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ACL–PCL and intercondylar notch impingement: magnetic resonance imaging of native and double-bundle ACL-reconstructed knees

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Abstract

Purpose The purpose of this study was to: (1) define the relationship between the ACL and PCL in normal knees; (2) determine whether ACL–PCL impingement occurs in native knees; and (3) determine whether there is a difference in impingement between double-bundle reconstructed and native knees.

Methods Eight subjects were identified (age 20–50; 6 females, 2 males). All were at least 1-year status postanatomic double-bundle ACL reconstruction (allograft; AM = 8 mm; PL = 7 mm) and had no history of injury or surgery to the contralateral knee. MRIs of both knees were performed with the knee at 0 and 30° of flexion. The images were evaluated by a non-treating surgeon and two musculoskeletal radiologists. Coronal and sagittal angles of AM and PL bundles, Liu's PCL index and the distance between ACL and PCL on modified axial oblique images were recorded. Impingement was graded (1) no contact; (2) contact without deformation; or (3) contact and distortion of PCL contour.

Results Seventy-five percent (6) of the native ACL's showed no contact with the roof of the intercondylar notch or PCL, compared to 25 % (2) of the double-bundle

reconstructed ACLs. One double-bundle reconstructed ACL showed intercondylar notch roof and ACL–PCL impingement (12.5 %). Significant differences were found between the native ACL and the double-bundle reconstructed ACL for the coronal angle of the AM (79° vs. 72°, $p = 0.002$) and PL bundle (75° vs. 58°, $p = 0.001$). No differences in ROM or stability were noted at any followup interval between groups based on MRI impingement grade.

Conclusion ACL–PCL contact occurred in 25 % of native knees. Contact between the ACL graft and PCL occurred in 75 % of double-bundle reconstructed knees. ACL–PCL impingement, both contact and distortion of the PCL, occurred in one knee after double-bundle reconstruction. This study offers perspective on what can be considered normal contact between the ACL and PCL and how impingement after ACL reconstruction can be detected on MRI.

Level of evidence Cohort Study, Level III.

Keywords ACL · PCL · Double-bundle · Impingement

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Introduction

Clinical success after anterior cruciate ligament (ACL) surgery requires the restoration of normal anatomic relationships and in turn, normal to near-normal tensile properties in the ACL graft. When excessive tension is placed on the ACL graft due to impingement against adjacent structures, significant consequences result including the loss of flexion and extension range of motion [2, 6], myxoid degeneration and decreased vascularity of the ACL graft [13, 25, 26]. Excessive graft tension and ultimate graft failure as a result of impingement of the ACL graft

against the intercondylar notch roof have long been studied [8, 12]. Typically, notch impingement was found to result from non-anatomic anterior tibial tunnel placement, vertical or "high" femoral tunnel placement or a combination of both [7, 17, 18]. Conventional magnetic resonance imaging (MRI) has proved to be useful for the diagnosis of ACL–intercondylar notch roof impingement [12]. However, conventional MRI may not be adequate to assess ACL–PCL impingement [18, 19] for several reasons. First, ACL–PCL contact or impingement is not maximal in full extension, but, rather, occurs as a dynamic phenomenon throughout the range of flexion. Secondly, conventional MRI is not oriented in a plane perpendicular or parallel to the long axis of the ACL graft or the long axis of the PCL [3]. Therefore, there is a need for studies on ACL–PCL impingement, using specially designed MRI sequences to adequately assess this.

Impingement is of interest in the native ACL [4], but it may even be more important following ACL reconstruction. Critics of double-bundle ACL reconstruction argue that inclusion of a second graft (AM and PL bundles) will lead to increased ACL–notch and ACL–PCL impingement, due to "over-stuffing of the notch". However, this has not been objectively studied. Specifically, in the literature, there is a lack of studies comparing the relationship between the ACL and PCL in the native knee to that in the ACL-reconstructed knee. Furthermore, there continues to be a wide variety in ACL reconstruction techniques [23].

