Posterior Cruciate Ligament: Anatomy and Biomechanics

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Abstract

Purpose of Review The purpose of this review is to present an in-depth look at the most recent literature regarding pertinent posterior cruciate ligament (PCL) anatomy and biomechanics.

Recent Findings The PCL is an important restraint of posterior tibial translation relative to the femur. In addition, the PCL acts as a secondary restraint to resist varus, valgus, and external rotation moments about the knee. While less common than ACL injuries, injuries to the PCL can occur from a posterior force directed on the tibia, most common with the knee in a flexed position.

Summary The PCL is composed of two functional bundles and has important implications for knee stability. The anterolateral and posteromedial bundles have different patterns of tensioning throughout knee range of motion. The two bundles therefore contribute to resisting posterior tibial translation and rotation at different angles of knee flexion.

Keywords Posterior cruciate ligament · PCL · Anterolateral bundle · Posteromedial bundle · Anatomy · Biomechanics

Introduction

The knee is comprised of a complex configuration of osseous and soft tissue structures that work in conjunction to allow three planes of motion. Dynamic and static stabilizers confer stability to the knee. The ligaments of the knee, which are static stabilizers, play an intricate role in adding stability to the knee throughout a full arc of motion. The posterior cruciate ligament (PCL) is one of two cruciate ligaments of the knee, which is the counterpart to the anterior cruciate ligament (ACL). The PCL is an important restraint of posterior tibial translation relative to the femur. In addition, the PCL acts as a secondary restraint to resist varus, valgus, and external rotation moments about the knee. While less common than ACL injuries, injuries to the PCL can occur from a posterior force directed on the tibia, most common with the knee in a flexed

position. It is critical for physicians to have an in-depth understanding of the anatomy and biomechanics of the PCL in order to properly evaluate, diagnose, and treat PCL injuries. In this review, we present an in-depth look at the most recent literature regarding pertinent PCL anatomy and biomechanics.

Anatomy (Figs. 1, 2, and 3)

The PCL is an intraarticular structure, as it resides within the knee joint itself, but similar to the ACL, is considered extrasynovial, as it is covered by synovium. The length of the PCL is typically between 32 to 38 mm, with an average cross-sectional area of approximately 11 to 13 mm² [1, 2]. The thickness of the PCL is nearly twice that of the ACL. The PCL originates from the anterolateral aspect of the medial femoral condyle within the notch and inserts along the posterior aspect of the tibial plateau, approximately 1 cm distal to the joint line. Voos et al. studied the average surface area of the PCL attachments to the femur and tibia, and found the area of the femoral footprint to be 209 mm² and tibial footprint to be 243 mm² [3]. Thus, the PCL insertion sites are roughly three times larger than its mid-substance. The PCL is comprised of two bundles: the larger anterolateral bundle (ALB) and smaller posteromedial bundle (PMB). According to Anderson et al., the distance between the center of the ALB and PMB femoral

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Fig. 1 (a) Anatomy of the PCL with the knee extended showing the anterolateral (1) and posteromedial (2) bundles, including the femoral and tibial footprints and (b) anterolateral and posteromedial bundles of the PCL relative to the lateral meniscus (3) and meniscomfemoral ligament of Wrisberg (4) (Courtesy of Jorge Chahla, MD, PhD)

attachments is 12.1 mm, while the distance between their tibial attachments is 8.9 mm [4]. There is a constant “medial intercondylar ridge” described by Forsythe et al. that determines the proximal extent of the femoral PCL footprint [5]. The two bundles of the PCL insert onto the tibia as a conjoined structure approximately 1.0 to 1.5 cm distal to the joint line, on a facet of the posterior tibia. The posterior horn of the medial meniscus serves as the anterior border of this PCL facet [6, 7]. In a cadaveric study by Moorman and colleagues, the authors found that the majority of the distal PCL attachment inserts on the posterior half of the PCL facet. The PCL is innervated by branches of the tibial nerve while its vascular supply comes from the middle geniculate artery [9].

