

# Three-Dimensional Reconstruction Computed Tomography Evaluation of the Tunnel Location and Angle in Anatomic Single-Bundle Anterior Cruciate Ligament Reconstruction: A Comparison of the Anteromedial Portal and Outside-in Techniques

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**Purpose:** The purpose of this study was to compare the geometry and position of the femoral tunnel between the anteromedial portal (AMP) and outside-in (OI) techniques after anatomic single-bundle anterior cruciate ligament (ACL) reconstruction.

**Materials and Methods:** We evaluated 82 patients undergoing single-bundle ACL reconstruction with hamstring autografts using either the AMP (n=40) or OI (n=42) technique. The locations of the tunnel apertures were assessed by postoperative 3-dimensional computed tomography imaging. The femoral graft bending angle, femoral tunnel aperture shape, femoral tunnel length, and posterior wall breakage were also measured.

**Results:** The mean femoral tunnel position parallel to the Blumensaat line was more caudally positioned in the AMP group than in the OI group ( $p=0.025$ ). The mean femoral graft angle in the OI group ( $99.6^\circ \pm 7.1^\circ$ ) was significantly more acute than that of the AMP group ( $108.9^\circ \pm 10.2^\circ$ ,  $p<0.001$ ). The mean height/width ratio of the AMP group ( $1.21 \pm 0.20$ ) was significantly more ellipsoidal than that of the OI group ( $1.07 \pm 0.09$ ,  $p<0.001$ ).

**Conclusions:** The mean femoral tunnel position was significantly shallower in the AMP technique than in the OI technique. The OI technique might be more disadvantageous than the AMP technique in terms of the more acute bending angle.

**Keywords:** Knee, Anterior cruciate ligament, Reconstruction, Three-dimensional computed tomography, Anteromedial portal technique, Outside-in technique

## Introduction

The conventional transtibial technique has been criticized by many authors because of the difficulty associated with anatomic

femoral tunnel placement in anterior cruciate ligament (ACL) reconstruction. Therefore, tibial tunnel-independent drilling has attracted interest in recent years for anatomic ACL reconstruction<sup>1-3</sup>. Among various tibial tunnel-independent drilling techniques, the anteromedial portal (AMP) and outside-in (OI) techniques appear suitable for centering the graft within the ACL femoral insertion<sup>1,4,5</sup>. However, these techniques also have disadvantages. To reduce the risk of a short femoral tunnel and damage to the posterolateral (PL) structures, the AMP technique requires deep knee flexion, which results in articular cartilage damage to the medial femoral condyle and a limited arthroscopic view<sup>6,7</sup>. With the OI technique, the disadvantages include the need for a lateral incision on the distal aspect of the thigh and the risk of graft abrasion at the rough intra-articular edges of the tunnel<sup>1,8</sup>.

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Several reports have described the use of computed tomography (CT) in postoperative evaluation of the reconstructed ACL. More recently, three-dimensional reconstructed computed tomography (3D CT) images have been used to evaluate tunnel positioning and length with high intra- and interobserver reliabilities<sup>9-11</sup>. An anatomic angle and placement of the ACL graft may provide improved biomechanical stability and reproduce the normal kinematics of the native ACL in all planes of motion. Therefore, the purpose of this study was to compare the geometry and position of the femoral tunnel using postoperative 3D CT between the AMP and OI techniques after anatomic single-bundle ACL reconstruction. We hypothesized that 1) both techniques would yield an anatomical tunnel position with no significant differences between techniques, and 2) the OI technique would result in a more acute femoral graft bending angle than the AMP technique.

