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SCIENTIFIC ARTICLE

Distal insertions of the semimembranosus tendon: MR imaging with anatomic correlation

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Abstract
Objective The purpose of this study is to investigate the distal insertions of the semimembranosus tendon with MR imaging, correlated with findings in cadavers.
Materials and methods Four fresh cadaveric specimens were studied with 3-T MR imaging. Sequences included proton density (PD) sequences (TE, 13; TR, 4957; FOV, 170 × 170; matrix, 424 × 413; NA, 2; slice thickness, 2.5 mm) in the axial, coronal, and sagittal planes and 3D fast field echo (FFE) sequences (TR 9.4; TE 6.9; FOV, 159 × 105; matrix, 200 × 211; NA, 2; slice thickness, 0.57 mm). One specimen was dissected and three specimens were sectioned with a bandsaw in the axial, coronal, and sagittal plane. The sections were photographed and correlated with MR images. To standardize the analysis, the semimembranosus muscle and tendon were assessed at seven levels for the axial sections, and at three levels for the coronal and sagittal sections.
Results Anatomic dissection revealed six insertions of the distal semimembranosus tendon: direct arm, anterior arm, posterior oblique ligament extension, oblique popliteal ligament extension, distal tibial expansion (popliteus aponeurosis), and meniscal arm. Axial MR images showed five of six insertions: direct arm, anterior arm, oblique popliteal ligament extension, posterior oblique ligament extension, and distal tibial expansion. Sagittal MR images showed four of six insertions: direct arm, anterior arm, oblique popliteal ligament arm, and distal tibial expansion. Sagittal MR images were ideal for showing the direct arm insertion, but were less optimal than the axial images for showing the other insertions. The anterior arm was seen but volume averaging was present with the gracilis tendon. Coronal MR images optimally revealed the anterior arm, although magic angle artifact was present at its posterior aspect. The common semimembranosus tendon and meniscal arm were also well depicted. The division in anterior arm, direct arm, and oblique popliteal ligament arm was poorly seen on coronal images due to volume averaging.
Conclusions Although the anatomy of the distal semimembranosus tendon is complex, six different semimembranosus insertions can be identified on routine proton density and FFE sequences at 3 T. Analysis of images at defined levels in the three imaging planes simplifies MR interpretation of the anatomy of the distal semimembranosus tendon.

Keywords Knee, MR imaging · Knee, anatomy · Knee, posteromedial corner · Semimembranosus tendon

Introduction

Although much emphasis has been placed on the posterolateral corner of the knee, recent reports emphasize the importance of the posteromedial corner [1–7]. Posteromedial corner injuries have been implicated in knee instability including anteromedial rotatory instability and genu recurvatum instability [1–4]. The distal semimembranosus tendon is an important component of the posteromedial corner. Complex and combined ligament and tendon injuries of the posteromedial corner may benefit from surgical intervention [4, 8]. Few imaging studies address the posteromedial corner structures

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in detail, in particular the imaging anatomy of the distal semimembranosus tendon [6, 9, 10]. The anatomy of this region is complex, evidenced by somewhat conflicting observations in the surgical, anatomical, and imaging literature [1, 2, 6, 7]. Robinson et al. [2] summarize the observations by different researchers, while LaPrade et al. [1] present the most detailed surgical anatomical study of the posterior aspect of the knee (Fig. 1). Several components of the posteromedial corner are recognized and include the medial collateral ligament, posterior oblique ligament, distal semimembranosus tendon, medial gastrocnemius tendon, and oblique popliteal ligament. The anatomy of the distal semimembranosus tendon is quite complex. Several insertions have been described. The distal arm attaches directly in a groove at the posteromedial aspect of the tibia. The anterior arm courses more anteriorly and attaches to the tibia deep to the medial collateral ligament. A broad component extends into the oblique popliteal ligament, which courses along the posterior capsule of the knee [1, 2]. The insertion that is directed towards the components of the posterior oblique ligament has been described as the capsular arm. A short meniscal arm attaches to the coronary ligament of the posterior horn of the medial meniscus. A distal arm also extends over the popliteus muscle. Additional connections to the posterior capsule and lateral meniscus have been reported [1, 2]. The purpose of our work was to investigate the imaging anatomy of the different insertions of the distal semimembranosus tendon by correlating magnetic resonance (MR) images and cadaveric sectional anatomy.

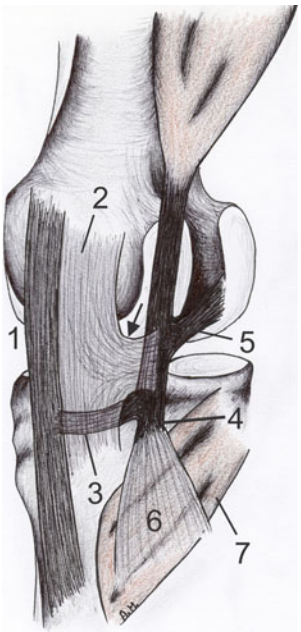

Fig. 1 Posteromedial aspect of the knee. The different insertions of the distal semimembranosus tendon are shown. *1* medial collateral ligament; *2* posterior oblique ligament and its arm (*arrow*) extending from semimembranosus tendon; *3* anterior arm; *4* direct arm; *5* oblique popliteal ligament extension; *6* distal tibial arm (popliteus aponeurosis); *7* popliteus muscle

Materials and methods

Our study was approved by the institutional review board. The donors had provided written approval for using their body for scientific research after death. Four fresh cadaveric specimens were harvested immediately after death and were deep frozen to −30 °C. All specimens were derived from elderly subjects. The specimens were thawed at room temperature for 24 h. MR imaging was performed on a 3-Tesla MR system (Achieva; Philips, Best, The Netherlands). Sequences included proton density-weighted (PD) images in the three imaging planes and 3D fast field echo (FFE) sequences. Parameters for the PD

