9.6 (±0.8) mm posterior and 0.7 (±0.4) mm lateral from the apex of the medial tibial eminence. The medial meniscus posterior root attachment center was located 3.5 (±0.4) mm lateral from the medial tibial plateau articular cartilage inflection point and directly anterior 8.2 (±0.7) mm from the most superior tibial attachment of the PCL (Table 1). The area of the medial meniscus posterior root attachment was 30.4 (±2.9) mm^2, whereas the area of the transverse shiny white fibers of the posterior horn of the medial meniscus was 47.3 (±4.4) mm^2 (Table 2).

Lateral Meniscus Posterior Root Attachment

The lateral meniscus posterior root attachment was qualitatively found to be posteromedial from the lateral tibial eminence apex, medial from the lateral articular cartilage edge, anterior from the PCL tibial attachment, and anterolateral from the medial meniscus posterior root attachment. In addition to its main root fiber attachment, there was a continuation of the posterior fibers that coursed to the posterior aspect of the lateral margin of the medial tibial eminence (Figures 1 and 2).

Using quantitative descriptions, the direct distance between the lateral tibial eminence apex and the lateral meniscus posterior root attachment center was 5.3 (± 0.3) mm. When split into directional components using the knee's main axes, the lateral meniscus posterior root attachment center was 4.2 (± 0.4) mm medial and 1.5 (±0.7) mm posterior from the lateral tibial eminence

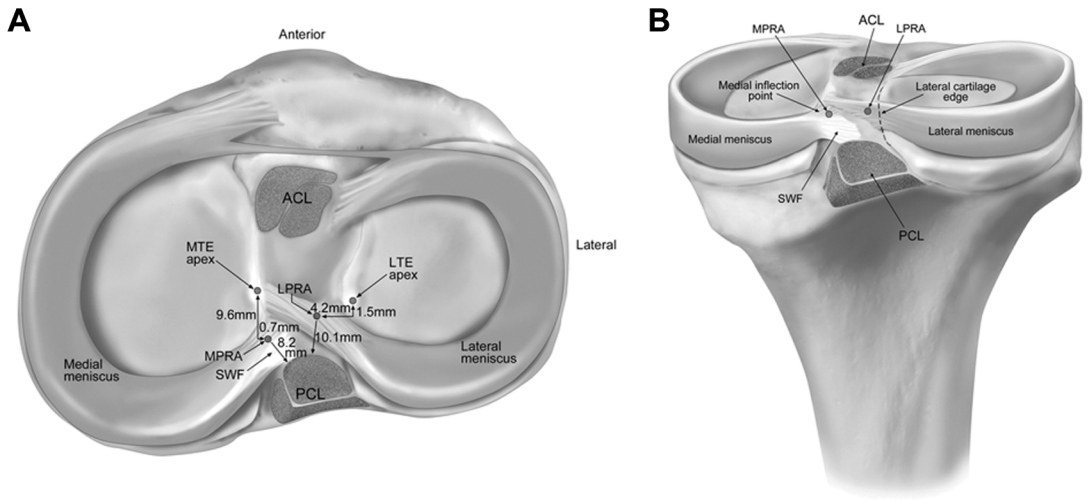

Figure 1. Illustration demonstrating the medial and lateral meniscal posterior root attachments and relevant arthroscopically pertinent anatomy (right knee). (A) Superior view and (B) posterior view. ACL, anterior cruciate ligament bundle attachments; LPRA, lateral meniscus posterior root attachment; LTE, lateral tibial eminence; MPRA, medial meniscus posterior root attachment; MTE, medial tibial eminence; PCL, posterior cruciate ligament bundle attachments; SWF, shiny white fibers of posterior horn of medial meniscus.

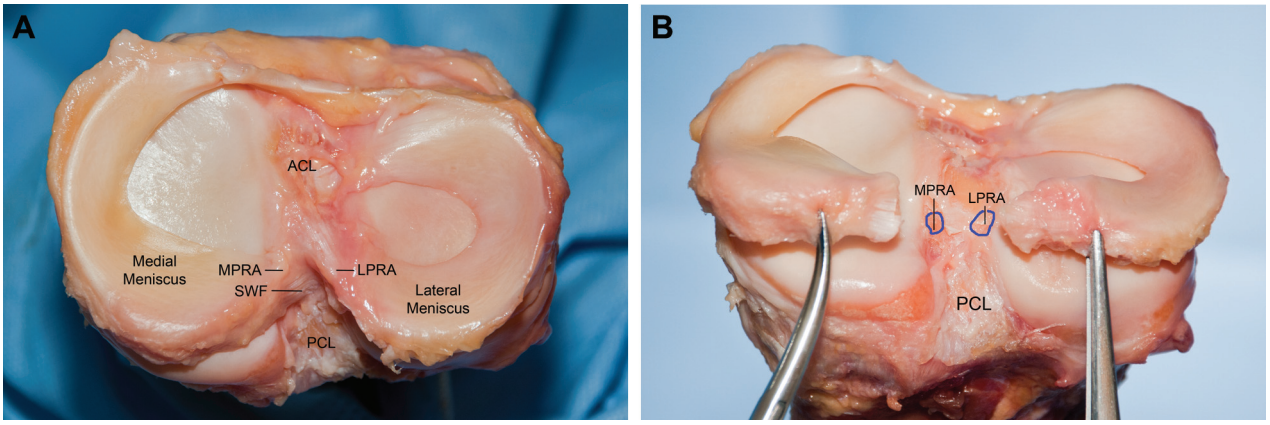

Figure 2. Photographs of the medial and lateral meniscal posterior root attachments and relevant arthroscopically pertinent anatomy. (A) Superior view and (B) posterior view. ACL, anterior cruciate ligament bundle attachments; LPRA, lateral meniscus posterior root attachment; LTE, lateral tibial eminence; MPRA, medial meniscus posterior root attachment; MTE, medial tibial eminence; PCL, posterior cruciate ligament bundle attachments; SWF, shiny white fibers of posterior horn of medial meniscus.