## Materials and Methods

### 1. Patient Selection and Study Design

From July 2011 to March 2014, 124 patients underwent arthroscopic ACL reconstruction with preservation of the remnant bundle using hamstring tendon autografts. The ACL reconstruction was performed by a single surgeon using one of the two techniques for femoral tunnel placement. Patients operated from July 2011 to June 2013 underwent ACL reconstruction using the AMP technique. From July 2013 to March 2014, the author performed ACL reconstruction with the OI technique. Of the 124 patients, 38 patients were excluded due to fractures, revisional ACL reconstruction, combined meniscal transplantation, or multiple ligament reconstruction. Thus, the study group included 82 consecutive patients undergoing single-bundle ACL reconstruction with either the AMP (n=40) or OI (n=42) technique. The two groups did not differ significantly in demographics (Table 1). All patients signed an informed consent form, and the study protocol was reviewed and approved by our Institutional Review Board.

### 2. Surgical Technique

An arthroscopic examination was performed through the anterolateral visualization portal and anteromedial (AM) working portal. After the diagnostic arthroscopy, all meniscal injuries were treated before ACL reconstruction. For all hamstring autografts, the semitendinosus and gracilis tendons, which had been harvested by using a tendon stripper, were prepared as a four-strand double-looped hamstring autograft. The remaining fibers of the ACL remnant were preserved as much as possible throughout

the entire procedure. The tibial tunnel was made by a tibial drill guide (Arthrex, Naples, FL, USA) with a 50° angle. The following intra-articular landmarks were used for tibial tunnel placement: 2–3 mm anterior to the inner border of the anterior horn of the lateral meniscus, just lateral to the medial eminence, and the AM aspect of the native ACL footprint.

#### 1) Anteromedial portal technique

In the AMP technique, a low AMP is required for femoral tunnel placement. Thus, a low AMP was created just above the anterior horn of the medial meniscus. The over-the-top offset guide was introduced through the low AMP with the knee in maximum flexion between 120° and 130°. The femoral tunnel was then prepared at the over-the-top position (10 o'clock position for a right knee and 2 o'clock position for a left knee) to leave a 1- to 2-mm back wall. The tunnel was positioned as close as possible to the center of the anatomic AM bundle footprint of the ACL femoral origin. The tunnel was over-drilled with a rigid cannulated reamer and dilator corresponding to the measured diameter of the graft. The Rigidfix guide frame (DePuy Mitek, Raynham, MA, USA) was inserted into the femoral tunnel to a depth of 30 mm through the low AMP with the window of the guide frame jig facing just inferior to the lateral femoral epicondyle. The sleeve-trocar assembly was inserted through the jig; the guide frame was removed and two sleeves were positioned. The guidewires were inserted through the two sleeves, and the central position of the guidewires within the femoral tunnel was confirmed with an arthroscope, which was inserted through the low AMP. The hamstring grafts were fixed within the femoral tunnel using a bioabsorbable Rigidfix cross pin (length, 42 mm; diam-

Table 1. Demographic of Patients

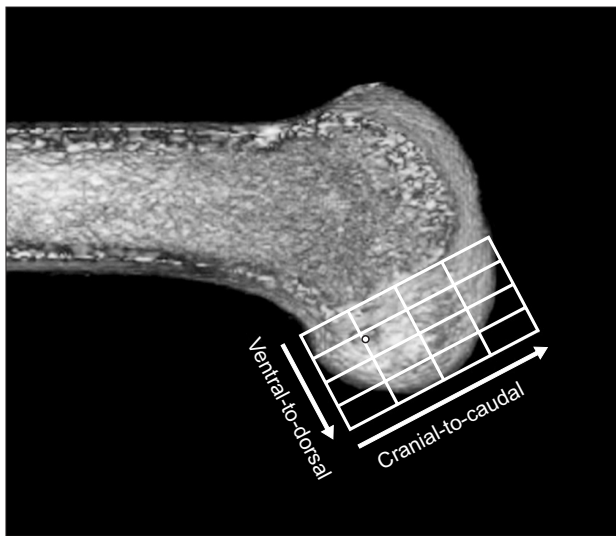
Parameter	AMP group (n=40)	OI group (n=42)	p-value
Age (yr)	29.2±9.2	26.4±7.0	0.190
Male/female	35/5	36/6	1.000
Time to surgery from injury (mo)	16.1±41.6	18.8±48.3	0.452
Combined intra-articular surgery			0.800
Meniscectomy	10	8	
Meniscal repair	20	23	
Chondroplasty	1	1	
Diameter of the hamstring graft (mm)	7.9±0.5	7.8±0.6	0.735

Values are presented as mean±standard deviation or number.  
AMP: anteromedial portal, OI: outside-in.

eter, 3.3 mm). After the graft was secured on the femoral side, the tibial side was fixed with a bioabsorbable interference screw and a staple, or post-tied to a 4.5-mm cortical screw.