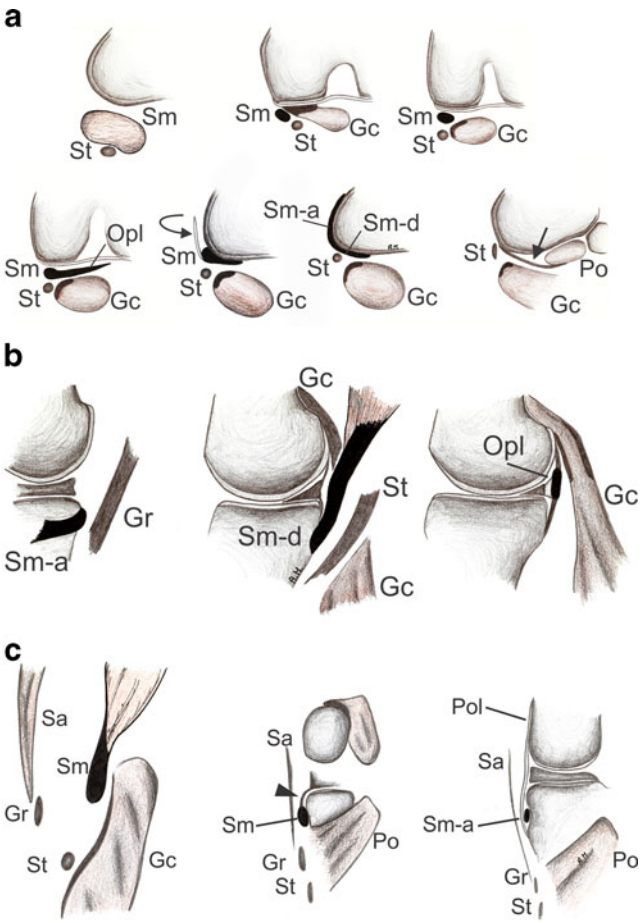

Fig. 2 **a**, **b**, **c** Assessed imaging levels in the axial (**a**), sagittal (**b**), and coronal (**c**) planes. Note varying relationship between medial gastrocnemius and semimembranosus tendon. *Sm* semimembranosus; *Gc* medial gastrocnemius tendon; *St* semitendinosus tendon; *Gr* gracilis tendon; *Opl* oblique popliteal ligament extension of the semimembranosus; *Sm-a* anterior arm of the semimembranosus tendon; *Sm-d* direct arm of the semimembranosus tendon; *Pol* posterior oblique ligament; *Po* popliteus muscle. On axial levels: *arrow*- distal tibial expansion of the semimembranosus; *curved arrow*-posterior oblique ligament extension. Coronal levels: *arrowhead*- meniscal arm

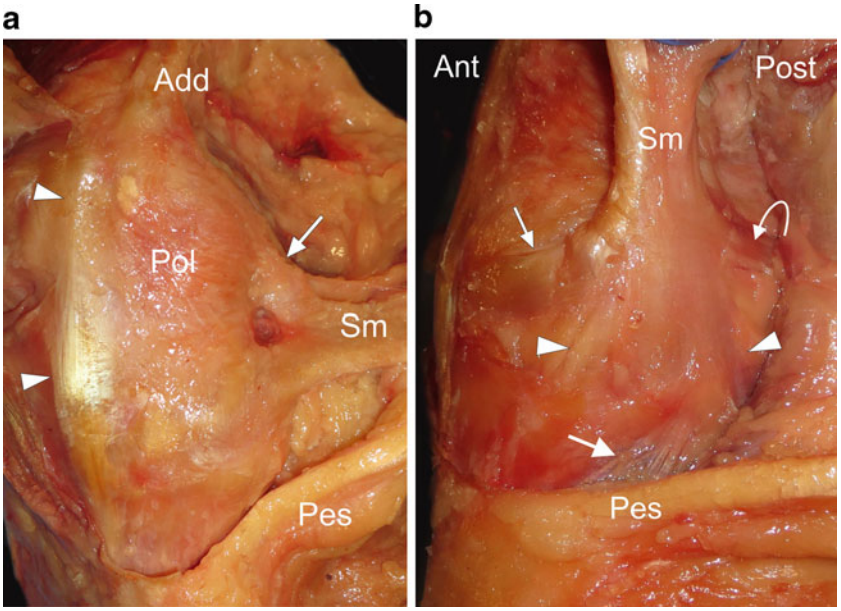

Fig. 3 **a**, **b** Anatomical dissection showing more superficial (**a**) and deep (**b**) structures. **a** Anteriorly, the whitish appearing medial collateral ligament is outlined (*arrowheads*). Posteriorly, the posterior oblique ligament is seen (*Pol*). Note posterior oblique ligament arm (*arrow*) of the semimembranosus tendon (*Sm*). The superior insertion of the posterior oblique ligament is in between the femoral insertion of the medial collateral ligament and the adductor tubercle (*Add*). Pes anserinus (*Pes*) is also noted. **b** Posteromedial view with deeper dissection. Note common semimembranosus tendon (*Sm*). The different insertions are seen. Note direct arm (between *arrowheads*), anterior arm (*thin arrow*), oblique popliteal ligament extension (*curved arrow*) and distal tibial expansion (*thicker arrow*). *Pes* pes anserinus

sequence were: TE, 13; TR, 4,957; FOV, 170 × 170; matrix, 424 × 413; NA, 2; slice thickness, 2.5 mm. Parameters for the FFE sequence were: TR 9.4; TE 6.9; FOV, 159 × 105; matrix, 200 × 211; NA, 2; slice thickness, 0.57 mm. After imaging, the specimens were deep frozen again for preservation. One specimen was thawed and dissected in three consecutive 3-h sessions spread over 1 month, being refrozen in between sessions. Three specimens were sectioned with a bandsaw while frozen (NSV, Modena, Italy), this in the axial, coronal, and sagittal planes. The sections were photographed and correlation with MR images was done by consensus of two readers. For systematic imaging analysis, the posteromedial corner was assessed in seven levels for the axial sections (from superior to inferior), in three levels for the sagittal sections (from medial to lateral), and in three levels for the coronal sections (from posterior to anterior) (Fig. 2). For presentation of findings, contrast of the photographs was optimized and the background was darkened.

Table 1 Overview of different insertions of the semimembranosus tendon (SM). Medial collateral ligament (MCL) ; posterior oblique ligament (POL); Sag, sagittal plane; Ax, axial plane; Cor, coronal plane

Insertion	Course and Insertion	Imaging planes
Direct	From common SM tendon towards posterior aspect of tibia 1 cm below joint	Sag>Ax>Cor
Anterior	From common SM tendon along posteromedial tibia, inserts deep to MCL	Cor=Ax>Sag
Oblique popliteal ligament	From common SM tendon towards oblique popliteal ligament	Ax>Sag
Posterior oblique ligament	Sheath over SM tendon at level of joint space coursing towards POL	Ax
Meniscal	From SM towards coronary ligament of posterior horn of medial meniscus	Cor
Distal	From distal aspect of SM tendon over popliteus muscle	Ax=Sag

