Superior clinical outcomes are thought to be obtained when graft placement is aligned with the native anterior cruciate ligament (ACL). Along with this strategy, restoration of the native footprint is important. The outside-in femoral tunnel procedure seems to be a more reliable and precise way to achieve an anatomic ACL reconstruction, although controversy persists regarding the best reconstructive procedures for the treatment of a torn ACL.

The purpose of this study was to compare the accuracy and reproducibility of the femoral tunnel location among 3 different viewing techniques used during outside-in ACL reconstruction with 3-dimensional (3-D) computed tomography (CT): (1) an anterolateral (AL) or anteromedial (AM) portal with a 30° arthroscope (A group) vs (2) a posterolateral (PL) portal with a 70° arthroscope (PL group) vs (3) a trans-septal (TS) portal with a 30° arthroscope (TS group). A total of 106 patients undergoing outside-in ACL reconstruction were recruited. Patients were divided into 3 groups according to viewing technique (A group=36 patients; PL group=35 patients; TS group=35 patients). Femoral tunnel locations were evaluated with the quadrant method and the anatomic coordinate axes measurement (ACAM) method in the medial wall of the lateral femoral condyle using 3-D reconstructed CT. The accuracy and reproducibility of the femoral tunnel locations were compared among the 3 techniques. The accuracy of the tunnel location was higher in the TS group by the quadrant method as well as the ACAM method. The reproducibility of the femoral tunnel position in the TS group was the highest, and the femoral tunnel locations of the TS group were more compactly distributed compared with those of the A and PL groups.

The accuracy and reproducibility of the femoral tunnel location could be improved with a TS portal viewed using a 30° arthroscope. Anteromedial/anteralateral and PL portals viewed using a 70° arthroscope showed no difference. [Orthopedics. 2016; 39(6):e1085-e1091.]

Accuracy and Reproducibility of the Femoral Tunnel With Different Viewing Techniques in the ACL Reconstruction

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abstract

The purpose of this study was to compare the accuracy and reproducibility of the femoral tunnel location among 3 different viewing techniques used during outside-in anterior cruciate ligament (ACL) reconstruction with 3-dimensional (3-D) computed tomography (CT): (1) an anterolateral (AL) or anteromedial (AM) portal with a 30° arthroscope (A group) vs (2) a posterolateral (PL) portal with a 70° arthroscope (PL group) vs (3) a trans-septal (TS) portal with a 30° arthroscope (TS group). A total of 106 patients undergoing outside-in ACL reconstruction were recruited. Patients were divided into 3 groups according to viewing technique (A group=36 patients; PL group=35 patients; TS group=35 patients). Femoral tunnel locations were evaluated with the quadrant method and the anatomic coordinate axes measurement (ACAM) method in the medial wall of the lateral femoral condyle using 3-D reconstructed CT. The accuracy and reproducibility of the femoral tunnel locations were compared among the 3 techniques. The accuracy of the tunnel location was higher in the TS group by the quadrant method as well as the ACAM method. The reproducibility of the femoral tunnel position in the TS group was the highest, and the femoral tunnel locations of the TS group were more compactly distributed compared with those of the A and PL groups.

The accuracy and reproducibility of the femoral tunnel location could be improved with a TS portal viewed using a 30° arthroscope. Anteromedial/anteralateral and PL portals viewed using a 70° arthroscope showed no difference. [Orthopedics. 2016; 39(6):e1085-e1091.]

During outside-in ACL reconstruction, anteromedial (AM) or anterolateral (AL) portals are usually used for viewing the femoral footprint. However, observing the posterior portion of the ACL femoral footprint (AM bundle footprint) using an AM or AL portal may be difficult due to blocking by an ACL remnant or ridge on the medial wall of the lateral femoral condyle. In addition, the ACL remnant may be worn out if the posterior side is accessed for a good view of the direct insertion of the femoral footprint.

Using a 70° arthroscope through a posterolateral (PL) portal, the posterior part of the ACL footprint can be seen directly. However, this view may be distorted be-
cause the wall of the ACL insertion should be seen from an anterior to posterior direction.4 The posterior trans-septal (TS) portal has greatly improved visualization of the posterior compartment, thus facilitating many troublesome arthroscopic surgeries.4,15-17 This portal can allow direct visual access to the posterior part of the ACL femoral footprint through the posteromedial (PM) portal.

The purpose of this study was to compare the accuracy and reproducibility of the femoral tunnel location among 3 different viewing techniques used during outside-in ACL reconstruction with 3-dimensional (3-D) computed tomography (CT): (1) an AL or AM portal with a 30° arthroscope (A group) vs (2) a PL portal with a 70° arthroscope (PL group) vs (3) a TS portal with a 30° arthroscope (TS group). The hypothesis of this study was that femoral tunnel locations would be more accurate and reproducible in the posterior viewing group (PL and TS), and the TS viewing technique would be the best because it offers the most direct view of the medial wall of the lateral femoral condyle.

