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Anatomy of the posterior cruciate ligament and the meniscofemoral ligaments

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Abstract This paper describes the anatomy of the posterior cruciate ligament (PCL) and the meniscofemoral ligaments (MFLs). The fibres of the PCL may be split into two functional bundles; the anterolateral bundle (ALB) and the posteromedial bundle (PMB), relating to their femoral attachments. The tibial attachment is relatively compact, with the ALB anterior to the PLB. These bundles are not isometric: the ALB is tightest in the mid-arc of knee flexion, the PMB is tight at both extension and deep flexion. At least one MFL is present in 93% of knees. On the femur, the anterior MFL attaches distal to the PCL, close to the articular cartilage; the posterior MFL attaches proximal to the PCL. They both attach distally to the posterior horn of the lateral meniscus. Their slanting orientation allows the MFLs to resist tibial posterior drawer.

Keywords Posterior cruciate ligament · Meniscofemoral ligament · Anatomy · Fibre bundles · Length changes

Introduction

This anatomical paper describes the posterior cruciate ligament (PCL) and the meniscofemoral ligaments (MFLs). It describes the bony attachments of the ligaments, their fibre anatomy, and the patterns of tightening and slackening of the ligament fibres during knee flexion–extension. This description can be tied in with other texts that describe the function of these structures.

The PCL is a very strong ligament, with a maximum tensile load reported in the range 739–1,627 N [13, 16, 18, 19, 22]. This is stronger than the anterior cruciate ligament (ACL) in specimens of similar age. The strength relates to a large cross-sectional area, and the fibres spread out to an extensive femoral attachment. Because of this, knee flexion–extension causes them to have different patterns of tightening and slackening, and so they become more or less important. This relates to the patterns of damage that are caused by injuries with the knee flexed or extended, and also to the importance of graft tunnel positions and tensioning protocols for restoring tibial posterior laxity to normal.

The PCL is the primary restraint to tibial posterior draw, contributing approximately 90% of the resistance across most of the arc of knee flexion [4, 20]. Recently, however, there has been increasing knowledge of the role of other structures in providing this function as the knee reaches extension [3]. This helps to explain why an isolated PCL rupture often does not lead to disabling instability, despite the strength of the damaged structure.

Femoral attachment of the PCL

The femoral attachment of the PCL extends more than 20 mm in an anterior–posterior (AP) direction across the roof and medial side of the femoral intercondylar notch. The PCL attachment is bounded distally by the margin of the articular cartilage of the medial femoral condyle and in general conforms to a ‘half-moon’ shape. The extent of the attachment is variable, and is influenced by the presence or absence of the MFLs. In the specimen illustrated in Fig. 1 the PCL attachment extends as far posteriorly as it can against the margin of the articular cartilage. In some knees the attachment is more compact than this and does not extend so far posteriorly.

The PCL does not attach solely to the medial side of the femoral intercondylar notch, but also to the roof of the notch. A straight posterior–anterior view reveals that the anterior fibres of the PCL, which are the most lateral part of it, pass in a sagittal plane to the roof of the notch. In contrast, the posterior fibres take an oblique path as they pass up to the wall of the femoral condyle medially and down to the tibia laterally.

When viewed from the anterior aspect of the flexed knee, the distal aspect of the PCL femoral attachment is revealed in the so-called ‘notch view’ (Fig. 2). It can be seen that the fibres extend in the left knee from approximately 12.00 to 1.00 o’clock, at the top of the notch, back round from approximately the 7.30 to 8.00 o’clock position, which is adjacent to the tibial plateau. Thus, the entire medial aspect of the femoral intercondylar notch has the PCL attached to it in this view. The anterior meniscofemoral ligament (aMFL) of Humphrey slants across the PCL and also attaches adjacent to the femoral condylar articular cartilage

