



Anatomy, magnetic resonance and arthroscopy of the popliteal hiatus of the knee: normal aspect and pathological conditions

Alberto Grassi¹
Nicola Pizza¹
Gian Andrea Lucidi¹
Luca Macchiarola¹
Massimiliano Mosca¹
Stefano Zaffagnini^{1,2}

- The popliteal hiatus is a complex region, formed by the confluence of various structures connecting the meniscus, popliteal tendon, tibia and fibula.
- The main structures that can be found are the three popliteomeniscal fascicles (anterior, postero-inferior and postero-superior), the lateral and posterior meniscotibial ligaments, the popliteofibular ligament and the meniscofibular fascicle.
- These structures can be identified in most cases using magnetic resonance imaging, and their 'static' assessment can be performed.
- Arthroscopic assessment is useful in identifying and testing 'dynamically' the integrity of the structures around the popliteal hiatus.
- Injuries or abnormalities of the popliteal hiatus and its structures could result in meniscal hypermobility and subluxation; however, these injuries are often unrecognized.
- Possible abnormalities in this region, apart from the well-known bucket-handle meniscal tear, are the Wrisberg Type III discoid meniscus, and meniscal fascicles tears.

Keywords: anatomy; arthroscopy; lateral meniscus; popliteal hiatus; popliteus tendon; magnetic resonance imaging

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Introduction

Despite the fact that the anatomy and function of the lateral meniscus has been well described, its capsular restraints and their role still represent complex issues.

In fact, the great mobility of the lateral meniscus, its thin and loose posterior capsule and the interruption of its capsular attachments at the popliteal hiatus represent important features that differentiate the lateral meniscus from the medial meniscus.¹ These are believed to derive from the evolutionary change in attachment of the popliteal tendon with the distal migration of the fibula, which could thus explain the complexities of the popliteal hiatus anatomy and the intra-articular position of the popliteal tendon in humans. In fact, when the proximal fibula moves distally from its original articulation with the distal femur to its current articulation at the proximal tibiofibular joint, the lateral capsule is pulled down, forming a new capsular layer between the distal femur and the proximal popliteus muscle.^{2,3} The many anatomical dissection studies that have tried to describe this complex anatomy have identified three distinct structures, the popliteomeniscal fascicles (PMFs), as the principal connections between the lateral meniscus and the popliteus tendon, where capsular connections are interrupted.^{1,2,4-7} However, this complexity generated great inconsistencies in terminology among authors during the last century,^{1,4,6,8-11} and the reported variability of the connections between the lateral meniscus and the popliteal tendon^{8,9} further increased the confusion. Moreover, apart from the well-known popliteofibular ligament (PFL) connecting the popliteus tendon with the tip of the fibula,^{4,10,11} the presence of a band directed from the meniscus to the fibula has been reported in several dissection studies as well, and described as the meniscofibular ligament (MFL).^{12,13}

The structures of the popliteal hiatus have been considered to cover a relevant role in meniscal stability,^{6,14,15} thus their integrity is considered necessary for a correct

kinematics of the whole postero-lateral compartment. Injuries or abnormalities of the popliteal hiatus and its structures have been described, resulting in meniscal hypermobility and subluxation.¹⁶ Hypermobile lateral meniscus has been described as a condition characterized by an excessive mobility of the posterior horn of the lateral meniscus leading to knee pain and/or locking symptoms mostly with kneeling or squatting; however, no precise definition is provided.

These injuries are often unrecognized due to their subtle presentation, their commonly reported normal appearances on magnetic resonance imaging (MRI) and the lack of arthroscopic visualization.^{16–19} Therefore, awareness of these abnormalities and a thorough understanding of the gross, MRI and arthroscopic anatomy of the popliteal hiatus are important when managing patients with lateral meniscal tears, hypermobility, and dislocation.

The aim of this review is thus to provide the anatomical description, MRI presentation and arthroscopic appearance of the popliteal hiatus and its structures. Both normal anatomy and pathological conditions with case presentation from the first author (AG) are described.

Gross anatomy

Based on the experience matured in the dissection of dozens of tibial plateaux dedicated to meniscal allograft transplantation,²⁰ in knee dissection of human donors for tissue harvesting and based on the available literature,^{1,6} a dissection protocol is suggested (Fig. 1) and a pictorial description of the popliteal hiatus is provided.

The popliteal hiatus can be described as an interruption of the continuity between the external border of the lateral meniscus and the joint capsule. Moreover, the three PMFs represent the connections between the external edge of the lateral meniscus and the popliteus tendon. While the ‘postero-superior’ and the ‘postero-inferior’ are named consistently among authors, inconsistencies exist regarding the definition of the most anterior PMF, which has been named either ‘antero-inferior’^{6,8} and ‘antero-superior’;¹ therefore, considering its oblique course, in the present manuscript it is named neutrally the anterior PMF (A-PMF), since no distinctions are needed among a superior and inferior structure such as for the posterior fascicles. The posterior meniscotibial ligament (PMTL) and the lateral meniscotibial ligament (LMTL) represent respectively the posterior and anterior connections between the inferior meniscal margin and the tibial plateau. The latter has been referred also as the ‘coronary ligament’, even if the acronym LMTL has been identified as being more appropriate to describe its anatomical characteristics.²¹ The hiatus is completed by two structures that provide a distal connection with

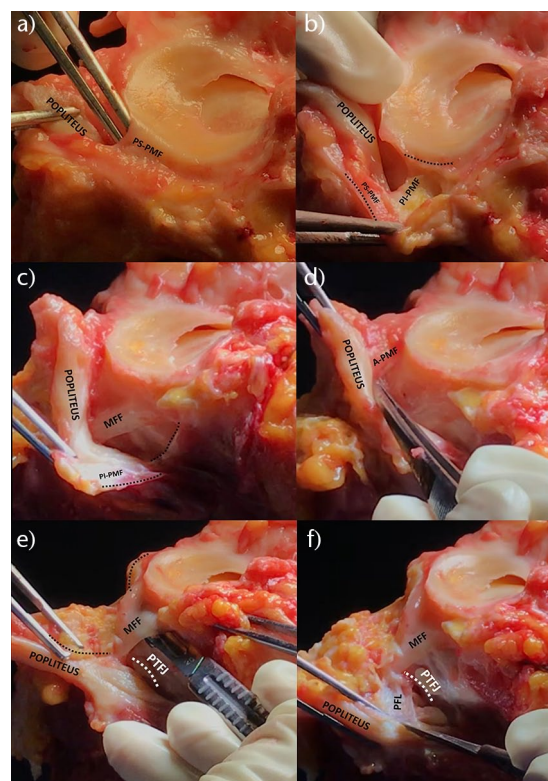


Fig. 1 Dissection protocol for the popliteal hiatus: after cutting the ligaments and capsule from femoral insertion and disarticulating the femur, the postero-superior popliteomeniscal fascicle (PS-PMF) is seen, and the recess underneath can be explored with a clamp (a). After sectioning the PS-PMF (black dotted line) and retracting the popliteus tendon, the postero-inferior popliteomeniscal fascicle (PI-PMF) is tensioned and seen, connecting the inferior meniscal border with the medial portion of popliteus tendon (b). After sectioning the PI-PMF (black dotted line) and further retracting the popliteus tendon, the meniscolibular fascicle (MFF) is seen, originating from the inferior border of the meniscal body and directed distally adhering to the tibial plateau (c). By retracting the more proximal part of the popliteus tendon, the anterior popliteomeniscal fascicle (A-PMF) is tensioned and appreciated connecting obliquely the lateral margin of the meniscal body and the more lateral portion of the popliteus tendon (d). After sectioning the A-PMF (black dotted line) and elevating the MFF with the scalpel, the proximal tibiofibular joint (PTFJ) is exposed, showing the lack of direct meniscotibial connections at this level (e). By retracting the popliteus tendon laterally, the popliteofibular ligament (PFL) is tensioned and seen originating from the inferior portion of popliteus tendon and converging with the MFF toward the fibular head (f).

the tip of the fibula: the popliteofibular ligament and the meniscolibular fascicle. The structure connecting the lateral meniscus and the fibula is referred to here as the meniscolibular ‘fascicle’ rather than ‘ligament’, due to its uncertain nature, exiguous thickness, inconsistent terminology and macroscopic appearance closer to the PMFs than other capsular ligaments.

