



# Femoral tunnel placement in single-bundle, remnant-preserving anterior cruciate ligament reconstruction using a posterior trans-septal portal



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## ABSTRACT

**Background:** Anatomic tunnel formation and remnant preservation are valuable aspects of anterior cruciate ligament (ACL) reconstruction. However, anatomic landmarks are difficult to observe during remnant-preserving ACL reconstruction (ACLR). The aims of this study were to evaluate the: 1) femoral tunnel location created with guidance from the apex of the deep cartilage margin (ADC) and footprint compared to anatomical reference; and 2) relationship between femoral tunnel location and outcomes of ACLR.

**Methods:** A total of 109 ACLR patients without revision ACLR, multi-ligament reconstruction, peri-knee fracture, and osteotomy were included. The femoral tunnel was formed at the most proximal corner of the femoral footprint using a posterior trans-septal portal as the viewing portal. The distance from the tunnel center to ADC was measured by computed tomography and arthroscopy. The two measurements were then compared. Finally, femoral tunnel location was compared to the anatomic reference and correlated with the outcomes.

**Results:** The average distance from ADC to the femoral tunnel center was  $7.0 \pm 1.4$  mm as measured by arthroscopy, and  $7.2 \pm 2.0$  mm using three-dimensional computed tomography. There was no statistically significant difference between the two methods ( $P = 0.420$ ). Clinical and stability outcomes were significantly improved postoperatively. Clinical outcome was not related to femoral tunnel location; however, stability outcome was related to femoral tunnel location: the more proximally located femoral tunnels showed better stability.

**Conclusion:** The ADC can be a possible landmark in remnant-preserving ACLR using a trans-septal portal. A more proximal femoral tunnel, which is located at the proximal corner of the ACL remnant, can provide stability advantage during remnant-preserving ACLR.

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## 1. Introduction

Many studies have reported that anatomic anterior cruciate ligament (ACL) reconstruction is a favorable approach for superior clinical outcomes and better kinematics [1–5]. The most important point during anatomic ACL reconstruction is femoral and tibial tunnel formation at the anatomical site; the femoral tunnel is assumed to be more important [6]. Surgeons use several land-

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marks such as the lateral intercondylar ridge, lateral bifurcate ridge, and cartilage margin for anatomical femoral tunnel formation [7–9]. However, these landmarks are difficult to check without remnant sacrificing. Nevertheless, remnant preservation has many advantages for proprioceptive function [10–12], stability preservation [13,14], and graft healing [15–18]. Therefore, many efforts are made to preserve remnant ACL.

For anatomic remnant-preserving ACL reconstruction, femoral footprints are not easily checked using anterior arthroscopy and few landmarks are introduced. Therefore, there is increased possibility of femoral tunnel malposition [19]. Some recent studies were conducted to detect the relationship between the landmarks and anatomic femoral tunnel in remnant-preserving ACL reconstruction. It was found that the apex of the deep cartilage margin (ADC) corresponds to the deep and high corner of the cartilage, and this could be a useful landmark to help in identifying femoral tunnel placement with remnant preservation [8,20]. Moreover, checking this landmark with remnant preservation was found to be more effective during posterior arthroscopic viewing [21,22].

Posterior arthroscopy has the important advantage of remnant preservation in native ACL footprint observation [21]. The trans-septal (TS) portal through the posterior septum, from the posteromedial to the posterolateral compartment or vice versa, has particularly high accuracy and reproducibility, and surgeons can make accurate femoral tunnels where they are intended to be [21,22]. Using this technique, ADC can be the sole landmark to be seen with remnant preservation and the ACL femoral footprint can also be easily seen. Therefore, the relationship between this landmark and ACL femoral footprint could provide important information for anatomic remnant-preserving ACL reconstruction.

Another important consideration when performing ACL reconstruction is stress pattern of the graft in the femoral tunnel aperture compared to the native ACL. The stress distribution of graft in the femoral tunnel aperture is known to be higher in the distal part rather than in the anterior, proximal, or posterior parts [23,24]. Therefore, it has been suggested that the femoral tunnel should be located proximal to the anatomical footprint [23].

