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Avoiding tunnel collisions between fibular collateral ligament and ACL posterolateral bundle reconstruction

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Abstract
Purpose The purpose of this study was to evaluate the risk of tunnel collisions of the fibular collateral ligament (FCL) and posterolateral bundle anterior cruciate ligament (PLB-ACL) tunnels during a combined FCL and double-dundle (DB) ACL reconstruction.
Methods Thirty-six 4th-generation synthetic femurs (Sawbones, Pacific Research Laboratories, Vashon, WA) were utilized, and two different femur sizes were used. A FCL tunnel and a PLB-ACL tunnel were reamed on each femur. The tunnels of synthetic specimens that did not have a collision were filled with an epoxy resin augmented with $BaSO_4$ and radiographic evaluation, and Multidetector CT exams of the specimens were performed.
Results The rate of tunnel collision when the FCL tunnel was reamed to a depth of 30 mm was 75 and 69.4% for the 25 mm depth. There was a significantly increased risk of tunnel collision when the FCL tunnel was reamed proximally with coronal angulations of 20° and 40°. No collisions were noted when the FCL tunnel was reamed parallel to the distal condylar line and with axial angulations of 20° and 40°.
Conclusion This study provides new insight into tunnel positioning during a combined FCL and DB-ACL reconstruction. The results show that a concomitant FCL injury do not represent a contraindication to perform a DB-ACL reconstruction as long as the FCL tunnel is reamed with no proximal angulation and is directed anteriorly with an axial angulation between 20° and 40°.

Keywords Double bundle anterior cruciate ligament reconstruction · Multiple ligament reconstruction · Fibular collateral ligament reconstruction · ACL reconstruction

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Introduction

Double bundle anterior cruciate ligament (DB-ACL) reconstructions are becoming increasingly more popular. Several biomechanical and clinical studies have concluded that DB-ACL reconstructions restore knee kinematics closer to the normal knee [1, 10, 11, 15, 16, 21, 28, 31]. Furthermore, ACL posterolateral bundle (PLB-ACL) reconstruction has been reported to significantly increase rotational stability when a DB-ACL reconstruction was compared to a single-bundle ACL reconstruction [11, 26, 27, 29, 30]. However, controversy still exists regarding creation of the PLB-ACL tunnel. Several studies have reported that to assure correct positioning of the PLB-ACL tunnel, the guide-wire should be placed through an accessory anteromedial arthroscopic portal at more than 110° of knee flexion [5, 7, 33]. When utilizing this technique, the tunnel placement is more lateral and closer to the main posterolateral corner complex (PLC) [8, 9, 19].

Awareness on treating PLC injuries has increased, because unrecognized PLC injuries have been reported to cause failure of ACL reconstruction grafts [20]. For this reason, it was asserted that PLC injuries should be concurrently repaired or reconstructed in the setting of a concurrent ACL reconstruction [12, 14]. However, with DB-ACL reconstructions, the PLB tunnel is placed more posterior and closer to the PLC structures. This tunnel placement could compromise graft fixation and the success of surgery during the PLC reconstruction when performed with a combined DB-ACL reconstruction. Although no study has assessed this topic and the feasibility of a combined reconstruction, it was asserted that the single bundle ACL reconstruction should be preferred in patients with multiple ligament injuries [23].

The purpose of this study was to use synthetic femurs to evaluate the risk of tunnel collisions between the FCL and PLB-ACL tunnels during a combined FCL and DB-ACL reconstruction and to identify the best location for both tunnels to avoid tunnel collisions. Based on the close proximity between both tunnels, the hypothesis was that tunnel collisions between the PLB-ACL and FLC tunnels was independent from angles of these tunnels, FCL tunnel depth and size of the lateral femoral condyle.

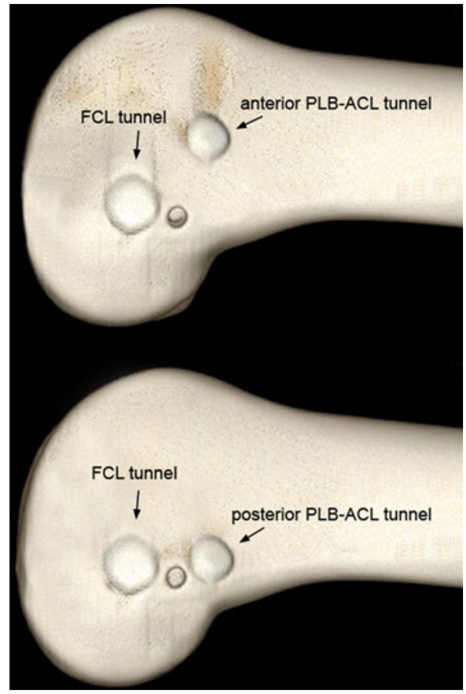

Fig. 1 Lateral view of the synthetic femur that shows two different exit points on the lateral femoral condyle cortex of the PLB-ACL tunnel. An anterior (A) or a posterior (P) PLB tunnel was created for each femur