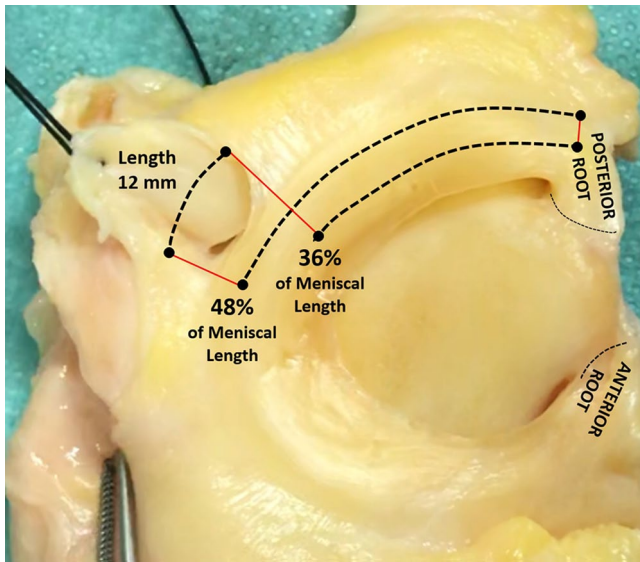


Fig. 2 Superior view of a right lateral meniscus with measures of the popliteal hiatus and its superior aperture according to Aman et al.¹

Popliteal hiatus complex

At a first visual inspection, it is possible to clearly identify the superior aperture of the popliteal hiatus, which is traversed by the popliteus tendon in an oblique disto-proximal and postero-anterior direction. This superior aspect of the popliteal hiatus, according to Aman et al¹ has a total length of 12.1 ± 2.5 mm and is delimited posteriorly by the postero-superior PMF, anteriorly by the anterior PMF, medially by the superior margin of the lateral meniscus and laterally by the popliteus tendon (Fig. 2). Its posterior margin corresponds to 36% of the total length of the lateral meniscus with respect to the posterior root attachment, at an average distance of 33.6 ± 3.7 mm.¹ The anterior margin is instead at 48% of the total meniscal length with respect to the posterior root attachment.

The inferior aperture, of which the anatomy is more complex than the superior one, is delimited posteriorly by the lateral extent of the PMTL, anteriorly by the LMTL, medially by the inferior border of the lateral meniscus and laterally by the popliteus tendon (Fig. 3). The PMTL connects the most medial portion of the meniscal inferior border to the tibial plateau near the posterior cruciate ligament (PCL) insertion, providing the stability of the posterior meniscal segment. It continues laterally with the postero-inferior PMF continuing the circumferential restraints. The LMTL connects the inferior meniscal surface to the tibial plateau, starting nearly the midpoint of meniscal length and directing towards its anterior portion.⁷ The inferior aperture thus represents an area where the inferior meniscal margin is free from any direct connections with the tibial plateau. However, from the meniscal inferior border at this point, the anterior PMF, the postero-inferior PMF and the

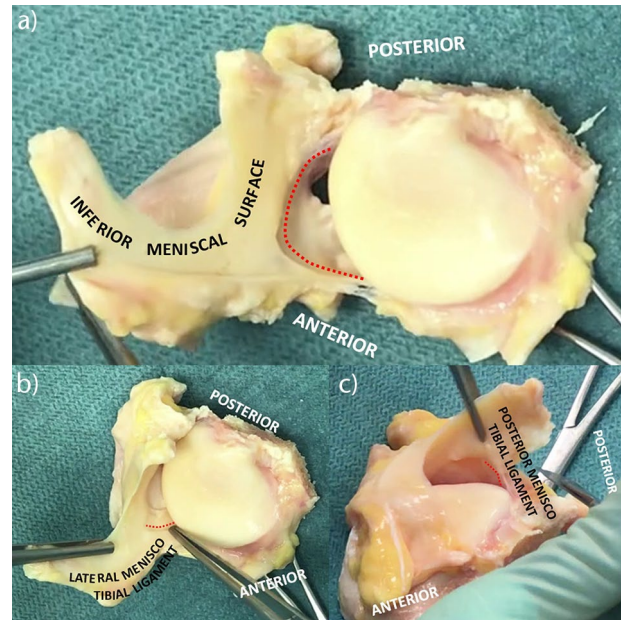


Fig. 3 Specimen of a right lateral tibial plateau where both anterior and posterior horns have been detached with a portion of the lateral meniscotibial ligament and the posterior meniscotibial ligament, in order to allow the eversion of the lateral meniscus. The whole lateral meniscus is everted to appreciate the inferior aspect of the popliteal hiatus (red dotted line) (a). By lifting up the anterior meniscal portion, the most posterior part of the lateral meniscotibial ligament is seen (b), while the posterior meniscotibial ligament is exposed by lifting up the posterior meniscal portion (c).

meniscotibial ligament originate to connect the meniscus to the popliteal tendon and the fibula. Further, the posterior margin of the meniscotibial ligament and the anterior margin of the postero-inferior PMF create a small orifice which has a variable width and that allows communication between the intra-articular space and the popliteal recess. These sub-meniscal structures have been previously described also as ‘membranes’ by Kimura et al,²² who reported a complete and continuous coverage of the popliteal tendons without any interruptions in nearly 20% of cases. Harley²³ also reported that the ‘inferior attachment may occasionally be continuous across the bursa, but deficiency of this ligament is an usual and normal situation’. This is also consistent with what was reported originally by Last in 1948,⁵ which described an occasional anatomical variant in which there was a broad aponeurotic attachment of the popliteus muscle to the entire posterior aspect of the lateral meniscus. This complexity could also be responsible for the inconsistencies in the identification of the postero-inferior PMF and meniscotibial ligament (or ligament).^{5,8}

Anterior PMF (A-PMF)

The A-PMF originates from the infero-medial portion of the popliteus tendon and inserts on the outer surface of

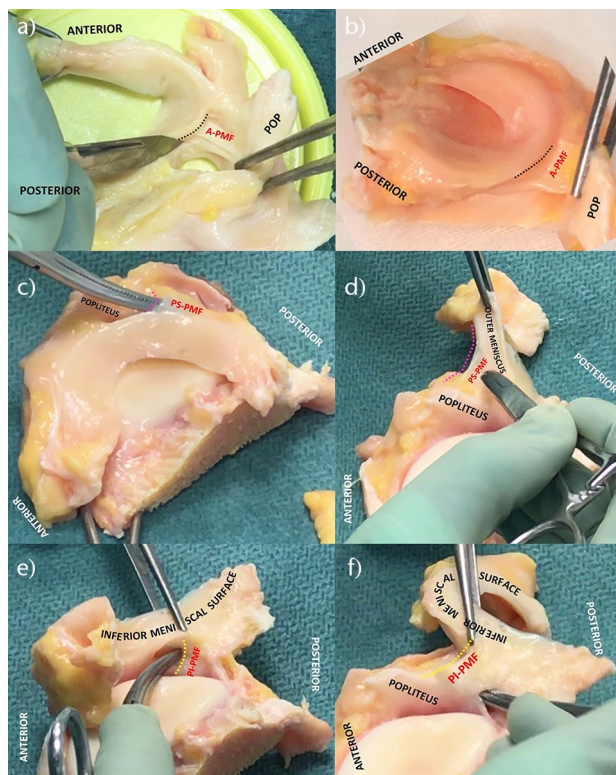


Fig. 4 In this right lateral meniscus specimen, retracting laterally the popliteus tendon is possible to tension and appreciate the course of the A-PMF (a). After removing the posterior connections of the popliteus tendon with the lateral meniscus and reflecting the popliteus tendon laterally, the oblique insertion of the A-PMF on the outer border of lateral meniscus can be seen (black dotted line) (b). In this right lateral tibial plateau specimen, a curved forceps is inserted in the popliteal hiatus, with the tip under the PS-PMF (purple dotted line) (c). After detaching the anterior horn, coronary ligament and antero-inferior PMF, the meniscus is everted and the inferior surface of the PS-PMF can be seen (d). In this right lateral tibial plateau specimen, the anterior and posterior horns have been detached and the meniscus elevated; inserting the tip of the forceps through the inferior aperture of the popliteal hiatus exposes the free margin of the PI-PMF (yellow dotted line) (e). After sectioning the lateral meniscotibial ligament and the antero-inferior PMF, the connection of the PI-PMF between the inferior surface of the meniscus and the popliteus can be seen (f).

