The Original Compared with Terminal in Anterior or Posterior Cruciate Ligament Tear

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Introduction

The Anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) play a vital role in maintaining normal knee function, which contributes to both anterior-posterior translation of the knee and rotational stability [1-3]. The ACL finds its origin on the medial surface of the lateral femoral condyle, runs an oblique course within the knee joint from lateral and posterior to medial and anterior, and inserts into a broad area of the central tibial plateau [4-7]. The PCL arises from a depression posterior to the intraarticular upper surface of the tibia anteromedial and behind the ACL to the lateral surface of the medial femoral condyle [8-11]. As a structure composed of numerous fascicles of dense connective tissue that connect the distal femur and the proximal tibia, the ACL and PCL (ACL/PCL) are prone to injury [12,13]. However, the overall structure and organization of a native ACL/PCL insertion site are not reproduced after ACL/PCL reconstruction and reflect an inability to recapitulate the events that occur during embryonic development with current surgical techniques [14-16].

The ACL is most commonly torn from its proximal attachment on the femur, and the PCL is most commonly torn from its distal attachment on the tibia [3,17-20]. The ACL/PCL inserts to bone via a direct type of insertion, similar to the transition seen from tendon to bone [4,7]. Microscopic examination of the sites of bony attachment show inter digitation of the collagen fibers with bone through four distinct transition zones: tendon, demineralized fibrocartilage, mineralized fibrocartilage, and bone [21]. This graduated change in stiffness allows for transmission of complex mechanical loads from soft tissue to bone while minimizing peak stresses at any single point along the ligament [21]. Cartilage-specific collagens including type II, VI, IX, X, and XI are found in the fibrocartilage insertion site. Collagen VI and X play key roles in maintaining the interface between mineralized and unmineralized zones [22-24].

Abstract

Background: It currently remains unclear why the anterior cruciate ligament (ACL) is most commonly torn from its proximal attachment on the femur and the posterior cruciate ligament (PCL) is torn from its distal attachment on the tibia. This study is designed to evaluate the difference of ligament attachment in bone through a comparison of the origin with the terminal ends in both the ACL and PCL.

Methods: A sample population of 203 knee patients was assessed through magnetic resonance imaging (MRI) and the difference of ACL/PCL femur and tibia attachment were evaluated, and a total of 1146 patients with an ACL injury of the knee and 112 patients with a PCL injury was assessed through MRI imaging and arthroscopy to evaluate the damage according to the specific tear location and type of ACL/PCL injury.

Results: The magnetic resonance imaging (MRI) of normal knee joint shows the ACL/PCL originates from the epiphyseal plate and inserts into the tibial and femur bone at a terminal attachment site. The patient research data suggests the ACL ruptures closer to its femoral attachment and PCL mostly ruptures closer to the tibial attachment.

Conclusion: This study revealed the ACL/PCL originated in the epiphyseal plate of distal femur and proximal tibia, and terminates in the tibial/femoral bone by fibrous ligament tissues that are directly grown into the bone. However, there were no fibrous ligament tissues directly grown into the originate bone of ACL/PCL in the femur and tibia. Comparing the terminal and originate structure of ACL/PCL, the originate site was more commonly the site of injury.

Keywords

Anterior cruciate ligament, Posterior cruciate ligament, Originate, Terminal, Epiphyseal plate, Attachment


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A clear understanding of the anatomy of the native ACL/PCL is critical in determining the ligament will be reconstructed [7,25,26]. Improved awareness of the anatomy and biomechanical properties of the normal ACL/PCL may lead to improvements in techniques for ACL/PCL reconstruction and an associated improvement in outcomes over traditional results [27-29]. In view of the ACL/PCL formation and the location of injury, the origin of ACL/PCL may be involved in the mechanism of ACL is mostly torn from its proximal attachment on the femur and the PCL on the distal attachment of the tibia [30]. However, no research studies have been published in regards to this matter. In this study, it has been demonstrated that the ACL originates from the distal epiphyseal plate of femur and PCL originates from the proximal epiphyseal plate of tibia. The fibers of the ACL/PCL extend in opposing directions from the originate sites (forming the characteristic “x” shape) and become embedded into a broad area of the bone on the medial condyle surface. The anatomical structure of this terminal site is not the same as where it originates from the epiphyseal plate.