The purposes of this study were to: (1) accurately determine the anatomic relationship of the ACL to PCL in native, uninjured knees; (2) determine whether there is contact between the ACL and PCL in native knees; and (3) determine whether the normal anatomic relationships between the ACL graft and PCL were restored or distorted after anatomic double-bundle ACL reconstruction. It was hypothesized that a similar degree of ACL–PCL contact or "impingement" would occur between the native and anatomically reconstructed knees.

Materials and methods

After approval from the institutional review board was obtained [IRB#: REN10070073 / PRO07060263], the prospectively enrolled Sports Medicine Registry was reviewed to identify patients who had undergone double-bundle ACL reconstruction by a single surgeon with a minimum of one-year follow-up. Clinical records were reviewed and patients who had made a full, uncomplicated recovery with return to sports were selected for inclusion in this study. Patients with postoperative complications (superficial wound infection, stiffness, re-injury) were excluded.

Because the aims of the study required the individual to have a contralateral normal knee for comparison to the ACL-reconstructed knee, individuals were included in the study if they had no history of injury or surgery of the contralateral knee and the contralateral knee was asymptomatic at the time of participation in the study. For standardization purposes, we selected a series of patients who all underwent anatomic DB ACL reconstruction with soft tissue allografts (tibialis anterior or tibialis posterior) of identical diameter (AM: 8 mm; PL: 7 mm). Based on these criteria, we enrolled eight subjects (average age 39 ± 13); 6 females and 2 males).

Upon enrolment, all subjects were evaluated by one of the primary investigators. A screening interview was performed to ensure that the reconstructed knee was free of repeat injury or complications and that the uninjured knee was truly asymptomatic and had never been previously injured. A complete orthopaedic examination of both knees was then performed to ensure that both knees were non-tender, free of effusion and stable. MRI safety screening questionnaires were completed by all patients.

Each subject then underwent MRI scans of both knees, in two positions ($0°$ and $30°$ of flexion), on a research 3.0-T scanner operating at VH3-M4 software (GE Medical Systems, Milwaukee, WI), with a dedicated knee coil. Brief scout images were obtained, and MRI sequences were altered/planed to maximize visualization of the ACL in relation to the PCL and intercondylar notch roof. The MR protocol consisted of coronal, sagittal, axial and the "modified axial oblique" proton-density-weighted fast spin echo (PD FSE) sequences with an echo time (TE) of 35 ms, repetition time (TR) of 3,700 ms, Slice/Gap of 3 mm/0 for the coronal, sagittal and axial sequences and 1.5 mm/0 for the oblique axial sequences. After acquiring sagittal and coronal scout views, slice orientation perpendicular to the long axis of the AM bundle in both planes generated the "modified oblique axial view" (Fig. 1).

