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## **Posterior Cruciate Ligament: Anatomy, Femoral Insertion and Relationships with the Anterior Menisco-Femoral Ligament in 23 Cadaver Knees**

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## **ABSTRACT**

**Background:** Abundant anatomic descriptions exist of the posterior cruciate ligament (PCL) and menisco-femoral ligaments (MFLs). There is broad agreement that the PCL is composed of two bundles and inserts on the femur near the distal cartilage. However, a different configuration with a single bundle and a complex femoral insertion has been reported. The main objective of our cadaver study was to determine the number of anatomical bundles forming the PCL. We also described the insertion of the PCL and its relationships with the anterior menisco-femoral ligament (AMFL).

**Hypothesis:** The PCL consists of a single ribbon-like bundle and inserts on the femur separately from the AMFL.

**Material and Methods:** We used 23 knees of fresh unembalmed cadavers, which we dissected under a microsurgery loupe. Inclusion criteria for the knees were freedom from trauma and scars. No age limits were set. The features of the PCL were studied using the clock method. Measurements were taken using callipers with a precision of 0.01 mm.

**Results:** No knees were excluded from the final analysis. Macroscopically, the PCL appeared as a single bundle forming a slender flat ribbon. With the knee flexed at 90°, the ligament footprint extended from 58 mm to 25 mm on the right and from 48 mm to 2 mm on the left. The femoral insertion of the AMFL started 2.07 mm from the distal cartilage and masked the distal insertion of the PCL. After removal of the AMFL, the middle of the femoral insertion of the PCL started on average 5.99 mm from the distal cartilaginous rim when the knee was flexed at 90°.

**Discussion:** Our study confirms descriptions of the PCL as a single bundle shaped as a flat ribbon. The presence of the AMFL gives the appearance of a double bundle and partially masks the femoral insertion of the PCL, which is located further back relative to the distal joint cartilage.

**Level of evidence:** IV; Experimental cadaver study

**Key Words:** Posterior cruciate ligament; PCL; Humphrey's ligament; meniscofemoral ligaments; anatomy

## 1 INTRODUCTION

The central pivot of the knee is often involved in knee injuries [1,2]. The anatomy and reconstruction techniques of the PCL are less often described than those of the anterior cruciate ligament (ACL), for several reasons: the PCL is less often damaged[3], the diagnosis of PCL injury is difficult[4], and isolated PCL tears heal well with functional treatment alone [5].

The PCL is widely believed to consist of two anatomically and functionally separate bundles [6], [7]: the larger is the antero-lateral bundle, which tightens when the knee is flexed, and the other is the postero-medial bundle, which tightens when the knee is extended [6], [8], [9].

The PCL femoral insertion has been described as a large fan-shaped structure located on the lateral aspect of the medial condyle, having its base towards the femur, and measuring over 30 mm along its long axis [10]. The surface area of the femoral footprint has been measured at 2.93 cm<sup>2</sup> [11]. The insertion of the antero-lateral band is described as anterior to that of the postero-medial band, with the mean distance between the two being 12.1±1.3 mm [7]. With the knee flexed at 90°, the insertion of the antero-lateral band is described as being located 1.5±0.8 mm from the distal cartilage, compared to 5.8±1.7 mm for the postero-medial band [6], [7], [12]. These insertions have been reported to form a surface that is concave overall or shaped like a comma [13], [14].

The PCL is accompanied anteriorly by the anterior menisco-femoral ligament (AMFL) (Humphry's ligament) and posteriorly by the posterior menisco-femoral ligament (PMFL) (Wrisberg's ligament). The femoral insertions of these ligaments are located on the lateral aspect of the medial femoral condyle and end at the posterior horn of the lateral meniscus.

The incidence of the two menisco-femoral ligaments has varied across studies from 0% to 64% [15], [16].

Recent studies have described the PCL as composed of a single bundle that forms a ribbon [17] or a continuum of fibres [18].

The main objective of our cadaver study was to determine the number of anatomical bundles forming the PCL. We also described the insertion of the PCL and its relationships with the anterior menisco-femoral ligament (AMFL). The hypothesis was that the PCL consists of a single ribbon-like bundle and inserts on the femur separately from the AMFL.