Anterolateral Bundle

Several authors have examined the characteristics of the anterolateral bundle (ALB) of the PCL, including its length and diameter, and the importance of the femoral and tibial footprints. In one cadaveric study, Osti et al. found that the average length and diameter of the ALB is 31.79 mm and 6.50 mm², respectively [10]. The ALB femoral footprint has been described to range anywhere from 112 to 118 mm² in cross-sectional area [5, 11•]. Takahashi et al. reported the femoral attachment of the ALB to be 9.6 mm from the articular cartilage using a line parallel to Blumensaat's line [12]. Arthroscopically, as noted by Anderson and colleagues, the center of the ALB femoral footprint is approximately 7.4 mm

from the trochlear point, 11.0 mm from the medial arch point, and 7.9 mm from the distal articular cartilage [11•]. Morgan et al. reported that the ALB originates 13 mm posterior to the medial articular cartilage-intercondylar wall interface, and 13 mm inferior to the articular cartilage-intercondylar roof interface of the femur [13]. The tibial footprint of the ALB represents an area of about 88 mm² and is bordered medially and posteriorly by the PMB with the bundle ridge separating it from the PMB [11•]. Arthroscopically, as noted by Anderson et al., the center of the ALB tibial footprint is approximately 6.1 mm from the shiny white fibers of posterior medial meniscus root, 4.9 mm from the bundle ridge, and 10.7 mm from the champagne glass drop-off of the posterior tibia [11•].

Posteromedial Bundle

Similar to the ALB, the anatomy of the posteromedial bundle (PMB) has been extensively researched. In one cadaveric study, Osti et al. found that the average length and diameter of the PMB is 32.42 mm and 5.62 mm², respectively [10]. The PMB is bordered by the medial intercondylar ridge proximally, the ALB anteriorly, and the anterior meniscomfemoral ligament, or ligament of Humphrey, (if present) distally [11•]. The femoral attachment of the PMB is reported to comprise an area between 60 and 90 mm², located between the anterior and posterior meniscomfemoral ligaments [11•]. Takahashi et al. described the femoral attachment of the PMB to be 10.6 mm from the

Fig. 2 Anatomic dissection of a right knee showing PCL bundles, including the anterolateral bundle (A) and posterolateral bundle (B) (Courtesy of Jorge Chahla, MD, PhD)

Fig. 3 Arthroscopic anatomy of a left knee PCL, including the anterolateral bundle (A) and posterolateral bundle (B) (Courtesy of Jorge Chahla, MD, PhD)

articular cartilage using a line parallel to Blumensaat's line, while Morgan et al. showed that the PMB originates 8 mm posterior to the medial articular cartilage-intercondylar wall interface and 20 mm inferior to the articular cartilage-intercondylar roof interface [12, 13]. Another bony landmark used to help identify the anatomy of the PCL is the medial bifurcate ridge, which separates the two bundles [5]. Arthroscopically, as noted by Anderson et al., the center of the PMB femoral footprint is approximately 11.1 mm from the medial arch point and 10.8 mm from posterior articular cartilage margin [11•]. On the tibial side, Anderson et al. have reported the PMB tibial footprint to be approximately 105 mm², which is more compact than the that of ALB [11•]. The PMB is described as having “2 arms” as it fans out along the posteromedial aspect of ALB. Arthroscopically, the center of the PMB tibial footprint is approximately 3.1 mm lateral from the medial groove of the medial tibial plateau articular surface and 4.4 mm anterior to the champagne glass drop-off of the posterior tibia [11•].

