Early Structural Results After Anatomic Triple Bundle Anterior Cruciate Ligament Reconstruction Validated by Tunnel Location, Graft Orientation, and Static Anteroposterior Tibia-Femur Relationship

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Purpose: To elucidate how closely the structural characteristics of the anterior cruciate ligament (ACL) grafts after anatomic triple bundle (ATB) reconstruction resembled those of the normal ACL. **Methods:** From 2012 to 2016, patients who underwent primary ATB ACL reconstruction using hamstring tendon autografts and the same number of healthy control subjects were included. Using magnetic resonance imaging (MRI) taken at 6 months postoperatively, ACL graft orientation was evaluated by the angles against the tibial plateau measured in the sagittal and oblique coronal planes at the anteromedial and posterolateral portions (ACL-tibial plateau angle [ATA]). For factors affecting the graft orientation, the static tibiofemoral relationship was evaluated by anteroposterior tibial translocation (APTT) in the identical MRI using a previously established method, and tunnel locations were evaluated using the quadrant method. To test equivalence, the widely used two one-sided test procedure was performed, with the equivalence margins of 5° and 3 mm for ATA and APTT, respectively. **Results:** Thirty-five patients were enrolled for each group. ATAs were not significantly different, and the 95% confidence interval (CI) of these differences was within 5° (sagittal: $P = .211$ [95% CI, −2.9 to 0.6]; oblique coronal ATA for the anteromedial and posterolateral portions: $P = .269$ [95% CI, −1.9 to 0.5] and $P = .456$ [95% CI,−2.1 to 0.9], respectively). The difference in APTT was neither statistically nor clinically significant ($P = .114$; 95% CI, −2.0 to 0.2). **Conclusions:** These data suggest that ACL grafts using the ATB technique achieved a graft orientation equivalent to that of the normal ACL, with an equivalent postoperative anteroposterior tibiofemoral relationship in the static MRI. Thus, the ATB ACL reconstruction technique with the presented tunnel locations produced grafts that were similar to the native ACL in orientation. **Level of Evidence:** Level III, case-control study.

Anatomic anterior cruciate ligament reconstruction (ACLR) is performed to reproduce the morphology and function of the native anterior cruciate ligament (ACL).[1] Recent studies on ACL anatomy have demonstrated a ribbon-like cross-section of its midsubstance with a crescent or C-shaped footprints.[2-4] However, as large-diameter round tunnels are created in the femur and the tibia in a conventional single-bundle reconstruction with a multistranded hamstring tendon graft, it is difficult to include all of the tunnel apertures inside the native ACL footprints. Because the soft-tissue graft inside the tunnel is subjected to eccentric shifting according to the pulling force of the graft,[5] even a single bundle graft via the tunnels exactly in the center of the footprint tends to run more vertically than the native ACL. Moreover, a 10-mm round tunnel in the real center of the tibial footprint damages the anterior horn of the lateral meniscus.[6]

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To resolve these issues and to better replicate the ACL anatomy, multiple bundle reconstruction techniques were developed. Double bundle reconstruction generally uses tunnels with smaller diameters and creates 2 tunnels inside the footprints. More recently, studies have shown that the native ACL consists of 3 bundles,[7-9] and the tibial footprint is C-shaped.[4] Based on these anatomic features, anatomic triple bundle (ATB) ACLR was proposed by Shino et al.[10,11] The advancement of this ATB technique over double-bundle reconstruction is the third tibial tunnel in the anterolateral portion of the footprint. These 3 tunnels, made by adding the 1 lateral to the anteromedial (AM) tunnel, make it possible to more closely mimic the C-shaped tibial footprint of the native ACL. A clinical study using an immediate postoperative laxity measurement showed that ATB ACLR efficaciously controlled anterior stability,[12] and the observation of the ATB graft by second-look arthroscopy showed a nicely mimicked fan-out appearance of the anterior tibial insertion.[13] Based on this background and scientific basis, we have been performing ATB ACLR.