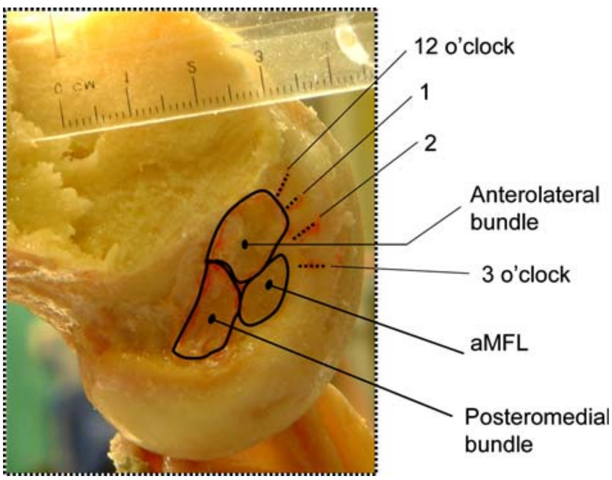

Fig. 1 The femoral attachment of the PCL. Lateral–medial view in a left knee after removal of the lateral femoral condyle. The anterolateral and posteromedial bundles of the PCL, plus anterior meniscofemoral ligament attachments are outlined

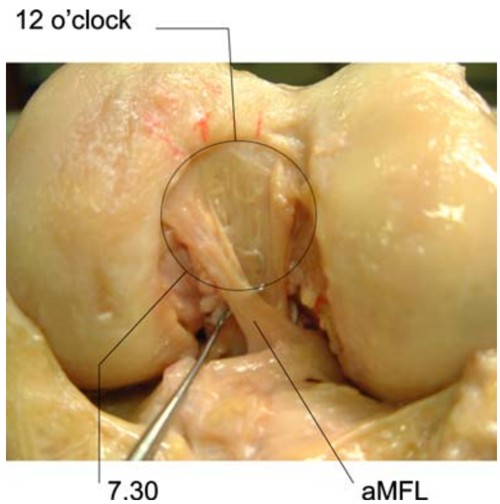

Fig. 2 The PCL attaches close to the edge of the condylar articular cartilage. It usually extends from approximately 7.30 to 12.30 o’clock position in a left knee; this example is wider. The aMFL slants across the PCL

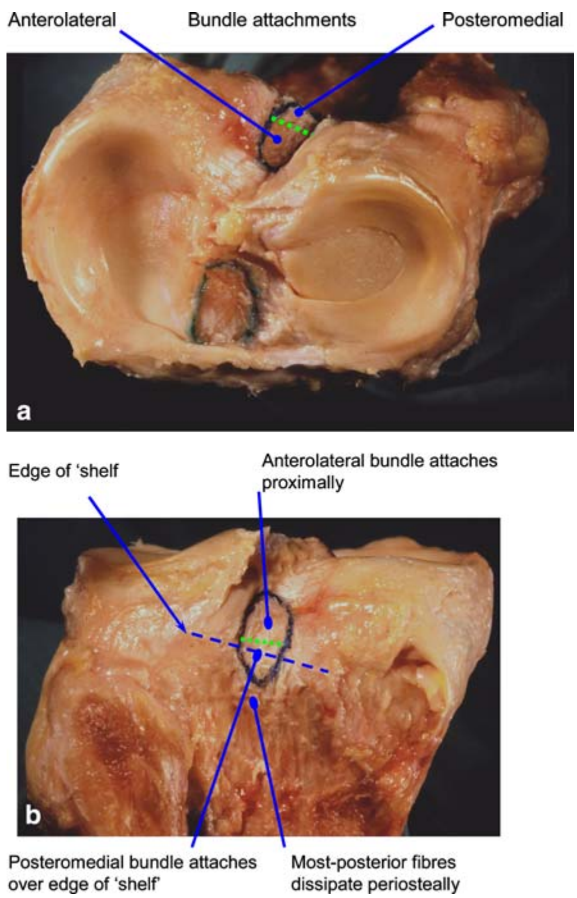

Fig. 3 **a** Proximal-distal view of tibial plateau with PCL attachment marked. **b** Posterior–anterior view of tibial plateau with PCL attachment marked. Note how the attachment area passes ‘over the back’

[1, 8]. When the femoral attachment area of the PCL is viewed in the PCL-deficient knee, it is seen that the bulk of the attachment area, that corresponds to the anterolateral (AL) fibre bundle, is between the 9.00 o'clock and 12.00 o'clock position in the left knee. The attachment also extends further down towards the tibial plateau, that is posteriorly on the femur, as the posteromedial (PM) fibre bundle area. The shape and size of the anteromedial bundle is consistent in most knees, however, the variability in the size and shape of the PCL is mostly reflected in variations in the PMB size both in mid-substance and its attachment. In some knees, the posterior meniscofemoral ligament (pMFL) is a significant and relatively large structure. This may have some bearing on PCL reconstruction technique, in that one may be able to replace the anterolateral bundle (ALB) alone if the pMFL is substantial and intact. Currently, this is simply a point of conjecture.

