Comparative Analysis of Femoral Tunnels Between Outside-In and Transtibial Double-Bundle Anterior Cruciate Ligament Reconstruction: A 3-Dimensional Computed Tomography Study

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Purpose: The objectives of this study were (1) to compare locations of the femoral tunnels created by outside-in and transtibial techniques and the reference data and (2) to compare the diameter of the tunnel entrance based on the real reaming size.

Methods: A comparative study was performed with 20 outside-in and 22 transtibial double-bundle anterior cruciate ligament reconstruction patients. Computed tomography scans of the operated knees of the outside-in and transtibial groups were performed at 1.25 days (range, 1 to 3 days) and 2.7 weeks (range, 3 days to 4 weeks), respectively. Three-dimensional surface models were then produced. For all 3 plane data sets, the positions of the femoral tunnels were measured by an anatomic coordinate axis method. For comparison of the tunnel diameter at the entrance of tunnel, the difference between the real reaming and measured diameter was determined first on computed tomography images. Subsequently, the differences in the outside-in and transtibial techniques were compared.

Results: In the comparison between outside-in and reference data, the posterior-anterior direction of the posterolateral (PL) tunnel showed an anterior position compared with reference data, even though it was positioned more posteriorly compared with that of the transtibial technique ($P = .003$). In the comparison between transtibial and reference data, the posterior-anterior direction of the anteromedial (AM) and PL tunnels showed an anterior position compared with reference data ($P = .019$ and $P = .005$, respectively). The transtibial technique showed significantly larger diameters in both AM and PL tunnels ($P < .001$ and $P < .001$, respectively).

Conclusions: The outside-in technique showed more accurate replication of the femoral tunnels than the transtibial technique, particularly the AM tunnel of the femur. The transtibial technique showed an ellipsoidal tunnel configuration at the entrance of the tunnel, which suggests that eccentric reaming is unavoidable because the reaming angle is determined by the tibial tunnel.

Level of Evidence: Level III, retrospective comparative study.

Recently, double-bundle anterior cruciate ligament (ACL) reconstruction techniques have been developed in an attempt to replicate the native anatomy of the ACL. Therefore double-bundle ACL reconstruction is gaining popularity, and some studies have reported similar or superior results compared with single-bundle reconstruction. These strategies are also supported by evidence showing that superior clinical outcomes occur when graft placement is aligned with the native ACL.

The transtibial drilling method has become widely accepted, and many studies have reported good results. On the other hand, in this technique, the femoral tunnel is determined by the tibial tunnel and both tunnels can be compromised because of coupled drilling. Recently, many studies have reported the limitations and disadvantages of this technique for the formation of the femoral tunnel, and some medial portal and outside-in techniques are re-evolving.
Several studies have examined the utility of conventional radiography, computed tomography (CT), and magnetic resonance imaging for the evaluation of the bone tunnel locations after ACL reconstruction. CT scans are frequently used to characterize the ACL footprint with its 2 bundles. CT scans, particularly 3-dimensional (3D) CT models, have advantages in terms of reproducing the bony geometry compared with 2-dimensional plain radiographs, 2-dimensional CT images, and magnetic resonance imaging studies. Kopf et al. evaluated the graphs, 2-dimensional CT images, and magnetic resonance images. The objectives of this study were (1) to compare the tunnel locations of the femoral tunnels created by outside-in and transtibial techniques and the reference data and (2) to compare the diameter of the tunnel entrance based on the real reaming size. The hypotheses of this study were that (1) the outside-in technique would produce a closer tunnel location to the reference data compared with the transtibial technique and (2) the diameters of the tunnel entrance would be different from the real size of reaming and this difference would be larger with the transtibial technique because reaming is performed in a more oblique manner to the inner wall of the lateral femoral condyle compared with the outside-in technique.

