

A Modified Anatomic Transtibial Double-Bundle Anterior Cruciate Ligament Reconstruction Provides Reliable Bone Tunnel Positioning



Takaki Sanada, M.D., Hiroshi Iwaso, M.D., PhD., Eisaburo Honda, M.D., Hiroki Yoshitomi, M.D., and Miyu Inagawa, M.D.

Purpose: To evaluate the femoral and tibial tunnel positions via a modified anatomic transtibial double-bundle anterior cruciate ligament (ACL) reconstruction. **Methods:** Patients who underwent double-bundle ACL reconstruction using the transtibial tunnel creation technique were identified. Double-bundle ACL reconstruction was performed for 94 knees using the transtibial tunnel creation technique. Tunnel aperture configurations and center positions of the anteromedial (AM) and posterolateral (PL) tunnels via postoperative 3-dimensional computed tomography were evaluated. **Results:** There were 94 knees included. Regarding the intra-articular tunnel aperture configurations, the AM and PL tunnels overlapped at the femoral and tibial aperture in 66.0% and 94.7% cases, respectively. The mean femoral bone tunnel center was located at $23.0 \pm 3.9\%$ in the posterior-to-anterior ratio and $28.7 \pm 6.0\%$ in the proximal-to-distal ratio for the AM tunnels and at $32.8 \pm 4.7\%$ and $51.2 \pm 5.2\%$ for the PL tunnels, respectively. In the tibial tunnels, the mean AM tunnel center was located at $31.4 \pm 3.6\%$ in the anterior-to-posterior ratio and $44.3 \pm 1.8\%$ in the medial-to-lateral ratio and at $47.5 \pm 3.8\%$ and $44.3 \pm 1.9\%$ in the PL tunnel center, respectively. The femoral tunnels of outliers, both those created in nonanatomic positions as well as the posterior wall blowouts, were revealed in 7.4% cases. The nonanatomical bone tunnel group had significant heavier weight patients, lower tibial posterior slope, and were anterior in the AM and PL tunnel position. Posterior wall blowouts were related to posterior and proximal PL bone tunnel positions. **Conclusions:** Modified transtibial double-bundle ACL reconstruction is a reliable tunnel creation technique with anatomic placement in 92.6% of the cases. The modification required that partially superimposing configuration of the 2 tibial tunnel apertures. The nonanatomic tunnels were related to patients of heavier weight and lower tibial posterior sloped knees, whereas the posterior wall blowouts were related to the posterior and proximal PL bone tunnel positions. **Level of Evidence:** Level IV, therapeutic case series.

Double-bundle anterior cruciate ligament (ACL) reconstruction has potential advantages over single-bundle reconstruction. Biomechanically, it provides better valgus and internal rotation kinematics and

anterior translational stability than the single-bundle reconstruction.¹⁻³ Clinical comparative studies provide several results from the equivalence of the 2 different reconstructions⁴⁻⁶ to the superiority of double-bundle reconstruction in regard to rotational stability tests, revision reconstruction rate, or further osteoarthritis incidence rate.⁷⁻⁹

Regarding the tunnel-creation technique, the transtibial technique is a widely used ACL reconstruction method. However, the traditional transtibial technique, which was completed by aiming at the isometric femoral tunnel position through the tibial tunnel, aligns the graft in the vertical position. It is unclear whether tunnels are created at the optimal anatomic position in the transtibial technique; therefore, meticulous positioning of the tibial tunnels is required. Current tunnel-creation techniques are enhanced with the transportal or outside-in methods because they set the tunnels at the anatomic positions on behalf of the conventional

From the Department of Sports Orthopedic Surgery, Kanto-Rosai Hospital, Kanagawa, Japan.

The authors report that they have no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as [supplementary material](#).

Received June 30, 2021; accepted October 19, 2021.

Address correspondence to Takaki Sanada, M.D., Department of Sports Orthopedics Surgery, Kanto Rosai Hospital, 1-1 Kizuki Sumiyoshi-cho, Nakahara-ku, Kawasaki-city, Kanagawa-Pref. 211-8510, Japan. E-mail: sanasana511@gmail.com

© 2021 THE AUTHORS. Published by Elsevier Inc. on behalf of the Arthroscopy Association of North America. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>). 2666-061X/21850

<https://doi.org/10.1016/j.asmr.2021.10.021>

transtibial tunnel creation.¹⁰⁻¹⁴ Conversely, transtibial reconstruction has some advantages over other independent drilling techniques. Compared with the transportal reconstruction, transtibial ACL reconstruction has lower relative risks for revision ACL surgery than the transportal reconstruction.^{15,16} Originally, the independent drilling techniques led to a steeper graft bending angle at the femoral tunnel aperture compared with the transtibial technique; hence, the peak torque and stress to the graft at the femoral tunnel aperture are greater in transportal or outside-in methods during knee extension.¹⁷⁻¹⁹ Moreover, the transtibial technique has superior graft maturation to the transportal ACL reconstruction.²⁰ These studies have demonstrated the clinical advantages of the transtibial tunnel creation technique owing to the lower biomechanical strain at the graft and the early biological graft incorporation in the transtibial drilling method.