Results

Anatomical dissection

After removal of the skin and subcutaneous fat, the fibrous sheath covering the distal semimembranosus tendon was revealed (Fig. 3a). In its anterior aspect, this fibrous sheath formed an expansion that was in continuity with the posterior oblique ligament. The different arms of the posterior oblique ligament were not discernable. The entire posterior oblique ligament was inseparable from the capsule and extended from the posterior margin of the superficial medial collateral

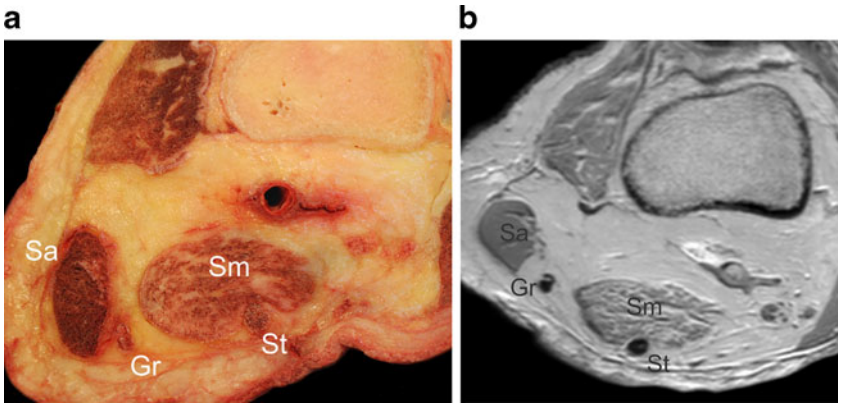

Fig. 4 **a**, **b** Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 1. The semitendinosus tendon (*St*) is located superficial to the semimembranosus muscle (*Sm*), the configuration has a 'cherry on the pie' appearance. Note slight fatty infiltration in semimembranosus muscle belly present in this specimen. Gracilis (*Gr*) tendon and sartorius muscle (*Sa*) are also seen

ligament to the sheath covering the semimembranosus tendon. The medial collateral ligament could be seen as a whitish band-like structure extending from the femoral epicondyle towards the tibia. At its inferior aspect, the tibial attachment of the medial collateral ligament was covered by the pes anserinus tendons.

With deeper dissection, the common semimembranosus tendon was seen (Fig. 3b). It fanned out in a broad structure inferiorly made up of the direct and anterior arms. No clear separation between the arms was seen. The arms had a tendinous appearance. The anterior arm extended about 1 cm below the joint line, along the posteromedial aspect of the tibia, and in its anterior part was covered by the medial collateral ligament. When the transition area between direct and anterior arm was sectioned, it was seen to be covered at its medial and lateral aspect by a synovial lining corresponding to the semimembranosus bursa. After sectioning of the anterior arm and dissection along the transition area between the direct and anterior arms, a small band-like extension was seen connecting the semimembranosus tendon to the meniscotibial ligament (coronary ligament) of the posterior horn of the medial meniscus. This band corresponded to the meniscal arm. The distal tibial expansion (popliteal aponeurosis) was seen as a fascia-like structure extending from the inferior aspect of the direct arm over the popliteus muscle (Fig. 3).

For posterolateral dissection, the medial gastrocnemius tendon was sectioned and the soft tissues covering the posterior aspect of the knee were removed. The common semimembranosus tendon could be seen to expand in the oblique popliteal ligament. The latter coursed along the posterior knee capsule (Fig. 3). It had a whitish appearance differentiating it from the rest of the posterior capsule.

MR imaging of the dissected specimen allowed visualization of the oblique popliteal ligament extension in the axial and sagittal plane. The direct arm was best seen in the sagittal plane, the anterior and meniscal arm in the coronal plane, and the distal tibial expansion in the sagittal and axial plane. The extension to the posterior oblique ligament was seen only in the axial plane.

MR and cadaveric sections

On MR images and cadaveric sections, the distal extensions of the semimembranosus tendon were analyzed in the three planes for visualization of components (Table 1). On MR images, all insertions exhibited low signal intensity except for the anterior

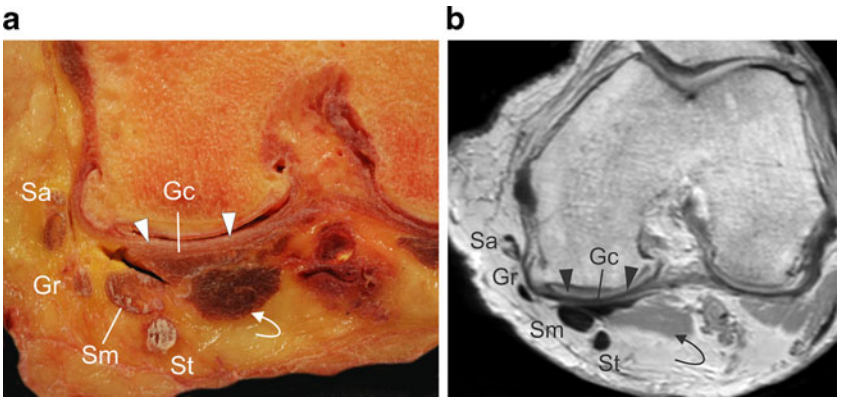

Fig. 5 **a**, **b** Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 2. The insertion of the medial gastrocnemius tendon (*Gc*) on the posterior capsule (*arrowheads*) is seen. Muscle belly of the medial gastrocnemius (*curved arrow*) is located posterolateral to tendon. Note more medial position of semimembranosus tendon (*Sm*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons

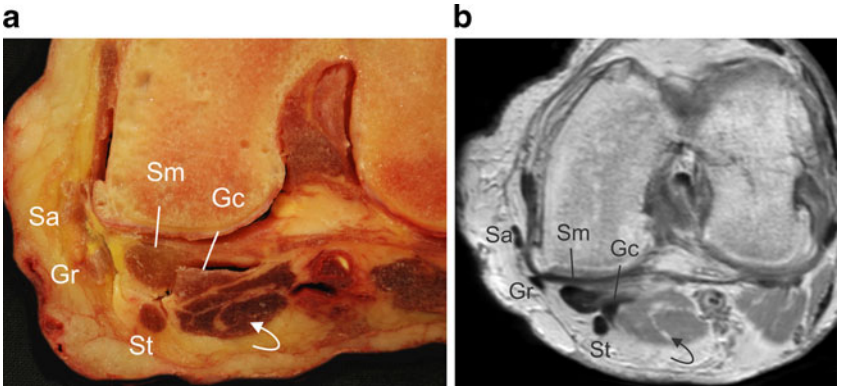

Fig. 6 Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 3. The semimembranosus tendon (*Sm*) is located immediately adjacent to the medial gastrocnemius (*Gc*) tendon in the same coronal plane. An oval shape of semimembranosus tendon and a C-shape of the medial gastrocnemius tendon are seen. Muscle belly of the medial gastrocnemius is located posterolaterally with respect to tendon (*curved arrow*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons

arm on coronal and axial images due to magic angle artifact. All findings were seen on PD and FFE images. The extension to the oblique popliteal ligament was depicted less well on FFE images, whereas the anterior arm was more clearly separable from the overlying structures on this sequence.