## 2) Outside-in technique

For the OI technique, the method of positioning the tibial tunnel was identical to that of the AMP technique described above. In the OI technique, the femoral tunnel was prepared with a PL portal using a 70° arthroscope. The arthroscope was inserted through the AMP and reached the PL compartment through the space between the ACL and the lateral femoral condyle. By use of a transillumination technique, a PL portal was established. For observation of the posterior aspect of the ACL femoral footprint, the 70° arthroscope was inserted through the PL portal and advanced to 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 PCL femoral guide (Arthrex), with a 70° to 75° angle was inserted through the AM portal. A 2- to 3-cm longitudinal skin incision was made just posterior to the lateral epicondyle of the femur. The iliotibial band was split longitudinally. The guide pin was inserted from the distal femoral surface to the 4- to 5-mm anterior distal area of the posterior-proximal margin of the ACL femoral footprint, which was the center of the anatomic AM bundle in the AMP technique. Drilling of the femoral tunnel was performed by a FlipCutter (Arthrex) with retro-reaming about



**Fig. 1.** Three-dimensional computed tomography of the lateral femoral side. The locations of transtibial and tibial-independent femoral tunnels were quantified and presented as the percentage distance from the deepest subchondral contour and the intercondylar notch roof to the center of the tunnel.

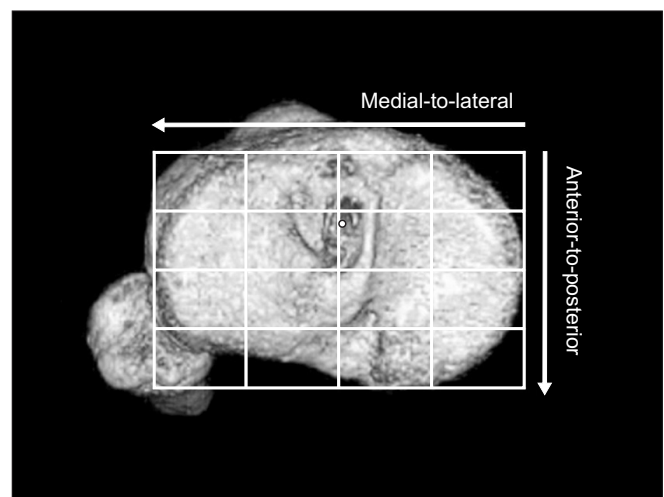
25 mm of the tunnel length corresponding to the measured diameter of the graft. The TightRope device (Arthrex) was used for femoral fixation. The TightRope button was pulled through the tibia and out the femur until it exited the lateral cortex, and the graft was advanced by tensioning on the TightRope shortening strands. Finally, the tibial side was fixed with the same method.

## 3. Computed Tomography Protocol and Imaging Analysis

The locations of the tibial and femoral tunnel apertures were assessed by immediate postoperative 3D CT (Brilliance 64 Channel Multi Detector CT; Philips, Petah Tikva, Israel) imaging with OsiriX imaging software (Pixmeo, Bernex, Switzerland). The knee was placed in full extension. The collimation was 16×0.625 mm. The tube parameters were 500 kVp and 140 mA. The acquisition matrix was 512×512. The field of view was 140 mm with a slice thickness of 2 mm. After extraction of Digital Imaging and Communications in Medicine (DICOM) data from the picture archiving and communication system, it was imported into PiViewSTAR ver. 5.0.9.98 (Infinit, Seoul, Korea).