To deal with the clinical advantages and nonanatomic tunnel placement in the transtibial methods, modified transtibial techniques have been introduced to induce the tunnels into the anatomic position.^{21,22} However, previous modified transtibial techniques were introduced as single-bundle ACL reconstruction techniques. Currently, we have applied the modified transtibial procedure to double-bundle ACL reconstruction, which conserves the potential for the biomechanical and clinical advantages of single-bundle reconstruction. In this study, we introduced the technical aspect of the modified double-bundle transtibial tunnel creation and investigated whether our transtibial technique can create the tunnels in the anatomic positions. The purpose of this study was to evaluate the femoral and tibial tunnel positions via a modified anatomic transtibial double-bundle ACL reconstruction. We hypothesized that the modified technique would be an adequate procedure for setting the tunnels in the anatomic positions.

Methods

Patients who underwent primary ipsilateral double-bundle ACL reconstruction between January 2018 and December 2019 by a single surgeon at our institution were identified. Inclusion criteria were that the procedure must be unilateral and be a primary ACL reconstruction. Exclusion criteria for the study were revision ACL reconstructions, histories of other multiple knee ligament surgeries, bilateral ACL reconstructions, and the primary bone-tendon-bone ACL reconstruction. Double-bundle ACL grafts comprised only ipsilateral semitendinosus and gracilis tendons or semitendinosus tendons only. There were no cases of switching procedure from the modified transtibial tunnel creation to the transportal or from the outside-in technique during surgery.

Femoral and tibial tunnel center positions for the anteromedial (AM) and the posterolateral (PL) were determined, and the intra-articular tunnel aperture configuration was classified into separated type or overlapped type via postoperative 3-dimensional computed tomography (3D-CT). All plotted femoral tunnel centers were sorted into anatomic tunnels and nonanatomic tunnels, as described in the report by Parkar et al.²³ In addition, posterior wall blowout tunnels were extracted as outliers. We compared the optimal tunnel positions with the outlier factors in relation to the physical status and intraoperative radiographic records findings (guidewire position, tibial plateau inclination, and tunnel insertion point from the anterior edge of the tibial articular surface). This research was approved by the institutional review board of the authors' affiliated institutions.

Surgical Technique

A guidewire for the tibial AM tunnel was inserted using a tibial target device from the medial proximal tibial cortex targeting the intra-articular anteromedial portion of the tibial ACL footprint, referring to the anterior intertubercle and the medial intercondylar ridges of the tibia. Next, the PL tibial guidewire was inserted, while the tibial target device tip was set at a site 5 to 10 mm posterior to the tip of the AM tibial guidewire within the area of the native tibial footprint. What is different from the conventional transtibial technique is the modified method constructed, where the AM and PL guidewire tip faces the corresponding anatomic femoral tunnel center. Intraoperative anterior-to-posterior and lateral radiographs were obtained to confirm the guidewire positions. Tibial tunnel creation was conducted using a 2-step overdrilling method to create an accurate tibial tunnel route. First, the primary tibial tunnel was created using a 4.0- or 4.5-mm cannulated reamer. Then, the second cannulated drill, which matched the diameter with the graft size, reamed out the tunnel, while the tibial guidewire in the small-diameter tibial tunnel was a controlled to ensure targeting the more accurate anatomic femoral tunnel center. After 2 tibial tunnels were created with the cannulated reamers, by overdrilling along the guidewires, the guidewires were targeted to the anatomic femoral centers through the corresponding tibial tunnels. First, the guidewire targets the femoral PL center through the tibial PL tunnel. After inserting the guidewire, the bone socket was created using a cannulated reamer, which coincided with the corresponding graft diameter. The rest of the femoral tunnel pathway was reamed with a 4.0- or 4.5-mm cannulated drill in diameter, according to the type of the femoral suspension device usage. The AM tunnel was created in the same manner. Usually, the guidewire tip caught the anatomic femoral tunnel center entry during knee

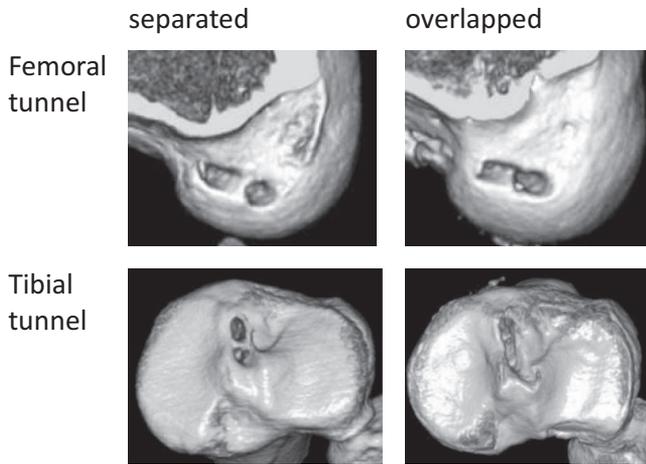


Fig 1. According to the relationship between the AM and PL tunnel positions via 3-dimensional computed tomography, bone tunnel configuration was classified into separated or the overlapped types. (AM, anteromedial; PL, posterolateral.)

extension, and the knee bent gradually, while the guidewire was inserted forward to secure adequate femoral tunnel length while avoiding the posterior wall blowout.