**Materials and Methods**

This study involved 203 patients with history of knee pain (ACL/PCL were normal) and 1146 patients with ACL torn and 112 patients with PCL torn. Magnetic resonance imaging (MRI) of the knee joint was taken after the clinical examination. MR imaging was performed with 1.5-T system (Phillips Medical Systems) at Institute of Radiology in the hospital. Two experienced radiologists reviewed the images blindly with no previous knowledge of patient history. The standardized MR imaging protocol consisted of sagittal, coronal, and axial sequences, in section thickness of 3-5 mm. The ACL/PCL was considered normal when it appeared as a band of fibers of low to intermediate signal intensity on both sagittal and coronal dual images. The ACL/PCL was considered to be partially torn when there was abnormal signal intensity within the ligament or when otherwise intact fibers appeared wavy on sagittal or coronal dual images. The ACL/PCL was considered to be completely torn if there was disruption of all fibers or if it was not discernible at all on MRI. For statistical analysis purposes, we considered normal as one group and complete tears and partially torn ligaments as another group.

After the composite data of ACL/PCL images via MRI were collected and arthroscopy performed to confirm lesion location, the patients were divided into three categories: originate, middle, and terminal. Upon confirmation of the injury site, the type of lesions was grouped into two subcategories: ligament rupture and avulsion fractures from attachment (ACL avulsion fractures of tibia tubercle or PCL posterior tibia attachment site avulsion fractures). All arthroscopic procedures were performed under standard hospital policy, on consented patients, and by experienced arthroscopic surgeons. Operative findings were documented in the patient’s official document, which included the survey of the entire joint and anatomical structure, lesions involved with the presence or absence of tear, its location, status of the cartilage and the tibiofemoral joint functionality.

**Statistical Analyses**

Statistical analyses were performed using SPSS Version 16.0 software. The data was expressed as the mean ± SD and was analyzed using analysis of variance (ANOVA). In the case of heterogeneity of variance, transformations were used to stabilize the variance. Results were considered statistically significant if the p value was less than 0.05 for continuous variables.

**Results**

The MRI of ACL/PCL normal knee joint is shown in figure 1, 2, 3. The normal knee joint study group of 203 patients consisted of 137 men (67.5%) and 66 women (32.5%), and average age was 13.5 years (range: 8 - 15 years). The knee composite of the femur, tibia, ACL and PCL, and epiphyseal plate were shown clearly. The ACL finds its origin from epiphyseal plate on the medial surface of the lateral femoral condyle, runs an oblique course within the knee joint and inserts into the central tibial plateau (Figure 1).

The PCL arises from a depression posterior to the intraarticular upper surface of the tibia epiphyseal plate and courses anteromedially behind the ACL and inserts into the medial femoral condyle (Figure 2).

It’s very clear that the ACL/PCL originated in the epiphyseal plate of distal femur and proximal tibia, and terminates in the tibia and femur by a fibrous ligament tissue directly grown into the bone tissue (Figure 3). However, there were no fibrous ligament tissue directly grown into the originate bone of ACL/PCL in femur and tibia.

The data of patients with ACL/PCL lesion were shown in table 1. The study group of 1146 patients consisted of 769 men (67.1%) and 377 women (32.9%) in ACL and 112 patients consisted of 81 men (72.3%) and 31 women (27.7%) in PCL. The average age was 26.5 years (range: 15 – 47 years) in ACL and 29.3 years (range: 18 – 51 years) in PCL. Maximum number of patients (n = 746) who suffered knee injuries were in the age group of 21-30 years in ACL and 29 patients in 30 - 42 years in PCL. The right knee was involved in 635 cases (55.41%) and the left knee in 511 (44.59%) in ACL and 76 cases (62.81%) in right and 45 (37.19%) in left knee in PCL.