Materials and methods

Thirty-six 4th-generation synthetic femurs (Sawbones, Pacific Research Laboratories, Vashon, WA) were utilized. Two different femur sizes were used. Eighteen femurs were each medium and large sizes, with a lateral femoral condyle width of 28 and 36 mm, respectively. A FCL tunnel and a PLB-ACL tunnel were reamed on each femur obtaining 36 tunnel combinations.

Each femur was transected 15 cm from the joint line and anchored to a custom-made device to ensure the reproducibility of the tunnel directions. Confirmation of the anatomical location of the PLB femoral attachment point was performed with a lateral radiograph according to a previously described technique [32]. A k-wire was drilled through the centre of the femoral attachment of the PLB which exited proximally on the lateral cortex of the femur. On the basis of previous studies, two different exit points of the guide-wire on the lateral femoral cortex were chosen for each femur to simulate different PLB tunnel directions that could be obtained through an accessory anteromedial (AM) portal at 110° or 120° of knee flexion. [17–19]. In this way, an anterior (A) or a posterior (P) PLB-ACL tunnel was created for each femur with an angulation of 30° and 32°, respectively, in the anteroposterior radiograph view and 53° and 30°, respectively, in the lateral view. At this point, a 7 mm reamer was passed over the guide-wire and a PLB-ACL tunnel was created which breached the lateral femoral condyle cortex [24] (Fig. 1). Concerning the FCL femoral reconstruction tunnel, the entry point of the guide-wire was anatomically located and the correct position was confirmed through both AP and lateral radiographs [22]. Nine different guide-wire orientations were created using 20° intervals in both the coronal and axial planes (Figs. 2, 3). To confirm correct placement of the guide-wires, radiographs and degree measurements were obtained. Once the desired correct orientation was confirmed, an 8- and a 9-mm FCL tunnel were reamed over the guide-wire respectively in the medium and large femurs. In order to evaluate the role of the FCL tunnel depth as a possible cause of tunnel collision, both 25 and 30 mm tunnel depths were reamed.

Radiograph and CT measurements

Each tunnel of synthetic specimens was filled with an epoxy resin augmented with $BaSO_4$ to allow for a radiologic measurement. Radiographs were then performed in AP, lateral and axial views, and tunnel collisions were observed and recorded. Furthermore, a Multidetector CT with 1.3 mm slice thickness was performed on synthetic specimens that did not have tunnel collisions. Multiplanar reconstructions (MPR) of axial, sagittal and coronal plane CT images were obtained. The minimum distance between the PLB-ACL tunnel and the FCL tunnel was calculated for each plane by an independent radiologist blinded to the subject and purpose of the study (Fig. 4). Volume-rendering 3D CT

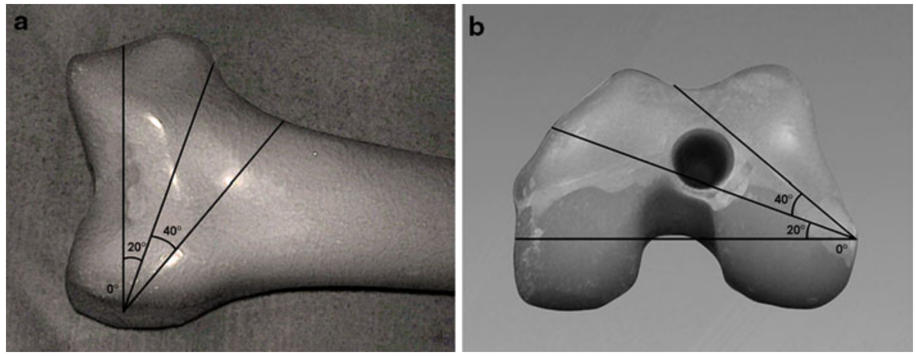

Fig. 2 20° intervals in both the coronal (**a**) and axial (**b**) planes were used to create the FCL tunnel. The neutral position (0, 0) was considered when the guide-wire was placed parallel to the posterior condylar axis and parallel to the tangent line to the distal ends of the medial and lateral femoral condyle