In the axial plane, the relationship between semimembranosus and medial gastrocnemius tendons was best seen, as were the divisions in the major insertions. Most superiorly, the semitendinosus tendon was seen to be located superficial to the semimembranosus muscle belly (Fig. 4). More inferiorly, the common semimembranosus tendon formed, and the origin of the medial gastrocnemius tendon from the posterior capsule was seen (Fig. 5). At the next level, the common semimembranosus tendon coursed adjacent to the medial gastrocnemius tendon and muscle, both located in the same coronal plane (Fig. 6). Inferior to this level, the broad band-like extension of the common semimembranosus tendon in the oblique popliteal ligament was seen (Fig. 7). The signal intensity of the oblique popliteal ligament extension was slightly lower than that of the common semimembranosus tendon. Below this level the extension to the posterior oblique ligament was seen as a band like area coursing along the superficial aspect of the semimembranosus tendon (Fig. 8). More inferiorly, the semimembranosus tendon fanned out to form the anterior and direct arms. Both arms inserted along the posteromedial aspect of the tibia, the anterior arm more anterior relative to the direct arm (Fig. 9). Slight magic angle artifact was seen in the anterior arm. More inferiorly, a thin band-like structure was seen to extend from the distal aspect of the direct arm over the popliteus muscle, corresponding to the distal tibial expansion (Fig. 10).

In the sagittal plane at the most medial level analyzed, the anterior arm of the semimembranosus tendon was seen, but its posterior margin was difficult to differentiate from the gracilis tendon due to volume averaging (Fig. 11). On the next more lateral level, the direct arm insertion on the posterior tibia was best seen (Fig. 12). On proton density and FFE images, thin hyperintense striations were seen in the direct arm. More laterally, the oblique popliteal ligament was seen as a band-like structure embedded in the posterior knee capsule (Fig. 13).

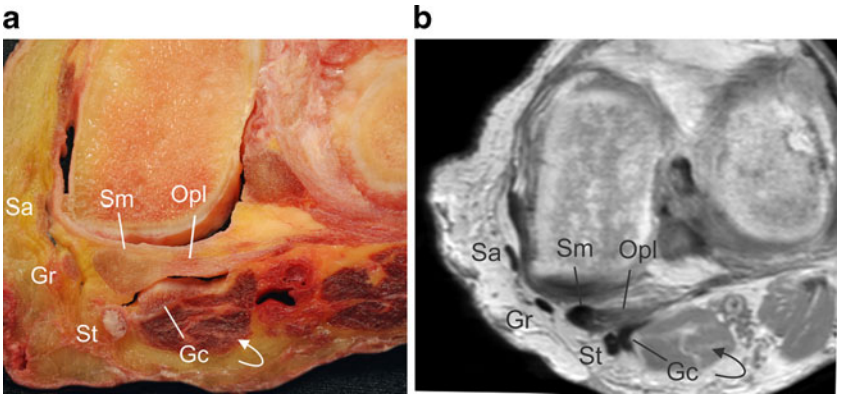

Fig. 7 **a**, **b** Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 4. The oblique popliteal ligament extension is seen (*Opl*) to extend laterally from the semimembranosus tendon (*Sm*). Signal of oblique popliteal ligament extension is slightly higher than that of semimembranosus tendon. Medial gastrocnemius tendon (*Gc*) is superficial to oblique popliteal ligament. Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons. Gastrocnemius muscle belly (*curved arrow*)

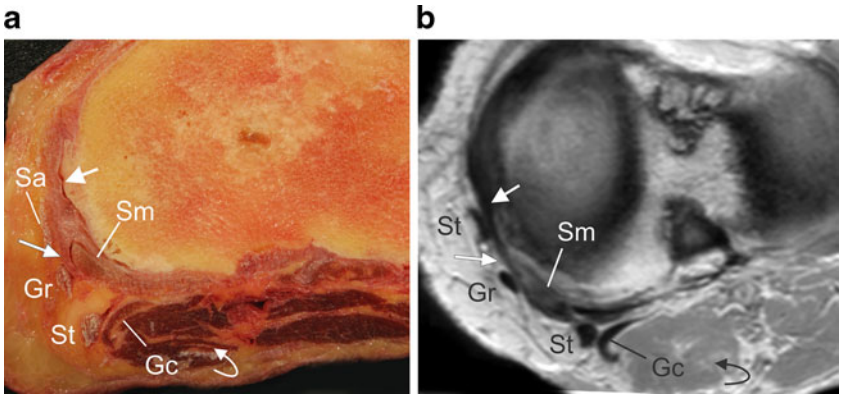

Fig. 8 **a**, **b** Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 5. The extension to the posterior oblique ligament (*arrow*) is seen to course from the sheath covering the semimembranosus tendon (*Sm*) towards the posterior oblique ligament (*short arrow*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons. Gastrocnemius muscle (*curved arrow*)

In the coronal plane, at the most posterior level, the common semimembranosus tendon was seen (Fig. 14). At the next more anterior level, the tendon fanned out to form anterior and direct arms, but the visualization was limited due to volume averaging. First, the transition zone between direct and anterior arms was seen, and next the posterior aspect of the anterior arm (Fig. 15). At the posterior aspect of the anterior arm, marked magic angle artifact was present both on proton density and FFE sequences. At this level, the small band-like meniscal arm was also depicted. At the next more anterior level, the anterior arm was thinner and located deep to the posterior aspect of the medial collateral ligament (Fig. 16). The coronal plane was best at showing the anterior arm.

Discussion

The anatomy of the posteromedial corner of the knee is complex. Recent studies suggest that the different components including the medial collateral ligament, posterior oblique ligament, and distal semimembranosus tendon are functionally different [2, 10]. Isolated medial ligamentous injuries are often not repaired. However, combined and complex injuries of the posteromedial structures may benefit from surgical reconstruction [8]. If such interventions are not performed, chronic pain, genu recurvatum instability, anteromedial rotatory instability, and cruciate graft failure may occur [1–4, 10].