Tibial attachment of the PCL

Looking down onto the tibial plateau from a proximal viewpoint it is seen that the PCL attachment is relatively compact (Fig. 3a). It is onto the superior aspect of the posterior tibial 'shelf'. The attachment is nestled between the posterior horns of the two menisci.

When viewed posteriorly the PCL tibial attachment is seen to extend over the posterior rim of the shelf. Above the shelf the attachment relates mostly to the AL fibre bundle area of the PCL. The attachment of the PM fibre bundle includes the most posterior area above the shelf, and also the area immediately below the shelf (Fig. 3b). The ALB occupies a central area covering almost the entire flat intercondylar surface of the posterior tibial plateau ('posterior intercondylar fossa') from the posterior edge of the root of the posterior horn of the medial meniscus to within 2 mm of the posterior rim of the plateau. Its shape is trapezoidal, wider posteriorly.

The posteromedial bundle (PMB) occupies a central area of the posterior surface of the tibia from immediately above the plateau rim. The bundle's most posterior and distal attachment occurs distal to the tibial plateau. Its fibres blend with those of the tibial periosteum and the attachment of the knee joint capsule to the tibia and is demarcated by the presence of a small transverse ridge on the tibia. Superiorly its attachment meets that of the AL bundle. The overall orientation of the tibial attachment reflects the path of the fibres of the PMB, slanting postero-lateral-distally. Thus the PMB attachment is distal and lateral to the ALB attachment. When the PCL is intact, the most-posterior fibres pass 'over the top' of the tibial shelf and extend distally and insert into the distal periosteum close to the attachment area of the popliteus muscle.

The fibre anatomy of the PCL can be divided into two main fibre bundles: AL and PM [1, 5, 12, 17, 19, 23]. The split between the two bundles in Fig. 4 has been created by dissection; this is an artificial division and not a natural phenomenon. This division between the two bundles is based on their different tightening and slackening behaviour during knee flexion and extension. It can be seen that the ALB attaches mostly to the roof of the intercondylar notch, while the PMB attaches mostly to the medial side wall of the notch on to the medial femoral condyle. There is some overlapping of the bundles from anterior to posterior, with the PMB attaching slightly proximal to the ALB. The ALB has a larger cross-sectional area than the PM, and is much stronger [19]. Although the mid-substance proportions of the AL and PMBs are considerably different, the tibial attachments have much more similar areas.

The fibre bundles do not twist around themselves in the extended knee. Rather, the AL fibres are on the anterior aspect of the tibial attachment and the PM fibres are posterior and, therefore, are superficial to the anterior fibres when the knee is viewed from the posterior aspect. Because of this arrangement, the anterior fibres are shortest and the posterior fibres are longest. If a surgeon performs a single-bundle PCL reconstruction, aiming to reconstruct the AL fibre bundle, the graft should be brought up from the tibia underneath (anterior to) any remnant of the natural PCL. If the graft is brought out of the tibia into the back of the knee joint and then to the femur, it will cause a twisted structure that is not anatomical.

In addition, some anatomists have identified posterior oblique fibres of the PCL. These may sometimes be confused with the pMFL of Wrisberg if their distal attachment is not identified correctly [6]. This is because,

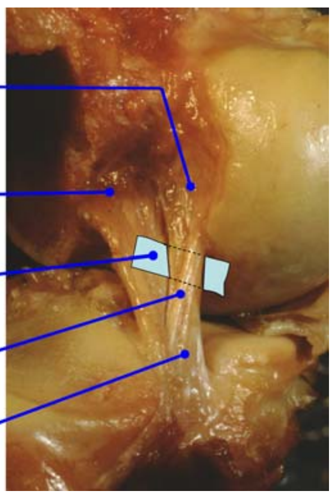

Fig. 4 The PCL fibres have been separated into the ALB and the PMB. Posterolateral view of left knee after removal of the lateral femoral condyle