Using this information, the current institution has been performing ACL reconstruction using the TS portal with remnant preservation. The femoral tunnel is at the proximal corner of the direct femoral fiber, and it was made reference to ADC that is at the same level in the anterior–posterior direction at 90 degrees flexed knee [8].

The aims of this study were to evaluate the: 1) location of the femoral tunnel created under guidance of the ADC and femoral footprint compared to anatomical reference data, and 2) relationship between femoral tunnel location and outcomes of ACL reconstruction. It was hypothesized that: 1) ADC would be a good landmark for remnant-preserving ACL reconstruction; and 2) proximal position of the femoral tunnel would produce better stability compared to a tunnel that was made in the footprint center.

## 2. Materials and methods

### 2.1. Patient demographics

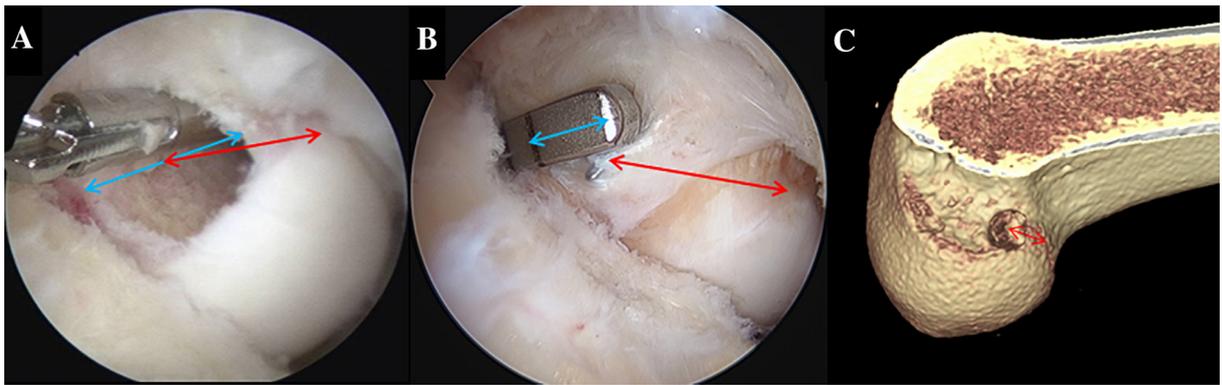
Between April 2014 and December 2015, 138 ACL reconstructions were performed. The femoral tunnel location was checked using an immediate postoperative computed tomography (CT) scan. Total ACL rupture patients were included. Exclusion criteria were: 1) revision ACL reconstruction (14 patients); 2) multi-ligament reconstruction (nine patients); 3) combined peri-knee fracture or osteotomy (three patients); 4) lost to follow-up (three patients). A total of 109 patients was finally included in this study. However, among them, the distance was able to be measured from arthroscopic viewing in 68 patients. Therefore, 68 patients were analyzed by arthroscopic viewing and three-dimensional (3-D) CT, 41 patients were analyzed using 3-D CT only.

There were 89 male and 20 female patients. The mean age of patients at the time of surgery was  $30.5 \pm 12.1$  years (range, 14–59). Fifty-seven right and 52 left knees were operated. The average height of patients was  $171.0 \pm 8.2$  cm (range, 150–192) and the average weight was  $73.4 \pm 11.3$  kg (range, 47–108). Hamstring autograft was used in 90 patients and allograft in 19 patients. The average follow-up period was  $24 \pm 6$  months (range, 1–3). The protocol was approved by the institutional Review Board (B-1408-264-114).

### 2.2. Tunnel position measurement

The ADC and ACL femoral footprints were used as landmarks in ACL reconstruction. ADC was well-visualized by arthroscope, but not well-defined by 3-D CT. Therefore, ADC was considered to be the point at the apex of the proximal curvature of the femoral articular margin by 3-D CT and was compared to the distance from ADC to femoral tunnel center by arthroscope [25]. By arthroscope, these values were measured indirectly by using an ACL femoral guide or tunnel diameter. In 3-D CT, these values were measured directly by using 3-D reconstructed CT images (Figure 1).