Images were evaluated by a non-treating sports medicine fellowship–trained surgeon following consultation with two musculoskeletal fellowship–trained radiologists, using Osirix Medical Imaging Software Version 3.2.1, an open-source software workstation for navigating multidimensional DICOM images. Coronal and sagittal angles of AM and PL bundles, Liu's PCL index (14) and the distance between the ACL and PCL on axial oblique images were recorded. The Liu index is a previously described measure of PCL configuration defined as the ratio B/A, with B equalling the length of the line between the posterior inferior tibial and the superior anterior femoral attachment of the PCL, and A equalling the maximum perpendicular distance from this line to the PCL (14) (Fig. 2). ACL–PCL impingement was graded based on a previously described classification system (12) as; (1) no contact; (2) contact
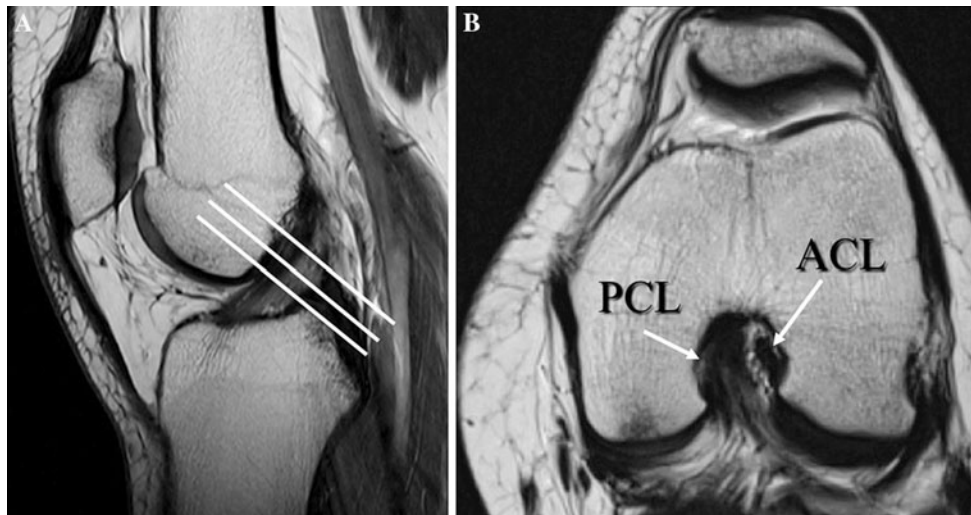
Fig. 1 a Modified axial oblique views of native knee. Following scout imaging, the beam is oriented perpendicular to the long axis of the ACL as shown. **b** Single modified axial oblique in normal knee
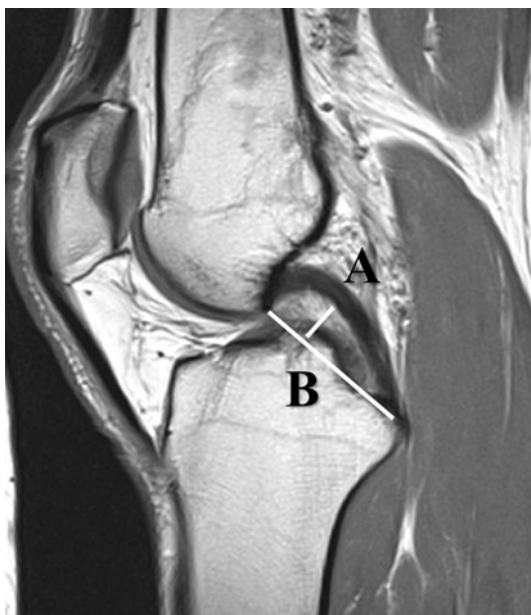
without deformation; (3) contact and distortion of PCL contour (Fig. 3).

Statistical analysis

Descriptive statistics, including mean, range, standard deviation and frequencies, were calculated for all variables. For the continuous variables including the coronal angles

Fig. 2 The Liu index is used to measure PCL configuration and is defined as the ratio *B/A*, with *B* equalling the length of the line between the posterior inferior tibial and the superior anterior femoral attachment of the PCL, and *A* equalling the maximum perpendicular distance from this line to the PCL

showing the ACL in perfect cross-section adjacent to the PCL. Note the normal fat stripe between the ACL and PCL

of the AM and PL bundle, Liu index and the distance between ACL and PCL, the measurements of the three observers were averaged. Subsequently, the differences between the native ACL and the double-bundle reconstructed ACL for the eight subjects were compared using paired t-tests. For the nominal variables including roof, PCL, axial oblique and sagittal impingement, the three observers were asked to reach consensus. The results were then compared between the native ACL and the double-bundle reconstructed ACL using the McNemar test for paired observations. The alpha level for statistical significance was set at $p < 0.05$.

Results

The coronal angles of the AM and PL bundle, Liu indices and the distance between ACL and PCL for the native ACL and the double-bundle reconstructed ACL are displayed in Table 1. Significant differences were found between the native ACL and the double-bundle reconstructed ACL for the coronal angle of the AM (79° vs. 72°, $p = 0.002$) and PL (75° vs. 58°, $p = 0.001$) bundles. There were no significant differences for the Liu index and the ACL–PCL distance.