Note. A-PMF, anterior popliteomeniscal fascicle; PS-PMF, postero-superior popliteomeniscal fascicle; PI-PMF, postero-inferior popliteomeniscal fascicle; POP, popliteus tendon.

the lateral meniscus near its half, delimiting the anterior margin of the superior aperture of the popliteal hiatus (Fig. 4a, b). The course of its meniscal insertion is oblique, with a postero-inferior to antero-superior direction, and has been reported to have an average length of 8.0 ± 1.9 mm.¹ This configuration hosts the oblique course of the popliteus tendon as it becomes intra-articular. Inferiorly, the anterior PMF blends with the meniscofibular fascicle, creating a unit that reaches the fibular head.

Postero-superior PMF (PS-PMF)

Among the three PMFs, the postero-superior is the one that is most clearly visible and identified, since it originates from the posterior surface of the popliteus tendon and terminates mainly on the superior part of the posterior horn of the meniscus. It also covers the most medial part of the popliteus tendon (Fig. 4c, d). The average length of its attachment to the lateral meniscus is 6.5 ± 1.5 mm.¹ With the postero-inferior PMF it creates a small pouch, or recess, behind the meniscal wall and in communication with the popliteal space.

Postero-inferior PMF (PI-PMF)

The PI-PMF is considered the most difficult PMF to isolate through anatomical dissection, because it can be easily cut from the deep surface of the popliteus.⁵ The postero-inferior PMF is believed to be the structure described more than 70 years ago by Last as the ‘quadrilateral aponeurosis’, which connects the inferior margin of the lateral meniscus to the superior and medial portion of the popliteus muscle (Fig. 4e, f).⁵ The direct attachment of the anterior and deep surface of the popliteus muscle to the tibia thus provides an indirect tibial attachment to substitute for the lack of a coronary ligament just medial to the popliteal tendon. According to Aman et al,¹ the average length of postero-inferior PMF attachment to the lateral meniscus is 8.5 ± 1.8 mm. Inconsistencies in descriptions of the third popliteomeniscal fascicle and doubts about its existence have been reported.⁸ This may relate both to specimen preparations without considering the more medially located capsular aponeurotic extension of the popliteus tendon, and also to the presence of anatomical variants where a single complete structure, not distinguishable from the meniscofibular fascicle, is attached to the inferior border of the posterior meniscus, impeding access to the popliteus tendon below the meniscus from the intra-articular space.^{5,22,23}

Popliteofibular ligament (PFL)

The popliteofibular ligament has been identified in nearly 100% of dissected knees.^{4,10,11} It originates from the medial popliteus tendon just proximal to the myotendinous junction and attaches to the medial fibular styloid, posteriorly to the lateral collateral ligament (LCL) (Fig. 5a, b). Three different morphologies of the PFL have been described, with a single, double or Y-shaped types.^{10,11} Based on cadaveric studies, the ligament has been described as a strong structure with a mean length of between 10 and 14 mm, a mean anteroposterior diameter of 7 to 9 mm, and an average thickness of around 2 mm.¹⁰ Stäubli and Birrer reported that the posterior limb of the popliteofibular fascicle inserted proximally on the inferior PMF (here named anterior PMF), thus describing a short connection between the meniscus and the fibular head.⁶

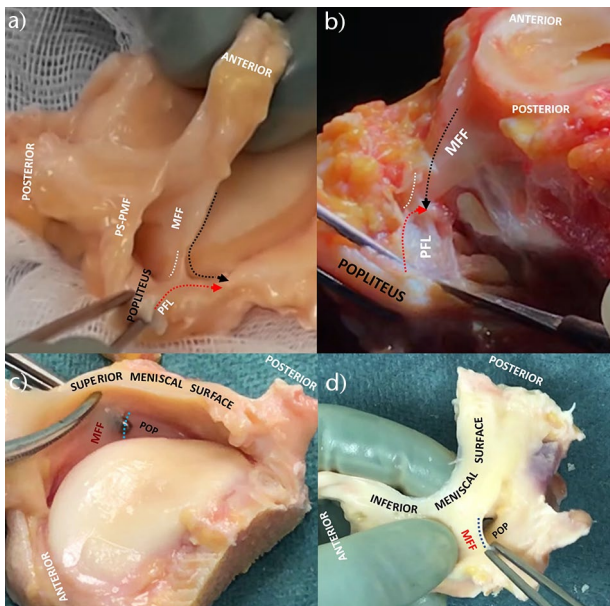


Fig. 5 Popliteofibular ligament (PFL) meniscofibular fascicle (MFF). In this right lateral tibial plateau specimen, the meniscus anterior horn is detached and the A-PMF sectioned, allowing the popliteus tendon to be reflected laterally; here it is possible to appreciate the inferiorly directed course of the MFF (black dotted arrow) and PFL (red dotted arrow) with their connection (white dotted line) (a). A similar configuration to (a) is noted in this posterior view of a left tibial plateau after reflecting the popliteus tendon postero-laterally (b). In this right lateral tibial plateau, the meniscus is lifted up with forceps and a clamp is inserted through the popliteal hiatus; the tip of the clamp protrudes behind the MFF (blue dotted line) (c). Observing the inferior surface of the meniscus from the same specimen after complete detachment from the tibial plateau, the expansion toward the PFL could be seen (d).

Note. A-PMF, anterior popliteomeniscal fascicle; PS-PMF, postero-superior popliteomeniscal fascicle; PI-PMF, postero-inferior popliteomeniscal fascicle; MFF, meniscofibular fascicle; PFL, popliteofibular ligament; POP, popliteus tendon.

Meniscofibular fascicle (MFF)

The MFF is a thin strip-like fibrous band that originates from the inferior meniscal surface inferiorly and posteriorly respect to the anterior PMF. It has been neglected in most anatomical dissection studies, but in the few reports that investigated its presence, an incidence near 100% was reported.^{12,13} Superiorly, the meniscofibular fascicle blends with the anterior PMF, representing a sort of its postero-distal extension. Anteriorly, the meniscofibular fascicle also blends with the LMTL. The MFF direction is distal and posterior, towards the tip of the fibula, with an oblique course which crosses the route of the popliteal tendon; it thus represents a layer interposed between the popliteus tendon and the convex tibial plateau, to which it adheres. In its distal portion, the meniscofibular fascicle has an expansion that connects with the popliteofibular ligament (Fig. 5c, d). A structure originating from the posterior part of the fibular head near the tibiofibular joint and

inserting both on the popliteus tendon and the meniscus (through the popliteomeniscal fascicle) was described in 1990 by Stäubli and Birrer, which named it the 'posterior limb of popliteofibular fascicle'.⁶

Thus, the anterior PMF, the popliteofibular ligament and the LMTL form a common unit, which has been recently named the 'menisco-tibio-popliteus-fibular complex (MTPFC)' by Masferrat-Pino et al.²¹ In this context, the meniscofibular fascicle represents the junctional element between all these restraints; in fact, it blends superiorly with the anterior PMF and inferiorly with the popliteofibular ligament (posteriorly) and the LMTL (anteriorly), thus indirectly connecting the meniscus respectively with the popliteus tendon, the fibula and the tibial plateau, in a peculiar bare area of its postero-lateral outer margin where direct capsular attachments to the tibia are lacking. Inconsistencies and controversies in anatomical origins, shape and names of these structures are generated by their complex anatomy and interconnections between each other, which could inevitably lead to selective and partial isolation according to the dissection technique.

MRI anatomy

Magnetic resonance is an effective diagnostic method to assess the presence and integrity of the popliteal hiatus and its structures.⁹ MRI has been reported to be able to detect normal anterior PMF, postero-superior PMF and popliteomeniscal ligament in nearly 90% of cases,^{18,24,25} while the postero-inferior PMF and the meniscofibular fascicle in less than half of cases;^{8,26} thus, a deep knowledge of popliteal hiatus anatomy is needed. It should also be acknowledged that low-quality MRI with thick slices could easily miss some of these structures and that, considering the oblique course of PMFs, a proton-density weighting oblique-coronal images and 45–50° slice angle with the posterior tibial condyle is recommended for their assessment.¹⁸ Nevertheless, standard MRI could be helpful to detect gross 'static' abnormalities, especially examining the sagittal plane (Table 1).

Popliteal hiatus complex

The popliteus tendon is seen as a hypointense cord-like structure on T2-weighted images. Its femoral insertion on the popliteal notch is best appreciated on coronal slices, while its course through the popliteal hiatus and underneath the postero-lateral capsule when it becomes extra-articular is better seen on sagittal slices.²⁷ On the most lateral sagittal slices, when the popliteus tendon descends from the femur, it is possible to note the superior aperture of the popliteal hiatus, which is filled with hyperintense fluid (Fig. 6a, b). Prosecuting toward more medial sagittal slices, the fluid enters the inferior aperture and delineates distally the inferior popliteal recess (which arrives

Table 1. MRI aspect of popliteal hiatus.