The semimembranosus tendon is a major component of the posteromedial corner. Part of the hamstrings muscles, it arises with the biceps femoris and semitendinosus from the ischial tuberosity. The semimembranosus tendon stabilizes the posterior capsule through its connection with the oblique popliteal ligament. It acts synergistically with the popliteus muscle by its expansion over this muscle. The connection to the posterior oblique ligament provides stability to the medial aspect of the joint [7]. In knee extension, the semimembranosus tendon prevents valgus, whereas in knee flexion it prevents external rotation. During knee flexion, the semimembranosus tendon retracts the medial meniscus posteriorly [3, 11].

Several attachments of the distal semimembranosus tendon have been described, with general agreement regarding three of those (Fig. 1) [1, 2, 12]. The arms that are agreed upon include the direct arm, anterior arm, and expansion in the oblique popliteal ligament. Other insertions include connections to the components of the posterior oblique ligament, meniscal arm, distal tibial arm (or popliteal aponeurosis),

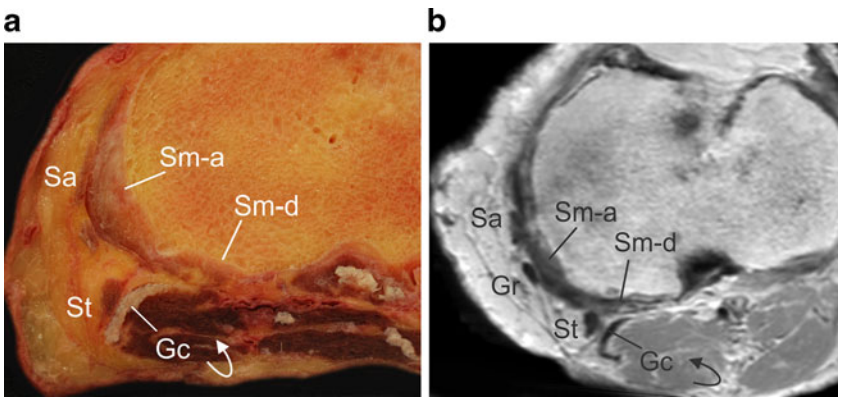

Fig. 9 **a**, **b** Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 6. Semimembranosus tendon is seen to fan out in anterior (*Sm-a*) and direct (*Sm-d*) arms. Note C-shaped medial gastrocnemius tendon (*Gc*), and adjacent muscle belly (*curved arrow*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons

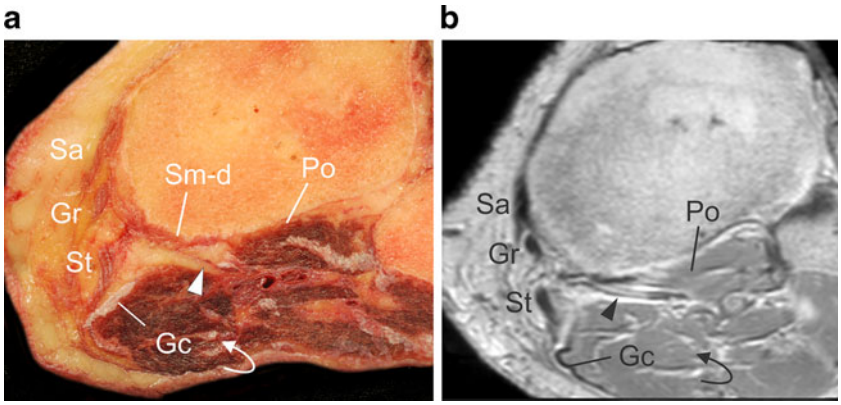

Fig. 10 **a**, **b** Axial anatomical slice (**a**) and axial proton density-weighted MR image (**b**) at level 7. The distal tibial expansion of the semimembranosus is seen (*arrowhead*) extending over popliteus muscle (*Po*). Note medial gastrocnemius tendon (*Gc*), and adjacent muscle belly (*curved arrow*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons

and proximal posterior capsular arm. The description of the distal semimembranosus tendon is complicated by variable terminology. We prefer terminology presented by LaPrade et al. but also include other terminologies in our discussion for completeness [1].

The posterior oblique ligament is located posterior to the superficial medial collateral ligament (Fig. 3a) [11]. It is made up of a capsular, central and superficial part, also designated as 'arms', which should not be confused with the insertions of the semimembranosus some of which are also referred to as 'arms' [2, 8, 12, 13]. The posterior oblique ligament is considered by some anatomists to be part of the medial collateral ligament, representing its posterior extension, but by others as a separate structure [10]. What is certain is that it is functionally different from the medial collateral ligament [10].

The semimembranosus tendon connects to the posterior oblique ligament, but it is mentioned by Warren et al. [14] that it is the tendon sheath rather than the tendon itself that attaches here (Figs. 3a and 8). The term 'capsular arm' has been used [7] to describe this connection. LaPrade et al. describes this region as 'the extension to components of the posterior oblique ligament (capsular, tibial, and superficial arm)'. Since the semimembranosus tendon may contribute to the several 'arms' of the posterior oblique ligament [1], we feel the designation 'posterior oblique ligament arm' may be appropriate to describe this extension. In our anatomical dissections, we were able to discern the fibrous sheath covering the semimembranosus tendon. It extended anteriorly in continuity with the posterior oblique ligament (Figs. 3a and 8). The discrete arms making up the posterior oblique ligament were not discernable in our study, a finding that is in agreement with the observations of Robinson et al. [2]. The extension of the semimembranosus tendon to the posterior oblique ligament was seen on our dissection, axial anatomic sections, and MR images (Figs. 3a and 8) [7]. This extension expanded from the sheath covering the distal semimembranosus tendon towards the posterior oblique ligament and was best seen in an axial plane at the level of the joint space. This extension is generally

