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Anatomical study of the femoral and tibial insertions of the anterolateral and posteromedial bundles of human posterior cruciate ligament

Masaaki Takahashi · Takamasa Matsubara · Mitsuhito Doi · Daisuke Suzuki · Akira Nagano

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Abstract For posterior cruciate ligament (PCL) reconstruction, two root, anterolateral and posteromedial bundles restruction are performed. However, little has been mentioned of anatomical measurements of the insertions to the bone of these bundles in previous publications. The aim of this study is to determine the precise anatomical measurements of the femoral and tibial insertions for anterolateral and posteromedial bundles of PCL. A total of 32 femur and 33 tibiae were selected from 50 cadavers after exclusion of knees that displayed macroscopically degenerative changes or evidence of trauma. PCL were divided into anterolateral bundles and posteromedial bundles to the insertion footprint, and those locations were measured and described. The distance from the center of the femoral insertions of the anterolateral and posteromedial bundles, and the Wrisberg ligament to the anterior margin of the medial femoral condyle averaged 9.6, 10.6, and 17.1 mm, respectively. The distance from the center of the femoral insertions of the anterolateral, posteromedial bundles, and Wrisberg ligament to the intercondylar roof averaged 4.8, 11.4, and 10.4 mm, respectively. The distance from the medial margin of the articular cartilage of the tibial plateau to the center of the tibial insertions of the anterolateral and posteromedial bundles averaged 51.0 and 50.0% of the total widest width of the tibial plateau, respectively. The vertical distance from the tibial insertion of the center of the posteromedial bundle to the plane of the tibial articular surface averaged 4.6 mm. This study leads to a better definition of the anatomy of the anterolateral and posteromedial bundles of PCL. It is very important to know the precise anatomy of PCL bundles when performing PCL reconstruction, and to evaluate PCL reconstruction surgery on an anatomical basis.

Keywords Posterior cruciate ligament · Anatomy · Anterolateral bundle · Posteromedial bundle · Wrisberg ligament

M. Takahashi (✉) · T. Matsubara · M. Doi · D. Suzuki · A. Nagano
Department of Orthopaedic Surgery,
Hamamatsu University School of Medicine,
1-20-1 Handayama, Hamamatsu 431-3192, Japan
e-mail: taka1m@hama-med.ac.jp

Introduction

The posterior cruciate ligament (PCL) reconstruction is a fairly recent innovation, mostly performed either by two-root technique which makes two bundles of PCL, anterolateral and posterolateral bundles, or inlay technique [2, 4, 9, 10, 14, 16, 19]. To perform either technique, a better understanding of the anatomical structure of the two bundles of PCL is very important. Although there have been studies on PCL and a few studies on the bundles of PCL [1, 8, 13, 17], there have been few studies on the numerical anatomical measurements of the insertions to the femur and tibiae of the anterolateral and posteromedial bundles of PCL. Therefore, the aim of this study is to describe the numerical measurements of the attachment sites of the two bundles of PCL to facilitate more rational PCL reconstruction.

Subjects and methods

Fifty cadavers from the anatomical course for medical students at Hamamatsu University School of Medicine were inspected. The cadavers were perfusion-fixed in embalming fluid containing 5% formaldehyde. The measurements of height and weight of the donors were recorded by the anatomy department. Hundred knees from 50 cadavers were dissected in order to select the bilateral knee joints in best condition for inclusion in this study. Furthermore, knees that displayed macroscopically degenerative changes or evidence of trauma, such as osteoarthritis, meniscal tears or ligament injury, were excluded. Finally, 32 femur (18 male joints, 14 female joints) and 33 tibiae (19 male joints, 14 female joints) specimens were examined, the age range of which was 68–97 years old. Of the 32 femur specimens, the cadaver height averaged 153.5 cm, ranging from 138 to 168 cm, and the body weight averaged 38.4 kg, ranging from 21 to 60 kg. Of the 33 tibia specimens, the cadaver height averaged 153.0 cm, ranging from 138 to 168 cm, and the body weight averaged 37.7 kg, ranging from 21 to 60 kg. Only one knee was used from each cadaver pair.