### 1) OsiriX

To measure the femoral tunnel position, the DICOM data were imported to OsiriX to create a 3D model of the distal femur. Initially, the distal femoral model was positioned horizontally in the “strict lateral position”, where the femoral condyles were superimposed, as described by Bernard and Hertel<sup>12)</sup> for the lateral radiograph of the knee. 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



**Fig. 2.** Top view of the proximal tibia. The locations of tibial tunnels were measured from the anterior border (medial to lateral) and medial border (anterior to posterior).

notch, leaving the lateral femoral condyle. Finally, the model was rotated back to the strict lateral position. The location of the tunnel was quantified and presented as the percentage distance from the deepest subchondral contour and the intercondylar notch roof to the center of the tunnel (Fig. 1). For the tibial side, a true superior tibial plateau view was obtained (Fig. 2).

After 3D CT reconstruction images were created, 2D quadrant method analysis was used. The central femoral footprint coordinates were calculated by using the ventral to dorsal (VDa) and cranial to caudal (CCa) positions (Fig. 1). The tibial study followed the criteria of Takeda et al.<sup>3)</sup> The anterior-posterior axis position was calculated as the percentage of the distance from the anterior border of the tibial plateau to the aperture tibial center, while the medial-lateral axis position was calculated as the percentage of the distance from the medial border of the tibial plateau to the tibial aperture center (Fig. 2). The femoral graft bending angle plane, in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of the intra-articular aperture of the tibial tunnel were viewed together, was selected to measure the femoral graft bending angle (Fig. 3). To measure the femoral tunnel length, the plane in which the entire length of the femoral tunnel showed maximum width was selected with the OsiriX imaging software. We measured the length and shape of the femoral tunnel aperture (height/width ratio) on a cross-sectional plane parallel to the medial wall of the lateral femoral condyle near the femoral tunnel aperture. After a cross section of the femoral tunnel aperture was obtained, the



Fig. 3. The femoral graft bending angle plane, in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of the intra-articular aperture of the tibial tunnel were viewed together and selected to measure the femoral graft bending angle.

height and width of the femoral tunnel aperture were measured (Fig. 4). Posterior wall breakage of the femoral tunnel was also assessed. All CT studies were reviewed by two orthopedic surgeons blinded to the arthroscopic findings, clinical history, and initial CT interpretations. The two authors performed all of the measurements twice with an interval of one week.

#### 4. Statistical Analysis

A two-sample *t*-test and a Mann-Whitney *U*-test, with or without the Bonferroni correction, were used to compare the two groups. All statistical analyses were performed with SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA). The reliability of measurements was assessed by examining the inter- and intraobserver reliabilities using the intraclass correlation coefficient (ICC), which quantifies the proportion of the variance of the rating due to variability between measurements<sup>13)</sup>. The ICC was interpreted as poor when it was less than 0.4; marginal when it was greater than or equal to 0.4 but less than 0.75; and good when it was greater than 0.75. *p*-values <0.05 were considered statistically significant.

#### Results

The AMP and OI techniques did not differ significantly in terms of the femoral tunnel position perpendicular to the Blumensaat line. However, the mean femoral tunnel position parallel to the Blumensaat line was significantly more caudal in the AMP group than in the OI group ( $p=0.025$ ) (Fig. 5). The two groups did not differ significantly in terms of the tibial tunnel position.

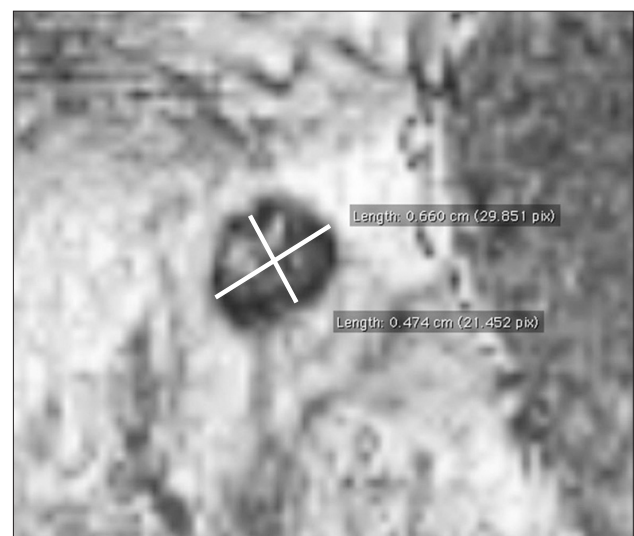


Fig. 4. The femoral tunnel aperture shape (height/width ratio) was assessed on a cross-sectional plane parallel to the medial wall of the lateral femoral condyle near the femoral tunnel aperture.



