Proximity of Lateral Critical Structures to the All-Epiphyseal Outside-In Femoral Tunnels in Pediatric Anterior Cruciate Ligament Reconstruction

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Purpose: To describe the proximity of the lateral critical structures (peroneal nerve [PN], popliteus tendon [PT], lateral collateral ligament [LCL], and articular cartilage [AC]) to the femoral tunnel for outside-in all-epiphyseal anterior cruciate ligament (ACL) reconstruction in reference to knee flexion angle. **Methods:** All-epiphyseal ACL reconstructions were performed in 12 human cadaveric knees using arthroscopy and outside-in drilling for anatomic femoral tunnel placement that was ensured by identifying the center of the total ACL footprint. Fluoroscopy was used to confirm tunnel position and reconstructions were performed with quadrupled semitendinosus and gracilis autograft with Xtendobutton (Smith & Nephew, Andover, MA) fixation on the femoral side. After reconstruction, the lateral side of the knee was dissected and the LCL, PT, distal and posterior AC, and the PN were identified. The distances of these structures from the center of the exiting femoral tunnel were then measured using a digital caliper at 0°, 30°, 60°, 90°, and 120° of knee flexion. Any gross damage to these structures caused by the femoral drilling was also noted. Data were compiled and the mean and standard deviations (SD) of the distances from the pin to the structures of interest were calculated. The normality of the data at each flexion angle was assessed using Shapiro-Wilk tests ($P > .05$), and the relationship between flexion angle and average distance was evaluated using repeated measures analysis of variance ($P < .05$). Any significant relationships were then evaluated using paired *t*-tests ($P < .05$) with a Benjamini-Hochberg adjustment for each possible pair of flexion angles. Averages, SD, and *P* values are reported. A post hoc power analysis was performed. **Results:** The violation of the LCL was noted in 3 specimens and that of the PT in 1 specimen as a result of femoral tunnel drilling at flexion angles ranging from 90° to 120°. The distance between the PT and the femoral tunnel also decreased significantly ($P < .001$) with knee flexion with average distances to the center of 8.07 mm at 0°, 7.75 mm at 30°, 6.33 mm at 60°, 4.12 mm at 90°, and 1.89 mm at 120°. The mean ± SD for distances from the femoral tunnel to the center of the PT at 0° was 8.07 ± 7.15, at 30° 7.75 ± 6.66, at 60° 6.33 ± 6.79, at 90° 4.12 ± 5.71, and at 120° 1.89 ± 5.56. As the knee was progressively flexed, the distance between the LCL and the femoral tunnel decreased significantly ($P < .001$) with an average distance of 6.52 mm at 0°, 6.26 mm at 30°, 4.23 mm at 60°, 2.38 mm at 90°, and 0.4 mm at 120°. The mean ± SD for distances from the femoral tunnel to the center of the LCL at 0° was 6.52 ± 5.93, at 30° 6.26 ± 7.32, at 60° 4.23 ± 7.82, 90° 2.38 ± 7.31, and at 120° 0.4 ± 7.01. The PN was remote from the femoral tunnel at all flexion angles with a mean distance of 42.83 to 59.22 mm. The PN to guide pin distance increased significantly with progressive knee flexion ($P < .001$). The AC was not damaged in all specimens. **Conclusions:** The LCL and PT are at significant risk during percutaneous femoral drilling for all-epiphyseal anatomic ACL reconstruction using an outside-in technique. This risk was maximized at 120° flexion and minimized in full extension. These findings suggest that the optimal position for femoral drilling in all-epiphyseal ACL reconstruction is full or near-full extension of the knee that can be accomplished by placing the knee in 30° of flexion (after using fluoroscopic guidance to pass the guide pin past the lateral critical structures) to visualize the footprint of the ACL. **Clinical Relevance:** Information garnered from this study may help clinicians better understand the risk to the lateral critical structures when an outside-in femoral tunnel is not drilled in the appropriate degree of knee flexion.