## **2 MATERIAL AND METHODS**

### **2.1 The experimental model**

Between November 2017 and May 2018, 23 knees of fresh unembalmed cadavers were included in our anatomical study. The study followed a standardised protocol that was first validated by four dissection tests in the presence of at least two of the authors, at the Pathology Laboratory of the Nantes School of Medicine, Nantes, France. All dissections were performed by a single author. The 23 knees were not matched: there were 11 right and 12 left knees. Males contributed 12 knees and females 11 knees. Mean age of the subjects at death was 85 years (range, 72-106 years).

All knees that were free of trauma and scars were included, with no age limit. Exclusion criteria were a partial or complete PCL tear, advanced osteoarthritis of the notch precluding dissection, and synovial disease.

The antero-medial approach was used. After removing the extensor apparatus and collateral ligaments, the ACL and medial meniscus were removed. The synovial membrane of the PCL was then removed under a microsurgical loupe.

An oscillating saw was used to perform bony cuts in the lateral condyle and in the tibial metaphysis perpendicularly to the mechanical axis of the tibia.

The dissection specimen thus prepared isolated the medial femoral condyle, the tibial epiphysis, the PCL, the menisco-femoral ligaments (MFLs), and the lateral meniscus (Figures 1 and 2). By mobilising the femoral component, it was possible to completely remove the synovial membrane by dissection under a microsurgical loupe. We routinely looked for a cleavage zone producing a single-bundle or double-bundle PCL.

The anatomical references used to describe the femoral cartilage were anterior/posterior and proximal/distal.

## **2. 2 Data collection**

The following parameters were recorded:

- antero-posterior length of the femoral insertion of the AMFL in millimetres (mm);
- distance between the distal cartilage and the femoral insertion of the AMFL in mm;
- site of the PCL insertion in minutes (see below);
- antero-posterior length of the femoral insertion of the PCL, in mm;
- medio-lateral length of the femoral insertion of the PCL, in mm;
- distance between the anterior cartilage and the proximal insertion of the PCL, in mm (Figure 3);
- distance between the distal cartilage and the middle of the femoral insertion of the PCL; the middle of the femoral insertion of the PCL corresponded to the centre of the femoral footprint of the PCL;
- distance between the posterior cartilage and the distal insertion of the PCL, in mm.

To describe the insertions, we used the clock-face method used for arthroscopy and anatomical descriptions [6]. A frontal photograph was taken with the knee flexed at 90°. A circle was then drawn in the middle of the knee so that it contained the entire notch (Figure 4). The 12 o'clock position corresponded to the apex of the notch. The o'clock positions of the insertions of the AMFL and PCL were thus recorded. The mean distribution corresponded to the difference between the anterior and posterior limits of the insertion of each PCL.

All measurements were performed using manual millimetric callipers (Splash-Proof Digital Caliper®, Digital Measurement Metrology, Brampton, Canada), which had a precision of  $\pm 0.01$  mm. Digital photographs were taken at each step of the dissection using a Nikon Reflex D5000® camera (Shinagawa Intercity Tower C, Tokyo, Japan).

## **2.3 Statistical analysis**

All the data reported in mm were described with two decimal places, the mean value, and the range.

## **3 RESULTS**

### **3.1 Frequency of the menisco-femoral ligaments**

The AMFL was present in 20/23 (87%) knees and the PMFL in 18/23 (78%) knees. Fifteen (65%) knees had both MFLs and all knees had at least one MFL.

### **3.2 Anterior menisco-femoral ligament (AMFL)**

The mean length of the AMFL was 24.25 mm (21.38-27.39) and its mean medio-lateral calibre was 5.99 mm (4.25-7.99).

The antero-posterior length of the insertion of the AMFL was 9.19 mm. The middle of its femoral insertion was located on average at 12 mm (9-14) for the right knees and at 49 mm (47-52) for the left knees. The femoral insertion of the AMFL was located 2.07 mm away from the distal femoral cartilage (Figure 5).

The AMFL was anterior to the PCL at its femoral insertion.

### **3.3 Gross anatomy of the posterior cruciate ligament (PCL)**

After complete removal of the synovial membrane and MFLs, the PCL was consistently seen to be composed of a single band visible as a taut ribbon (Figure 6). In none of the knees did we find a cleavage zone within the PCL. After turning the femoral condyle in external rotation, the PCL appeared flat (Figure 7).

### **3.4 Femoral insertion of the posterior cruciate ligament (PCL)**

For the proximal insertion of the PCL, the range was 58 mm to 25 mm for the right knees, with a mean value of 22 mm. For the left knees, the range was 2 to 40 mm with a mean of 15 mm. The middle of the insertion of the PCL was located on average at 11 mm (1-14) for the right knees and at 52 mm (49-54) for the left knees.