The proximal tibia was cut with a bone saw 2 cm below the articular surface and the distal femur was cut including the intercondylar notch. All tissues except ACL and PCL were removed from each knee. The intercondylar portion of the femur specimen was cut with a bone saw between the insertions of ACL and PCL prior to division. The PCL was divided into an anterolateral (AL) bundle and posteromedial (PM) bundle to the insertion footprint, and marked with ink pen around the periphery of the bundles. In some specimens, Wrisberg ligament was identified and dissected to the insertion footprint on the femur, and marked. After marking the periphery of the bundles, the bundles were completely abraded from the bone (Figs. 1, 2). Femur and tibia specimens were photographed with a measurement scale (one picture of each femur specimen, two pictures of each tibia specimen, top side and back side) and the photographs loaded into a personal computer. The measurements and analysis were performed using MacSCOPE software (Mitani-corp, Fukui, Japan).

Anatomical measurements were performed on the femoral and tibial insertions of AL, PM, and Wrisberg ligament as described below. At the femur site, the distance from anterior to the center of each insertion was measured (Fig. 3). Anterior distance to the insertion center was defined as the distance from the anterior border of the articular cartilage to the center of the insertion. This line is parallel to the Blumensaat line.

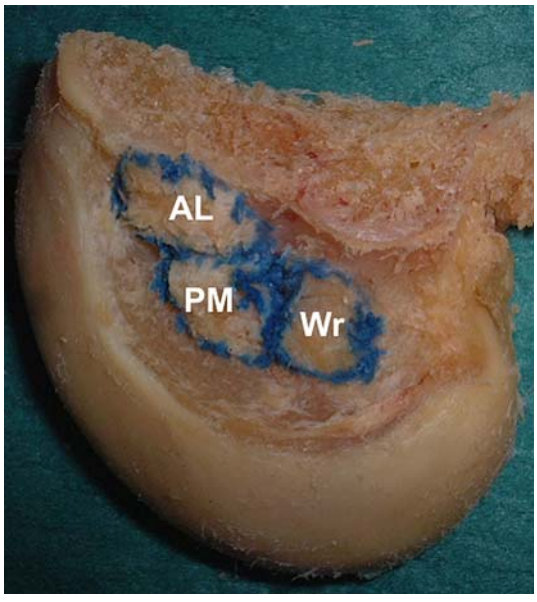

Fig. 1 Femoral footprints of the insertions of anterolateral (*AL*), posteromedial (*PM*) bundles of the PCL, and Wrisberg ligament (*Wr*)

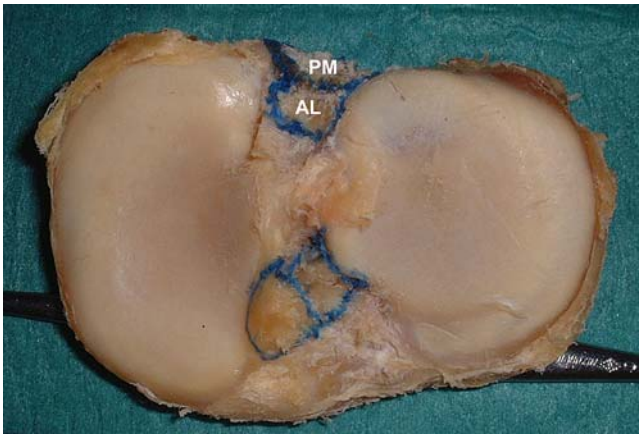

Fig. 2 Tibial footprints of the insertions of anterolateral (*AL*) and posteromedial (*PM*) bundles of the PCL

This anterior distance was also express as a percentage of the length of the Blumensaat line. The notch distance to the insertion center was defined as the distance from the notch roof of the femoral condyle to the center of each insertion (Fig. 3). The measure is perpendicular to the Blumensaat line, and also expressed as a percentage of the longest length between the distal border of the articular cartilage and the Blumensaat line. The area of each femoral insertion (footprint) was then calculated.