These values were compared with those of previously studied anatomic ACL footprints [26]. The quadrant method, which was previously developed and described by Forsythe et al., was used to compare location of the femoral tunnel with anatomic ACL footprint [27]. Femoral tunnel location was evaluated in the medial wall of the lateral femoral condyle using 3-D CT (Figure 2). 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 was a line tangent to the distal subchondral bone contour of the condyle. The shallowest 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 contour to the tunnel. The *y*-axis



**Figure 1.** Indirect measurements of the distance using A) tunnel diameter, B) anterior cruciate ligament femoral guide, and C) direct measure of distance using 3-D reconstructed image. Blue arrow, reference length. Red arrow, real distance.

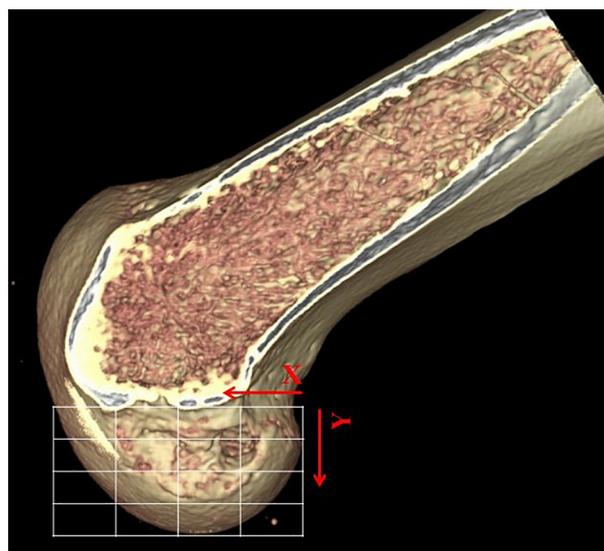
was perpendicular to the  $x$ -axis in the high-low direction at the plane of the condyle wall. The location of the anatomic ACL footprint was referenced in the systematic review article that has already been mentioned.

### 2.3. Outcome measurement

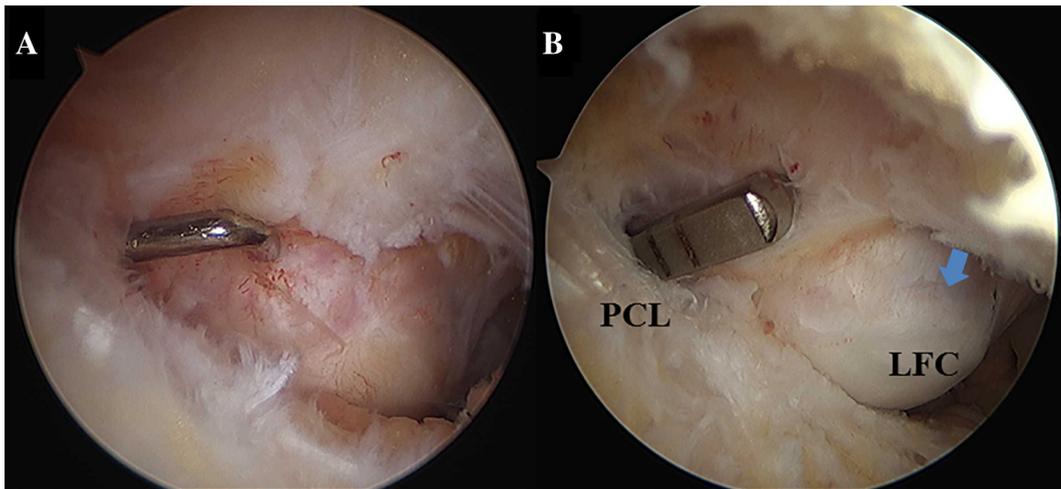
The clinical and stability outcomes were analyzed according to femoral tunnel position. For clinical evaluation, the International Knee Documentation Committee (IKDC) subjective and objective scores and Lysholm score were evaluated preoperatively and postoperatively. For anterior stability evaluation, side-to-side difference was evaluated using Telos stress radiographs (Telos, Weiterstadt, Germany) with the knee in 30° flexion and 15-N anterior stress. Minimal clinically important difference (MCID) and minimal detectable change (MDC) were calculated according to the guidelines established by Harris et al [28]. The MCID for the IKDC was 16.7 and MDC was 8.9 for Lysholm [28]. These results were correlated with the center of the femoral tunnel.