The degree of ACL–intercondylar notch roof and ACL–PCL impingement on the axial oblique are displayed in Table 2. Seventy-five percent (6) of the native ACL's showed no contact with the roof, compared to 25 % (2) of the double-bundle ACL reconstructions. There was one case of ACL to roof impingement in the double-bundle reconstructed ACL group (12.5 %) compared to no cases in the native ACL group (Table 2).
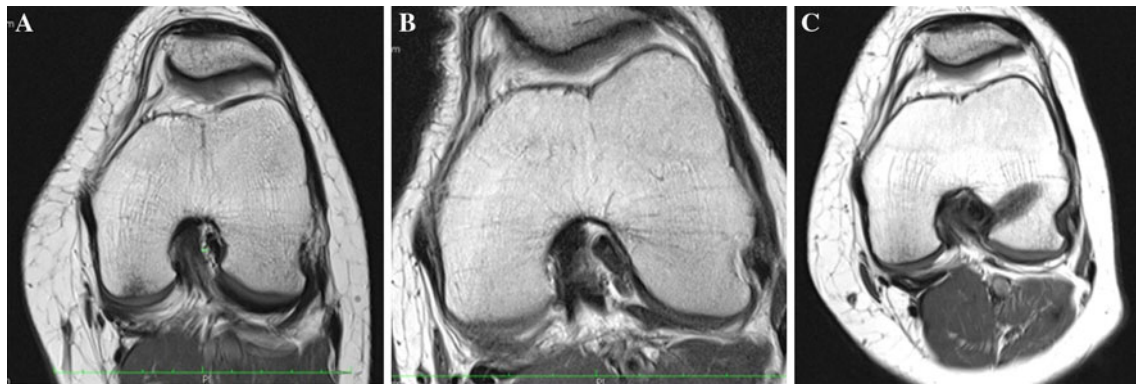
Fig. 3 Classification system of impingement as seen on axial oblique view: **a** no impingement, clear fat plane between ACL and PCL; **b** contact between ACL and PCL without deformation of PCL; **c** impingement between ACL and PCL with deformation of the PCL

Table 1 Comparison between native ACL and anatomically reconstructed double-bundle ACL: continuous variables

Measurement	Native ACL	DB ACL	Significance
Coronal angle AM	78.5 (±2.4)	72.3 (±3.1)	0.002[†]
Coronal angle PL	75.3 (±9.2)	58.0 (±3.7)	0.001[†]
Sagittal Liu A	0.8 (±0.1)	0.9 (±0.2)	ns
Sagittal Liu B	3.6 (±0.3)	3.6 (±0.5)	ns
Sagittal Liu C	0.2 (±0.0)	0.2 (±0.0)	ns
ACL–PCL distance	0.2 (±0.1)	0.2 (±0.0)	ns

DB, double-bundle; *AM,* anteromedial bundle; *PL,* posterolateral bundle; *ACL,* anterior cruciate ligament; *PCL,* posterior cruciate ligament; *ns,* not significant

[†] Significant

Table 2 Comparison between native ACL and DB–R–ACL for impingement

	Native ACL	DB ACL
Roof impingement		
No contact	75 % (6)	25 % (2)
Contact, no deformation	25 % (2)	62.5 % (5)
Contact + distortion PCL	0 % (0)	12.5 % (1)
ACL–PCL impingement		
No contact	75 % (6)	25 % (2)
Contact, no deformation	25 % (2)	62.5 % (5)
Contact + distortion PCL	0 % (0)	12.5 % (1)

DB, double-bundle; *ACL,* anterior cruciate ligament; *PCL,* posterior cruciate ligament

There was no contact with the PCL in 75 % of the native ACL's and 25 % of the reconstructed ACL's (Table 2). Contact between the ACL and PCL was seen in 25 % of native knees compared to 62.5 % of knees after double-bundle ACL reconstruction. ACL–PCL impingement occurred in zero native knees and one knee (12.5 %) after double-bundle ACL reconstruction (Table 2). Statistical analysis to compare the native ACL and the double-bundle reconstructed ACL was not possible due to the small sample size, which resulted in zero cases for some of the categories.

Discussion

The most important finding of the present study was that there is contact between the ACL and PCL in 25 % of native knees. However, this percentage was 75 % for double-bundle ACL-reconstructed knees.

This study sought to more accurately determine normal anatomic relationships between: (1) ACL and intercondylar notch roof and (2) ACL to PCL in native and double-bundle reconstructed knees. The normal anatomic relationship of the ACL relative to the PCL has never truly been well defined with advanced imaging studies. Specifically, the extent of contact or "impingement" that occurs in normal knees had not been studied prior to this. ACL impingement on the notch is better defined, and relatively easily demonstrated using routine clinical MRI sequences with the knee in full extension [10]. However, Fujimoto et al. [5] and Nishimori et al. [16] showed that to study ACL–PCL impingement, the authors required additional ACL–PCL-dedicated MR sequences to make a true diagnosis of "impingement". In the present study, MRI imaging with multiple sequences was used in actual patients after double-bundle ACL reconstruction.