After the creation of 2-tunnel routes, each bundle of the ACL graft was fixed using a cortical suspension device of ENDOBUTTON CL (Smith & Nephew, Inc., Andover, MA) or TightRope RT (Arthrex, Naples, FL) on the femoral cortex, and affixed to the tibial post screw (length, 25 mm; diameter, 6.5 mm) with a 10.5-mm diameter washer (Meira GTS, Nagoya, Japan). Of the 94 knees, ipsilateral semitendinosus tendons were used in 90 knees, wherein the autograft was divided into the AM and PL bundles, whereas ipsilateral semitendinosus and gracilis tendons were used in the remaining 4 knees.

Regarding additional procedures, 47 knees underwent meniscal procedures: 46 meniscal repairs and 1 partial meniscectomy. Seven knees underwent concomitant medial collateral ligament surgical treatment, 6 underwent medial collateral ligament repair, and 1 underwent medial collateral ligament reconstruction using the ipsilateral gracilis tendon autograft.

Radiographic Evaluation

Tunnel Configuration

According to the relation between the AM and PL tunnel positions, bone tunnel aperture configurations were classified via the postoperative 3D-CT images as a type of separated tunnel in which 2 tunnels were created independently with a bone bridge preservation or a type of overlapped tunnel that partially connected with 2 tunnels into a bottle-shaped aperture (Fig 1).

Tunnel Centers

All patients underwent CT examination 1 week after the surgery. Femoral tunnel centers were measured via 3D-CT images and reconstructed into a condylar split image, according to Bernard and Hertel's quadrant method.²⁴ The posterior-to-anterior ratio along Blumensaat's line and the proximal-to-distal ratio along the intercondylar height were estimated for the femoral AM and PL tunnel centers (Fig 2A). The tibial bone tunnel centers were estimated using the 3D-CT imaged tibial joint surface view. The anterior-to-posterior ratio of the tibial tunnel center and the medial-to-lateral ratio of the tibial tunnel center were calculated (Fig 2B). When the tunnel aperture configuration is a combined oval, the cross point of the long axis and the short axis of each oval aperture is determined as the tunnel center. Two orthopaedic surgeons measured each tunnel center twice on different days. The individual tunnel center was labeled as a mean of 4 estimated centers. The interclass correlation coefficient for the femoral and tibial tunnel centers was >0.85 for all sections (Table 1). For further investigation, all plotted tunnel centers were classified into anatomic or nonanatomic femoral tunnel centers according to the anatomic centers reported by the research of Parkar et al.²³ In our study, a nonanatomic femoral bone tunnel center was defined as the point where it was more proximal or anterior than Parkar et al.'s anatomic tunnel center distribution. In addition to determining the nonanatomic femoral tunnel positions, we investigated the posterior wall blowout tunnel for another outlier via postoperative 3D-CT.

Intraoperative Insertion Angle and Entry Point of the Tibial Guidewire

As leading factors of the tibial tunnel position, the guidewire insertion angles in the 2 planes (Fig 3 A and B) and the guidewire entry point, which was defined as the vertical distance from the anterior edge of the tibial articular surface to each tunnel center on the postoperative 3D-CT images (Fig 3C), were evaluated.

Tibial Posterior Slope Angle and Coronal Inclination Angle

We estimated the radiologic features of the tibial posterior slope angle and coronal angle. The tibial posterior slope was measured as the angle between the posterior inclination line of the tibial surface and the vertical line of the tibial shaft axis in the lateral view. The coronal angle was defined as the angle between the medial inclination line of the tibial plateau and the vertical line of the tibial shaft axis (Fig 4A and B).