At the tibial site, the insertions of AL, PM bundles were measured on the posterior plane of the tibia (Fig. 4). The lateral distance of the tibial insertions were defined as the distance from the medial aspect of

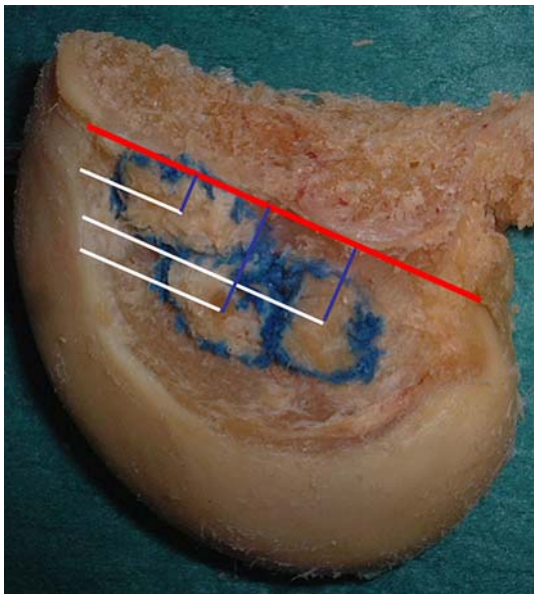

Fig. 3 The determination of the distance between the femoral insertion center and the anterior and the notch. The distance from the anterior is parallel to the Blumensaat line. The distance from the notch is perpendicular to the Blumensaat line

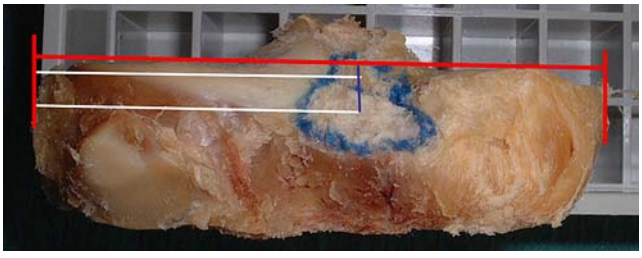

Fig. 4 The determination of the distance between the tibial insertion center and the medial border of the tibia and the tibial articular plane on the posterior plane of tibia. The vertical distance from the tibial articular plane was measured only in PL insertions

the tibia to the center of each bundle footprint, and also expressed as a percentage of the width of the tibia. The vertical distance from the tibial articular surface to each insertion (footprint) was measured. The area of each insertion to the tibia was calculated. The area of AL insertion was then calculated on the photograph of the articular surface of the tibia (Fig. 2), as well as the area of PL insertion on the back of the tibia (Fig. 4).

Results

The anterolateral and posteromedial bundles were measured in all 32 femurs and all 33 tibiaes, whereas the Wrisberg ligament could only be measured in 19 of the total 32 femurs (59.4%).

The numerical measurements of the location of the center of the femoral insertions of AL, PM, and Wrisberg ligament are presented in Table 1. The distance from the anterior to the center of the femoral insertions of AL, PM, and Wrisberg ligament averaged 9.6, 10.6, and 17.1 mm, respectively. The percentages for the anterior distance against the length of the Blumensaat line of AL, PM, and Wrisberg ligament averaged 29.2, 32.4, and 52.2%, respectively. The distance from the notch to the center of the femoral insertions of AL, PM, and Wrisberg ligament averaged 4.8, 11.4, and 10.4 mm, respectively. The percentages of the distance from the notch against the longest length between the distal border of the articular cartilage and Blumensaat line of AL, PM, and Wrisberg ligament averaged 25.3, 59.9, 54.2%, respectively.

The numerical measurements of the location of the center of the tibial insertions of AL and PM bundles are presented in Table 2. The distance from the medial to the center of the tibial insertions of AL and PM bundles averaged 48.2 and 47.4 mm, respectively. The percentages of the distance from the medial against the width of the tibia of AL and PM bundles averaged 51.0 and 50.0%, respectively. The vertical distance from the articular plane to the tibial insertion of the PM bundle averaged 4.6 mm. The AL distance was not measured due to the center of the tibial insertion of AL being located on or very close to the articular plane.