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There are approximately 250,000 to 300,000 complete anterior cruciate ligament (ACL) ruptures in the United States per year, with 1,250 to 9,000 of these occurring in the skeletally immature athletes.[1] Historically, delayed treatment of ACL insufficiency was advocated in the pediatric population because of the risk of physeal injury with reconstruction.[2] However, concomitant meniscal injury has been reported in up to 69.3% of ACL tears, most frequently in the lateral compartment.[3] "Benign neglect" of these injuries has been shown to result in an increased rate of radiographic osteoarthritis[4,5] as well as an increased rate of irreparable meniscal tears.[5-7] Therefore, early and anatomic reconstruction of the pediatric ACL is advisable to treat knee instability as well as to prevent future meniscal tears and cartilage injury.[8]

Pediatric ACL reconstructions may be performed using a variety of techniques including transphyseal, extra-articular, partial-transphyseal, and all-epiphyseal.[8] Transphyseal techniques are generally nonanatomic and vertical, and may cause risk of limb length inequality or angular deformity.[9,10] Extra-articular techniques have shown good outcomes but are not anatomic.[11] Several techniques allowing anatomic physeal-sparing ACL reconstruction have been described.[2,8,12-14] One such technique is the outside-in physeal-sparing, which involves free-hand placement of a guide pin on the lateral aspect of the lateral femoral condyle and drilling toward the ACL footprint under fluoroscopic guidance.[10] The results from another paper by the same author describing this technique showed no clinically significant leg length discrepancy and a side-to-side difference of 1.5 $\pm$ 1.1 mm on KT-1000 arthrometer testing.[14] However, because of the location of the femoral physis, the entry point for this guide pin is quite distal on the lateral femoral condyle, and in close proximity to lateral critical structures including the peroneal nerve (PN), the lateral collateral ligament (LCL), the popliteus tendon (PT), and the articular cartilage.[14] Anderson[14] concluded in his paper that this is a technically demanding procedure with a small margin of error, but it can still be performed in prepubescent patients with efficacy and relative safety by accomplished knee surgeons. Conventional outside-in guides do not take into account the location of the growth plate and are not parallel to the growth plate.[10]

Surgical techniques for ACL reconstruction that respect the anatomy of the physis have become increasingly pertinent. However, physeal-sparing anatomic ACL reconstruction leads to a femoral tunnel that is more horizontal and distal in the lateral femoral condyle.[9] This tunnel placement has the potential to compromise the critical lateral knee structures including the LCL, PT, PN, and lateral condyle articular surfaces.[10] Damage to these structures during ACL reconstruction can have serious consequences.[15] Studies in adult ACL reconstruction using far anteromedial drilling have shown that the PN is least at risk with high knee flexion (>120°); the authors were unable to find a similar study performed for outside-in pediatric ACL reconstructions.[15-19]

The purpose of this study was to describe the proximity of the lateral critical structures (PN, PT, LCL, and articular cartilage) to the femoral tunnel for outside-in all-epiphyseal ACL reconstruction in reference to knee flexion angle. We hypothesized that 0° to 30° of knee flexion would afford the greatest margin of safety for the lateral critical structures during outside-in all-epiphyseal femoral drilling.

Methods

Twelve unpaired fresh-frozen cadaveric knees, 6 male and 6 female, with an average age of 58.2 $\pm$ 16 years with a range of 49 to 68 years were used. Specimens were included in the study irrespective of age. Specimens were excluded if there was evidence of gross deformity or previous surgical or traumatic scaring. Ultimately, no specimens were excluded. The specimens were assessed by the senior author (K.K.). The technique described by Anderson[14] was used in this study with some modifications as used in clinical practice by one of the sports medicine fellowship-trained surgeons (K.K.). For the femoral tunnel, a perfect lateral fluoroscopic view of the distal femur was first obtained (Fig 1). The knee was kept in full extension. A guidewire was then placed at the radiographic landmark of the ACL footprint based on Luites' guidelines who described the relative positions of the centers of the ACL's anteromedial and posterolateral bundles using a percent from deep to shallow at Blumensaat's line and high to low for the condyle depth.[20] The entry point was confirmed with an anteroposterior view of the distal femur, and the guidewire was advanced perpendicular to the femur in the coronal plane and parallel and distal to the physeal scar (Fig 2). The knee was then bent to between 15° and 30° of flexion and the arthroscope was placed through the medial portal. The entrance of the guidewire into the intercondylar notch was visualized arthroscopically (Fig 3) and the view modified as needed by slightly flexing the knee so as to enter the center of the footprint of the ACL, between the anteromedial and posterolateral bundles. An 8- or 9-mm reamer, based on the quadruple graft size, was inserted over the guide pin in full extension. The near cortex was reamed and the knee was then placed in 15° to 30° of flexion, whereas the arthroscope was inserted in the anteromedial portal to visualize the entry point on the lateral wall. The tibial tunnels were reamed using an all-epiphyseal or transphyseal technique based on the allocation of the knee to a group