METHODS

From March 2010 to March 2011, a comparative study was performed in 20 outside-in and 22 transtibial double-bundle ACL reconstruction patients, each of whom had a unilateral ACL-deficient knee that had undergone double-bundle ACL reconstruction. The mean age of the transtibial and outside-in groups was 31.67 years (range, 19 to 50 years) and 28.8 years (range, 22 to 46 years), respectively. The preoperative demographic data of the 2 groups were similar. Consecutive patients in whom examination of CT scans was possible were enrolled in this study without randomization. Patients with combined ligament injury and revision reconstruction were excluded. Two different surgeons performed surgery. One surgeon performed all transtibial techniques, and the other surgeon performed all outside-in techniques. CT scan was performed at early post-operative period during hospital stay, or the first visit to the outpatient clinic. CT scans (Siemens Somatom Definition; Siemens, Forchheim, Germany) of the operated knees of the outside-in and transtibial groups were performed at 1.25 days (range, 1 to 3 days) and 2.7 weeks (range, 3 days to 4 weeks), respectively. Institutional review board approval of each institute was obtained before we commenced the study, and all patients provided informed consent for participation.

A continuous scan was obtained from approximately 10 cm above to 10 cm below the joint line. Coronal reconstructions were performed at a level parallel to a line joining the posterior femoral condyles, whereas the sagittal reconstructions were performed at a level parallel to the outer rim of the lateral femoral condyle. Three-dimensional surface models were then produced using Somaris/7 syno CT 2008G (syno CT Workplace VA20A; Siemens) and an EBW workstation (version 3.5.0; Philips Medical Systems, Best, The Netherlands). The measurement was performed with a PiViewSTAR system (version 5.0.9.2; Infinitt, Seoul, South Korea).

For all 3 plane data sets, the positions of the femoral tunnels were determined using an anatomic coordinate axis method (Fig 1). As described by Forsythe et al., a true medial view of the femur was established at 90° of knee flexion, allowing standardized visualization of the medial wall of the lateral femoral condyle. To improve visualization of the medial wall of the lateral femoral condyle, the medial condyle was removed from the 3D CT model at the most anterior aspect of the distal notch. The tunnel positions were determined in the posterior-to-anterior and proximal-to-distal directions, parallel to the respective anatomic axes. The measurements were made twice by 2 orthopaedic surgeons for all patients. To compare the tunnel locations created by the outside-in and transtibial techniques and reference data, the centers of the femoral tunnel apertures were determined on a sagittal-plane grid aligned to the Blumensaat line from 3D CT reconstruction images.

To test the second hypothesis regarding the diameter of the tunnel entrance, the longest tunnel diameter was measured at the medial wall of the lateral femoral condyle and the data were compared with the real reaming size. For a comparison of the tunnel diameter at the entrance of the tunnel, the difference between the real reaming and measured diameter on CT was first determined. Subsequently, the differences in the outside-in and transtibial techniques were compared (Fig 2).

Surgical Procedure and Rehabilitation

Outside-In Technique: With a focus on the femoral tunnel, the arthroscope was inserted through the
anteromedial (AM) portal and the femoral guide, set at a 90° angle, was inserted through the central portal (Fig 3). The tip of the guide pin was pointed at the central portion of the footprint of each bundle using an outside-in technique. If the footprint was not well visualized, the lateral intercondylar ridge and lateral bifurcate ridge were used as landmarks.2,24

Mild dilation was performed with a punch for the insertion of the ligament plate (Solco Biomedical, Seoul, South Korea) at the exit portion of the AM femoral tunnel. The AM bundle of the femoral side was suspended at the ligament plate, and the posterolateral (PL) bundle was suspended at the ligament plate using 2 Mersilene tapes (Ethicon, Somerville, NJ). For tibial fixation, double post-tie fixation was performed using tension and a terminal tie. Two bundles were fixed simultaneously at 15° of knee flexion.

**Transtibial Technique:** The knee was held at 90° flexion, and the ACL guide (Acufex Microsurgical, Mansfield, MA) was inserted at 55° through the AM portal, with the guide tip pointing to the most PL aspect of the footprint.10,25 The starting point was located just anterior to the medial collateral ligament. The tibial exit point is normally located just at the AM portion of the lateral meniscus posterior horn insertion.