This study aimed to accurately determine the normal anatomic relationship of the ACL to PCL in native, uninjured knees and to determine whether ACL–PCL "impingement" occurs in the native knee. We found that ACL–PCL contact occurred in 25 % of native knees, implying that ACL–PCL contact does occur to some extent in the normal knee. We also sought to determine whether normal anatomic relationships were restored or distorted

with respect to the reconstructed ACL and the native PCL. We hypothesized that a similar degree of ACL–PCL contact or "impingement" would occur between the native knee and anatomically reconstructed knees. Our findings demonstrated contact between the ACL and PCL were more frequent after double-bundle reconstruction compared to the native knee (75 vs. 25 %). However, because of the small sample size, which resulted in 0 counts for one or more of the cells in the analysis, we were unable to determine the significance of this difference. At final follow-up, no clinically evident difference was noted based on these findings. Iriuchishima et al. [9] looked at contact between the ACL and roof of the intercondylar notch with computed tomography (CT) scanning. Similar to our study, they used three categories: no contact, contact without deformation and contact with deformation (impingement). They found that in their 24 subjects, there was intercondylar roof impingement. In 12 subjects, the ACL graft touched the roof but no graft deformation was observed. In the remaining 12 subjects, there was no contact. No significant difference in femoral and tibial tunnel placement was observed between the two groups. In our study, we found similar results. There was no contact in 25 %, contact without deformation in 62.5 % and contact with deformation in only 12.5 %.

Prior studies on impingement after ACL reconstruction were predominately based on single-bundle, transtibial ACL reconstruction techniques [7, 8, 18]. Such reconstruction techniques might be more prone to impingement due to the non-anatomic tunnel position [11, 15, 24]. The present study evaluated anatomic double-bundle ACL reconstruction. We do recognize a higher percentage of knees, demonstrating contact between the ACL and PCL after double-bundle reconstruction knees when compared to the native knees. A logical explanation would be that the placement of two grafts for double-bundle reconstruction exceeded the volume of the intercondylar notch [17]. It is important to note that at the time this study was conducted, double-bundle reconstruction was not yet performed in its current "anatomic" fashion [22]. Specifically, we had not yet defined specific parameters for anatomic single-bundle versus double-bundle reconstruction based on ACL insertion site and notch size. Also, graft size was uniform in all patients (8 mm AM graft and 7 mm PL graft), regardless of individual variation in insertion site size and bony morphology [14, 21]. We acknowledge that there may have been potential mismatch in some patients and therefore, led to over-stuffing of the notch and subsequent impingement. Future studies will have to focus on the comparison between the native ACL and anatomic double-bundle ACL reconstruction that uses grafts that are sized according to the morphology of each individual patient [1, 20].

The strengths of this study are that the contralateral knee of the same patient was used for the comparison between the native and double-bundle reconstructed knee. Therefore, each comparison had an internal control, which reduces selection bias. In addition, adequate clinical follow-up was achieved for all patients that were included in this study, specifically return to full activity without problems at >1 year after surgery was seen in all subjects. In addition, strict inclusion and exclusion criteria were applied in patient selection. The present study also has limitations. Specifically, the sample size was relatively small limiting the ability to statistically compare all three different categories of impingement across groups.

This study is clinically relevant, as it is the first study to report on the normal relationship between the ACL and PCL in native knees. The MRI technique used, allows for the optimal visualization of the ACL–PCL relationship. This study illustrates that there is contact between the ACL and PCL in native knees in about 25 % of subjects. This can now be compared to the ACL-reconstructed knee to determine whether there is impingement after ACL surgery.

Conclusion

In summary, ACL–PCL contact occurred in 25 % of native knees versus 75 % of DB knees. ACL to PCL impingement occurred in one case after double-bundle ACL reconstruction.

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