The innovations of these reconstruction techniques (i.e., from single and double to triple bundles) aim to better replicate the structure of the normal ACL. The structure is very important when considering the function of reconstructed grafts, and it is primarily represented by the attachments and the orientation, considering that ligaments are point-to-point restrainers. Indeed, tunnel malposition is predominantly claimed to be a factor for graft failure,[14,15] whereas the precise tunnel location remains controversial.[16] Meanwhile, several reports have elucidated the relevance of the graft orientation on knee biomechanics.[17-20] These laboratory-based studies elucidated the strong link between biomechanical function and orientation of ACL grafts. The former is often analyzed by a complicated method using specific and expensive equipment, whereas the latter is easily measurable using magnetic resonance imaging (MRI). These studies suggest that evaluating the graft orientation with regard to the normal ACL may ultimately provide insight to physicians regarding the functional outcomes.

In this regard, this study explored the graft orientation after ATB ACLR and statistically tested its equivalence against that of the normal ACL, using routine MRI. Most studies on graft orientation have used the sagittal and coronal planes, although Hosseini et al.[21] clearly demonstrated that the axial and sagittal orientations are informative. To evaluate the 3-dimensional orientation of ACL grafts without missing axial information, we analyzed the sagittal and oblique coronal planes, because the oblique coronal plane gives both coronal and axial orientation information. In addition, graft orientation is influenced by the tibiofemoral relationship; therefore, we also examined static tibial translation against the femur in the identical MRI. The purpose of this study was to elucidate how closely the structural characteristics of the ACL grafts after ATB reconstruction resembled those of the normal ACL. Our hypothesis was that the orientation of the ACL grafts was statistically equivalent to that of the normal ACL, with the normal tibiofemoral relationship maintained after ATB ACLR.

Methods

Patients who underwent primary ACLR with the ATB technique performed by one of the authors between 2012 and 2016 were retrospectively identified. Because the primary purpose of this study was imaging analysis, the inclusion criteria were a minimum of 6 months' follow-up and agreement with the postoperative MRI examination, compliance with our rehabilitation program for an untorn graft, and an informed consent. Because graft orientation is affected by the knee flexion angle, knees with any loss of extension at the time of MRI examination were excluded. For acute injuries, surgery was not indicated unless the range of motion (ROM) of the index knee had recovered normally. This study was approved by the institutional review board of the hospital where the surgeries were performed.

Surgical Technique and Postoperative Regimen

ATB ACLR using an autogenous hamstring tendon graft was technically detailed previously.[10] Briefly, a semitendinosus tendon was harvested from its tibial insertion with an approximately 3-cm skin incision. After removing muscular tissue, the harvested tendon was transected in half and then folded to make a pair of doubled grafts. An EndoButton-CL (Smith & Nephew Endoscopy, Andover, MA) was placed at the loop end of the graft. Two No. 3 polyester sutures were placed at the free ends of the posterolateral (PL) graft. The AM graft was left bifurcated, and 1 No. 3 polyester suture was placed at each free end. Two femoral tunnels were created at the lateral wall of the intercondylar notch; these tunnels were parallel to and posterior to the resident's ridge and were created for the AM and PL bundles of the ACL graft.[11] Three tibial tunnels were created in the ACL footprint surrounded by the anterior ridge, medial intercondylar ridge, and anterior horn of the lateral meniscus. The 2 anterior tibial tunnels were created for the AM graft (tunnels for medial and lateral portions of the AM bundle; AM-M and AM-L tunnels, respectively), and the posterior tibial tunnel was created for the PL graft. The diameter of each tunnel was determined by the harvested graft volume. The PL graft was passed through the tibial tunnel to the femoral tunnel and fixed with EndoButton-CL. The AM graft was passed through the portal and fixed likewise at the femoral cortex. Then the free ends of the intra-articular AM graft were introduced into the AM-M