### 2.4. Surgical technique

A routine arthroscopic examination of the knee joint was performed using standard anteromedial (AM) and anterolateral (AL) portals. For observation of the posterior aspect of the ACL femoral footprint, the arthroscope was inserted through the AL portal and reached the posteromedial (PM) compartment. A PM portal was made using a trans-illumination technique. A posterolateral (PL) portal was also established using the same technique. The PM and PL compartment were connected through the TS portal, and the anterior-superior small portion of the posterior septum was excised using a shaver. After establishing the TS portal, the



**Figure 2.** The total sagittal diameter of the lateral femoral condyle was measured along the Blumensaat line ( $x$ -axis). The height of the intercondylar notch was measured from the Blumensaat line to a line tangent to the distal subchondral bone contour of the condyle ( $y$ -axis).



**Figure 3.** Trans-septal portal view A) probing the direct and indirect fibers of the anterior cruciate ligament footprint, B) distance from femoral guide to apex of the deep cartilage margin was used as a reference to make the anterior cruciate ligament femoral tunnel. Arrow, apex of deep posterior cartilage margin. LFC, lateral femoral condyle; PCL, posterior cruciate ligament.

ACL femoral footprint was directly viewed without remnant sacrificing through the TS portal. Under visualization through the TS portal, direct fibers of the ACL were checked using a probe, and a femoral tunnel guide tip was placed via the AL portal at the proximal corner of the direct fiber using a FlipCutter drill guide system (Arthrex, Naples, Florida, USA) (Figure 3). The tip of the guide hook was pointed toward the posterosuperior corner of the ACL remnant, and its center usually corresponded with the ADC [22,29]. Retrograde reaming of the femoral tunnel was performed with a FlipCutter at approximately 30 mm of the tunnel length. Reaming of the femoral side was adjusted according to graft diameter.

A tibial tunnel was prepared with remnant preservation by localizing the tibial footprint. The tip of the tibial guide hook was inserted at the anteromedial corner of the tibial footprint. A suitable reamer corresponding to the graft size was introduced over a guide pin toward the joint. After the tunnel was made, the auto hamstring or allo tibialis graft was passed through the tunnel. A suspensory device was used for femoral side graft fixation, and an interference screw and post-tie fixation were used for tibial side graft fixation.

### 2.5. Statistical analysis

All statistical analyses were performed by using SPSS statistical package (version 22.0, IBM Corp., Armonk, NY, USA). A Z-test was used to compare the femoral tunnel position to that of the anatomic reference data. Paired *t*-test was used to compare the differences in the femoral tunnel position between CT and arthroscopy image. Bivariate correlation analysis was used to identify the relationship between femoral tunnel position and clinical and stability results. All CT measurements were performed by a sports medicine fellow who did not participate in the operation. *P*-values <0.05 were considered statistically significant.

**Table 1**  
Comparison between femoral tunnel center in the current study and theoretical center.

	Mean ± standard deviation	
<i>Distance from ADC to femoral tunnel center</i>		
Distance in the current study, mm	7.0 ± 1.4 (arthroscopy)	
	7.2 ± 2.0 (3-D CT)	
Distance in reference data, mm	12.9 ± 0.6	
<i>P</i> -value	<0.001 (arthroscopy)	
	<0.001 (3-D CT)	
<i>Quadrant method</i>		
	<i>x</i> -axis	<i>y</i> -axis
Femoral tunnel center in current study, %	24.0 ± 5.0	24.1 ± 6.6
Center in reference data, %	28.4 ± 5.1	35.7 ± 6.9
<i>P</i> -value	<0.001	<0.001

ADC, apex of deep posterior cartilage margin; 3-D, three dimensional; CT, computed tomography.