The area of the insertions of AL, PM, and Wrisberg ligament on the femur and the insertions of AL and PM on the tibia are presented in Table 3. The area of the insertions of AL, PM, and Wrisberg ligament on the femur averaged 58.0, 64.6, and 39.4 mm^2, respectively. The area of the insertions of AL and PM on the tibia averaged 46.7 and 115.8 mm^2, respectively.

Table 1 The location of the center of the femoral insertions for anterolateral (AL), posteromedial (PM) bundles, and Wrisberg ligament

	From anterior Mean ± SD (mm)	From notch Mean ± SD (mm)
AL	9.6 ± 1.9 (29.2) (6.8–13.4)	4.8 ± 1.3 (25.3) (2.4–7.5)
PM	10.6 ± 3.1 (32.4) (5.8–18.3)	11.4 ± 2.2 (59.9) (7.6–16.0)
Wrisberg	17.1 ± 4.1 (52.2) (11.7–24.5)	10.4 ± 3.0 (54.2) (3.4–14.2)

Values in parenthesis are mean% and range

The distance from the anterior was also expressed as the percentage to the length of the Blumensaat line. The distance from the notch was also expressed as the percentage to the longest length between the distal border of the articular cartilage and the Blumensaat line

Table 2 The location of the center of the tibial insertions of AL and PM bundles

	From medial Mean ± SD (mm)	From articular plane Mean ± SD (mm)
AL	48.2 ± 7.3 (51.0) (35.2–61.0)	(–)
PM	47.4 ± 8.3 (50.0) (34.9–65.6)	4.6 ± 3.6 (0–11.9)

Values in parenthesis are mean% and range

The distance from the medial of the tibia to the center of each bundle footprint is also expressed above in parenthesis as the percentage against the width of the tibia

(–): The location of AL from the articular plane was not measured due to the center of the tibial insertion of AL being located on or virtually on the articular plane

Table 3 The mean areas of the insertions of AL, PM, and Wrisberg ligament on the femur and the insertions of AL and PM on the tibia

	Femur Mean ± SD (mm^2)	Tibia Mean ± SD (mm^2)
AL	58.0 ± 25.4 (26.3–148.6)	46.7 ± 15.6 (24.3–82.9)
PM	64.6 ± 24.7 (27.2–116.4)	115.8 ± 54.6 (38.7–241.8)
Wrisberg	39.4 ± 13.7 (14.1–65.8)	

Values in parenthesis represents range

Discussion

There have been several reports about the numerical anatomical data of PCL or schematic description of the bundles of PCL. Girgis et al. [5] reported on the anatomical measurements of the total PCL footprint, but not for the two bundles. Van Dommelen and Fowler [18] described the femoral insertion of PCL as being located in the anterior part of the medial aspect of femoral intercondyle. Cosgarea and Jay [3] reported that the center of the femoral insertion of the PCL is located 1 cm posterior from the cartilage border of the medial condyle of the femur. Wind et al. [19] reported the center of the femoral insertion of the PCL as located 1 cm proximal from the cartilage border of the medial condyle of the femur. Mejia et al. [15] reported on PCL femoral attachment measurements which were made using several measurement lines, referenced from several clock positions, of the intercondylar notch and roof. They measured and described the distal and proximal attachment from the distal articular cartilage margin on the medial femoral condyle using those reference methods. The above are all about the description of PCL. To our knowledge, there has been little in the literature reporting on the numerical anatomical measurements of the insertions to the femur and tibiae of the anterolateral and posteromedial bundles of PCL. The anatomy of the femoral origin of two bundles of PCL was studied by Morgan et al. [17], although it was not a cadaver study. They dissected and studied the anatomy of the femoral origin of two bundles of PCL in 20 knees at the time of total knee replacement. The central origin point for each bundle was marked, and its distance was measured in reference to three axes. The anterolateral bundle central point was on average 13 mm posterior to the medial articular cartilage–intercondylar wall interface and 13 mm inferior to the articular cartilage–intercondylar roof interface. The posteromedial bundle central point was on average 8 mm posterior to the medial articular cartilage–intercondylar wall interface and 20 mm inferior to the articular cartilage–intercondylar roof interface. Their data from the medial articular cartilage–intercondylar wall interface is in accordance with our data, whereas the length from the intercondylar roof is greater than in our data. The reason for this is that they measured the distance of the articular cartilage–intercondylar roof interface while we measured the distance perpendicular to the intercondylar roof.