Surrounding Structures

Overall, an understanding of the anatomy of the PCL, as determined from the above-described cadaveric, imaging, and arthroscopic studies, is essential to aid in accurate restoration of native anatomy at the time of surgical reconstruction. It is important to be mindful of the location of the PCL relative to other important structures within the knee, particularly those structures within the popliteal fossa, including the tibial nerve, popliteal artery, and popliteal vein. In a simulated arthroscopy study by Kramer et al., the authors found that the mean sagittal distance from the mid-PCL to the popliteal area was 29.1 ± 11 mm, ranging from 18 to 55 mm, while the mean sagittal distance from the proximal PCL fovea to the popliteal artery was 9.7 ± 5 mm, ranging from 3 to 15 mm [14•].

In a cadaveric study by Matava and colleagues, the authors looked at the impact of increasing knee flexion angle on the distance between the PCL tibial insertion and the popliteal area [15]. The authors found that the average distance between the PCL tibial insertion and the popliteal artery (across all flexion angles ranging from 0° to 100°) was 7.6 mm in the axial plane and 7.2 mm in the sagittal plane. Notably, although increasing the amount of knee flexion increased the distance between the ligament insertion site and the artery (distance of 9.9 and 9.3 mm in the axial and sagittal planes, respectively), the popliteal artery is still at risk during simulated transtibial PCL tunnel drilling.

Biomechanics

The PCL functions as one of the main stabilizers of the knee joint and serves primarily to resist excessive posterior

translation of the tibia relative to the femur. The PCL also acts as a secondary stabilizer of the knee preventing excessive rotation specifically between 90° and 120° of knee flexion [16]. The long-held notion of PCL biomechanics was that the two bundles functioned independently, with the ALB acting primarily during flexion and the PMB in knee extension [1, 17]. More recent research, however, suggests that the two bundles function synergistically [18–21]. Multiple studies have examined knee biomechanics by sectioning the PCL, which collectively demonstrate that an isolated tear of either bundle does not result in a clinically significant increase in posterior translation of the tibia [20, 22]. Multiple studies have demonstrated that isolated PCL ruptures have the greatest effect at 90° of knee flexion, and thus, the integrity of the PCL should be tested clinically at 90° of knee flexion [23, 24].

In the setting of knee flexion, the ALB is tight and the PMB is lax, whereas in extension, the ALB is lax and the PLB is tight. Notably, in situ forces are increased in both the ALB and PMB as the flexion angle is increased under a posterior tibial load [25]. Kennedy et al. reported that the PCL provides restraint to internal rotation beyond 90° of knee flexion. Kennedy et al. also showed that when subjected to equivalent internal and external torques, a knee with a sectioned PCL will demonstrate increased internal and external rotation as compared to a knee with an intact PCL [22]. Furthermore, other biomechanical studies performed in vitro have demonstrated increased external rotation when subjected to a posterior tibial load after PCL resection [26, 27]. Thus, recent literature suggests that the PCL plays a larger role in rotational stability than previously assumed, especially beyond 90° of flexion. While patients may tolerate a PCL-deficient knee, it has been reported that the PCL-deficient knee results in distorted loads and different kinematics during functional activities [16].

The tensile strength of the PCL is well documented in the literature and ranges from 739 to 1627 N [28–30]. This may be an underestimation as the PCL fibers resist forces in different directions. For example, Butler et al. suggested that PCL fascicles have significantly more strength than previous results of whole ligament biomechanical testing due to the strength of the PCL in various directions. [31]. The majority of the strength of the PCL comes from the ALB, as the tensile strength of the ALB is 1620 N while the tensile strength of the PMB is 258 N [32]. The difference in strength is largely attributed to the significant variation in cross-sectional area of these two bundles (43 and 10 mm²) [33].

Summary

The PCL is composed of two functional bundles and has important implications for knee stability. Knowledge of the exact anatomy in addition to the kinematics of the PCL allows surgeons to reconstruct the ligament anatomically and with the

correct tension. The anterolateral and posteromedial bundles have different patterns of tensioning throughout knee range of motion. The two bundles function to resist posterior tibial translation and rotation at different angles of knee flexion. While much is known about the PCL, further research about the nuances of the ligament's biomechanics is needed.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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