**Table 2**

Clinical and stability outcomes.

	Preoperative	Postoperative	<i>P</i>
IKDC Subjective	49.1 ± 15.3	89.4 ± 10.1	0.014
IKDC Objective (A/B/C/D)	0/4/43/62	64/38/7/0	<0.001
Lysholm	51.2 ± 19.0	88.1 ± 10.6	0.025
Telos stress radiograph (Side-to-side difference)	7.8 ± 3.5 mm	1.6 ± 2.1 mm	<0.001

IKDC, International Knee Documentation Committee.

### 3. Results

#### 3.1. Relationship between ADC position detected by arthroscopy and 3-D CT

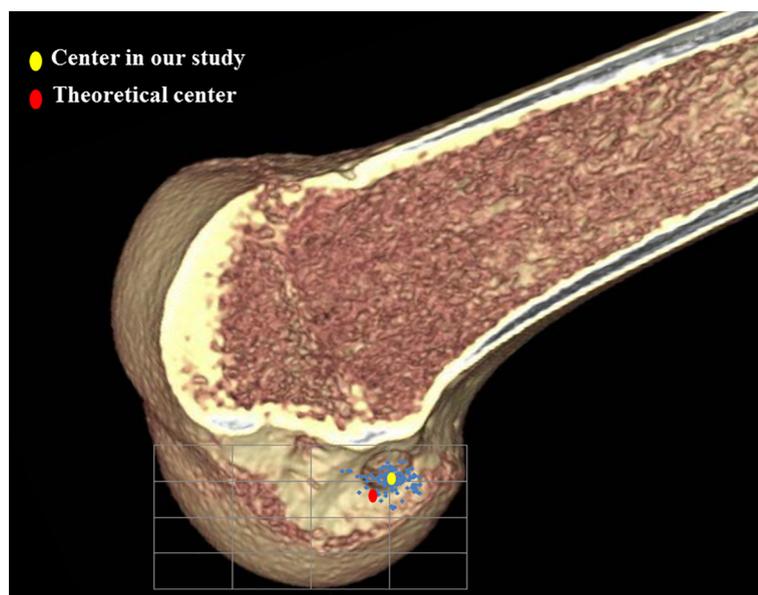
The distances from possible anatomical landmarks to the femoral tunnel center are summarized in Table 1. The average distance from ADC to femoral tunnel center was  $7.0 \pm 1.4$  mm, as measured by arthroscopy and  $7.2 \pm 2.0$  mm by 3-D CT. No statistically significant difference was found ( $P = 0.420$ ) between the two distances and the correlation coefficient was high (Pearson correlation coefficient = 0.819,  $P < 0.001$ ). However, these values were significantly shorter than those ( $12.9 \pm 0.6$  mm) detected by a previous cadaveric study (both  $P < 0.001$ ) [8].

#### 3.2. Tunnel position and outcome

Using the quadrant method, average distances from the femoral tunnel center were  $24.0 \pm 5.0\%$  on *x*-axis and  $24.1 \pm 6.6\%$  on *y*-axis. Both clinical and stability outcomes were significantly improved postoperatively (Table 2). The IKDC subjective score was improved from  $49.1 \pm 15.3$  preoperatively to  $89.4 \pm 10.1$  postoperatively ( $P = 0.014$ ), with 100 of 109 patients achieving MCID. The IKDC objective score also improved ( $P < 0.001$ ). Lysholm improved from  $51.2 \pm 19.0$  preoperatively to  $88.1 \pm 10.6$  postoperatively ( $P = 0.025$ ), with 99 of 109 patients achieving MDC. Side-to-side difference in Telos stress radiograph was improved from  $7.8 \pm 3.5$  mm preoperatively to  $1.6 \pm 2.1$  mm postoperatively ( $P = 0.014$ ).