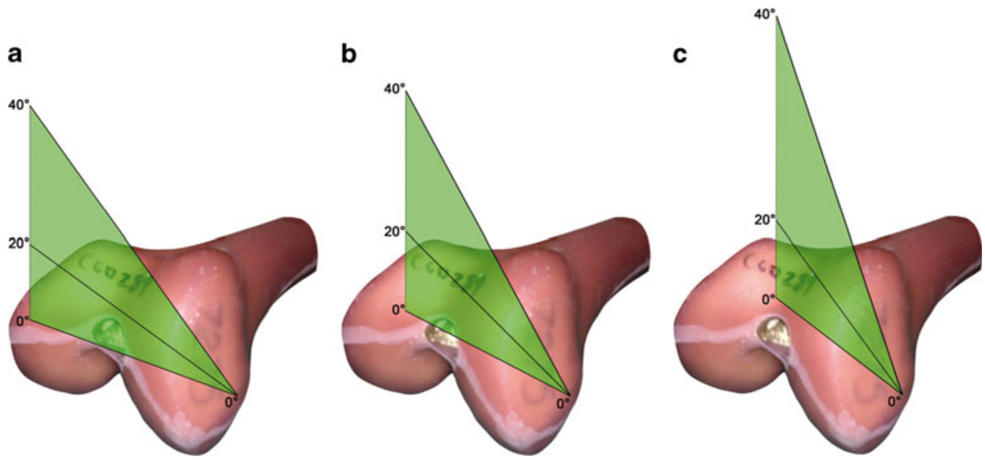

Fig. 3 For each coronal angulation **a** 0°; **b** 20°; **c** 40°, three different axial angulations were chosen [0°, 20°, 40°]. In this way, nine different guide-wire orientations were used to create FCL tunnels

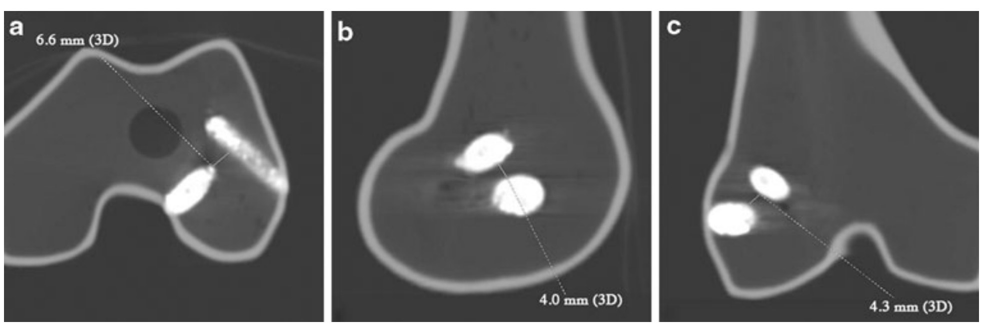

Fig. 4 The minimum distance between the PLB-ACL tunnel and the FCL tunnel was calculated on axial (**a**) sagittal (**b**) and coronal (**c**) plane

reconstructions were also performed, and 3D images were then obtained to determine tunnel position.

Statistical analysis

Frequencies were calculated for each parameter (no collision vs. collision; anterior/posterior PLB-ACL tunnel; permutation FCL tunnel). For sagittal deviation, FCL tunnel angulations were dichotomized (0° = 1; 20°–40° = 2). The comparison between collision/no collision, PLB-ACL tunnel direction and the angulation degree of FCL tunnel was carried out using Chi-square statistics. Data were analysed using SPSS statistical software, version 11.0 (SPSS, Inc., Chicago, IL, USA), and the level of significance was $P \leq 0.05$ for all analyses.

Results

The overall rate of tunnel collision when the FCL tunnels were reamed to a depth of 30 mm was 75%. The rate of tunnel collision decreased to 69% when the FCL tunnel was reamed to a depth of 25 mm.

A collision rate of 96% was observed when the FCL tunnel was directed proximally at 20° and 40° of coronal angulation, for both femur sizes and for both 25 and 30 mm

FCL tunnel depths. However, in regard to the two PLB-ACL tunnel orientations, the collision rate decreased from 100% using an anterior PLB-ACL tunnel to 92% using a posterior PLB-ACL tunnel. The rate of tunnel collision was significantly higher when the FCL tunnel was reamed with a proximal deviation of 20° and 40° in all axial permutations compared with the FCL tunnel reamed with no proximal deviation ($P < 0.001$).

When the FCL tunnel was reamed in neutral position with no coronal and axial angulation (0, 0), tunnel collision occurred close to the femoral notch and to the PLB-ACL tunnel origin (Fig. 5). No collisions were observed when the FCL tunnel was reamed parallel to the distal condylar line and with axial angulations of 20° and 40°, for both femur sizes (Figs. 6, 7). This was also observed for both PLB-ACL orientations and for both 25 and 30 mm FCL tunnel depths.