MATERIALS AND METHODS

Demographics

Between June 2011 and August 2014, 106 patients undergoing single-bundle, outside-in, remnant-preserving ACL reconstruction were recruited.4 Patients were divided into 3 groups according to viewing technique (A group=36 patients; PL group=35 patients; TS group=35 patients). All patients agreed to be evaluated using 3-D CT within 1 week postoperatively. Surgeries in the A and PL groups were performed by 1 surgeon (J.H.A.), and surgeries in the TS group were performed by another surgeon (Y.S.L.) at a different institution. Demographic characteristics among the groups were not significantly different in terms of sex (P=.737) and age (P=.691). The protocol of this retrospective, cross-sectional, comparative study was approved by the authors’ institutional review board.

Surgical Technique

Anterior Portal Using a 30° Arthroscope. A routine arthroscopic examination of the knee joint was performed using the standard AL and AM portals with a distended knee joint at the arthroscopic infusion pump. For the remnant preservation, a straight suture hook (Linvatec, Largo, Florida) with No. 0 polydioxanone (Ethicon, Somerville, New Jersey) was introduced through the AM portal. The sharp tip penetrated the ACL remnant near the proximal end, and the free end of the suture in the intercondylar notch was grasped and brought up to the AM portal. This step was repeated until 3 sutures were placed.

With the knee in 90° of flexion, the microfracture awl was inserted through the AM portal and positioned at the center of the anatomic AM bundle footprint of the ACL femoral origin as closely as possible. If the ACL footprint could not be observed because of the notchplasty or chronic ACL deficiency, a marking hole was made using a microfracture awl at the 5- to 6-mm anterior-distal area of the posterior-proximal margin of the cartilage-bone border of the lateral femoral condyle. Drilling of the AM tunnel was performed with a FlipCutter (Arthrex, Naples, Florida), and the aperture of the tunnel was aligned with the inner margin of the cartilage. The FlipCutter chosen to match the diameter of the graft was used to cut a socket into the femur at the desired depth (Figure 1A). Retro-reaming was then performed at approximately 30 mm of tunnel length until the FlipCutter bottomed out on the drill sleeve (Figure 1B). After the surgeon removed the FlipCutter by pushing it back into the joint and straightening the blade tip, a suture retriever with looped No. 1-0 Maxon (Covidien, Mansfield, Massachusetts) and No. 1-0 Prolene (Ethicon) was inserted through the femoral tunnel for the graft and remnant bundle passage with 3 polydioxanone sutures.

A tibial tunnel was made with a commercial tibial drill guide (Linvatec), with a 50° angle between the aiming arm and the drilling arm, and a guide pin was placed at the inner border of the anterior horn of the lateral meniscus. Reaming of the tibial side was also adjusted according to the graft diameter.14

Posterolateral Portal Using a 70° Arthroscope. The method for preserving the remnant bundle and tibial tunnel formation are similar to the already described method. For the observation of the posterior aspect of the ACL femoral footprint, the arthroscope was inserted through the AM portal and reached the PL compartment through the interval between the ACL and lateral femoral condyle. A PL portal was
made using a trans-illumination technique. The 70° arthroscope was then inserted through the PL portal and advanced to reach the posterior aspect of the intercondylar notch. With this approach, the posterior margin of the ACL femoral footprint could be clearly observed. Under visualization through the PL portal, the ACL tibial drilling guide (Linvatec) or Acufex ACL femoral guide (Smith & Nephew, Andover, Massachusetts) was introduced through the AL portal (Figure 2A). A guide tip was placed at the 4- to 5-mm anterior-distal area of the posterior-proximal margin of the ACL femoral footprint. Drilling of the AM tunnel was performed with a FlipCutter, and the aperture of the tunnel was aligned with the inner margin of the cartilage (Figure 2B).4

**Trans-septal Portal Using a 30° Arthroscope.** A posterior TS portal was established. The first step was to establish a posteromedial portal, and the second step was to establish a PL portal. Finally, an aperture at the posterior septum was made. Compared with the TS portal in other surgeries, only the upper portion of the septum was partially removed (Figure 3A). After establishing the TS portal, the arthroscope was introduced through the posterior septum, and the femoral attachment of the ACL remnant was directly viewed. The method of positioning the femoral tunnel was similar to the already described PL portal technique. A guide tip was placed at the 4- to 5-mm anterior-distal area of the posterior-proximal margin of the prominent ACL femoral footprint, but not on the fibrous extension (Figure 3B).