Statistical Analysis

Statistical analysis of data was performed using Bell-Curve for Excel version 3.21 for Windows (Social

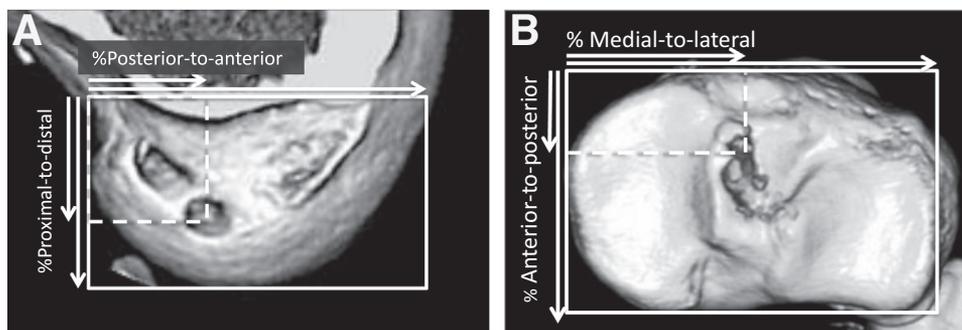


Fig 2. The femoral tunnel centers were measured using the 3-dimensional computed tomography (3D-CT) quadrant method. The grid was surrounded by 4 borders: Blumensaat's line, the anterior, and the posterior and inferior margins of the lateral condyle. The highest and deepest corner of the posterior condyle was the initial estimate point with the posterior-to-anterior ratio along Blumensaat's line and the proximal-to-distal ratio along the intercondylar height (A). In addition, tibial tunnel centers were estimated via postoperative 3D-CT. The anterior-to-posterior ratio was calculated as the ratio between the maximum anterior-to-posterior distance on the tibial plateau and the distance from the anterior tibia margin to each tunnel center and the medial-to-lateral ratio of the tibial tunnel center was defined as the ratio between the maximum tibial plateau width and the distance from the medial border of the tibia to the tunnel center (B).

Survey Research Information Co., Ltd). For the statistical analysis between both the groups, Mann–Whitney *U* tests or Student *t* test for continuous variables and the Fisher exact test and χ^2 test for categorical variables were used. Interclass correlation coefficients were calculated for intraindividual and intraobserver variation. Values of $\leq .05$ were considered statistically significant.

Results

Between January 2018 and December 2019, 100 patients underwent the primary ipsilateral double-bundle ACL reconstruction by a single surgeon at the facility. After excluding 6 patients who did not complete the intraoperative radiographic examination or postoperative CT, this case series study enrolled 94 knees (62 female, 32 male). The patients' mean age, height, and weight were 30.4 (range 13-68) years, 163.7 (range 145-185) cm, and 60.7 (range 40-135) kg, respectively. The preoperative median Tegner activity score was 6 (range 3-10).

The Tunnel Aperture Configuration

The separated and overlapped type were noted in 34.0% (32/94) and 66.0% (62/94) of the cases in the femoral tunnel, respectively. On the tibial side, the

corresponding tunnel configuration types were noted in 5.3% (5/94) and 94.7% (89/94), respectively.

Geometric Centers of the Femoral and Tibial Tunnels

Dispersion of the plotted femoral and tibial tunnel centers via 3D-CT was estimated (Fig 5A and B). On the femoral side, the mean \pm standard deviation of the posterior-to-anterior ratio and proximal-to-distal ratio was $23.0 \pm 3.9\%$ and $28.7 \pm 6.0\%$ at the AM bundle center and $32.8 \pm 4.7\%$ and $51.2 \pm 5.2\%$ at the PL bundle center, respectively. On the tibial side, the mean anterior-to-posterior ratio and medial-to-lateral ratio were $31.4 \pm 3.6\%$ and $44.3 \pm 1.8\%$ at the AM bundle center, and $47.5 \pm 3.8\%$ and $46.7 \pm 1.9\%$ at the PL bundle center, respectively (Table 2).

Outliers of the Nonanatomic Tunnel Position and Blowout Tunnels

A total of 92.6% (84/94) of the cases were set in the anatomic area. The remaining 7.4% (7/94) were nonanatomic outliers. Although all AM tunnels were set at the anatomic position, 7 nonanatomic outliers were derived from the PL tunnels. Six cases were located at far anterior positions and one was at a far proximal position from the normal anatomic area (Fig 6). The incidence of posterior wall blowout tunnels was in 7.4%. All blowouts were derived from AM tunnels, with no PL tunnel blowouts were involved (Fig 7).

Patient Characteristic and Geometric Data

The nonanatomic tunnel group comprised patients of significantly heavier weight ($P = .00013$). Although intraoperative guidewire settings were not significantly different between 2 groups, the tibial posterior slope

Table 1. Interclass Correlation Coefficient for the Tunnel Center Plots

Tunnel Center	Intraobserver		Interobserver
	Observer 1	Observer 2	
Tibia	0.862	0.984	0.907
Femur	0.931	0.989	0.959