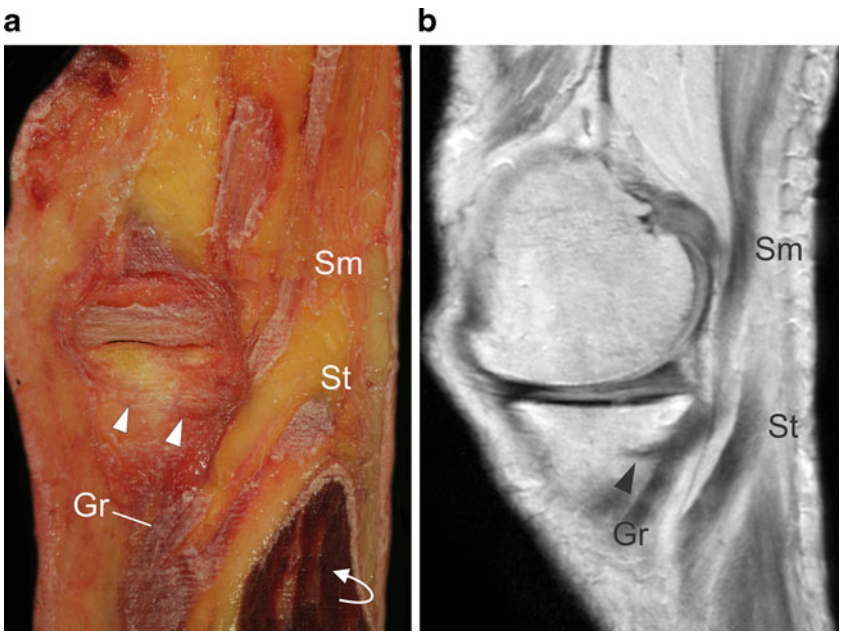

Fig. 11 **a**, **b** Sagittal anatomical slice (**a**) and sagittal proton density-weighted MR image (**b**) at level 1. The anterior arm (*arrowheads*) is noted about 1 cm below the joint line. The common semimembranosus tendon (*Sm*) is located more posteriorly deep to the semitendinosus tendon (*St*). Also note gracilis (*Gr*) and gastrocnemius muscle belly (*curved arrow*). Gracilis is adjacent to anterior arm of semimembranosus and this causes volume averaging

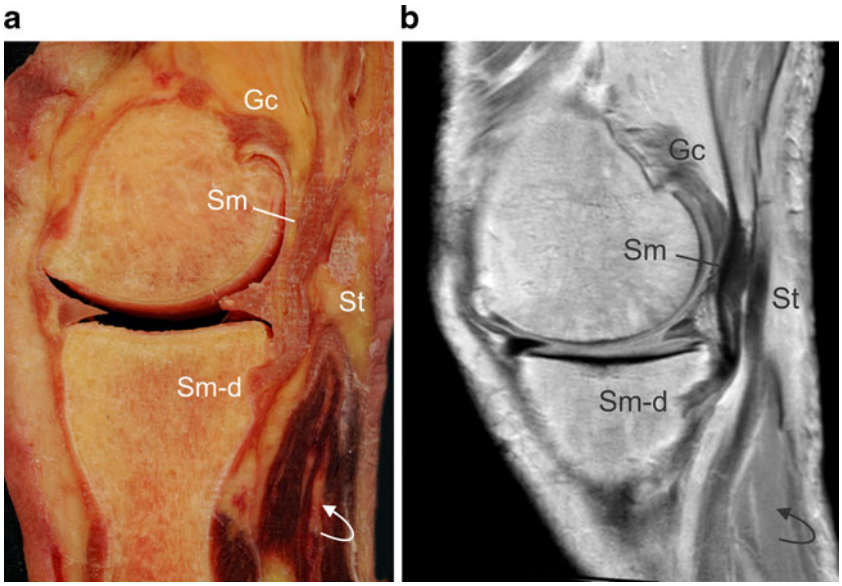

Fig. 12 **a**, **b** Sagittal anatomical slice (**a**) and sagittal proton density-weighted MR image (**b**) at level 2. Direct arm (*Sm-d*) insertion is seen at posterior tibia. The common semimembranosus tendon (*Sm*) is seen in continuity with the direct arm (*Sm-d*). Note striations in insertion corresponding to normal fatty streaks or magic angle artifact. Note attachment of gastrocnemius tendon (*Gc*) on posterior capsule and gastrocnemius muscle (*curved arrow*)

regarded as an important structure in posteromedial knee stability. We found it to be relatively thin and since it has an oblique course, this may explain why it is difficult to visualize it on coronal and sagittal MR images and anatomic sections. Beltran et al. [7] report that the extension to the posterior oblique ligament could be better seen with distension of the joint, and in our specimens there was no joint effusion and we did not obtain MR arthrographic images in our study.

In its course, the common semimembranosus tendon is located adjacent to the medial gastrocnemius tendon (Figs. 5, 6, 7, 12, and 13). The common semimembranosus tendon forms a tendinous expansion towards the oblique popliteal ligament about 2 cm above the joint line (Figs. 7 and 13). The oblique popliteal ligament is a fascial sheet over the posterior knee with a length of 5 cm and a width of 1–1.5 cm. At the posterolateral aspect of the knee, there are attachments to the posterior capsule, fabella (bony or cartilaginous), and tibia [1]. LaPrade et al. [1] report the extension to the oblique popliteal ligament and the oblique popliteal ligament itself as two separate structures, but we were unable to make this distinction. The extension to the oblique popliteal ligament is best assessed on axial images. Its signal intensity is slightly higher than that of the common tendon (Fig. 7). On sagittal images, it appears embedded in the posterior capsular structures deep to the medial gastrocnemius muscle and tendon (Fig. 13). The oblique popliteal ligament arm cannot be discerned on coronal images due to partial volume averaging.

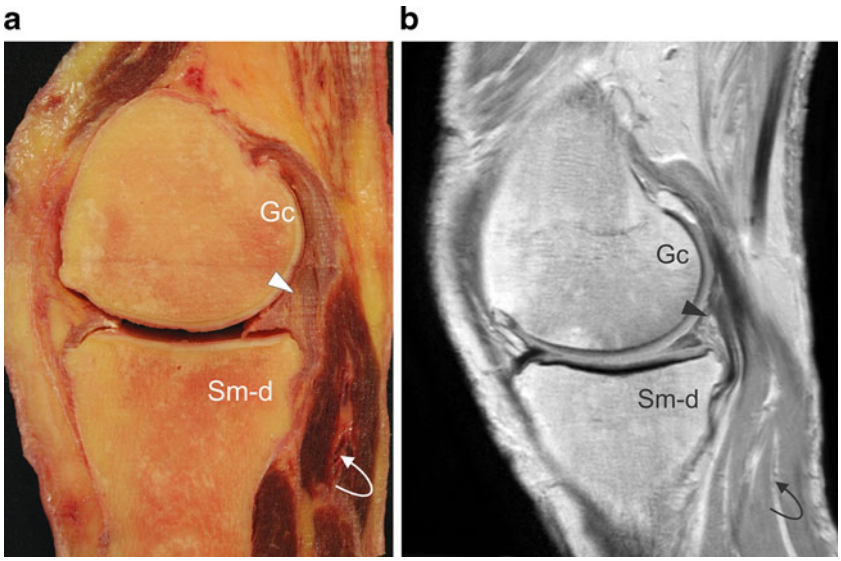

Fig. 13 **a**, **b** Sagittal anatomical slice (**a**) and sagittal proton density-weighted MR image (**b**) at level 3. The oblique popliteal ligament (*arrowhead*) is seen embedded in the posterior capsule. Note gastrocnemius tendon (*Gc*) and muscle (*curved arrow*). *St* semitendinosus. Lateral fibers of direct arm (*Sm-d*) are also seen

