Microsurgical Dissection

Of The Posterior Cruciate Ligament

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Abstract

In twenty-four cadaveric knees, we measured the main dimensions of the Posterior Cruciate Ligament (PCL) and its femoral and tibial attachment sites. We dissected the ligament using magnifying loupes and an operative microscope in order to verify the exact fiber anatomy, always careful to avoid creating artificially separated bundles. Different fiber-regions of the PCL were, afterwards, substituted with patellar tendon-bone graft. The behavior of the graft during joint motion was recorded.

The PCL consists of four fiber-regions, partially separate from the anatomic point of view, but functionally distinct. These fiber-regions are the anterior, central, posterior-longitudinal and posterior-oblique, named for their orientation and the osseous sites of their insertion.

The anterior and central fiber-regions are the bulk of the ligament, while the remaining 15% of the ligament consists of the posterior fiber-regions. During joint motion, changes in the length of these fiber-regions were observed. The anterior fiber-region appears to be the most non-isometric and acts as a primary restraint to posterior tibial translation mainly between 30° and 90° flexion. The posterior fiber-regions (especially the posterior-oblique) appear to be the most isometric and act as primary restraints in extension and partially in deep flexion, respectively. The central fiber-region appears to have an intermediate behavior as regards length changes and acts as a primary restraint to posterior tibial translation between 30° and 120° flexion. Additionally, it appears to be the widest of the fiber-regions. Similar to the

aforementioned behaviors were observed, when the patellar tendon-bone graft substituted the anterior, posterior and central fiber-regions, respectively.

Based on these observations, one can conclude that selective isometric reconstruction of the posterior fiber-regions does not appear ideal since it would leave the bulk of the ligament largely unreconstructed. Contrarily, anatomic reconstruction using a large graft, following the central fiber-region orientation and attachment sites, could yield good results even for patients requiring stability in deep flexion.

Key words

Posterior Cruciate Ligament, Functional anatomy, Fiber-regions, Microsurgical dissection, Anatomic reconstruction.

Introduction

During the last 20 years, there has been increased awareness regarding the importance of the Posterior Cruciate Ligament (PCL) in maintaining normal knee kinematics and functioning. Recent basic science research has advanced our understanding of the morphology and mechanical behavior of the PCL. Nevertheless, different terms are used in the literature to determine distinct bundles or fiber groups of the PCL, originating from different attachment sites and exhibiting different behavior during motion of the knee.

Traditionally, the PCL has been morphologically characterized as consisting of two parts or so-called bands, termed anterior or anterolateral and posterior or posteromedial(3,11,15,21,23).The relatively large cross-sectioned anterior group has been observed to tighten in flexion and relax in extension. The smaller cross-sectioned posterior group has been described as being somewhat lax in flexion, but visibly tight in extension. In a relatively recent study(19), the ligament was described as being comprised of a large anterior bundle, representing 95% of the PCL, and a small posterior-oblique bundle originating at the posterosuperior aspect of the femoral attachment, passing obliquely to insert the tibia posterolaterally and representing the remaining 5% of the PCL. In other studies(17,22), the PCL is morphologically characterized as consisting of anterior, middle and posterior fibers, according to the location of the femoral insertion.

Recent studies on the macroscopic and functional anatomy have characterized the ligament as a continuum of fibers, without truly separated bundles or bands.[7,10] An anatomic subdivision scheme has been proposed[7] recently in order for surgeons to understand the complex anatomy of the ligament. According to this scheme, the four consistent geographical fiber-regions are called anterior, central, posterior-longitudinal and posterior-oblique, mainly on the basis of their orientation, mechanical behavior during joint motion, and the osseous sites of their insertion.

The coexistence of these different terms in the literature regarding the fiber groups of the PCL, leads us to the purpose of our study, that is to elucidate, if possible, the exact fiber anatomy of the PCL, the dimensions and shape of the attachment sites and to observe any length changes during motion of the joint.