**Figure 1:** MR images (sagittal view) of the ACL originate (big arrow) and terminate (small arrow). The big arrow indicates the ligament directed originate from the epiphyseal plate, and the small arrow indicates the ligament terminated the bone which it attachment.
The ACL ruptures rate based on the MRI and arthroscopy criteria was 81.23% (931/1146) in the femur attachment, 9.34% (107/1146) in the middle, and 4.45% (51/1146) in the tibial attachment (P < 0.05). The PCL ruptures rate based on the MRI and arthroscopy criteria was 59.50% (72/121) in the tibial attachment, 13.22% (16/121) in the middle, and 11.57% (14/121) in the femur attachment (P < 0.05).

There were no avulsion fractures in femur attachment of ACL and PCL, and 4.98% (57/1146) case of ACL avulsion fractures of tibial tubercle and 15.70% (19/121) cases of PCL avulsion fractures of posterior tibial attachment.

Discussion

The purpose of this study was to assess the original and terminal sites of the ACL/PCL. The ACL finds its origin on the medial surface of the lateral femoral condyle (LFC), runs an oblique course within the knee joint from lateral and posterior to medial and anterior, and inserts into a broad area of the central tibial plateau [31,32]. The PCL arises from a depression posterior to the intraarticular upper surface of the tibia and courses anteromedially behind the ACL to the lateral surface of the medial femoral condyle. In this study, the MRI examinations demonstrate the ACL originate from epiphyseal plate on the medial surface of the lateral femoral condyle and the PCL originate from the tibia epiphyseal plate. These findings show that there was a relative tendency of originate end to be the site of injury because it not as anchored as the terminal end of ACL/PCL.

The ACL is most commonly torn from its proximal attachment on the femur, and the PCL is most commonly torn from its distal attachment on the tibia [9,33]. A direct insertion is observed in the ACL/PCL whereby the ligament attaches to the bone, similar in the transition of tendon to bone [4,7]. Microscopic examination of the sites of bony attachment show interdigitation of the collagen fibers with bone through four distinct transition zones, and this graduated change in stiffness allows for transmission of complex mechanical loads from soft tissue to bone while minimizing peak stresses at

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Note: F = femur, T = tibia
any single point along the ligament [21,22,24]. In the current study, the ACL/PCL originated in the epiphyseal plate of distal femur and proximal tibia, and terminates in the tibia and femur by ligament fibrous tissue directly grown into the bone tissue.

A clear understanding of the anatomy of the native ACL/PCL is critical in determining the ligament will be reconstructed [34]. The discussion regarding the avulsion of the PCL from its femoral attachment has not been studied with sufficient data [35]. However, the avulsion fracture of PCL tibial attachment were common [19]. A leading hypothesis holds that the ACL originates as a ventral condensation of the fetal blastula and gradually migrated posteriorly with the formation of the intercondylar space. Another proposed mechanism of fetal ACL formation is from a confluence between ligamentous collagen fibers and fibers of the periosteum. Rather than regenerating the four organized zones of direct insertion, the graft heals with an interposed zone of vascular, highly cellular granulation tissue between the graft and the tunnel wall.

In this study, the ACL ruptures mostly in the femur attachment and PCL mostly in tibial attachment. There were no avulsion fractures in femur attachment of ACL and PCL, and all avulsion fractures were in the tibial tubercle of ACL and in the posterior tibial attachment of PCL. These clinical data analyses were consistent with the MRI findings. Improved awareness of the anatomy and biomechanical properties of the normal ACL/PCL may lead to improvements in techniques for ACL/PCL reconstruction and an associated improvement in outcomes over traditional results [36,37].

Conclusions

The ACL/PCL originated in the epiphyseal plate of distal femur and proximal tibia, and terminates in the tibia and femur bone tissue by ligament fibrous tissue directly grown. However, there were no ligament fibrous tissue directly grown into the originate bone of ACL/PCL in femur and tibia. Comparing the terminal and originate structure of ACL/PCL, originate was much more easily prone to become injured.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

DY participated in the design of the study and drafted the manuscript. HZ, YS and ZW participated in the design of the study and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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