Magnetic resonance imaging (MRI) features of normal popliteal hiatus. Right-hand column indicates the difficulty of assessing the MRI feature: low (*), medium (**), high (***)

Normal anatomy	- Presence of postero-superior and postero-inferior PMFs on sagittal view	**
	- Presence of anterior PMF on coronal view	***
	- Presence of posterior meniscotibial ligament on sagittal view	***
	- Presence of lateral meniscotibial ligament on coronal view	**
	- Presence of popliteofibular ligament on coronal or sagittal view	***
	- Presence of meniscofibular fascicle on coronal or sagittal view	***
	- Meniscus 'C' shape on axial view	*
	- Meniscus 'Δ' shape on coronal and sagittal views	*
	- Hypointense signal of whole meniscus	*
	- Anatomical location of posterior and anterior horns	*

Note. PMF, popliteomeniscal fascicle.

up to the fibular apex), until the appearance of a thick isointense band that connects the inferior border of the meniscal posterior horn and the tibial plateau. This band represents the PMTL and the medial margin of the inferior hiatus aperture. Its anterior margin is instead delimited by the LMTL, which could be seen only in coronal slices at the level of the mid-meniscus body (Fig. 6a, c). The inferior aperture and the popliteal recess, indicating the interruption of the meniscotibial connections at the level of the popliteal hiatus, could be easily seen in the axial view – by scrolling slices from proximal to distal up to the tip of the fibula – as a crescent-like hyperintense image (Fig. 6d).

Anterior PMF (A-PMF)

The A-PMF can be identified with difficulty on coronal slices as an isointense horizontal band connecting the inferior border of the meniscus with the popliteus tendon (Fig. 7c, d, e). Considering the oblique course and the intimate connection with the popliteus tendon, it can hardly be discerned if no hyperintense fluid fills the popliteal space. On sagittal slices, its most posterior and inferior part can be glimpsed while blending with the meniscofibular fascicle.

Postero-superior PMF (PS-PMF)

The PS-PMF can be found in a medial position with respect to the popliteus tendon at the level of the popliteal hiatus. It extends in a posterior direction from the postero-superior corner of the posterior horn of the lateral meniscus to the posterior joint capsule immediately above the diverging popliteus tendon (Fig. 7b, d, e); in this region, the postero-superior PMF anchors the posterior horn of the lateral meniscus to the popliteus tendon. The postero-superior PMF is usually thick.

Postero-inferior PMF (PI-PMF)

The PI-PMF could be found in the most medial sagittal slices, between the meniscal root and popliteus tendon. It extends in an infero-posterior direction from the inferior margin of the posterior horn of the lateral meniscus toward

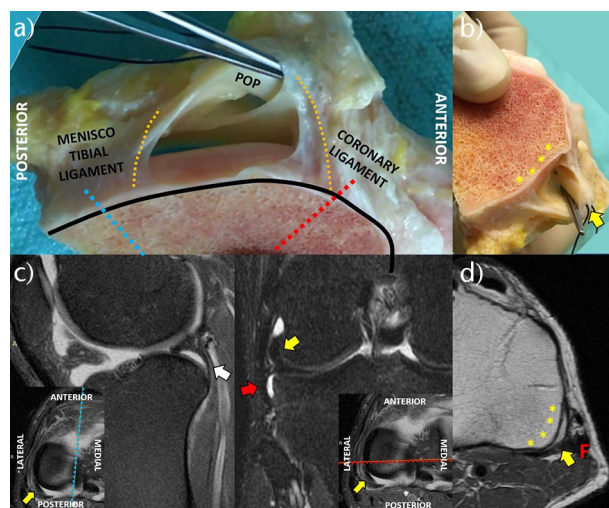


Fig. 6 In this posterior view of a right tibial plateau, the interruption of the joint capsule at the level of the popliteal hiatus can be seen (yellow dotted line), highlighting the lateral meniscotibial ligament anteriorly and the posterior meniscotibial ligament posteriorly (a). In this inferior view of the same specimen, the interruption of the meniscotibial connection at the level of the popliteal hiatus is seen (yellow asterisks) by retracting the popliteus tendon (yellow arrow) (b). In the sagittal MRI slice passing through the most medial portion of the lateral meniscus at the level of the blue dotted line (left), the posterior meniscotibial ligament (white arrow) can be seen connecting the inferior surface of posterior horn with the tibial plateau. Popliteus tendon cannot be seen at this level; in the coronal MRI slice passing through the midpoint of the lateral meniscus body at the level of the red dotted line (right), the lateral meniscotibial ligament (red arrow) could be seen connecting the inferior meniscal surface with the tibial plateau. At this level, the popliteus tendon (yellow arrow) has already passed the popliteal hiatus and is near its femoral insertion (c). In the axial MRI slice passing at the level of the fibular tip (red 'F') resembling the specimen in (b), it is possible to appreciate the inferior aperture and the popliteal recess as an hyperintense crescent-shape image (yellow asterisks), indicating the interruption of the meniscotibial connections at the level of the popliteal hiatus (d).

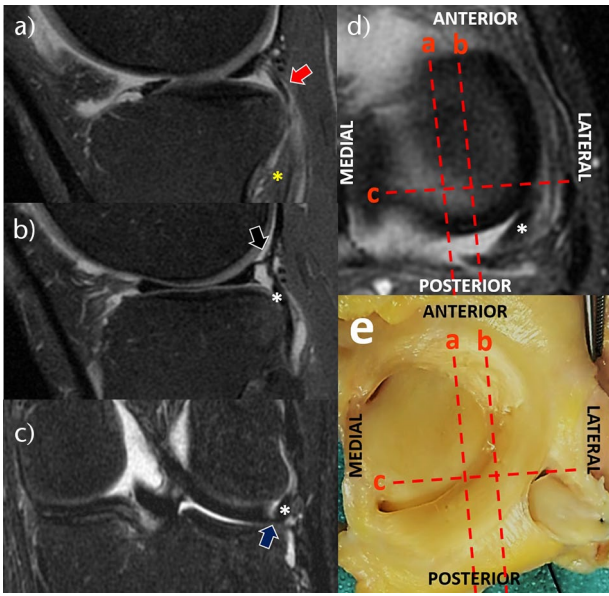


Fig. 7 Sagittal MRI slice passing medially with respect to the popliteus tendon, where the postero-inferior popliteomeniscal fascicle (red arrow) can be seen; the muscle fibres of the popliteus muscle (yellow asterisk) can be seen, with a thin hyperintense liquid line separating the muscle belly from the posterior tibial plateau (a). Sagittal MRI slice passing just medially with respect to the sovra-meniscal portion of the popliteus tendon, where the postero-superior popliteomeniscal fascicle (black arrow) can be seen connecting the lateral meniscus with the popliteus tendon (white asterisk) (b). Coronal MRI slice passing at the anterior portion of the popliteal hiatus, where the anterior popliteomeniscal fascicle (blue arrow) can be seen connecting the lateral meniscus with the popliteus tendon (white asterisk) (c). Axial slice from the same knee, where the corresponding slices ‘a’, ‘b’ and ‘c’ are marked with red dotted lines (d). Superior view of the popliteal hiatus presented in an anatomical specimen, mimicking the MRI axial view of ‘d’, with the corresponding dotted lines (e).

the medial aponeurosis of the popliteus musculotendinous region (Fig. 7a, d, e). Considering the anatomical variant of a continuous connection between the meniscal margin and popliteus tendon and aponeurosis,^{5,22,23} it is possible that a clear distinction between the meniscofibular fascicle and the postero-inferior PMF is not evident. This could be also affected by the orifice width between the two structures, their stretching or the MRI slice thickness.

Popliteofibular ligament (PFL)

The PFL usually appears as a small low-signal-intensity structure on coronal and sagittal images. On particular cuts it is possible to follow its entire course from the fibular apex to the popliteus tendon, especially on coronal slices (Fig. 8a, b, e, f). Its appearance is usually thicker with respect to the PMFs, and fluid collection around the popliteus tendon improves its visualization.