**Measurement With 3-Dimensional Computed Tomography.** Measurement of the tunnel location with 3-D CT was performed using a technique that was previously developed and described by Forsythe et al.18 Initially, the distal femur model was positioned horizontally in the strictly lateral position, wherein both femoral condyles were superimposed as described by Bernard et al.19 The model was then rotated to a distal view, and the medial femoral condyle was virtually removed at the highest point of the anterior aperture of the intercondylar notch, leaving the lateral femoral condyle. Finally, the model was rotated back to the strictly lateral position, which was confirmed through superimposition of a full distal femur model. Femoral tunnel locations were evaluated with the quadrant method and the anatomic coordinate axes measurement (ACAM) method in the medial wall of the lateral femoral condyle using 3-D reconstructed CT. The accuracy and reproducibility of the femoral tunnel locations were compared among the 3 techniques.

**Quadrant Method.** A rectangular measurement frame was drawn over the mediolateral view of the lateral condyle by placing the superior border at the intercondylar notch roof (X-axis). The inferior border of this rectangle is a line tangent to the distal subchondral bone contour of the condyle. The most shallow and deepest limits of the rectangle were the shallowest and deepest borders of the condyle, respectively. The positions of the tunnels were quantified from the deepest subchondral bone contour of the condyle. The accuracy and reproducibility of the femoral tunnel locations were compared among the 3 techniques.
from the anatomical center (AC) reference location to the actual postoperative tunnel center (TC) location was measured with the following formula: $\Delta XY = \sqrt{(X_{AC} - X_{TC})^2 + (Y_{AC} - Y_{TC})^2}$.

**Anatomic Coordinate Axes Measurements Method.** Tunnel positions were determined in the posterior-to-anterior and proximal-to-distal directions, parallel to the respective anatomical axes. More specifically, posterior-to-anterior positions were calculated as percentages of the distance from the line running through the posterior border of the medial wall of the lateral condyle to the line running through the most anterior point of the notch. Proximal-to-distal positions were calculated as percentages of the distance from the line running through the proximal border of the notch to the line running through the distal point of the notch roof (Figure 5).18 The Euclidean distance was calculated by the already described method. The ACL center based on the value of the AM bundle center by Forsythe et al19 ($X_{AC}$: 23.1%±6.1%, $Y_{AC}$: 15.3%±4.8%) was used: $\Delta XY = \sqrt{(X_{AC} - X_{TC})^2 + (Y_{AC} - Y_{TC})^2}$.

**Statistical Analysis**

PASW Statistics 18 statistical software (IBM, Armonk, New York) was used for statistical analysis. The continuous variables measuring the distance from the mean femoral tunnel aperture center to the actual tunnel position were normally distributed (by Kolmogorov-Smirnov test). The accuracy was calculated using the mean of the Euclidean distance. The differences in distance between the 3 ACL reconstruction techniques and those among the other continuous variables were analyzed with 1-way analysis of variance. The Kruskal-Wallis test was used to compare the categorical ordinal data of the 3 groups. Scheffe’s post hoc test was used to determine the significant differences between the groups.

Reproducibility of the procedure was defined by means of the standard deviation (SD) of the absolute differences.20 All measurements were performed by 2 investigators (Y.S.L., T.S.K.), and 2 repeat measurements were performed by 2 investigators (Y .S.L., T.S.K.), and 2 repeat measurements were performed by 2 investigators. The reproducibility of the total tunnel positioning procedure within and between investigators was also determined, calculating the absolute differences (% accuracy) and SDs (% reproducibility) between the positions of the tunnel marks of both measurements by the surgeon. Intra- and interobserver agreement for the signal intensity was evaluated using the kappa correlation coefficient, with 95% confidence interval (CI). $P$ values less than .05 were considered statistically significant.

**RESULTS**

**Accuracy of the Tunnel Position**

The TS group was the closest to the anatomical center with both measurement methods (Figures 5-6). Using the quadrant method, average distances from the tunnel center to the anatomical center were 12.03%±4.70% (range, 2.87%-19.43%), 13.31%±4.50% (range, 4.49%-21.91%), and 7.15%±1.96% (range, 3.13%-10.47%) in the A, PL, and TS group, respectively. The accuracy of the tunnel position was the highest in the TS group (A group vs TS group: $P<.001$; PL group vs TS group: $P<.001$) by the quadrant method.

Using the ACAM method, average distance from the tunnel center to the anatomical center was 14.02%±5.64% (range, 1.73%-24.42%), 11.01%±5.84% (range, 1.71%-21.72%), and 7.10%±2.70% (range, 2.59%-12.58%) in the A, PL, and TS group, respectively. The accuracy of the tunnel position was highest in the TS group (A group vs TS group: $P<.001$; PL group vs TS group: $P<.001$).