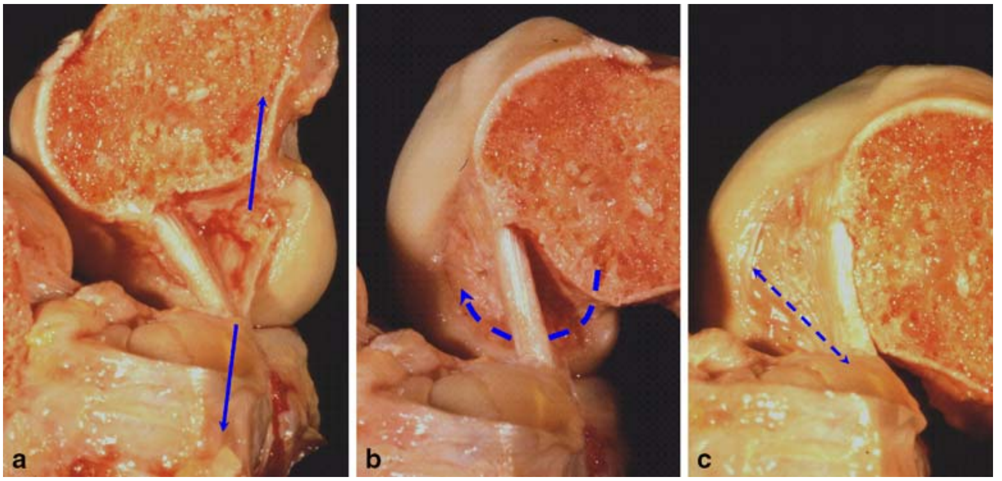

Fig. 5 The posteromedial fibre bundle of the PCL: **a** it is tight and oriented proximal–distal in the extended knee; **b** it passes between the ALB and the medial condyle in mid-flexion; and **c** it is tight and oriented to withstand posterior draw in the flexed knee

like the pMFL, these fibres are situated posteriorly on the PCL and follow a slanting path, from medial on the femur to lateral on the tibia, where they attach to the bone below the level of the posterior horn of the lateral meniscus (Fig. 4). This similarity may cause confusion between a complete rupture of the PCL with intact pMFL, and a partial rupture of the PCL.

PCL tension pattern with knee flexion–extension

A video of the PCL during knee flexion–extension motion[1] clearly shows the movements and tightening–slackening behaviour of the different structures. There are three main structures to consider: the ALB, the PMB, and the MFLs. The importance of the length changes is that they inform us of the role of each of the structures in controlling tibial posterior draw laxity, and how these roles become more or less important as the knee flexes and extends. The PCL is known to be the primary restraint to tibial posterior draw across most of the arc of knee flexion [4, 20].

First, the PMB of the PCL. This is tight and aligned in a proximal–distal direction in the extended knee (Fig. 5a). Thus, it is not aligned to withstand tibial posterior draw, but appears to resist hyperextension. The PM fibres slacken when the knee starts to flex. In mid-flexion the PM fibres pass between the medial side wall of the notch and the AL fibre bundle of the PCL, where they are slack (Fig. 5b). In deep flexion the PM fibre attachment moves anteriorly and also upwards away from the tibial plateau and so the PM fibres then become tight again (Fig. 5c). Thus, in deep knee flexion the PM fibre bundle is both tight and well aligned to withstand tibial posterior draw [20, 23].

[1] See http://www.imperial.ac.uk/people/a.amis

The AL fibre bundle is seen to be curved in the sagittal plane and, therefore, is slack in the extended knee (Fig. 6a). This curved path is seen clearly in MRI scans of the extended knee. When the knee flexes, this fibre bundle becomes tight and also takes a steeper angle away from the tibial plateau (Fig. 6b). In deep knee flexion the AL fibre bundle rests against the roof of the femoral intercondylar notch (Fig. 6c). Its steep orientation means that it is now less efficient at withstanding tibial posterior draw.