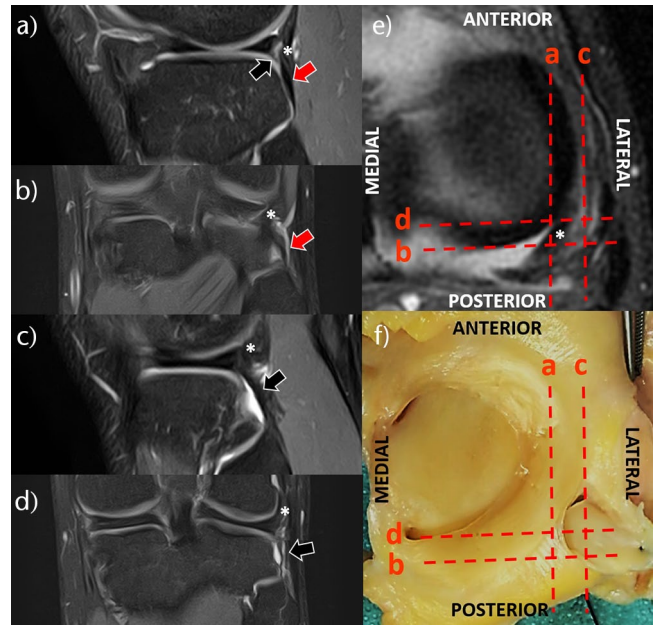


Fig. 8 Sagittal MRI slice passing at the level of the proximal tibiofibular joint, where the popliteus tendon (white asterisk) passes at the level of the lateral meniscus posterior horn; the popliteofibular ligament (red arrow) is seen a isointense thick band connecting the popliteus tendon with the fibula. A portion of the meniscofibular fascicle (black arrow) is seen originating from the inferior meniscal border (a). Coronal slice passing at the level of the popliteal hiatus; the popliteofibular ligament (red arrow) is seen originating from the inferior portion of the popliteus tendon (white asterisk) (b). Sagittal slice passing at the outer margin of the lateral meniscus, where the popliteus tendon (white asterisk) has exited the popliteal hiatus; the meniscofibular fascicle (black arrow) is seen (c). Coronal slice passing through the anterior portion of the popliteal hiatus, where the popliteus tendon (white asterisk) lies above the meniscus; the meniscofibular fascicle (black arrow) is seen running from the inferior surface of the meniscus and the tip of the fibula (d). Axial slice from the same knee, where the corresponding slices of ‘a’, ‘b’, ‘c’ and ‘d’ are marked with red dotted lines (e). Superior view of the popliteal hiatus presented in an anatomical specimen, mimicking the MRI axial view of ‘e’, with the corresponding dotted lines (e).

Menisco-fibular fascicle (MFF)

The MFF could be seen in its entire length only in the far lateral sagittal slices when the popliteus tendon is at the level of lateral meniscus and above (Fig. 8c, e, f). It extends in an infero-posterior direction from its attachment at the lateral aspect of the body of the lateral meniscus to the tip of the fibula, adhering to the convexity of the tibial plateau. Sometimes it is hardly distinguished from the popliteus tendon; differently, it is easily identified in the more medial sagittal slices, however, without appreciating its full length due to non-orthogonal cuts. At times, the meniscofibular fascicle can be seen in coronal slices as well (Fig. 8d, e, f).

Arthroscopic anatomy

Arthroscopically, a clear view of the popliteal hiatus and all its structures can be achieved in most knees using a 30° scope through the standard antero-medial and antero-lateral portals. However, in certain circumstances, some structures can be clearly appreciated while others could remain inaccessible. It is important to be familiar with the arthroscopic appearance of the popliteal hiatus and its structures in order to check their integrity and perform a ‘dynamic’ assessment, as they can be responsible for subtle clinical symptoms if abnormal.

Popliteal hiatus complex

With the knee in the figure-of-four position and applying varus stress, through the standard antero-lateral portal it is possible to see and palpate the supra-meniscal portion of the popliteus tendon and the superior aperture of the popliteus hiatus. Lifting up the meniscus with the probe and pushing the scope under the meniscus, the infra-meniscal portion of the popliteus tendon could be appreciated in most cases. Here, the popliteus tendon is covered by the meniscofibular fascicle and the postero-inferior PMF; their free margins form an orifice through which the tendon can be seen. In 1992, Kimura et al.²² described this structure arthroscopically as a ‘membrane-like portion of the coronary ligament’; they reported that this structure covered entirely the popliteus tendon beneath the meniscus in nearly 20% of cases, while in most cases a defect was present through which the popliteus tendon was visible.

Considering this variability and the limited access to the undersurface of the lateral meniscus, especially taking into account the convex shape of the lateral tibial plateau, the LMTL connecting the inferior border of the meniscus to the tibial margin could be seen with difficulty just anterior to the meniscofibular fascicle, as a visible thickened structure when lifting up the meniscus with a probe (Fig. 9). Its vertical course and its tightness allow it to be appreciated as a clearly distinct structure with respect to the meniscofibular fascicle. Differently, due to its more posterior and medial position, the PMTL is difficult to access through standard arthroscopic portals.

With the knee with 0–20° of flexion and neutral rotation, the scope could be moved through the anterolateral portal in the lateral recess and pushed through the so-called ‘popliteal tunnel’.⁶ Here it is possible to appreciate the supra-meniscal portion of the popliteus tendon, as it passes through the superior aperture of the popliteal hiatus (Fig. 10). Its integrity could be examined with the help of internal and external rotation of the leg.

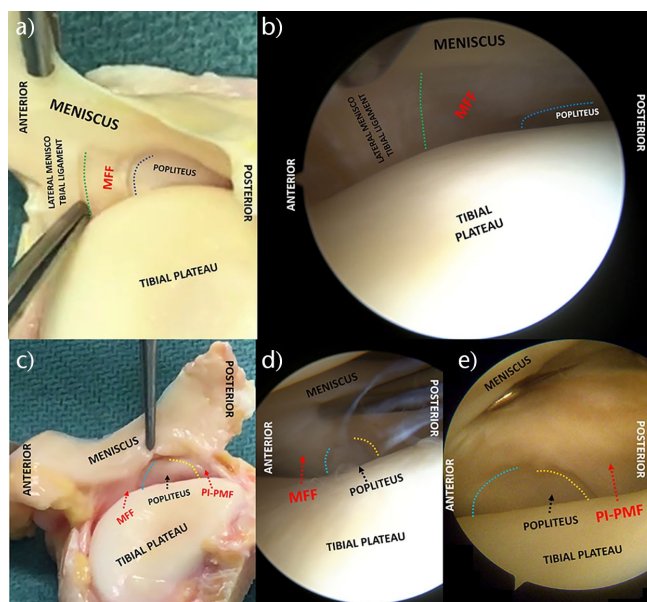


Fig. 9 Anatomical specimen of a right lateral tibial plateau (a) and arthroscopic view of a right knee lateral meniscus (b). Lifting up the meniscus with a probe, the LMTL (green dotted line) is put under tension and the free margin of the MFF seen (blue dotted line); posteriorly to it, the popliteus tendon can be seen through the orifice between the two MFF and the PI-PMF. Anatomical specimen of a right lateral tibial plateau (c) and arthroscopic view of a right knee lateral meniscus (d, e). Lifting up the meniscus with a probe, the inferior orifice between the posterior margin of the MFF (blue dotted line) and the anterior margin of the PI-PMF (yellow dotted line) is revealed; through this orifice, which could have a variable size, the popliteus tendon is glimpsed.

Note. LMTL, lateral meniscotibial ligament; A-PMF, anterior popliteo-meniscal fascicle; PI-PMF, postero-inferior popliteo-meniscal fascicle; MFF, menisco-femoral fascicle.

Anterior PMF (A-PMF)

This structure can be noticed by pushing down with the probe the meniscal portion anterior to the popliteus tendon (Fig. 10c, d). Moreover, by inserting the scope in the ‘popliteal tunnel’, the anterior PMF can be clearly seen inferiorly with respect to the popliteus tendon (Fig. 10a, b).

Postero-superior PMF (PS-PMF)

From the antero-lateral portal, the postero-superior PMF can be clearly seen and tested for integrity with a probe. Its visualization is eased by pulling down the meniscus with a probe (Fig. 10c, e). It covers the medial portion of the popliteus tendon as it exits the popliteal hiatus. The most peripheral part of the postero-superior PMF could also be seen by inserting the scope in the ‘popliteal tunnel’, just medial and superior with respect to the popliteus tendon (Fig. 10a, b).