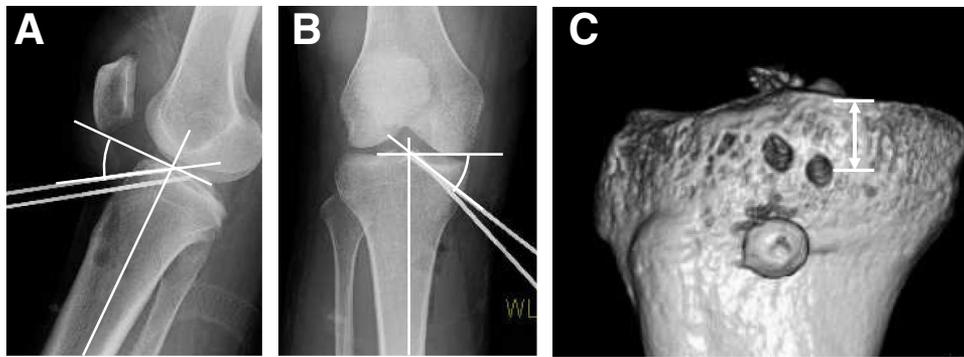


Fig 3. The sagittal and coronal insertion angles of the tibial guidewire were defined as the angle between the vertical line of the tibial anatomical axis and the line of the guidewire from the lateral roentgenographic view (A) and anterior-to-posterior view (B), respectively. The tibial guidewire entry point was defined as the vertical distance between the tibial joint surface and the center of the tibial tunnel entry on the anterior tibial cortex (the length of the white arrow) (C).

angle was significantly smaller in the nonanatomical group ($P = .0019$). In terms of the tunnel positions, tibial tunnels did not differ between the 2 groups. In contrast, the mean femoral AM tunnel center was located at a more anterior position in the nonanatomical group ($P = .0028$), whereas all AM tunnels were created within the anatomic area. The mean PL tunnel center was also significantly more anterior in the nonanatomic tunnel group. Six of the even nonanatomic PL tunnels were created in anterior positions whereas 1 PL tunnel created a proximal nonanatomic position (Table 3). Concerning nonblowout to blowout tunnels, no patient characteristic difference or intraoperative guidewire position difference was detected between the 2 groups. No significant difference was detected in the AM or PL tibial tunnel positions. However, blowout cases were composed of a significantly proximal-and-posterior femoral AM tunnel mean accompanied by a proximal-and-posterior femoral PL tunnel mean (Table 4).

Discussion

The most important finding of our study is that the transtibial double-bundle ACL reconstruction technique has adequate accuracy to set the bone tunnels among the anatomic area with a technical modification. Concerning the comparison studies between the transtibial and transportal methods regarding the single-bundle ACL reconstruction techniques, transportal creation could accomplish the tunnels with more accurate anatomic placements compared with the transtibial methods.^{10,13,14,25} Only one study claimed that the transtibial single-bundle technique could accomplish anatomic reconstruction with meticulous guidewire positioning.¹² The same trend was observed in the double-bundle transtibial ACL reconstruction. A case series reported that the tibial wire could be set in the anatomic position reproducibly, but the femoral

wire position was more proximal and anterior compared with the native ACL footprint attachment.¹¹ However, these comparison studies were concerned with the conventional transtibial tunnel creation versus substitutional techniques and did not refer to the current modified transtibial technique.

Previous studies have investigated the anatomic footprint of native ACL fibers and AM and PL fiber centers.²⁶⁻²⁹ Most reports that evaluated the created tunnel position compared the native ACL fiber center and the authors' created tunnel centers. According to the versatile method, our mean AM femoral tunnel center was more posterior and distal than that reported by Yamamoto et al.²⁸ and Tsukada et al.²⁷ but more anterior and proximal than that reported by Zantop et al.²⁹ and Lorenz et al.²⁶ Our mean PL tunnel center was more anterior and distal than that reported by Yamamoto et al.²⁸ and Lorenz et al.,²⁶ but more

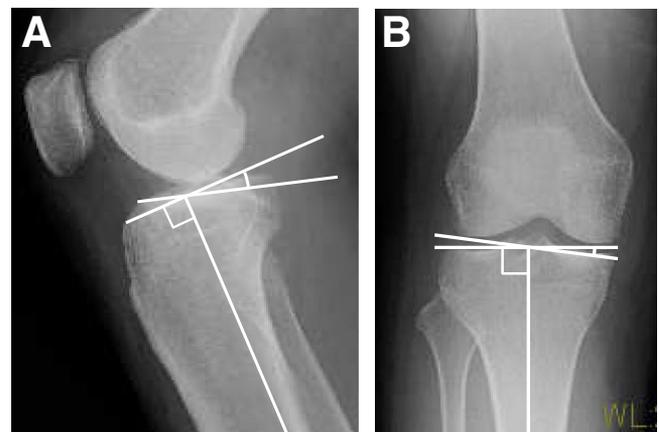


Fig 4. The tibial posterior angle was defined as the angle between the vertical line to the tibial axis and the slope line on the tibial joint surface in the lateral view (A). The medial inclination angle was defined as the angle between the vertical line to the tibial axis and the coronal joint slope line (B).