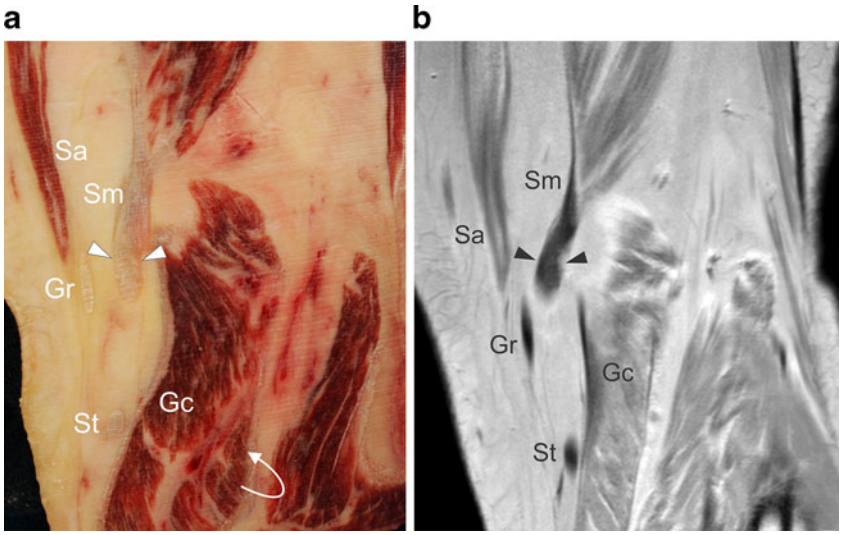

Fig. 14 **a**, **b** Coronal anatomical slice (**a**) and coronal proton density-weighted MR image (**b**) at level 1. The common tendon of the semimembranosus is seen (*Sm*, *arrowheads*). Note medially located medial gastrocnemius tendon (*Gc*) and lateral muscle belly (*curved arrow*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons

More distally, the semimembranosus tendon broadens and fans out to form the direct and anterior arms (Figs. 3b, 9 and 15C) [1]. On dissection, at this level, both arms are not separable. The direct arm courses directly inferiorly and attaches to the tibia in a groove at the posteroinferior aspect of the tibia, about 1 cm distal to the joint line (Figs. 9 and 12). The inferior margin of the groove is termed the tuberculum tendinis [1, 2]. Although this tuberculum has been defined as the insertion point, we found in our anatomical specimens that the footprint corresponds to a larger oval-shaped area with a diameter of 1 cm centered at the groove. The direct arm insertion is best seen on sagittal MR images (Fig. 12). At its insertion site, hyperintensity can be appreciated in the tendon, and should not be considered abnormal. It has been suggested that this hyperintensity is caused by accumulation of fat in the tendon [7, 11]. Magic angle artifact also could cause this hyperintensity, given the abrupt angle change. In the axial plane, the direct arm appears in continuity with the anterior arm, and both insertions together form a C-shaped 5-mm-thick band covering the posteromedial aspect of the tibia (Fig. 9). On axial images, only at the most distal aspect of the insertion of the direct arm it is separable from the anterior arm. On coronal images, assessment of the direct arm is hampered by partial volume averaging (Fig. 15c).

The anterior arm is a thick tendinous structure arising at the anteromedial aspect of the distal semimembranosus tendon. It

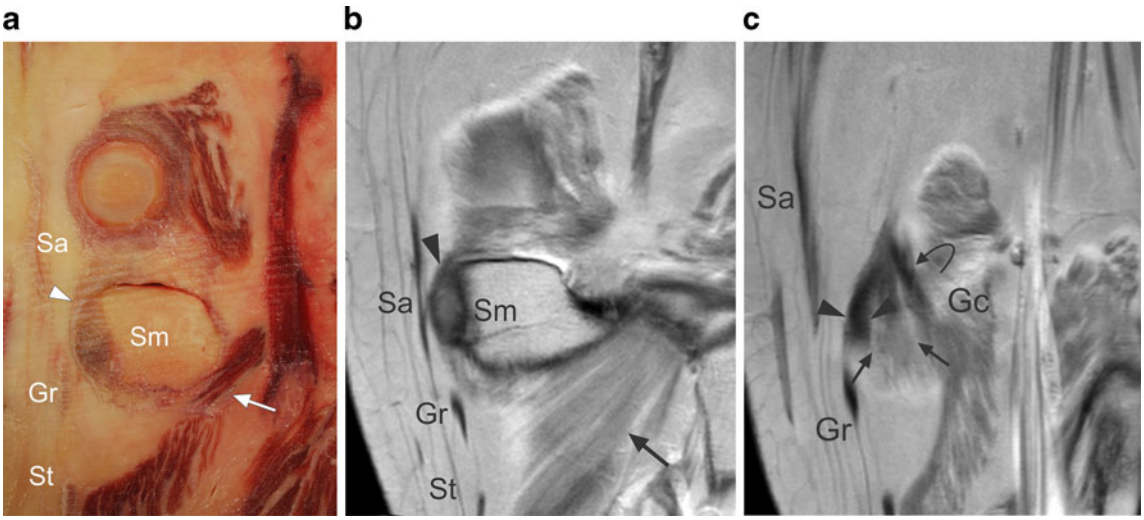

Fig. 15 **a**, **b**, **c** Coronal anatomical slice (**a**) and coronal proton density-weighted MR image (**b**, **c**) at level 2. **c** Slightly more posterior than **b**. **a**, **b** Level of most posterior aspect of anterior arm of semimembranosus (*Sm*). SM tendon is located in sulcus at posteromedial tibia. Thin meniscal arm is seen (*arrowhead*) to extend towards meniscotibial band of posteromedial meniscus. Note popliteus muscle (*arrow*). Also note semitendinosus (*St*), gracilis (*Gr*), and sartorius (*Sa*) tendons. **c** Slightly more posterior level. Transition zone between anterior and direct arms (compare to Fig. 3b). Note direct arm (between *arrows*), anterior arm (between *arrowheads*). Volume averaging is present. *Gc* gastrocnemius muscle; *curved arrow* gastrocnemius tendon. Also note Sartorius (*Sa*) and gracilis tendons (*Gr*)