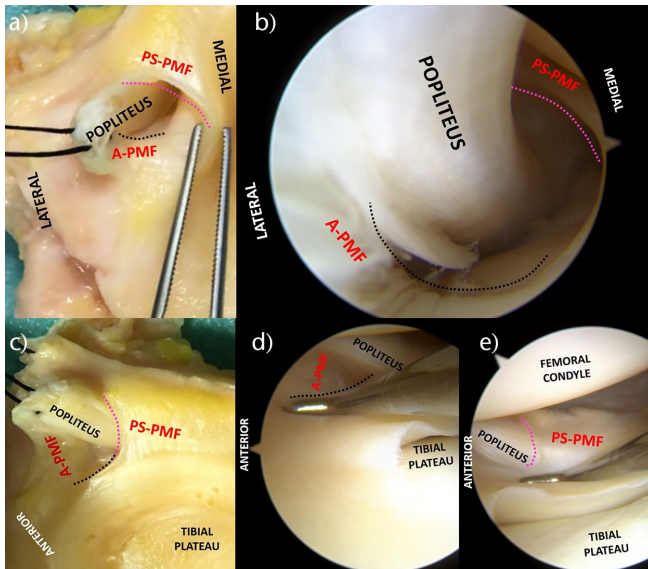


Fig. 10 Anatomical specimen of a right lateral tibial plateau at the level of the popliteal hiatus (a) and arthroscopic view of a right knee ‘popliteus tunnel’, with extended knee and the scope in the lateral recess through the antero-lateral portal (b). It is possible to appreciate the integrity of the popliteus tendon, the free margin of the PS-PMF (purple dotted line) and the outline of the A-PMF (black dotted line). Anatomical specimen of a right lateral tibial plateau (c) and arthroscopic view of a right knee lateral meniscus (d, e). Pushing down the meniscus with a probe, it is possible to expose and examine the integrity of the PS-PMF (purple dotted line) posteriorly to the popliteus tendon, and of the A-PMF (black dotted line) anteriorly.

Note. PS-PMF, postero-superior popliteomeniscal fascicle; A-PMF, anterior popliteomeniscal fascicle.

Postero-inferior PMF (PI-PMF)

This structure is the most difficult to test, since it is the aponeurosis of the popliteal tendon. Arthroscopically, it is located medially with respect to the orifice through which the popliteus tendon is seen (Fig. 9c, d, e). As reported, the distinction between the meniscomfibular fascicle and the postero-inferior PMF is not always possible, nor it is always possible to appreciate the infero-meniscal portion of the popliteus tendon.²³

Popliteofibular ligament (PFL)

This ligament presents a challenging arthroscopic exploration, since it is located below the anterior portion of the popliteus tendon and thus behind the meniscus and the meniscomfibular fascicle. In a cadaveric setting, Arowowitz et al²⁸ were able to identify arthroscopically the popliteomeniscal ligament only after performing a partial removal of the lateral meniscus body, which allowed them to uncover this more peripheral structure. Viewing underneath the lateral meniscus in the region of the popliteal hiatus, vertically oriented fibres descending from the

inferior surface of the popliteus tendon were seen, in particular with the arthroscope in the anteromedial portal.

Meniscomfibular fascicle (MFF)

The arthroscopic aspect of the meniscomfibular fascicle is variable. In most cases²² it could be seen as a distinct structure, between the LMFL anteriorly and the orifice of the postero-inferior PMF posteriorly; lifting up the meniscus with the probe, the meniscomfibular fascicle, the postero-inferior PMF and the LMFL are put in tension, easing their visualization and exposing the orifice (Fig. 9a, b). Through this space, which is variable in size, the popliteus tendon can be seen. Here, the posterior free margin of the meniscomfibular fascicle can be palpated as well.

Pathological conditions involving the popliteal hiatus

The popliteal hiatus and its structures could be subjected to injuries or abnormalities. Considering the relevant role of these structures for meniscal stability, a correct diagnosis and treatment is mandatory to obtain satisfactory results. However, the complex anatomy of the posterolateral portion of the meniscus makes MRI and arthroscopic assessment difficult. Differential diagnosis between fascicle tears, Type III Wrisberg-type discoid lateral meniscus and bucket-handle tears is not always easy, especially considering the unspecific symptoms.

Meniscal fascicles tear

Injuries to PMFs or other structures around the popliteal hiatus have been described and have been reported to be responsible for clinical symptoms such as pain, snapping and popping.^{16,29,30} However, their occurrence as isolated injuries is considered extremely rare⁹ and is considered more frequent in the case of Anterior Cruciate Ligament (ACL) injury⁶ or postero-lateral corner injuries with popliteal tendon involvement.⁹ Thus, PMFs tears in the context of ACL or Postero-Lateral Corner (PLC) injuries could often be misunderstood, since their biomechanical and clinical effects could be masked by the preponderant consequences of ligaments rupture. Differently, the rare isolate meniscal fascicles are responsible for suggestive clinical symptoms such as lateral joint pain, snapping and popping. Symptom onset is always after a well-defined trauma (even minor) and involves usually young and active patients.^{29,30} The rupture of the meniscal fascicles is difficult to appreciate using MRI, therefore other indirect signs should be examined to establish a correct diagnosis (Table 2). Thus, arthroscopy represents the gold-standard for the diagnosis of such lesions (Fig. 11, Fig. 12). These lesions could be seen as linear interruption of the fascicle, which could be palpated and explored. Meniscal fascicle tears are

Table 2. MRI aspect of meniscal tears around the popliteal hiatus.

Magnetic resonance imaging (MRI) features of meniscal tears around the popliteal hiatus. Right-hand column indicates the difficulty of assessing the MRI feature: low (*), medium (**), high (***)

Meniscal fascicles tear	- Irregularity of postero-superior and postero-inferior PMFs on sagittal view	**
	- Irregularity of anterior PMF on sagittal view	***
	- Presence of posterior meniscotibial ligament on sagittal view	***
	- Presence of lateral meniscotibial ligament on coronal view	**
	- Irregularity of popliteomeniscal fascicle on coronal or sagittal view	***
	- Irregularity of meniscofibular fascicle on coronal or sagittal view	***
	- Meniscus 'C' shape on axial view	*
	- Meniscus 'Δ' shape on coronal and sagittal views	*
	- Hyperintense signal in popliteus tendon area	**
	- Anatomical location of posterior and anterior horns	*
Bucket-handle tear (dislocated)	- Usually concomitant ACL lesion, PLC lesion, tibiofemoral bone bruises	*
	- Presence of postero-superior and postero-inferior PMFs on sagittal view	**
	- Presence of anterior PMF on sagittal view	***
	- Presence of posterior meniscotibial ligament on sagittal view	***
	- Presence of lateral meniscotibial ligament on coronal view	**
	- Presence of popliteofibular ligament on coronal or sagittal view	***
	- Presence of meniscofibular fascicle on coronal or sagittal view	***
	- Truncated 'Δ' shape on coronal and sagittal views	*
	- Part of meniscal tissue attached to the capsule on sagittal, coronal and axial view	*
	- Anterior-medial dislocation of posterior horn fragment	*

Note. PMF, popliteomeniscal fascicle; ACL, anterior cruciate ligament; PLC, postero-lateral corner.

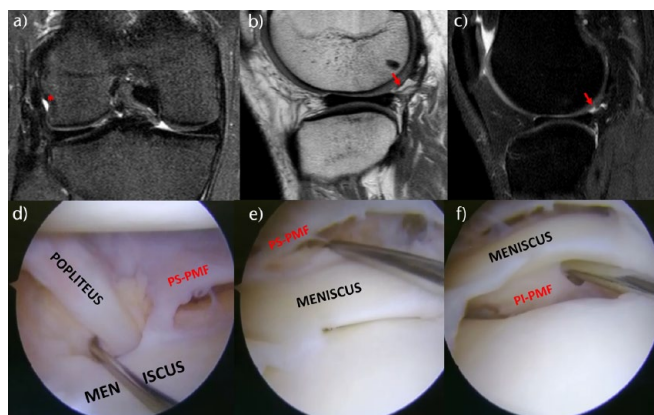


Fig. 11 Case 1, 20-year-old male patient. He complained of varus thrust while walking and severe right knee instability after a knee trauma during a motorcycle accident. He had +++ Lachman, +++ Pivot-Shift, +++ Varus stress, +++ Dial test, negative posterior drawer. Magnetic resonance imaging (MRI) on the coronal plane showed detachment of the popliteus tendon from the femoral sulcus (red asterisk) but no abnormalities of the meniscal periphery (a). MRI on sagittal plane showed abnormalities of the PS-PMF (red arrow) (b) and hyperintense signal of liquid around the popliteal tendon (c). At arthroscopic inspection, an abnormal opening of the lateral compartment was noted; the popliteus tendon was elongated and detached from the femoral insertion (d). The PS-PMF was torn medially to the popliteus tendon (e) while inspecting the inferior surface of the lateral meniscus, the PI-PMF was found intact (f). Under probing, the meniscus was stable due to the integrity of other restraints; therefore, only ACL and PLC reconstructions were performed.