**Figure 1.** The femoral anatomic axis posterior-to-anterior measurements were made from a line running through the posterior border of the medial wall of the lateral femoral condyle to a line running through the most anterior point of the notch. The proximal-to-distal measurements were made from a line running through the proximal border of the notch to a line running through the distal point of the notch roof. The posterior-to-anterior measurements for the AM and PL tunnels were calculated as B/C and A/C, respectively. The proximal-to-distal measurements were calculated as a/c and b/c, respectively.2

**Figure 2.** (A) The transtibial technique showed an ellipsoidal tunnel configuration whereas the (B) outside-in technique showed a round configuration at the tunnel entrance.
and the PL corner of the ACL footprint. The guide pin was advanced to the femoral footprint, which is located below the intercondylar ridge and anterior to the bifurcate ridge. Once the pin was in an acceptable position, the tunnel was drilled through both the tibia and femur in 1 step using a 4.5-mm EndoButton drill (Smith & Nephew Endoscopy, Andover, MA), and the depth of the tunnel was measured. The tunnel is usually 35 to 40 mm, and the inner tunnel was reamed 25 to 30 mm in length with a 6-mm reamer. Subsequently, the guide pin for the AM bundle was positioned in a more AM aspect on the tibial footprint with an ACL guide at an angle of 45°. The guide pin was then advanced to the proximal posterior portion of the footprint located 5 mm anterior from the over-the-top position, and mild mismatches of the point were adjusted while reaming. For this purpose, a Kelly clamp was usually used to maintain the correct femoral tunnel (Fig 4). The tip of the guide pin was positioned at the intended position of the femoral tunnel with curving of the guide pin achieved by clamping the tip area. However, this sometimes caused breakage of the bony bridge between the 2 tibial tunnels.

**Rehabilitation:** All patients immediately began active quadriceps isometric exercises and active range-of-motion exercises. At 3 days after surgery, crutches were used to allow partial weight bearing. At 4 or 5 days after surgery, an ACL brace was put on and mini-squat exercise was allowed. At 4 weeks after surgery, 90° of motion was allowed, and at 6 weeks after surgery, 120° of motion was permitted. At 6 months after surgery, straight-line running was allowed, and at 9 months after surgery, changing the direction while running was allowed.

**Statistical Methods**

The SPSS statistical package (version 18.0; SPSS, Chicago, IL) was used. $P < .05$ was considered sig-

![Figure 4](image)

**Figure 4.** (A) The tip of the guide pin was positioned at the intended position of the femoral tunnel with curving of the guide pin achieved by clamping the tip area. (B) However, this sometimes caused breakage of the bony bridge between the 2 tibial tunnels.
significant. Independent \( t \) tests were used to compare the tunnel positions created by the conventional transtibial technique with the reference data and tunnel diameter.

**RESULTS**

The interobserver and intraobserver reliabilities for tunnel measurement were satisfactory, and the mean values were 0.84 (range, 0.78 to 0.92) and 0.84 (range, 0.75 to 0.84), respectively. Post hoc power analysis was performed to determine whether the sample size had sufficient power to detect a significant difference in tunnel positions. If the difference between the reference data and measured tunnel position was greater than 5%, it was assumed that this would show clinically different results. The \( \alpha \) value was .05. Twenty-two patients and 20 patients showed 91% and 85% power, respectively.

In the comparison between outside-in and reference data, the posterior-anterior direction of the PL tunnel showed an anterior position compared with reference data, even though it was positioned more posteriorly compared with that of the transtibial technique \((P = .003)\). The remaining 3 parameters showed no significant differences. In the comparison between transtibial and reference data, the posterior-anterior direction of the AM and PL tunnels showed an anterior position compared with reference data \((P = .019\) and \(P = .005\), respectively). The remaining 2 parameters showed no significant differences (Table 1). In the comparison of tunnel diameters at the tunnel entrance, the transtibial technique showed significantly larger diameters in both AM and PL tunnels \((P < .001\) and \(P < .001\), respectively). The measurements are listed in Table 2.