apex. The lateral meniscus posterior root attachment was located 4.3 (±0.5) mm medial from the nearest lateral tibial plateau articular cartilage margin, directly 12.7 (±1.1) mm from the most superior margin of the tibial attachment of the PCL, and directly 10.1 (±0.8) mm from the posteromedial corner of the anterior root attachment of the lateral meniscus (Table 1). The area of the lateral posterior root attachment was 39.2 (±2.4) mm^2 (Table 2).

DISCUSSION

We found reproducible distances from arthroscopically pertinent landmarks for the posterior root attachments of the medial and lateral menisci. We believe that the 3 most applicable and reproducible landmarks for the medial meniscus root attachment were (1) the distance from the medial tibial eminence, which was 9.6 mm posterior and 0.7 mm lateral; (2) the medial tibial plateau articular cartilage inflection point, where the medial meniscus posterior root attachment center was 3.5 mm lateral; and (3) the most proximal PCL tibial attachment, which was directly 8.2 mm from the medial posterior root attachment center. Intraoperatively, our findings suggest that one should first identify the medial tibial eminence apex, and, while applying proper directionality, track posterior along the bony surface to obtain an accurate identification of the anatomic attachment site of the medial meniscus root. After a provisional transtibial guide pin is placed for reaming a tunnel to repair the root attachment, the distance to the most

superior PCL edge and the distance to the medial tibial plateau articular cartilage inflection point can be used as secondary landmarks to ensure accuracy of the tunnel placement.

The most applicable findings of the lateral meniscus posterior root attachment center were (1) 1.5 mm posterior and 4.2 mm medial to the lateral tibial eminence apex, (2) 4.3 mm medial to the lateral tibial plateau articular cartilage edge, and (3) directly 12.7 mm to the most proximal edge of the PCL tibial attachment. We believe that similar methods can be used as with the medial meniscal posterior root attachment when locating this attachment site. These distances are arthroscopically pertinent because intraoperatively, the landmarks can be readily identifiable.

It has been widely reported that placement of the meniscus root attachments in proper anatomic locations is critical to restoring meniscus function.[7,19,20] However, there is still a lack of quantitative studies on the posterior meniscal root attachments. Several reports have qualitatively described the location of the medial meniscus posterior root attachment as directly anterior to the PCL tibial attachment and posteromedial to the root attachment of the lateral meniscus,[4,9,13] but arthroscopically pertinent quantitative anatomy measurements are required to improve surgical repairs.

The relationships between the PCL margins and the posterior meniscal root attachments are important to understand during both meniscal root repairs and PCL reconstructions. Nonanatomic tunnel placement in either of these surgeries may compromise other attachment points, leading to potential injuries of normal structures. Therefore, an understanding of the posterior tibial attachments of the menisci and the PCL, as well as assessment of guide pin placement before reaming of tibial tunnels, is critical to avoid PCL compromise in meniscal root repairs, and meniscal root compromise during PCL reconstructions.

The footprint area of the main central attachment fibers of the medial meniscus posterior root averaged 30.4 mm^2, which correlates to a 6-mm diameter tunnel size to reproduce the native attachment area. Our reported area is smaller than other reports because the transverse shiny white fibers of the medial meniscus were not considered part of the root attachment.[9,13] Upon inclusion of the transverse shiny white fibers of the medial meniscus,[2] in addition to the central fibers of the medial meniscus posterior root attachment, the sum of these 2 areas yielded a total area of 69.6 mm^2, which was similar to other reports of the medial meniscus posterior insertion area as 47.3 mm^2 and 80 mm^2.[9,13] Therefore, inclusion of the transverse shiny white fibers causes the overall area of the attachment fibers of the medial meniscus posterior root attachment to display a considerably larger area than the tunnel size used during root repair surgeries. This study used only the densest fibers of the medial meniscus root attachment, a method that has not been reported in prior anatomic studies. Placing the tunnel in the densest fiber area, and not solely using the geometric center point of the entire posterior meniscal horn attachment, should be considered to restore the function of the medial meniscus.

The lateral meniscus posterior root attachment footprint averaged 39.2 mm^2, which indicates the use of a 7-mm diameter tunnel could be used to replicate its attachment. This area also compares to previous reports of a lateral meniscus posterior root attachment area of 28.5 mm^2 and 115 mm^2.[9,13] The variation between these reported measurements likely results from differences in identification and measurement technique. We reported only the main fiber attachment area and did not include the lateral meniscal attachment, which coursed to the lateral edge of the medial tibial eminence (Figures 1A, 2A).

This is an anatomic study that describes the native anatomy of the meniscus root attachments. Further studies are needed to determine surgical outcomes using the anatomic locations described by these data. We also acknowledge that this study has some limitations. We used a relatively small specimen sample size. Also, calculation of the local coordinate system representing the anatomic directions of each knee was limited by our accuracy in selecting the pertinent anatomic points. These limitations could partially contribute to the minor variations reported within our measurements.

CONCLUSION

This quantitative study reproducibly identified the posterior root attachment centers of the medial and lateral menisci in relation to arthroscopically pertinent landmarks and guidelines. We recommend that these data be used as a basis for assistance in anatomic repairs for meniscal root tears.

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