Note. PS-PMF, postero-superior popliteo-meniscal fascicle; PI-PMF, postero-inferior popliteo-meniscal fascicle; ACL, anterior cruciate ligament; PLC, postero-lateral corner.

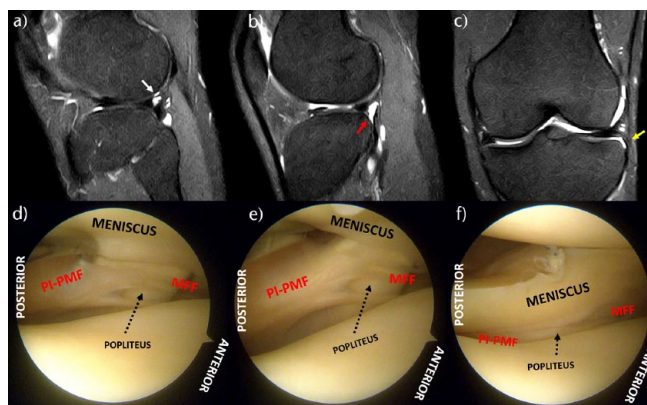


Fig. 12 Case 2, 26-year-old male patient. He complained of knee instability and lateral pain after a left knee sprain. He had ++ Lachman, +++ Pivot-Shift, negative varus-valgus stress and posterior drawer. Magnetic resonance imaging (MRI) on sagittal slices showed the integrity of the PS-PMF (white arrow) (a) while abnormalities of the MFF (red arrow) with hyperintense fluid around the popliteus tendon can be seen (b). The lateral meniscotibial ligament was intact (yellow arrow) on coronal slices (c). At arthroscopic inspection, lifting up the meniscus with a probe, the PI-PMF was found intact (d), while a tear was noted at the level of MFF (e). This resulted in an abnormal anterior displacement of the meniscus under probing, and therefore a single all-inside suture was placed to close the tear to stabilize the meniscus (f).

Note. MFF, meniscofibular fascicle; PS-PMF, postero-superior popliteomeniscal fascicle; A-PMF, anterior popliteomeniscal fascicle; PI-PMF, postero-inferior popliteomeniscal fascicle.

responsible for increased mobility of the posterior meniscal portion,¹⁵ but due to the other meniscal restraints, it is not possible to completely dislocate the meniscus within the intercondylar notch. The excessive/augmented translation

Table 3. MRI aspect of Type III Wrisberg-type discoid meniscus

Magnetic resonance imaging (MRI) features of in situ and dislocated Type III Wrisberg-type discoid meniscus. Right-hand column indicates the difficulty of assessing the MRI feature: low (*), medium (**), high (***)

Type III Wrisberg-type discoid meniscus (in situ)	- Absence of postero-superior and postero-inferior PMFs on sagittal view	**
	- Absence of anterior PMF on sagittal view	***
	- Absence of posterior meniscotibial ligament on sagittal view	***
	- Absence of lateral meniscotibial ligament on coronal view	**
	- Meniscus 'C' shape on axial view	*
	- Meniscus 'Δ' shape on coronal and sagittal views	*
	- Possible hyperintense signal of anterior horn (intra-meniscal lesion)	*
	- Possible hyperintense signal of meniscal body (radial tear)	**
	- Anatomical location of posterior and anterior horns	*
	- Hyperintense signal at meniscocapsular junction on coronal view	*
	- Absence of postero-superior and postero-inferior PMFs on sagittal view	**
Type III Wrisberg-type discoid meniscus (dislocated)	- Absence of anterior PMF on sagittal view	***
	- Absence of posterior meniscotibial ligament on sagittal view	***
	- Absence of lateral meniscotibial ligament on coronal view	**
	- Meniscus 'S' shape on axial view	*
	- Deformation of meniscus shape on coronal and sagittal views	**
	- Possible hyperintense signal of anterior horn (intra-meniscal lesion)	*
	- Possible hyperintense signal of meniscal body (radial tear)	**
	- Anterior-medial dislocation of posterior horn and body	*
	- No meniscal tissue attached to the capsule on sagittal and coronal view	*

Note. PMF, popliteomeniscal fascicle.

of the most unstable part of the posterior portion of the lateral meniscus to, or close to, the centre of the lateral tibial plateau can be elicited with fluid aspiration (Tom's test) or with the probe without meniscus tear. Isolated lesions should be repaired either with all-inside devices³⁰ or sutures.³¹ Attention should be paid to not place too many sutures which may cause meniscal overconstraint (Fig. 12f). It is advised to tighten the sutures without rippling the meniscal surface and without pushing the meniscus too peripherally, limiting excessively its physiological mobility. A deep and precise patient history should be collected, coupled with a comprehensive arthroscopic examination, since symptoms and MRI aspect of isolated meniscal fascicle tears, especially the PMFs, could mimic the hypermobile Type III Wrisberg-type discoid meniscus.

Type III Wrisberg-type discoid meniscus

The discoid lateral meniscus is an anatomic variant which is present in 1–5% of the population.³¹ The Wrisberg variant is the rarest subtype, with a reported arthroscopic prevalence of 0.2%.³² It is characterized by a normal anatomical 'C' shape, which is thus not true discoid; however, the posterior horn could be hypertrophic. Moreover, the meniscotibial coronary ligaments and the PMFs are lacking, with the meniscofemoral ligament of Wrisberg or Humphrey as the only posterior stabilizing structure.^{31,32} The absence of normal posterior attachments predisposes the posterior horn to hypermobility, subluxation and even real dislocation within the intercondylar notch. This situation leads to a suggestive clinical presentation of pain, popping and fixed irreducible locking. Differently from isolated PMFs tears, the symptoms at onset are not well defined, and knee abnormalities

are reported since childhood or adolescence without recalling any traumatic event;³³ moreover, bilateral presentation is possible.³⁴ The MRI presentation of Type III Wrisberg-type discoid menisci is not specific, but it could be helpful to exclude the presence of a true discoid meniscus, especially in patients younger than 14–16 years and in those with no history of trauma (Table 3). However, when the lateral meniscus is in situ, the diagnosis could be difficult³⁵ (Fig. 13), thus the patient's demographics and history are fundamental to differentiate between a traumatic or dysplastic aetiology. In some cases, when the hypermobile meniscus dislocates and relocates repetitively, a radial tear could be present at the level of the meniscal midbody, where the meniscus folds while dislocating (Fig. 14). Differently, when the hypermobile meniscus is dislocated at the time of MRI, the clinic-radiological diagnosis is almost straightforward (Table 3). Similarly to isolate PMF tears, the diagnosis confirmation is obtained arthroscopically (Fig. 15a-d); however, with the probe it is possible to completely dislocate and relocate the meniscal posterior horn and body within the notch, even if this practice is not advisable in cases where the meniscus is already in situ after spontaneous reduction. In this regard, attention should be paid since it is common for patients with a dislocated meniscus at time of MRI to present with a reduced meniscus when examined arthroscopically. In these cases, meniscus mobility and anatomical abnormalities should be carefully examined. The most appropriate treatment is represented by meniscal stabilization, which could be obtained with all-inside sutures (Fig. 15e-f). Considering the enormous hypermobility of the whole posterior half of the lateral meniscus, a secure fixation is usually obtained with more sutures with respect to meniscal fascicle tears, until a