The numerical measurements of the footprint area of the anterolateral and posteromedial bundles were reported by Harner et al. [8]. In their study, the area of the anterolateral bundle was slightly greater than that of the posteromedial bundle in both femur and tibia. Amis et al. [1] also recently reported on the anatomy of the anterolateral and posteromedial bundles of the PCL; the insertions of the two bundles were nicely illustrated and their clock position described, although numerical measurements were not performed. They described that while the anterolateral bundle has a larger cross-sectional area than the posteromedial bundle in the mid-substance portion, the tibial attachments were found to have similar areas. In the present study, the insertion area on the femur of posteromedial bundle was found to be slightly greater than that of the anterolateral bundle, and the insertion area on the tibia was much greater than that of anterolateral bundle.

Posterior cruciate ligament architecture has also been described as four fiber regions based on their orientation, with more than two bundles of PCL. Makris [13] divided PCL into four parts and reported on their insertion footprints.

On the anatomy of the tibial insertion for total PCL, Girgis et al. [5] reported it 2–3 mm distal from the articular plane, Van Dommelen and Fowler [18] reported it 1 cm (10 mm) distal, and Cosgarea and Jay [3] reported it 1–1.5 cm (10–15 mm) distal. Our data on two bundles showed the anterolateral bundle insertion located virtually on the articular plane (close to 0 mm), and the posteromedial bundle insertion location averaged 4.6 mm distal from the articular plane. Therefore,

the midpoint location of anterolateral bundle (0 mm) and posteromedial bundle (4.6 mm) insertions in our study is in accordance with the data for total PCL reported by Girgis et al. (2–3 mm).

There are two meniscofemoral ligaments which connect the lateral meniscus to the intercondylar aspect of the medial femoral condyle. It was reported that at least one meniscofemoral ligament is present in 93% of specimens, and Wrisberg ligament is present 70% on average [6]. The Wrisberg ligament passes posterior to the PCL and attaches proximally, close to the roof of the intercondylar notch. In the present study, the Wrisberg ligament was measured in 59.4% of the specimens, which does not mean that this ligament was present at the rate of 59.4%. We did observe a higher rate of presence of Wrisberg ligament in the present study, however, in some specimens, the Wrisberg ligament was sacrificed to examine the two bundles of PCL as this was the aim of this study. Therefore, two bundles of PCL and the Wrisberg ligament were prepared and measured in 59.4% of cases. There have been studies reporting on the cross-sectional area of the Wrisberg ligament. Kusayama et al. [12] reported it as 6.7 mm^2, Jamieson et al. [11] as 12.7 mm^2, and Harner et al. [7] as 10.1 mm^2, all of which are smaller than our result of 39.4 mm^2 because we measured the insertion area to the bone, whereas others measured the mid-section of the ligament. Nevertheless, our data for the insertion area of two bundles of PCL and Wrisberg ligament indicate that the Wrisberg ligament is significantly compatible with anterolateral and posteromedial bundles anatomically, and therefore may have nearly equal function to those bundles.

The present study described the numerical anatomical measurements of the insertions to the femur and tibiae of the anterolateral and posteromedial bundles of PCL. The contribution of this study to a better understanding and definition of the anatomy of the anterolateral and posteromedial bundles of PCL will lead to better outcomes in PCL reconstructions. Furthermore, the anatomical information given here may be useful when evaluating tunnel placement using radiographs, CT, or MRI after reconstructive surgery in order to optimize reconstruction for more positive outcomes.

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