#### 3.3. Comparison of the femoral tunnel center with the anatomic data

Compared to the anatomic reference data ( $28.4 \pm 5.1\%$  on *x*-axis and  $35.7 \pm 6.9\%$  on *y*-axis), obtained values were significantly lower in *x*-axis and *y*-axis ( $P < 0.001$ ,  $P < 0.001$ ) [26]. The femoral tunnel was shifted toward the proximal position compared to the anatomic reference data (Figure 4).



**Figure 4.** Femoral tunnel center obtained in the current study and the anatomic reference data using a quadrant method.

**Table 3**Correlation analysis between femoral tunnel location and outcomes (*P*-value).

	IKDC Subjective	IKDC Objective	Lysholm	Telos (SSD)
Quadrant <i>x</i> -axis (%)	0.65	0.45	0.93	0.04
Quadrant <i>y</i> -axis (%)	0.39	0.45	0.86	0.23
Distance from femoral tunnel center to ADC	3-D CT	0.96	0.66	0.35
	arthroscopy	0.33	0.26	0.73

IKDC, International Knee Documentation Committee; SSD, side-to-side difference; ADC, apex of deep posterior cartilage margin; 3-D, three dimensional; CT, computed tomography.

#### 3.4. Correlation between tunnel position and outcome

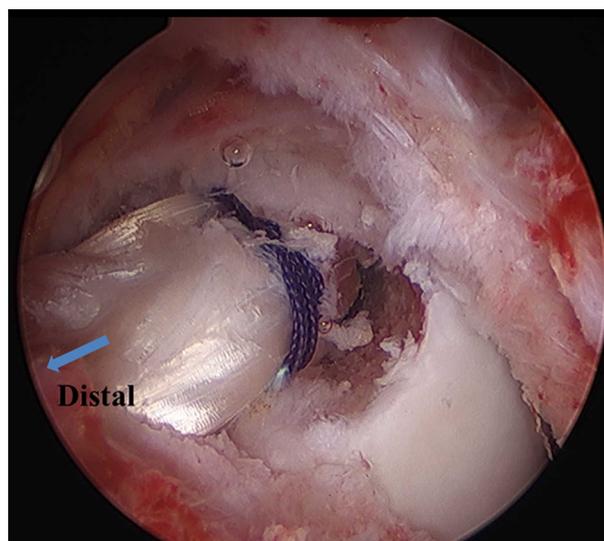
The correlations between location of the femoral tunnel center and clinical stability outcomes are summarized in Table 3. The correlation between *x*-axis location of the femoral tunnel center and stability outcome was statistically significant ( $P = 0.04$ ) and Pearson correlation coefficient was 0.210. No other statistically significant variables were found.

#### 4. Discussion

The principal findings of this study were as follows: 1) the femoral tunnel center was made at a more proximal position using the TS portal and ADC as a reference compared to the anatomic reference data, and 2) clinical outcome was not related to the femoral tunnel location; however, stability outcome was related to the femoral tunnel location, and a more proximally located femoral tunnel showed better stability.

It could be difficult to simultaneously achieve both ACL remnant preservation and accurate tunnel creation. Some surgeons consider that ACL tunnel position is more important than remnant preservation; therefore, they sacrifice remnant ACL fibers to more accurately make the tunnel. However, remnant preservation could have some value in terms of proprioceptive function [10–12], stability [13,14], and graft healing [15–18], although it is difficult to observe well-known bony landmarks such as lateral intercondylar ridge and bifurcate ridge with ACL remnant preservation, especially during femoral tunnel formation. As an alternative, ADC can be used as another landmark for ACL femoral tunnel [8]. However, although ADC can be visualized without remnant ACL sacrificing, it is also difficult to be observed with routine anterior arthroscopic viewing with remnant preservation. The current study used the TS portal technique, which allows posterior structure observation and excellent visualization of the entire posterior compartment of the knee joint; moreover, it allows direct vision of the ACL femoral footprint [30]. It is also known that the TS portal technique has higher accuracy and reproducibility without sacrificing remnant ACL footprint compared to anterior arthroscopic viewing [21]. With TS portal viewing, ADC and ACL footprint can be seen directly, and surgeons can easily adjust the location of the femoral tunnel.