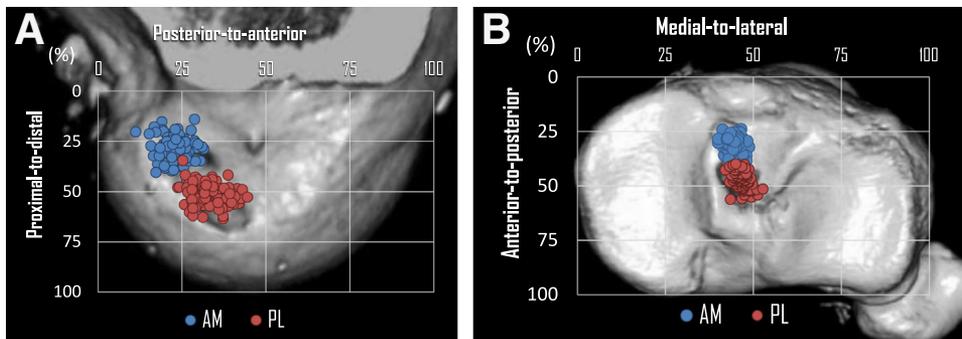


Fig 5. The dispersion of all femoral (A) and tibial (B) tunnel centers were plotted using 3-dimensional computed tomography. The blue points are the anteromedial (AM) tunnel centers, and the red points are the posterolateral (PL) tunnel centers.

posterior and distal than that reported by Tsukada et al.²⁷ and more anterior and proximal than that reported by Zantop et al.²⁹ We assume that our tunnel centers are represented among native fiber centers; thus, the modified transtibial tunnel creation technique may be valued as an anatomic procedure. However, this evaluation was conducted by comparison with the representative mean values among the groups, and it could not adequately evaluate the accuracy of individual created tunnel positions. A recent study²³ reported the presence of an anatomic native fiber insertion area. Using these results, we evaluated the tunnel positions whether the individual plotted tunnel centers could exist among the anatomic areas. In our study, we defined the anatomical ACL area as using Parkar et al.'s proposal definition region and expanded the definition to include the posterior and distal regions of the fan-like extension fibers attachment area. We used this expanded definition because the original report of Parkar et al.²³ composed of the anatomy of the direct fiber attachment area. Incidental histologic studies proved that the femoral ACL insertion area had spread more distally and posteriorly into the region called the area of indirect insertion or fan-like extension fibers.³⁰⁻³² The fan-like extension fibers significantly functioned with increasing ACL failure load.³⁰ According to the modified definitive area of ACL fiber attachment, the accuracy of our modified double-bundle transtibial tunnel creation technique was estimated at 92.6% of the anatomic tunnel creation.

In the transtibial technique, all tunnel positions are regulated according to the tibial guidewire's insertion position. According to Tsuda et al.,³³ the angle between

the tibial tunnel and the vertical line to the tibial long axis in the sagittal and coronal planes can be estimated to be 49.7° and 66.7° at the AM tunnel and 53.4° and 48.9° at the PL tunnel, respectively. Giron et al.¹¹ set the instrument at the coronal angles of 65° and 45° in the AM and PL tunnels, respectively. Conversely, the mean sagittal and coronal insertion angles in the 94 cases of our technique were $39.5 \pm 5.4^\circ$ and $53.2 \pm 5.6^\circ$ at the AM guidewires and $43.6 \pm 5.7^\circ$ and $42.0 \pm 4.3^\circ$ at the PL guidewires, respectively. Modified transtibial tunnel creation can be accomplished at a lower guidewire setting angle. According to the guidewire insertion angle, the entry point located near the joint line. A cadaver study proved that the transtibial trajectory required a tibial starting point of 14.1 mm from the tibial plateau in single-bundle reconstruction.²⁵ Regarding modified transtibial double-bundle reconstruction, the mean entry points of the 94 cases were ensured at shorter distances from the joint line of 10.2 ± 2.0 mm for the AM tunnels and 12.0 ± 2.1 mm for the PL tunnels. Conclusively, the individual tibial tunnel lay down parallel to the joint line. Hence, the configuration of the tibial tunnel aperture is elongated to an oval shape. A study reported that the tibial intra-articular tunnel aperture via the transtibial tunnel creation elongated 38% anteroposterior dimension compared with the transportal tunnel creation.³⁴ In the double-bundle tunnel creation cases, the anteroposterior aligned AM and PL tunnel aperture are assumed to coalesce. Indeed, 94.7% cases resulted in a tibial tunnel aperture connection in our series. Consequently, the lower angle tibial guidewire position, which elongated the anteroposterior diameter at the