The minimum distance observed between tunnels through the CT exam is illustrated on Table 1.

Discussion

The most important finding of the present study was that the risk of tunnel collisions between the femoral FCL and PLB-ACL tunnels during combined anatomical FCL and DB-ACL reconstructions was high. However, tunnel collision could be avoided by directing the FCL tunnel anteriorly with an axial angulation of 20° or 40° and limiting proximal angulation of the FCL tunnel. Under these circumstances, the main finding was that both depths of the FCL tunnel and width of the lateral femoral condyle had no

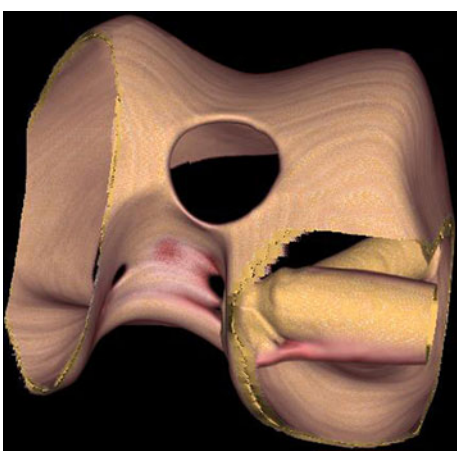

Fig. 5 3D reconstruction shows tunnel collision occurred at the femoral notch and close to the PLB-ACL tunnel origin. This was observed when the FCL tunnel was reamed in neutral position with no coronal and axial angulation (0, 0). The collision was independent from the direction of the PLB-ACL tunnel. However, no collision was observed on large femurs when the FCL was reamed to a depth of 25 mm, for both PLB-ACL tunnel directions

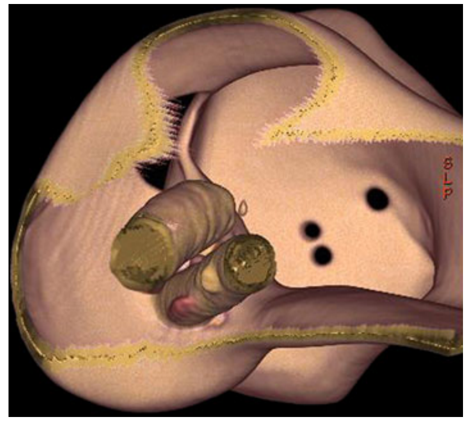

Fig. 6 3D reconstruction that did not shows tunnel collision between the posterior PLB-ACL tunnel and the FCL tunnel when this was reamed parallel to the distal condylar line and with axial angulations of 20°. This was observed for both PLB-ACL tunnels and femur sizes

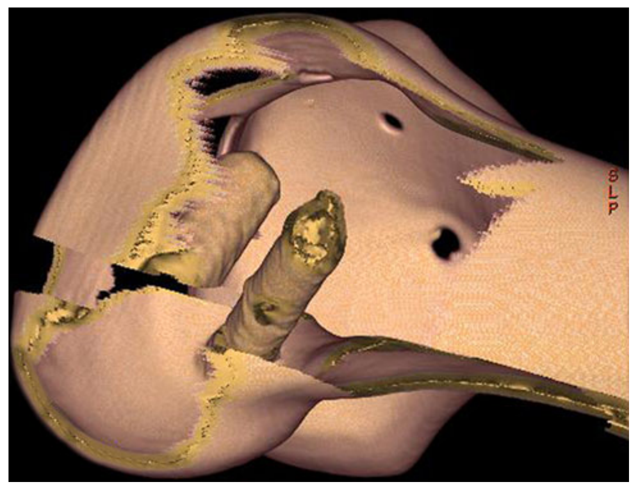

Fig. 7 No collisions were noted between the anterior PLB-ACL tunnel and the FCL tunnel when this was reamed parallel to the distal condylar line and with axial angulations of 40°

Table 1 Minimum distance between the FCL and PLB-ACL tunnels when the FCL tunnel was reamed parallel to the distal condylar line and with axial angulations of 20° and 40°

	Medium femur (mm)	Large femur (mm)
Anterior PLB-ACL tunnel		
20° FCL tunnel	1.4	1
40° FCL tunnel	3.9	5
Posterior PLB-ACL tunnel		
20° FCL tunnel	2.1	2.6
40° FCL tunnel	6.7	7.3