Material and Methods

Twenty-four cadaveric knees were taken from 16 male donors and 8 female donors (mean age 62 years). The integrity of the capsule-ligament structures and menisci was confirmed and there was no evidence of marked articular degeneration. All specimens were freed from soft tissue. The patella, the patellar tendon and the extensor mechanism were also resected to obtain an anterior intra-articular approach. A subtotal posterior capsulectomy also permitted a dorsal approach to the PCL. Starting with the posterior capsulectomy, the whole procedure was performed with the assistance of magnifying loupes (magnification 4X), an operative microscope (magnification 10X), as well as microsurgical scissors and forceps. The synovial sleeve and the surrounding paratenon were both removed (Fig. 1a), starting from the tibial and working towards the femoral attachment of the PCL.

We manipulated the joint at different degrees of flexion, simultaneously dissecting the ligament, ventrally and dorsally. The repetition of this process permitted to us to define different fiber groups within the bulk of the ligament, always careful to avoid creating artificially separated bundles (intact epitenon) (Fig 1b). The main dimensions of the PCL were measured using a micrometer. The lateral femoral condyle and the Anterior Cruciate Ligament were removed only for the photographic needs of the study. Finally, the PCL was sectionally resected and all attachment sites, including those of each fiber group, were marked at the femur and the tibia using a dye-pen. The femoral attachment sites of the meniscofemoral ligaments were also marked.

The previously defined, different fiber groups were, afterwards, substituted with patellar tendon-bone graft. The osseous part of the graft was cylinder-shaped, 25 mm in length and 9 mm in diameter. The tendinous part of the graft was 9 mm in width. The osseous part of the graft was fixed at 3 different regions of the PCL femoral insertion (anterior, central, posterior), using the press-fit technique. The tendinous surface of the graft was placed at the most proximal margin of the femoral anatomic footprint of the PCL. The tendinous part of the graft was passed from the center of the PCL tibial attachment to the anterior surface of the tibia, through a bone tunnel, 10 mm in diameter. The graft was, then, secured at the tibia with trans-osseous sutures. The grafts, that substituted the anterior and central fiber-regions of the PCL, were secured in 70° of flexion, while the one substituted the posterior fiber-regions, was secured in 30° of flexion.

Results

The length of the ligament, measured at 90° of flexion, was 38 ± 2 mm. The anteroposterior diameter, measured at the midportion of the ligament, was 5 ± 0.5 mm, while the mediolateral diameter was 14 ± 0.8 mm. The anteroposterior diameter of the femoral attachment was 31 ± 1 mm, while the proximal-distal diameter averaged 11 mm for the anterior and central part, and 6.5 mm for the posterior part. The tibial attachment averaged 14 X 14.4 mm. The femoral attachment was found to be bullet-like in shape. The distance between the most proximal margin of the femoral attachment and the articular margin averaged 8 mm, 10 mm and 12 mm for the anterior, the central and the posterior fiber-regions, respectively. The distance between the most posterior-proximal margin of the femoral attachment and the roof of the intercondylar notch averaged 15 mm.

The meniscofemoral ligaments were found in 22 out of 24 specimens (91.7%). Fifty percent (50%) of the meniscofemoral ligaments alone were posterior (Wrisberg's ligament) and 25% were anterior (Humphry's ligament). In four specimens (16.7%), both meniscofemoral ligaments were observed together. The femoral attachment of the posterior meniscofemoral ligament was found proximally to the posterior third of the PCL anteroposterior diameter. The femoral attachment of the anterior meniscofemoral ligament was found distally to the middle third of the PCL anteroposterior diameter.

The PCL was found to consist of 4 partially separated fiber-regions. Partial separation of the fiber-regions could be performed and observed only at the dorsal surface of the

PCL. These fiber-regions were named anterior, central, posterior-longitudinal and posterior-oblique, based on their femoral and tibial insertion sites. The only completely separate fiber-region (in 50% of the specimens) was the posterior-oblique. The anterior and central fiber-regions represented the bulk of the PCL, while the posterior fiber-regions represented the remaining 15% to 20% of the ligament (Fig. 2).

The anterior fiber-region constituted the most anterior part of the femoral and tibial attachment. The central fiber-region, which appeared to be the widest region, constituted the middle portion of the femoral attachment and the middle and slightly lateral part of the tibial attachment. The posterior fiber-regions made up the posterior part of the femoral attachment and the most posterior part of the tibial attachment, with the posterior-longitudinal joining the tibia medially and the posterior-oblique joining it laterally (Fig. 3).