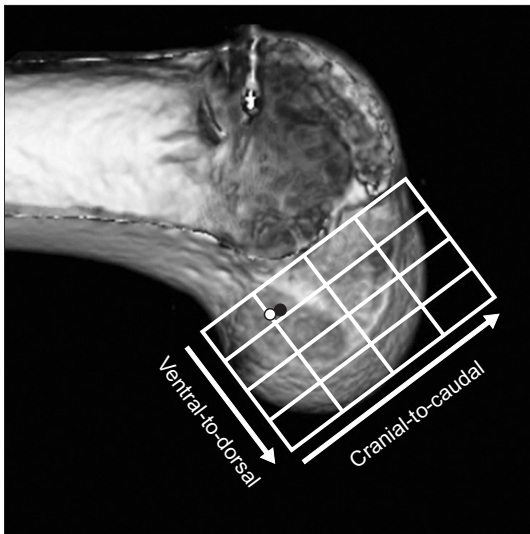


Fig. 5. Femoral tunnel positions in the anteromedial portal (AMP, black point) and outside-in (OI, white point) techniques. The mean femoral tunnel position parallel to the Blumensaat line was significantly more caudal in the AMP group ( $28.30 \pm 5.40$ ) than in the OI group ( $25.08 \pm 7.17$ ).

The mean femoral tunnel length did not differ between the AMP ( $36.1 \pm 0.34$  mm) and OI groups ( $35.6 \pm 0.37$  mm,  $p=0.548$ ). The number of cases with a femoral tunnel length of less than 30 mm was 0 in the AMP group and 2 (4.8%) in the OI group ( $p=0.259$ ). The mean femoral graft angle was significantly more acute in the OI group ( $99.4^\circ \pm 7.1^\circ$ ) than in the AMP group ( $108.6^\circ \pm 10.2^\circ$ ,  $p<0.001$ ). The mean height/width ratio in the AMP group ( $1.21 \pm 0.21$ ) was significantly more ellipsoidal than in the OI group ( $1.07 \pm 0.09$ ) (Table 2). Posterior wall breakage was detected in 3 cases (7.5%), all in the AMP group.

The ICC for intraobserver (0.76 and 0.95) and interobserver (0.68 and 0.91) reliabilities ranged from 0.68 to 0.95. The ICC was greater than 0.8 for the tunnel position but slightly lower for the height/width ratio (0.68 and 0.82).

## Discussion

The most important findings of this study were that the OI technique resulted in a more acute femoral graft bending angle than the AMP technique, and the aperture shape of the femoral tunnel in the AMP group was significantly more ellipsoidal than in the OI group. Our study indicates that the OI technique with a PL portal is comparable to the AMP technique in terms of the tunnel position and femoral tunnel length.

Recent biomechanical studies have shown that anatomic single-bundle ACL reconstruction can restore a similar degree of kinematic control of knee rotation and anterior translation as double-