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<th>Table 1. Tunnel Positions of 3 Methods</th>
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<td>AM Tunnel of Femur (%)</td>
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Abbreviations: PA, posterior-anterior location; PrD, proximal-distal location.

**DISCUSSION**

The principal findings of this study were that the posterior-anterior direction of the PL tunnel showed an anterior position compared with reference data using an outside-in technique and the posterior-anterior direction of the AM and PL tunnels showed an anterior position compared with reference data using a transtibial technique. The posterior-anterior direction of the PL tunnel using an outside-in technique also showed a more anterior position than the reference data, even though it was positioned more posteriorly compared with that of the transtibial technique. The transtibial technique showed significantly larger diameters at the entrance of both the AM and PL tunnels between the real reaming size and measured diameter on the CT scan. The transtibial technique showed an oblique tunnel configuration that originated from eccentric reaming because the reaming angle is determined by the tibial tunnel.

These results suggest that the PL bundle inserts very closely to the posterior articular cartilage. Zantop et al.26,27 reported potential cartilage damage during PL tunnel formation of the femur. They recommended a low medial portal in high knee flexion. During outside-in femoral drilling of the PL tunnel, the starting point is the anterior side of the lateral epicondyle, and it must be directed to the most posterior side near the articular cartilage. In this situation, it may be difficult to position the femoral tunnel of the PL bundle correctly because it also causes some eccentric reaming, even though the angle is small compared with transtibial drilling.

The most difficult part of double-bundle ACL reconstruction is the creation of 2 tunnels in the femur and tibia while keeping an intact bone bridge between them.23 Recently, some studies have reported that it is possible to duplicate the native femoral footprint char-
acteristics of the ACL with specific instruments without breaking the bone bridge.\textsuperscript{2,23} Transtibial drilling has some advantages. A CT scan allows accurate tunnel visualization, as well as direct graft or native ACL observation without artifacts, and a 3D reconstruction allows accurate quantification of the angles, diameters, and distances.\textsuperscript{22} Forsythe et al.\textsuperscript{2} developed a new measurement technique that is called the anatomic coordinate axis method, which was developed for 3D model–based analysis of the bone tunnel positions. This technique showed high reliability with regard to both intraobserver and interobserver variation because the position of the tunnels relative to the known osseous landmarks was determined from 3D bone models.\textsuperscript{2} Although this 3D anatomic study of the femoral footprint was performed in old cadaveric knees, it is very valuable because most previous studies used 1-dimensional measurement and it has directly evaluated the femoral footprint.\textsuperscript{2,14} Kopf et al.\textsuperscript{14} also evaluated the location of the femoral tunnel using these anatomic data from cadaveric knees, and the demographics were similar to our study.

A strength of our study is that CT scan was performed postoperatively within 6 weeks, which could rule out postoperative tunnel enlargement because most tunnel widening occurs during the first 3 to 6 months.\textsuperscript{23} On the other hand, this study has some limitations that must be considered. First, in the reference data, the centers of the tunnels were determined using a combination of methods. In contrast, the centers of the tunnels were determined using only the 3D reconstructed model for the outside-in and transtibial techniques. Second, clinical results are lacking, even though many articles have reported that correct tunnel position and maintaining the bone bridge are important.\textsuperscript{1,2,7,23} Third, we used reference data from a cadaveric study, and our data were not sampled from the same underlying population of reference data.

\section*{CONCLUSIONS}

The outside-in technique showed more accurate replication of the femoral tunnels than the transtibial technique, particularly the AM tunnel of the femur. The transtibial technique showed an ellipsoidal tunnel configuration at the entrance of the tunnel, which suggests that eccentric reaming is unavoidable because the reaming angle is determined by the tibial tunnel.

\section*{REFERENCES}