In deep knee flexion the PCL passes through a narrowing gap between the posterior aspect of the femur, at the posterior outlet of the femoral intercondylar notch, and of the tibial plateau. It is easy to imagine that it may be nipped or sheared between the bones during hyperflexion, and that this is a potential injury mechanism when a person falls on to the tibial tuberosity with the knee flexed (Fig. 6c).

The above description shows that the fibre bundles of the PCL undergo significant length changes as the knee flexes and extends. Thus, the PCL cannot be approximated by an isometric reconstruction. It has been shown that an isometric graft over-constrains the knee in extension, where the bulk of the natural PCL is slack, and does not tighten enough to control laxity normally in deep flexion [21]. Because of this, several studies have examined ‘anatomical’ double-bundle reconstructions [10, 15, 21]; a review of these [2] has shown that all three investigations found biomechanical advantages for this method, although clinical advantages have not been found.

The other significant functional deduction from the observations of the fibre bundles is that neither of them is set up to control tibial posterior draw in the extended knee; the ALB is slack, and the PMB is not orientated correctly. This may explain why an isolated PCL rupture may not cause knee instability; other structures, partic-

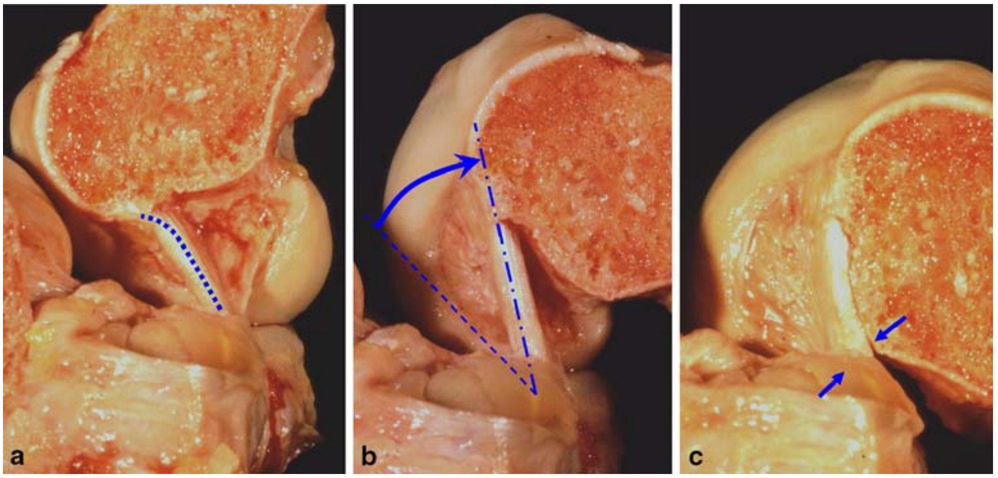

Fig. 6 The anterolateral fibre bundle: **a** it is curved and slack in the extended knee; **b** it is tight and takes a steeper slope in mid-flexion; and **c** it wraps against the roof of the intercondylar notch in deep flexion and could be nipped between the bones in hyperflexion (*arrows*)

ularly at the PL and PM aspects, are then acting to stabilise the extended knee [3].

The meniscofemoral ligaments

The aMFL of Humphrey slants across the distal aspect of the PCL in the flexed knee. It attaches to the femur distal to the PCL and, therefore, is superficial when viewed in the flexed knee. It is immediately adjacent to the articular cartilage, in the 10.00 o'clock position in a left knee. Its fibres intermingle with those of the PCL immediately adjacent to their femoral attachment. Its distal attachment is to the posterior horn of the lateral meniscus (Fig. 7a). It is difficult to identify this attachment when the knee is intact; it has been demonstrated here by excising the ACL, to allow the tibial plateau to sublux anteriorly. When the PCL is viewed arthroscopically, the aMFL may be identified by the slanting orientation of its fibres, which is in contrast to the vertical orientation of the PCL fibres.