The long axis of the femoral insertion of the PCL had a mean value of 21.51 mm (17.28-24.14) in the antero-posterior direction and 13.38 mm (10.65-16.53) in the medio-lateral direction.

The femoral insertion of the PCL started on average 2.45 mm (1.23-4.01) from the anterior cartilage at the roof of the notch. After resection of the AMFL, the entire femoral insertion was visible and the middle of the insertion was located 5.99 mm (4.42-7.80) from the distal cartilage (Figures 8 et 9).

## **4 DISCUSSION**

The main finding from this study is that the PCL is composed of a single flat band. Furthermore, the middle of the femoral insertion of the PCL starts on average 5.99 mm away from the distal cartilage and is clearly separate from the insertion of the AMFL, confirming our initial hypothesis.

### **4.1 The posterior cruciate ligament (PCL) is composed of a single flat band**

Our findings are consistent with observations of Kato et al. [17] indicating that the PCL is not composed of an antero-lateral bundle and a postero-medial bundle but is a flat ribbon twisted along its axis (Video 1), as suggested previously for the ACL [19]

#### ***Video 1***

The PCL runs an oblique course downwards and laterally. It forms a large fan inserted on the lateral aspect of the medial femoral condyle and ends on the retro-spinal surface of the tibia.

Published descriptions of the PCL are conflicting. Kato et al. [17] described a single band forming a slender ribbon. Mejia et al. [18] considered that the PCL was a continuum of fibres. Finally, Makris et al. [20] described a complex configuration with four separate

bundles. However, the most prevalent view is that the PCL is composed of two separate bundles [6].

In our study, we found no full-thickness cleavage zone within the PCL. When looking frontally at the knee flexed at 90°, the presence of the ACL and synovial membrane can make the appearance of the PCL misleading. After removing the ACL, the AMFL can create the impression that the PCL has two bundles. The AMFL is in direct contact with the anterior aspect of the PCL, and its more oblique course can create the illusion of an antero-lateral band of the PCL (Figure 10).

#### **4.2 The middle of the femoral insertion of the PCL is located on average 5.99 mm from the distal cartilage**

The length of the femoral insertion was 21.51 mm in the antero-posterior direction and 13.38 mm in the medio-lateral direction. The insertion formed a broad fan with its base towards the femur. Amis et al. [6] reported that the femoral insertion was more than 20 mm long in the antero-posterior direction and was shaped as a half moon. In our study, the insertion was not limited only to the lateral aspect of the medial condyle but extended to the roof of the intercondylar notch: 58 minutes to 25 minutes for the right knee and 40 minutes to 2 minutes for the left knee.

Kato et al. [17] described the insertion of the PCL from 12 h to 4 h on the right and from 8 h to 12 h on the left. Meija et al. [18] reported 11:21±15 minutes to 4:12±20 minutes on the right and 7:48±20 minutes to 12:39±15 minutes on the left. Edwards et al. [21] found that the antero-lateral bundle was between 9 and 12 h and the postero-medial bundle between 7:30 and 10:30 h at the left knee.

In our study, the proximal insertion of the PCL (Figure 9) was located on average 2.45 mm from the anterior cartilage, at the roof of the notch. This value is consistent with previous publications [18].

Our findings differ from earlier reports regarding the middle of the insertion of the PCL (in red on Figure 3), behind the AMFL. Mejia et al. [18] found that the middle portion of the PCL footprint was located 2.38 mm from the distal cartilage, with no significant difference between the distance from the anterior cartilage to the femoral insertion of the PCL and the distance from the distal cartilage to the femoral insertion of the PCL. Our findings do not support this insertion adjacent to the distal joint cartilage.

In our study, the PCL formed a fan of fibres that did not distribute uniformly behind the articular cartilage. After resection of the AMFL, the middle portion of the insertion of the PCL was 5.99 mm on average from the distal cartilage. These results are in agreement with those reported by Edwards et al, [21], who found that the middle of the antero-lateral bundle was at 10:20 h,  $7\pm 2$  mm on average from the edge of the cartilage, and that the postero-medial bundle was at 8:30 h,  $10\pm 3$  mm from the edge of the cartilage, for left knees.