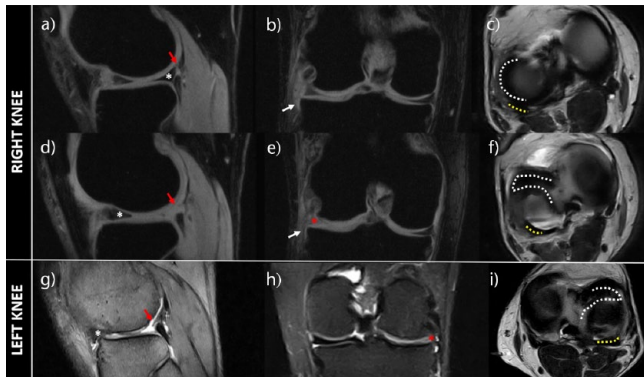


Fig. 13 Case 3, 38-year-old male patient. Heavy worker, non-athletic except for recreational cycling. He complained of right knee popping and locking episodes over the past 8 months. The first magnetic resonance imaging (MRI) was reported as inconclusive with an apparently normal posterior horn of the lateral meniscus (white asterisk); a retrospective review allowed to note abnormalities at the level of PS-PMF (red arrow) on sagittal slices (a) and absent lateral meniscotibial ligament (white arrow) substituted with an hyperintense signal on coronal slices (b). The axial view was normal, with a ‘C’-shaped lateral meniscus (white dotted line) and correct relationship with the popliteus tendon (yellow dotted line) (c). A second MRI performed after two months due to symptom persistence without any traumas revealed the complete anterior displacement of the lateral meniscus posterior horn (white asterisk) (d) without any peripheral rim on both sagittal and coronal slices (red asterisk) (e). The axial view showed an abnormal shape of the lateral meniscus (white dotted line) with no peripheral rim at the level of the popliteus tendon (yellow-dotted line) (f). In a deep patient history, the patient reported having suffered from vague bilateral knee complaints since the age of 14 years; thus MRI of the contralateral left knee was obtained, showing similar features on all sagittal (g), coronal (h) and axial planes (i).

secure fixation of the whole meniscus is obtained. High suspicion should be used in these patients, since displaced Wrisberg III discoid menisci could be mistaken for displaced bucket-handle tears, especially if peripheral.

Displaced bucket-handle tear

This type of tear, which could involve the meniscal portion at the level of popliteal hiatus, is more common than meniscal fascicle tears or Type III Wrisberg-type discoid meniscus; however, differential diagnosis within these entities could be challenging in some cases. The clinical scenario of bucket-handle tears usually involves patients with a variety of ages, often young and athletic, with symptom onset after a well-defined trauma; moreover, combined ACL injury is frequent.³⁶ The MRI diagnosis is usually straightforward (Fig. 16a-c); however, displaced lesions near the meniscocapsular junction could be mistaken for a displaced Wrisberg III discoid meniscus. It is important assess the presence of even a small peripheral

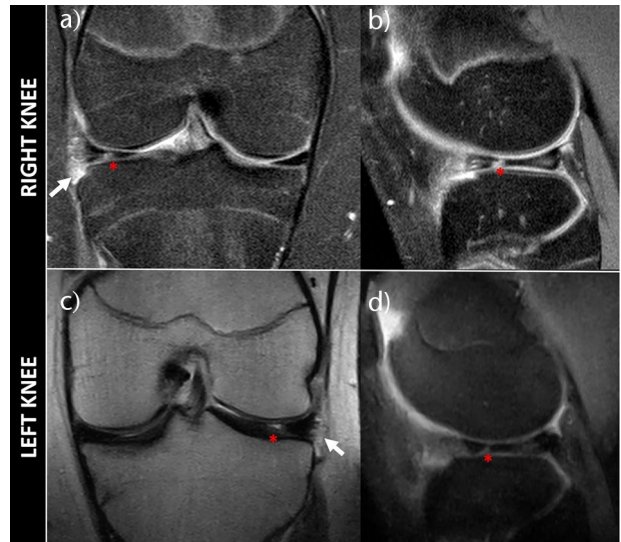


Fig. 14 Case 4, 15-year-old male footballer. He complained of bilateral knee pain and popping, with locking episodes during sporting activity. He underwent bilateral knee arthroscopy without symptom resolution. Magnetic resonance imaging (MRI) of the right knee shows normal triangular shape of the lateral meniscus; however, the coronary ligament is not seen, substituted by an hyperintense signal (white arrow) (a), and a linear tear is present at the level of the midbody (red asterisk) (b). MRI of the contralateral left knee showed similar features in both the coronal (c) and sagittal planes (d).

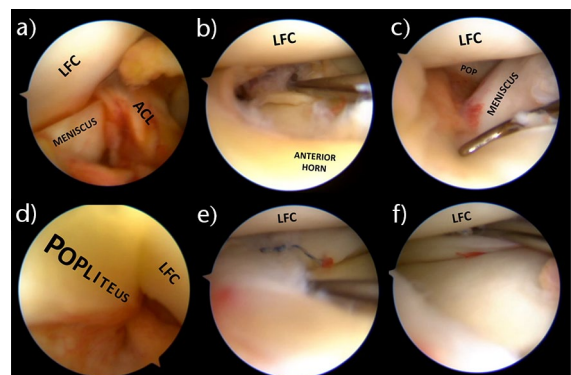


Fig. 15 Case 4, 15-year-old male footballer (same patient as Figure 14). After a locking episode of the right knee with impossibility to reach full extension, the patient underwent arthroscopy. The lateral meniscus was found engaging the intercondylar notch and impinging the ACL (a). After the reduction of the meniscus in the anatomical position, an incomplete radial tear with delamination at the level of the midbody was found (b). Lack of PMFs was noted both inspecting the popliteal hiatus (c) and the ‘popliteus tunnel’ view (d). The radial tear was repaired with a horizontal all-inside suture (e), and the postero-lateral portion of the meniscus stabilized with another three all-inside sutures, obtaining a satisfactory stability upon probing (f).
Note. ACL, anterior cruciate ligament; PMFs, popliteo-meniscal fascicles; LFC, lateral femoral condyle.

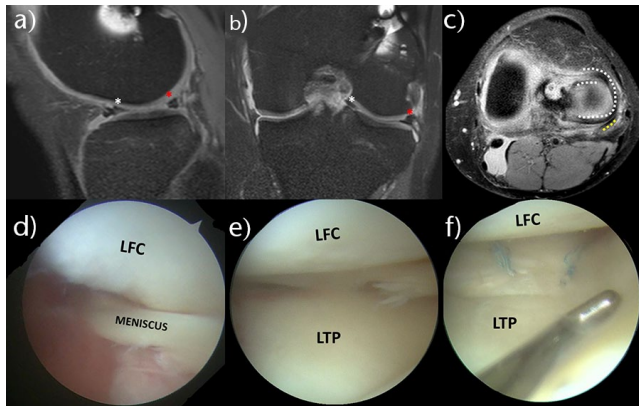


Fig. 16 Case 5, 33-year-old male patient. He complained of knee instability and lateral pain after a knee sprain. He had positive +++ Lachman, +++ Pivot-Shift, negative varus-valgus test and negative posterior drawer. The magnetic resonance imaging (MRI) showed rupture of the ACL and a displaced bucket-handle tear of the lateral meniscus. In the sagittal slices, a portion of the posterior horn was displaced anteriorly (white asterisk), while a peripheral rim was present (red asterisk) (a). In the coronal slices, the meniscal free margin was displaced within the notch (white asterisk), but a peripheral rim with intact lateral meniscotibial ligament was present (red asterisk) (b). A peripheral rim (white dotted line) was also noted in the axial slices, near the popliteus tendon (yellow dotted line) (c). At arthroscopic assessment, the free edge of the lateral meniscus was displaced within the notch (d). After reduction (e), the tear was sutured with three all-inside sutures (f).

Note. ACL, anterior cruciate ligament; LFC, lateral femoral condyle; LTP, lateral tibial plateau.

meniscal rim, and other signs to exclude anatomical abnormalities (Table 2). The arthroscopic presentation is similar between displaced bucket-handle and Wrisberg Type III discoid meniscus. However, the displaced portion is smaller and more mobile in the case of a tear (Fig. 16d–e). It is important to differentiate the bucket-handle lesion from the Wrisberg III discoid meniscus, since the surgical approach, despite being similar, could differ in the placement of suture due to the presence or absence of a meniscal rim (Fig. 16f).

Conclusions

The anatomy of the popliteal hiatus is complex and could be variable. Therefore, beside the classical lateral meniscus tears, uncommon subtle injuries or abnormalities of this region such as meniscal fascicle tears or Type III Wrisberg-type discoid meniscus could be overlooked and not treated properly. Therefore, a deep knowledge of anatomy, MRI presentation and arthroscopic appearance of the popliteal hiatus, either in normal or pathological situations, should be possessed by the orthopaedic surgeon.

AUTHOR INFORMATION

¹Ila Clinica Ortopedica e Traumatologica, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy.

²Dipartimento di Scienze Biomediche e Neuromotorie DIBINEM, Università di Bologna, Italy.

Correspondence should be sent to: Alberto Grassi, IRCCS Istituto Ortopedico Rizzoli – Ila Clinica Ortopedica e Traumatologica, Via Pupilli 1, Bologna 40136, Italy.

Email: alberto.grassi@ior.it

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