The pMFL of Wrisberg extends between the medial side wall of the femoral intercondylar notch and the posterior horn of the lateral meniscus (Fig. 7b). The femoral attachment is proximal to the PM fibres of the PCL and so it is superficial to the PCL when viewed from the posterior aspect. Unlike the aMFL, its femoral attachment is separate to that of the PCL, so there is no intermingling of its fibres with those of the PCL. It therefore rests on the posterior/superior aspect of the surface of the PCL. This means that the pMFL is very deep in the notch when viewed from an anterior portal, and is usually difficult to identify, because the PCL hides it. In order to make a positive identification of

Fig. 7 **a** The anterior MFL slants across the PCL in the flexed knee. It attaches close to the femoral condylar articular cartilage and to the posterior horn of the lateral meniscus (femur displaced posteriorly after ACL resection). **b** The posterior MFL attaches proximal to the PCL on the medial femoral condyle, and to the posterior horn of the lateral meniscus. **c** The two MFLs embrace the PCL in knees where they are both present (lateral femoral condyle removed for clarity)

the pMFL, it should be noted that it attaches directly to the posterior horn of the lateral meniscus, whereas the oblique posterior fibres of the PCL pass down to the posterior rim of the tibial plateau and so, by definition, are not *menisco*femoral. If an MFL is tugged using a hook, this will cause the lateral meniscus to move. If that does not occur, then the fibres may be a remaining part of the PCL after a partial rupture, and not an MFL.

Not all knees have both of the MFLs present [6]. However, when they are present, they embrace the PCL anteriorly and posteriorly (Fig. 7c). Because their distal attachment is to the relatively mobile meniscus, it is possible for the PCL to be ruptured and for the MFLs to remain intact. The illustration shows that they may act as a splint to keep the PCL in position while it heals, and this anatomical arrangement may be significant in relation to the conservative treatment of an isolated PCL rupture.

A review of the published literature shows that the presence of the MFLs has been sought in a total of approximately 1,200 knees [6]. These studies have found a prevalence of approximately 93% of all knees having at least one MFL and approximately 50% having both. Some studies have reported a higher prevalence of pMFL than others; this may have resulted because of misidentification of the posterior oblique fibres of the PCL.

The MFLs are variable structures and when present, their bulk may vary considerably. They have a mean strength of approximately 300 N and so mechanically they are equivalent to the PMB of the PCL [7, 14]. Because of their slanting arrangement from the posterior horn of the meniscus up to the femoral intercondylar notch, they are oriented so that they can help to withstand tibial posterior draw, and this function has been proven recently [9].

It is easy to misdiagnose the posterior oblique fibres of the PCL as being a posterior MFL. The posterior intracapsular examination has to extend distally so that the attachment to either the meniscus or to the tibia can be identified if these structures are to be differentiated [8].

The femoral attachments of the aMFLs and pMFLs are distal and proximal to the PCL attachment, respectively. These positions mean that the aMFL is slack in the extended knee and tightens with knee flexion, when it is well aligned to withstand tibial posterior draw. Conversely the pMFL is tight in the extended knee and slackens with knee flexion, because its femoral attachment moves down towards the tibial plateau as the knee flexes.

In a video that shows flexion and extension movement of a knee that has an aMFL,[1] but not a pMFL, the aMFL is slack in the extended knee and is collapsed underneath the anterior fibres of the PCL. When the knee flexes, this structure is seen to straighten out and tighten. When the knee extends, the aMFL is seen to buckle and become visibly slack.

Conclusions

This paper has given an overview of the gross anatomy of the PCL and MFLs. The movements and tightening–slackening patterns of the fibre bundles help to explain their differential functions in stabilising the knee, particularly against tibial posterior draw, at different angles of flexion. More detailed description of the behaviour of the ligaments may be found in the references listed below.

In the context of reconstructive surgery, the description of the PCL fibre bundles suggests that double-bundled reconstructions are a logical development, but although there is laboratory evidence to support this idea [2, 10, 15, 21], it has not been supported by reports of superior clinical results. Similarly, although the MFLs have been treated as unimportant vestigial structures, now that their function in helping to control posterior laxity has been demonstrated [9], it suggests that maybe they should be preserved if possible, rather than being treated as a nuisance that gets in the way of a PCL reconstruction. The idea that the embrace of the MFLs around the PCL acts to splint it after an isolated rupture is also attractive as a way to explain the success of conservative treatment of an isolated PCL rupture.

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