Anderson et al. [7] described the centre of the antero-lateral bundle as located 7.4 mm from the apex of the notch and 11 mm from the medial edge of the notch. They found that the postero-medial bundle was 11.1 mm from the medial edge of the notch, 10.8 mm from the posterior point, and 5.8 mm from the distal cartilage.

#### **4.3 The menisco-femoral ligaments (MFLs)**

At least one of the two MFLs was present in all knees. The AMFL was present in 87% and the PMFL in 78% of knees. Both MFLs were present in 65% of knees.

The prevalence of the MFLs varies across studies. The presence of at least one MFL was reported in 82% to 100% of knees [22], of the AMFL in 0% to 88 % of knees [15, 23],

of the PMFL in 15 to 100% of knees [23], [22], and of both MFLs in 0 to 64% of knees [15], [16].

In a magnetic resonance imaging study of 342 patients, Röhrich et al. [24] observed the presence of at least one MFL in 94% of knees, of the AMFL in 71% of knees, of the PMFL in 71% of knees, and of both MFLs in 47% of knees.

#### **4.3.1 Anterior menisco-femoral ligament (AMFL)**

The mean length of the AMFL was 24.25 mm in our study compared to  $22\pm 3$  mm in a study by Röhrich et al. [24], with no significant difference between males and females. In our study, the calibre of the AMFL was 5.99 mm, which is in keeping with previous data [17], [16].

The anterior-posterior length of the insertion of the AMFL was 9.19 mm in our population compared to 8.7 mm in a study by Kato et al. [17].

The femoral insertion of the AMFL was separate from that of the PCL, whereas Mejia et al. [18] reported that, of 9 knees having an AMFL, 7 had intertwined fibres from the AMFL and PCL at the femoral insertion. In our study, the insertion of the AMFL was on average at 12 minutes for the right knees and 49 minutes for the left knees. Its femoral insertion was 2.07 mm behind the distal cartilage, anterior to the most distal fibres of the PCL.

The main limitation of our study is that, due to the advanced age of the subjects, the knees contained osteophytes that may have led to errors when measuring the distance between the ligament insertion and the edge of the cartilage. Furthermore, there was inevitably a risk of dissection artefacts, which we sought to minimise by using a microsurgical loupe. Finally, we did not quantify the external rotation needed to obtain a flat ribbon.

## **5 CONCLUSION**

Our anatomic study suggests that the PCL is configured as a ribbon, which becomes flat when the femur is rotated externally. The position of the PCL is separate from the insertion of the AMFL. The insertion of the PCL is partly masked by the AMFL and is located on average 5.99 mm away from the distal femoral cartilage.

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## **Conflict of interest statement**

None of the authors has any conflict of interest to declare in relation to this publication.

T. Noailles declares financial ties with ARTHREX, STRYKER, SMITH & NEPHEW, and SANOFI.

A. Hamel declares financial ties with MEDICREA.

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### **Author Contributions**

J. Cousin performed all the dissection for the study and drafted the manuscript.

C. Decante and A. Hamel participated in the test dissections.

T. Noailles and A. Hardy contributed to establish a clear dissection protocol and revised the manuscript for important intellectual content.

All authors read and approved the final version of the manuscript.

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## FIGURE LEGENDS

**Figure 1.** Final appearance of the dissection specimen, frontal view of the knee: visualisation of the AMFL (blue), PCL (red), and PMFL (green).

**Figure 2.** Sagittal view of the knee: visualisation of the AMFL (blue), PCL (red), and PMFL (green)

**Figure 3.** After resection of the AMFL, visualisation of the proximal femoral insertion of the PCL opposite the anterior cartilage (blue) and of the middle of the femoral insertion of the PCL opposite the distal cartilage (red)

**Figure 4.** Use of the clock-face method to characterise the insertion of the PCL (blue)

**Figure 5.** Femoral insertion of the AMFL (red) and PCL with the knee hyperflexed

**Figure 6.** PCL composed of a single band

**Figure 7.** Visualisation of the flat ribbon

**Figure 8.** Femoral insertion of the PCL after resection of the AMFL, with the knee hyperflexed.

**Figure 9.** Lateral view of the knee: femoral insertion of the PCL after resection of the insertion of the AMFL (red) and of the PMLF (green)

**Figure 10.** Appearance of the PCL suggesting a double-bundle configuration after removal of the ACL (a) and synovial membrane (b)

**Video 1.** After untwisting, the PCL appears as a flat ribbon.



