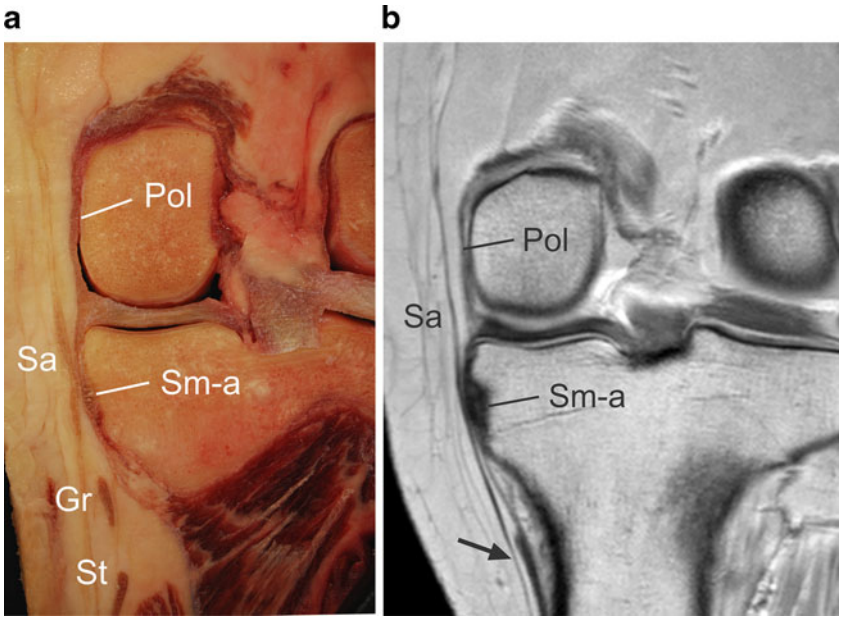

Fig. 16 **a**, **b** Coronal anatomical slice (**a**) and coronal proton density-weighted MR image (**b**, **c**) at level 3. Level at more anterior aspect of the anterior arm (Sm-a) where it is thinner and located deep to the posterior oblique (*Pol*). Note Sartorius (*Sa*), gracilis (*Gr*) and semitendinosus tendon (*St*). On MR imaging, gracilis and semitendinosus cannot be separated (*arrow*)

has also been referred to as reflected tendon, pars reflexa, and tibial arm [1, 6, 13]. The designation 'tibial arm' should not be confused with the 'distal tibial expansion' used by LaPrade et al. [1] and discussed later. At its posterior aspect, the anterior arm is thick and rounded whereas along its anterior aspect it becomes thinner (Figs. 3b, 9, 15 and 16). This anterior insertion is located deep to the tibial attachment of the superficial band of the MCL. The anterior arm can be best evaluated on coronal MR imaging (Fig. 16). Its anterior insertion deep to the medial collateral ligament can be easily discerned (Fig. 16). Along its thicker posterior portion, magic angle artifact is present due to the oblique course of the tendon and this should not be mistaken for evidence of tendinosis (Fig. 15). Magic angle artifact was also present in the anterior arm on axial MR images (Fig. 9). On sagittal MR images, the anterior arm was visualized with some volume averaging from the adjacent gracilis tendon (Fig. 11).

In our cadavers, we observed the semimembranosus bursa presenting as a synovial lined space wrapping around the transition zone between the direct and anterior arms. As was reported previously, the semimembranosus bursa surrounds the tendons and demonstrates a reverse 'J' shape when distended [1, 7]. We did not observe the bursa on imaging, as it was not distended.

The meniscal arm has been reported to arise at the deep aspect of the direct arm just proximal to its insertion [1]. The meniscal arm corresponds to a short band-like connection between the semimembranosus tendon and the meniscotibial band ('coronary ligament') of the posterior horn of the medial meniscus. In our study, we found the meniscal arm to arise rather from the posterior part of the anterior arm, than the direct arm. On MR imaging, the meniscal arm is best visualized on coronal images (Fig. 15).

The distal tibial expansion of the semimembranosus forms a fascial layer over the popliteus muscle belly [1]. LaPrade et al. [1] also refer to it as popliteus aponeurosis, as it extends over this muscle. This author reports that it is made up of a medial and lateral division. The lateral division courses over the popliteus muscle, whereas the medial division courses more anteriorly towards the posterior margin of the medial collateral ligament. The distal tibial expansion has been termed 'inferior or popliteal arm' by other authors [6, 7, 13]. In our study, we mainly discerned the lateral division. In our dissected specimen, the distal tibial expansion appeared thin (Fig. 3b), however on MR imaging and anatomic sections, the distal tibial expansion was thicker and was well seen (Fig. 10). Cardinal et al. have reported that the distal tibial expansion may be more prominent than we observed in our study [15]. The distal tibial expansion was best appreciated in the axial and sagittal imaging planes, as a band-like structure extending from the most inferior aspect of the direct arm towards the superficial surface of the popliteus muscle (Fig. 10).

The proximal posterior capsular expansion has been described as a thin area of fibers coursing along the superior aspect of the semimembranosus extension to the oblique popliteal ligament, and having several fine attachments to the posterior capsule [1]. We were not able, in our specimens or MR images, to observe this delicate expansion.

An additional connection of the semimembranosus tendon to the posterior horn of the lateral meniscus has been described by Kim et al. [16]. This connection is not specifically mentioned by LaPrade et al. and we did not observe it either [1].

Some limitations of our study should be considered. Since the number of specimens was limited, our study may not fully take into account anatomic variation. Nevertheless, our observations were similar to other recent surgical and anatomical studies [1, 2]. We used only a limited number of imaging sequences, and no specialized imaging planes. We think it is important to evaluate the ability of routine MR sequences and imaging planes to assess the posteromedial corner. We did not study T1-weighted images or fat-saturated images, and hence cannot determine if the visualization of structures would be similar. However, signal intensity on T1-weighted images is typically not very different from that on PD-weighted images. Finally, our study was performed on a 3-T system, and it can be expected that more anatomical detail will be appreciable compared to 1.5-T systems.

Our findings provide insight into the complex imaging anatomy of the distal semimembranosus tendon. Six distal insertions of the semimembranosus tendon can be well visualized when combining imaging findings in the three imaging planes. A proton density sequence typically used in a routine knee exam is sufficient for this purpose. Our systematic analysis of the distal semimembranosus insertions at defined levels simplifies imaging interpretation.

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Conflict of interest The authors declare that they have no conflicts of interest.

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