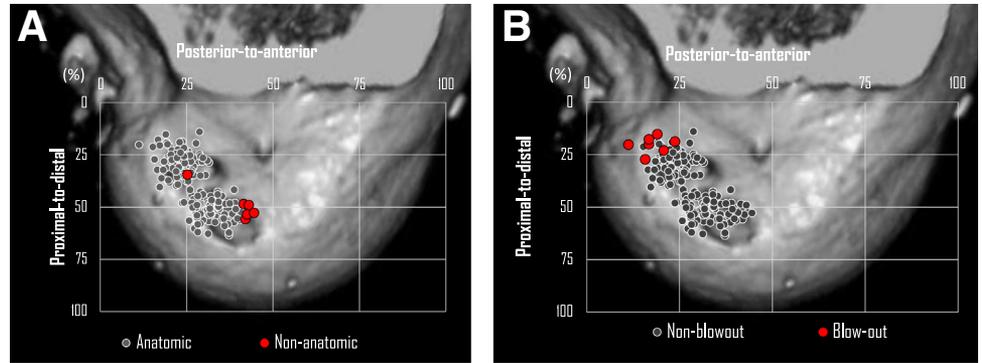
Table 2. Dispersion of the Femoral and Tibial Tunnel Centers

	Femoral Tunnel		Tibial Tunnel	
	Posterior-To-Anterior	Proximal-To-Distal	Anterior-To-Posterior	Medial-To-Lateral
AM (%)	23.0 (3.9)	28.7 (6.0)	31.4 (3.6)	44.3 (1.8)
PL (%)	32.8 (4.7)	51.2 (5.2)	47.5 (3.8)	46.7 (1.9)

NOTE. Values are mean (standard deviation).

AM, anteromedial; PL, posterolateral.

Fig 6. Extraction of nonanatomic tunnel center points (A) and posterior blowout points (B) from all femoral dispersion plots with red dots. All nonanatomical centers were PL tunnel centers (n = 7). Six of the seven cases were located in the anterior nonanatomic area and one case in the proximal nonanatomic area. All blowout cases were from anteromedial (AM) tunnels (n = 7).



oval AM and PL tibial tunnel, eventually connected both the apertures.

The dual-aperture connection had a favorable effect on creating the anatomic femoral tunnels. In general, the vertical tunnel route, with a rounded tunnel aperture by the conventional double-bundle tunnels comprising a completely separated and steep angle, restricts the space to target the accurate femoral center (Fig 7A). However, a feature of tunnel connected creation via the modified double-bundle transtibial technique can provide a wider guidewire targeting arc for the trajectory femoral tunnel center in the larger aperture outlet (Fig 7B). Indeed, the tibial tunnel coalition is a relatively common phenomenon in double-bundle ACL tunnel creation.³⁵ Generally, native AM and PL fibers do not exist separately divided by a bone bridge between the 2 components. From these viewpoints, tunnel separation is not always compulsory for anatomic ACL reconstruction; moreover, tunnel aperture overlap may better imitate the topographic characteristics of native ACL fibers than separated tunnels.

in contrast, the effect for the clinical outcomes of overlapping tibial tunnel aperture is controversial. In a biomechanical study, double-bundle ACL reconstruction with 1 tibial tunnel provided the same translation and rotational stability as a 2-tunnel reconstruction.³⁶ Tunnel communication does not affect clinical outcomes.³⁷ Conversely, Nukuto et al.³⁸ stated that the tibial tunnel coalition could not effectively control the pivot-shift.

On the femoral tunnels, aperture connection type was noted in 66% cases. The femoral insertional area of the native ACL fibers was apparently defined in relation to intercondylar bony landmarks. The semicircle attachment area is surrounded by a line of 18.1 mm length lateral intercondylar ridge and a curved posterior cartilage margin with 11.7 mm height a bifurcate ridge.³⁹ Fitting 2 femoral oval tunnels within a relatively narrow anatomic area while preserving the bone bridge between 2 bone tunnels requires a meticulous setting position. Because the apertures in the modified transtibial technique are theoretically oval, tunnels

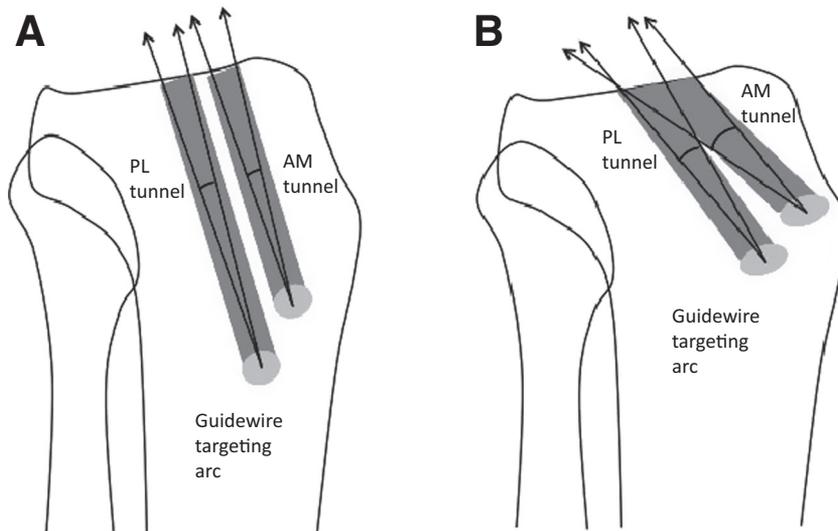


Fig 7. Conventional transtibial tunnels can align vertical tibial tunnels with a longer length of the tunnels, and the intrajoint tibial tunnel aperture becomes circular and located separately. The guidewire must target the anatomic femoral center in a narrow-angle arc (black arrows). The vertical tunnel conducts the guidewire to achieve a greater femoral entry (A). Conversely, the modified transtibial tunnels were aligned at a low angle to the joint line with a shorter distance. Two ovalized tunnels at the intrajoint tended to connect the 2 tibial tunnel outlets. The connected apertures provide a wider space for the guidance arc of the guidewire to target the femoral anatomic center (black arrows) (B). (AM, anteromedial; PL, posterolateral.)