During passive joint motion, the behavior of the fiber-regions differentiated:

- In extension: The posterior fiber-regions were tight, while the anterior fiber-region was fully slack. The central fiber-region was less slack than its anterior counterpart (Fig. 4).
- During flexion (up to 90°): The posterior fiber-regions slackened slightly, while the anterior and central fiber-regions tightened.
- In further flexion (90° to 120°): The posterior fiber-regions tightened again. The anterior fiber-region remained tight, albeit slightly less so. The central fiber-region showed no signs of slackening even in deep flexion.

These changes in the condition of the PCL fiber-regions during joint motion were observed to be progressive from one fiber-region to the other.

Similar to the aforementioned behaviors were observed, when the patellar tendon-bone graft substituted the anterior, posterior and central fiber-regions, respectively. The graft, that substituted the anterior fiber-region, was fully slack in extension (Fig. 5a) and at the initial phase of flexion. Signs of slackening were, also, observed in deep flexion. The graft, that substituted the central fiber-region was slightly slack only in extension (Fig. 5b) and at the initial phase of flexion. The graft, that substituted the posterior fiber-regions presented an almost isometric behavior through range of motion. It was, however, too posteriorly located and too vertically oriented (Fig. 5c).

The posterior meniscofemoral ligament was observed to tighten in extension and relax after the first degrees of flexion, while the anterior meniscofemoral ligament was observed to tighten in flexion, thus pulling the posterior horn of the lateral meniscus anteriorly.

Discussion

The Posterior Cruciate Ligament is enveloped by a fold of synovium, originating from the posterior capsule, thus making the PCL an intra-articular yet extra-synovial ligament. The posterior distal third of the ligament was found to be in close contact with vascular synovial tissue of the posterior joint capsule. The clinical relevance of this observation may be useful in conservative treatment or in surgical augmentation of distal lesions of the ligament, since the PCL has been found to have a more abundant vascular supply than the ACL,[18] although other researchers suggest that there is no evidence to support this claim.[2]

The main dimensions of the ligament, as well as the femoral and tibial attachment sites, were similar to those reported in other studies.[11,13,14,16] The ESSKA Scientific Workshop described the femoral attachment as being on a curved three-dimensional surface which makes a transition from the lateral surface of the medial femoral condyle to the roof of the intercondylar notch. The outline of the PCL femoral attachment on the sagittal plane does not indicate that the bulk of the fibers originate from the roof of the notch rather than from the wall.[1] Our findings were in keeping with this description.???

In our study, the PCL was found to consist of four partially separate, but functionally distinct, fiber-regions. We adopted the term «fiber-regions», which was proposed by Covey et al,[7] to emphasize that there are no completely separate bundles in the PCL. We were able to define these four fiber-regions as partially separate fiber groups with different functional behavior, only as a result of using magnifying loupes and an operative microscope. The latter prevented us from creating artificially separated bundles. There is some similarity between our findings and the drawing presented in the aforementioned study.[7] The PCL is best described as consisting of a continuum of fibers and is not considered to be isometric as a whole. Different functional behavior by the different fiber-groups was observed during joint motion. The interfascicular connective tissue (epitenon)[5,9] likely plays a slip-assisting role in this process.

Although we performed an exclusively anatomic study, we were able to observe, in detail, the functional behavior of each of the four fiber-regions during joint motion. The posterior fiber-regions appeared to be the most isometric (very small length changes), but represented only 15% of the ligament. The anterior fiber-region appeared to be the most non-isometric (significant length changes). It was completely slack in extension and tight between 30° and 90° of flexion. Nevertheless, in further flexion (90° to 120°), the anterior fiber-region was slightly slack. The central fiber-region exhibited intermediate functional behavior (intermediate length changes). In extension, it was not as slack as the anterior fiber-region and remained tight in flexion further than 90°. Additionally, it was the widest fiber-region.