In recent studies, the stress distribution of a graft in the femoral tunnel aperture is known to be higher in the distal part; therefore, the ACL graft was displaced distally (Figure 5) [23,31]. Obtained results suggest that even if the femoral tunnel is made in the anatomical center of the ACL femoral footprint, the mechanical center of the ACL graft does not match the anatomical



**Figure 5.** Arthroscopic view of the femoral tunnel aperture through trans-septal portal after anterior cruciate ligament reconstruction (right knee viewed from the posteromedial portal through trans-septal portal). The anterior cruciate ligament graft is positioned eccentrically to the distal portion of the femoral aperture. Blue arrow, femoral tunnel aperture.

center of ACL femoral footprint. To recover ACL function, restoring the mechanical center of the ACL could be more important than restoring the anatomical center. Therefore, some studies recommend that ACL femoral tunnel should be made more proximal than the anatomic ACL footprint, considering these mechanical properties [23]. The current study intentionally located the ACL femoral tunnel at a more proximal position than the anatomic ACL footprint center. The results show that the location of the femoral tunnel was placed in a more proximal position compared to the anatomic reference data, as was intended.

According to the current results (as shown in Table 3), the *x*-axis correlated with stability outcome. It could be assumed that stability was improved due to the fact that the femoral tunnel was placed more proximally. Nawabi et al. reported that high-located ACL fibers determined that the femoral footprint could bear more force during stability testing [31]. Therefore, they suggested that the femoral tunnel should be located at a higher position than the anatomical footprint center. However, the current study showed that proximal migration was more prominent, and only this position change was statistically significant. Other movements of the tunnel in an anterior–posterior direction and a little anteriorly (high location) did not show statistically significant changes. Therefore, a proximal position of the femoral tunnel could be a more important factor for stability.

Arthroscopy has the advantage of viewing the ADC through a TS portal; however, it also has the disadvantage that the direction from femoral tunnel to ADC cannot be precisely identified. 3-D CT has the advantage that the location of the femoral tunnel can be easily identified by the quadrant method; however, it also has the disadvantage that the ADC cannot be exactly identified because it is a cartilage margin. Therefore, both modalities were used in the current study to check the relationship between them. Based on the results, they could both be used for identifying the femoral tunnel because no statistical difference was found between them.

The current study had some limitations. First, only the TS portal technique with proximal femoral tunnel location was considered; therefore, the comparisons are only valid for TS portal technique and proximal femoral tunnel location. Second, distances were measured indirectly by arthroscopy, although a 30° arthroscope was used and viewing was nearly perpendicular to the ACL footprint. Therefore, there could be minor errors from the distorted view. Third, exact measurement or comparison of the preserved remnant was not performed, although it is possible that posterior TS could have advantages in remnant-preserving anatomic ACL reconstruction. Fourth, estimating the cartilage by 3-D CT could have been inaccurate, although there was one study that it could be accurate [25]. Fifth, this study was a retrospective case series, therefore, there were some limitations to the available material, and we could not use all patients' arthroscopic viewing and 3-D CT. Sixth, physical examination was performed to assess stability, but a Telos stress radiogram was only used for quantitative assessment of stability. Seventh, the difference between allograft and autograft was not reflected. However, the majority of patients used hamstring autograft, as described in the demographics.

## 5. Conclusion

ADC can be a good landmark in remnant-preserving anterior cruciate ligament reconstruction using a posterior TS portal. A more proximal femoral tunnel, which is located at the proximal corner of the ACL remnant, can provide advantages in terms of the stability of the remnant-preserving ACL reconstruction.

## Conflicts of interest

The authors have no conflicts of interest to declare.

## Level of evidence

Case series; Level of evidence, IV.

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