Table 2. Radiologic Parameters of the Femoral and Tibial Tunnels

Parameter	AMP group (n=40)	OI group (n=42)	p-value
<b>Tibia</b>			
Medial-lateral (%)	$44.60 \pm 3.14$	$44.47 \pm 2.60$	0.841
Anterior-posterior (%)	$35.36 \pm 7.26$	$35.23 \pm 5.51$	0.926
Tibial tunnel length (mm)	$3.60 \pm 0.45$	$3.50 \pm 0.33$	0.249
<b>Femur</b>			
Cranial to caudal (%)	$28.30 \pm 5.40$	$25.08 \pm 7.17$	0.025
Ventral to dorsal (%)	$20.71 \pm 9.28$	$18.77 \pm 11.39$	0.400
Femoral tunnel length (mm)	$36.1 \pm 0.34$	$35.6 \pm 0.37$	0.548
Tunnel height/width ratio	$1.21 \pm 0.21$	$1.07 \pm 0.09$	<0.001
<b>Graft angle</b>			
Bending angle ( $^\circ$ )	$108.6 \pm 10.2$	$99.4 \pm 7.1$	<0.001

Values are presented as mean  $\pm$  standard deviation.

AMP: anteromedial portal, OI: outside-in.

bundle reconstruction<sup>14,15</sup>. Various techniques for anatomic single-bundle ACL reconstruction have been described. One common technique is center-to-center anatomic reconstruction, where the tunnels are placed at the center of the femoral and tibial insertion sites<sup>2,5,16</sup>. On the other hand, tunnels positioned in the center of the tibial insertion footprint and the AM portion of the femoral footprint (center to AM construct) also resulted in excellent restoration of anterior translation and rotational stability in single-bundle ACL reconstruction<sup>17</sup>. In our study, anatomic single-bundle reconstruction with either technique was performed with the center to AM construct. Comparing our coordinate findings with those from a study of double-bundle ACL insertion in 36 cadaveric knees, the means of the center points of the AM bundle on the femoral side (17.8% in VDa and 25.9% in CCa positions) were very similar to our results for the femoral tunnel position<sup>18</sup>. In the current study, the AMP and OI techniques both led to the creation of femoral tunnels that were anatomically positioned at the center of the AM bundle of the ACL footprint.

Recently, the OI technique has gained popularity with the introduction of retractable retrograde cutting drills (FlipCutter) and modification of the technique<sup>4,19,20</sup>. Typically, the anterior side of the ACL footprint is relatively easily observed through routine anterior (AM and anterolateral) portals. However, viewing the posterior side of the ACL footprint is difficult with these portals, especially during remnant-preserving ACL reconstruction. Therefore, the PL portal with a 70° scope could be effective to observe the posterior side of the ACL femoral footprint<sup>4</sup>. The OI femoral tunnel procedure appears to be a more reliable and

precise method for achieving anatomic ACL reconstruction, and it also helps preserve the remnant bundle.

Several studies have investigated the position of the femoral tunnel in patients who underwent conventional transtibial and anatomic ACL reconstruction<sup>15,21-23</sup>. The transtibial technique appears to cause a graft that is oriented anteriorly with limited ability to restore the oblique orientation of the ACL or normal knee stability<sup>2,9</sup>. A few studies have compared the femoral tunnel position between the AMP and OI techniques using 3D CT after anatomic ACL reconstruction<sup>24,25</sup>. Other studies that have used an anatomic coordinate axis method have found no significant difference in the position of the femoral tunnel aperture between the AMP and OI techniques<sup>2,9</sup>. In contrast, Park et al.<sup>25</sup> showed that the mean femoral tunnel position is shallower with the OI technique than with the AMP technique. They suggested that the guide tip of the Flipcutter impacting the medial wall of the lateral femoral condyle during OI femoral drilling causes a mismatch between the aimed center and the drilling center. Although the OI technique in the present study involved a similar guide system with a Flipcutter, the results differed from those of Park et al.<sup>25</sup>. We found that the mean femoral tunnel position parallel to the Blumensaat line was more caudal in the AMP group than in the OI group. This difference may have occurred because the femoral tunnel was prepared with a PL portal using a 70° arthroscope in our study. Nevertheless, both techniques produced femoral tunnels that were anatomically positioned at the center of the AM bundle of the ACL footprint.