Note that the minimum distance between tunnels increased passing from 20° to 40° of axial angulation role in determining collision between tunnels. This could be asserted on the basis of this study if the PLB-ACL tunnel was created through a low AM portal at 110° or 120° of knee flexion. However, even while a tunnel collision was not observed, it was found that the minimum distance between the FCL and the PLB-ACL tunnels decreased from large to medium femurs (Table 1). This finding was expected as a result of the reduction of the femur size [25]. For this reason, the risk of tunnel collision could increase significantly for smaller femurs. Furthermore, the depth of the FCL tunnel and the lateral femoral condyle width could also determine tunnel collision, especially if the tunnel was created in neutral position (with no coronal and axial angulations). In large femurs (lateral femoral condylar width of 36 mm) reaming a 25 mm deep FCL tunnel was enough to avoid a collision with a PLB-ACL tunnel. However, for medium femurs (lateral femoral condylar width of 28 mm), reaming a 25 mm deep FCL tunnel resulted in a tunnel collision for both PLB-ACL tunnel orientations.

Recently, increased scientific and clinical interest in DB-ACL reconstruction techniques have been observed, because they could reproduce the strain patterns seen in the native ACL compared to single-bundle ACL reconstructions [4, 29, 30]. Following the recent increase of knowledge of the ACL footprint anatomy, it was recommended to drill the PLB-ACL tunnel through a low accessory AM portal at a high knee flexion angle. This was asserted in order to better control the trajectory of guide-wires and to obtain a more anatomical placement of the tunnel [2, 32]. In this study, on the basis of previous findings, the position of the PLB-ACL tunnel was chosen to mimic two different tunnel angulations that could be obtained through an AM portal at 110°–120° of knee flexion [5, 6, 9, 18, 19]. Concerning the FCL tunnel, a 20° interval on three planes was used to obtain significant values that would have been impossible to have for smaller angular values. For this reason, 0°, 20° and 40° angulations were used to direct the guide-wire on axial view, although at 40° the guide-wire presented a course that could penetrate the trochlea of the femur (Fig. 1).

On the basis of the results of the study, it was found that a combined FCL and DB-ACL reconstruction was technically difficult to perform because it requires creating tunnels in close proximity. Furthermore, there would be one more tunnel if a concurrent popliteus tendon reconstruction tunnel was required [13]. This can microscopically result in bone stock reduction or in an impairment of the vascular supply of the lateral femoral condyle increasing the risk of fracture and avascular necrosis. However, regarding tunnel collisions, a simultaneous FCL reconstruction does not represent a contraindication for a DB-ACL reconstruction technique. In the clinical setting, the surgeon should be aware that small lateral femoral condyle width (<28–30 mm) could lead to a reduction in the minimum distance between the two tunnels, which would increase the risk of tunnel collisions. In the operative room, the FCL tunnel should be reamed with an axial angulation of 20° or 40° and parallel to the tangent line to the distal ends of the medial and lateral femoral condyle. Nevertheless, if a collision occurs, it does not absolutely preclude the use of the tunnels during the ligament reconstruction even if it could compromise the graft fixation and the graft integrity. However, tunnel collisions during a combined ligament reconstruction requires further investigation to evaluate the impact of tunnel collision on graft tissue and to better define the surgical indications for combined FCL and DB-ACL reconstructions.

This study has some limitations. First, the biological variability between each individual human femur was limited by the use of synthetic specimens. However, in this study, the main variable that could influence tunnel collisions was the width of the lateral condyle. For this reason, two different sizes of synthetic femurs were used. Second, due to different factors such as the position of the anteromedial portal or the degree of knee flexion, PLB-ACL tunnel angles utilized partially reproduce those angles which could be obtained intraoperatively. Third, a very controlled laboratory situation was used that might be difficult to translate to clinical practice. Finally, increasing the knee flexion angle during drilling could result in a more horizontal PLB-ACL tunnel in the coronal plane which may cause a convergence between FCL and PLB-ACL tunnels during a combined ligament reconstruction [3].

Conclusion

The present study was performed to evaluate the risk of collision between the FCL and PLB-ACL tunnels during a combined reconstruction. The results have shown that the risk of tunnel collision was high and that it could be avoided by limiting proximal angulation of the FCL tunnel and directing the FCL tunnel anteriorly with an axial angulation between 20° and 40°. Furthermore, if lateral femoral condyle width was less than 28–30 mm, the risk of tunnel collision could increase dramatically with a concurrent DB-ACL reconstruction. This information should prove to be helpful for surgeons regarding surgical indications between a single or DB-ACL reconstruction if a combined FCL reconstruction is required.

Conflict of interest The authors declare that they have no conflict of interest.

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