Several investigators[4,13,16,17,20] have proposed a femoral insertion of the graft during PCL reconstruction in order to yield acceptable results as regards the functional behavior of the graft. Despite differences in terminology, we believe that all of these studies concluded that the proper placement of the graft is at the central fiber-region femoral attachment site, specifically at its proximal and posterior half. The ESSKA Scientific Workshop suggested that the optimal femoral graft placement is unconfirmed and that there is scope for further biomechanical and clinical outcome studies[1]. Selective reconstruction of only the relatively isometric posterior fibers does not appear ideal, since this would leave the bulk of the ligament (anterior and central fibers) largely unreconstructed[8]. Additionally, the location of the graft would, compulsorily, be too posterior and the orientation too vertical, thus biomechanically ineffective to restrain posterior applied forces. On the other hand, the bulk of the ligament is too large at its femoral attachment to be properly substituted even by a large graft. Therefore, the surgeon must select an area for graft placement within the limits of the natural femoral attachment of the bulk of the Posterior Cruciate Ligament. Although there is still a need for biomechanical confirmation, we believe, based on our observations, that PCL anatomic reconstruction following the orientation and insertion sites of the central fiber-region, could give good results even for those patients requiring stability in deep flexion. Placement of the graft should be performed with its tendinous surface at the proximal margin of the anatomic footprint of the central fiber-region, in order to obtain the least possible deviation from the isometric behavior[13]. Thus, with the knee flexed in 90°, the graft should be placed at the 2 o'clock or 10 o'clock position. The distance between the tendinous surface of the graft and the articular margin should be 20 to 21 mm (Fig. 6).

The posterior meniscofemoral ligament was observed to tighten in extension and relax after the first degrees of flexion, while the anterior meniscofemoral ligament was observed to tighten in flexion, thus pulling the posterior horn of the lateral meniscus anteriorly. This action of the meniscofemoral ligaments to the lateral meniscus increases the congruity between the meniscotibial socket and the lateral femoral condyle during joint motion. Similar to other studies[12,24], no meniscofemoral ligament was found to stem from the posterior horn of the medial meniscus. This may partially explain the increased pathology of this area. The meniscofemoral ligaments may also play a minor role as secondary restraints to posterior tibial translation after complete rupture of the PCL[6,24], especially in flexion. In any case, the femoral attachment sites and the orientation of these ligaments must be well known to the surgeon, as they may cause diagnostic problems during arthroscopy or PCL reconstructive procedures.

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Legends

Figure 1: a) Removal of the paratenon, using microsurgical scissors. **b)** Dissection and partial separation between anterior and central fiber-region of the PCL.

Figure 2: Partial preparation of the specimen. Posterior fiber-regions are identified as separate. Fiber-regions: **A**: anterior, **C**: central, **PL**: posterior longitudinal, **PO**: posterior oblique. **PML**: posterior meniscofemoral ligament. **LM**: lateral meniscus.

Figure 3: Posterior view of a prepared specimen. Microsurgical forceps set boundaries at the margin of the central fiber-region. Fiber-regions: **A**: anterior, **C**: central, **PL**: posterior longitudinal, **PO**: posterior oblique. **MM**: medial meniscus. **LTP**: lateral tibial plateau.

Figure 4: Lateral (left) and posterior (right) view of the PCL in extension. Posterior fiber-regions and posterior meniscofemoral ligament are tight. Anterior fiber-region is fully slack. Central fiber-region is slightly slack. Fiber-regions: **A**: anterior, **C**: central, **PL**: posterior longitudinal, **PO**: posterior oblique. **LFC**: lateral femoral condyle. **PM**: popliteus muscle. **LTP**: lateral tibial plateau.

Figure 5: Substitution of the anterior (a), central (b), and posterior (c) fiber-regions with patellar tendon-bone graft. In extension the anteriorly placed graft (a) is slack, while the posteriorly placed graft (c) is too vertical.

Figure 6: Suggested placement of the graft at the proximal margin of the anatomic footprint of the central fiber-region, with the knee flexed at 90°. At 2 o'clock or 10 o'clock position the graft must be placed with its tendinous surface at a distance (d) of 20 to 21 mm from the articular margin. **ACL**: anterior cruciate ligament. **LFC**: lateral femoral condyle.