**Reproducibility of the Tunnel Position**

The reproducibility of the femoral tunnel position in the TS group was the highest, followed by the PL group (SD with the quadrant method: A group, 4.68%; PL group, 3.75%; TS group, 1.34%. SD with the ACAM method: A group, 5.18%; PL group, 3.85%; TS group, 1.92%). The femoral tunnel locations of the TS group were more compactly distributed as compared with those of the A and PL groups.
Location of the Tunnel Center

Mean locations of the femoral tunnel center are summarized in the Table and Figure 6. Using the quadrant method, the femoral tunnel location of the TS group was lower and shallower than that of the A and PL group (each $P<.001$); the location was deeper in the PL group than the A group ($P=.027$). Using the ACAM method, the femoral tunnel location was more distal in the TS group than that in the PL group ($P<.001$). There was no significant difference in the remaining tunnel positions between the groups.

Discussion

In the current study, the femoral tunnel location was evaluated using 3 different viewing techniques in remnant-preserving, single-bundle, outside-in ACL reconstruction. The accuracy and reproducibility of the techniques were compared using 3-D CT. The principal finding of this study was that the femoral tunnel location viewed through the TS portal was the most accurate and reproducible technique. The tunnel position through the PL portal was more reproducible than through the A portal; however, there was no significant difference in the accuracy of the femoral tunnel location between these groups.

Greater accuracy in both the PL and TS groups was initially expected. However, the TS group showed a significantly higher accuracy than the PL group, and there was no significant difference between the A and PL groups. These findings may be explained by the different target points of the 2 techniques.

Femoral insertion of the ACL generally has 2 unique modes of insertion to the bone: direct insertion and indirect insertion. Direct insertion allows for a gradual force distribution and differential tensioning of all inserting components into the insertion site. However, the indirect type of insertion has a significantly simpler ultrastructure, extending to a line comprising the posterior cortical border of the femoral diaphysis. Under visualization through the PL portal with a 70° arthroscope, the posterior margin of the ACL femoral footprint can be clearly observed, but it may mostly show an indirect insertion. In contrast, the direct insertion of the ACL femoral footprint can be observed under visualization through the TS portal because a direct view is possible (Figure 4). Furthermore, in the TS group, the femoral tunnel position is closer to the anatomical center. For the anterior portal, the arthroscope was placed in the AL portal, and the ACL guide was inserted in the AM portal because there was a limitation in the ACL guide angle for the positioning at the posterior side and cartilage damage could occur with the AL insertion of the ACL guide. However, visualization would be difficult using this technique. Another option would be viewing the footprint from a low AM portal and marking the tunnel through an accessory AM portal.

Greater reproducibility in both the PL and TS groups would also be expected. A
possible explanation for the lack of precision in the A group is the presence of some obstacles while placing the ACL femoral guide on the anatomical footprints. Under visualization through the PL portal using a 70° arthroscope and through the TS portal, the anatomic femoral tunnel could be made with minimal damage to the remnant bundle and without interfering with the vision of the femoral footprint. The current study confirmed the validity of the methods of creating the femoral tunnel viewed through the PL and TS portals. Many authors believe that improper femoral tunnel placement is a common reason for ACL reconstruction failure. Favorable clinical outcomes could be impaired by a nonanatomic graft placement. Arthroscopically useful osseous landmarks and soft tissue landmarks are usually used to create a femoral tunnel as close as possible to the anatomic center of the native ACL footprint. However, the lateral intercondylar ridge has large positional and dimensional variations. A systematic review showed that the mean distance from the posterior edge of the footprint as a whole to the posterior border of the articular cartilage margin is 2.5 mm. Although the review had some controversial points, the posterior articular margin can be used as a landmark for the femoral footprint.

In the outside-in technique, one could place the guide pin near the center of the ACL footprint with a visible remnant, bony posterior articular cartilage, or other landmark. In the current study, the guide tip was placed at the 4- to 5-mm anterior-distal area of the posterior-proximal margin of the ACL femoral footprint. This placement was close to the AM bundle, and the authors preferred placement of the femoral tunnel close to the AM bundle rather than close to the native ACL femoral footprint center.

The current study has some limitations. First, only the outside-in technique was considered; therefore, the comparisons are only valid for the outside-in technique. Second, the surgeries were performed by 2 surgeons. Therefore, there is the possibility for selection and performance biases. Third, the study’s results were compared using previously published data on the center of the AM bundle. Fourth, the efficacy of these techniques regarding remnant preservation was not evaluated. Fifth, the posterior portal is technically demanding, and there is a possibility of the posterior neurovascular injury.

CONCLUSION
The accuracy and reproducibility of the femoral tunnel location may be improved with a TS portal viewing using a 30° arthroscope, and anterior and PL portal viewing using a 70° arthroscope showed no difference.

REFERENCES