Previous studies have reported that a short length of the femoral tunnel is one of the disadvantages of the AMP technique<sup>1,6,20</sup>. Lubowitz and Konicek<sup>26</sup> showed that the mean femoral tunnel length was greater with the OI technique than with the AMP technique after single-bundle ACL reconstruction. Park et al.<sup>25</sup> also reported that the mean femoral tunnel length was significantly longer with the OI technique than with the AMP technique. However, Chang et al.<sup>1</sup> found no significant difference in femoral tunnel length between the two techniques. We also found no difference between the AMP and OI techniques in terms of the average femoral tunnel length (AMP, 36.1±0.34 mm; OI, 35.6±0.37 mm;  $p=0.548$ ), and both techniques showed only a small amount of variation in terms of the standard deviation. Furthermore, only two cases, both from the OI group, had a femoral tunnel length of less than 30 mm. To prevent a short femoral tunnel length with the OI technique, we began the femoral tunnel drilling proximal and posterior to the lateral epicondyle with the knee in 90° of flexion. With the AMP technique, we created the femoral tunnels from the accessory AMP in a maximally flexed

knee position. Therefore, our technical guide for both techniques would result in a femoral tunnel length of more than 30 mm to ensure adequate graft length in the tunnel.

In our study, the OI group (99.4°) had a significantly more acute femoral bending angle than the AMP group (108.6°). This disadvantage with the OI technique has been identified in previous studies<sup>20,25</sup>. Kim et al.<sup>8</sup> reported that the mean AM and PL femoral graft bending angles were more acute with the OI technique than with the AMP technique after anatomic double-bundle ACL reconstruction. The more horizontal femoral tunnel angulation with the OI technique may result in a more acute femoral graft bending angle. This acute graft bending angle might be caused by the greater abrasion of the ACL graft at the intraarticular edges of the femoral tunnel when the graft is acutely bent and stretched. Lubowitz et al.<sup>19</sup> investigated the femoral OI drilling technique with respect to anatomic restoration of the morphologic length, width, area, and angular orientation of the ACL femoral footprint. They concluded that a guide pin entrance angle of 60° to a line perpendicular to the femoral anatomic axis, combined with a guide pin entrance angle of 20° to the transepicondylar axis, results in optimal reconstruction of the normal human anatomic ACL femoral footprint length, width, area, and angular orientation. Abrasive forces can be prevented by following their technical guide and by rasping in the femoral tunnel aperture site.

A number of studies have shown that the AMP technique can lead to posterior-wall blowout and potential damage to the posterior articular cartilage<sup>7,27,28</sup>. Gadikota et al.<sup>29</sup> suggested the incidence of a posterior femoral tunnel exit relative to the lateral epicondyle is higher with the AMP technique than with the OI and transtibial techniques. Chang et al.<sup>1</sup> reported that femoral tunnel-related complications were only found after ACL reconstruction using the AMP technique. In our study, the AMP group had a shallower femoral tunnel than the OI group, and all three cases of posterior wall breakage occurred in the AMP group. In this respect, the OI technique might have an advantage over the AMP technique.

This study had some limitations. First, this was a retrospective study without randomization or an assessment of clinical associations, such as the relationship between the technique and stability and clinical scoring. Prospective studies that assess the relationship between different techniques and the clinical outcomes over a long-term follow-up are needed. Second, we positioned the femoral tunnel close to the footprint center of the AM bundle rather than at the footprint center between the AM and PL bundles. Further studies are needed to demonstrate which femoral tunnel position leads to better biomechanics and clinical

cal outcomes after anatomic single-bundle reconstruction. Finally, both techniques were performed in different time periods. Therefore, the surgeon's technical familiarity could have played a role. However, the surgeon was experienced in both techniques and attempted to standardize the protocols to minimize any bias induced by the fact that all operations were performed by a single surgeon.

## Conclusions

The postoperative 3D CT showed a significantly shallower femoral tunnel after single-bundle anatomic ACL reconstruction performed using the AMP technique than the OI technique. The AMP technique resulted in a more ellipsoidal femoral tunnel with a greater risk of posterior wall breakage than the OI technique. The OI technique might be more disadvantageous than the AMP technique in terms of the more acute femoral graft bending angle.

## Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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