Table 3. Anatomic Versus Nonanatomic Tunnels

	Anatomic (n = 87)	Nonanatomic (n = 7)	P Value
Age, y	30.0 (13.1)	36.9 (17.1)	.27
Sex (male:female)	28:59	4:3	.18
Height, cm	163.5 (7.9)	164.7 (11.0)	.72
Weight, kg	59.1 (10.9)	79.6 (27.5)	.00013
Joint laxity (0-7)	2.5 (1.9)	1.3 (0.7)	.11
Guidewire insertion angle			
AM			
Sagittal, °	39.4 (5.3)	40 (5.9)	.78
Coronal, °	53.0 (5.6)	55.4 (4.8)	.27
PL			
Sagittal, °	43.5 (5.7)	44.4 (5.9)	.68
Coronal, °	42.0 (4.3)	41.4 (4.2)	.72
Entry point			
AM, mm	10.7 (2.1)	10.2 (2.0)	.53
PL, mm	11.9 (2.0)	12 (2.1)	.80
Tibial posterior slope, °	10.6 (2.8)	7.1 (1.6)	.0019
Tibial medial inclination, °	5.1 (2.1)	4.3 (0.7)	.29
Tunnel center			
AM tunnel (tibia)			
Anterior-to-posterior, %	31.5 (0.7)	30.9 (3.7)	.68
Medial-to-lateral, %	44.3 (1.8)	44.1 (1.7)	.80
PL tunnel (tibia)			
Anterior-to-posterior, %	47.6 (3.8)	46.2 (3.8)	.36
Medial-to-lateral, %	46.7 (1.9)	46.9 (1.4)	.76
AM tunnel (femur)			
Posterior-to-anterior, %	22.6 (3.7)	27.1 (3.9)	.0028
Proximal-to-distal, %	28.7 (6.0)	28.4 (6.6)	.89
PL tunnel (femur)			
Posterior-to-anterior, %	32.2 (3.9)	40.3 (6.2)	3.5×10^{-6}
Proximal-to-distal, %	51.3 (0.4)	49.5 (6.6)	.37

NOTE. Values are mean (standard deviation).

AM, anteromedial; PL, posterolateral.

within the anatomic area imply tunnel aperture communication. If the bone bridge preservation is prevailed, the anatomic AM tunnels will produce non-anatomic PL tunnels. Alternatively, anatomic PL tunnels may lead to the posterior wall blowouts of the AM tunnels. Tunnel connections may be inevitable because of the creating of 2 tunnels within the confined anatomic space.

In the series, 7.4% (n = 7/94) of the cases had nonanatomic tunnel placement. The mean weight of the nonanatomic tunnel group was significantly high. The modified transtibial tunnel creation requires gradual knee bending and tibial internal rotation position while the guidewire is inserted forward. Heavy patients with thick legs may prevent the surgeon from maintaining a precise guidewire entry while maintaining accurate knee flexion. In addition, the tibial posterior slope angle differed between the 2 groups. The slope was steeper in the anatomic tunnel group. The modified transtibial tunnel creation technique requires setting the tibial guidewire at a more horizontal angle at a mean of 39.4° in the sagittal plane. A lower tibial posterior slope would decrease an adequate working angle arc to securely target the anatomic femoral tunnels in the tibial tunnel route. Moreover, all

nonanatomic tunnel placements were composed of PL tunnel outliers accompanied by significant anterior AM tunnels means than the rest of the anatomic cases. Six of the seven nonanatomic PL tunnels were anterior nonanatomic positions in the 3D-CT quadrant evaluation. In conjunction with the primary creation of a nonanatomic PL tunnel, secondary AM tunnel creation is induced to the anterior position in the nonanatomical group. Concerning the posterior wall blowout, although there was no significant difference in patients' physical demographic data and intraoperative guidewire position between the anatomic and non-anatomic group, both mean PL and AM tunnels were more posterior and proximal in the blowout cases. In our tunnel creation technique, a PL tunnel was created before the AM tunnel, the position of the AM tunnel was influenced by the PL tunnel position. AM blowout cases were interlinked with the posterior and proximal PL tunnel position. Precise positioning of the PL tunnel is key to preventing the nonanatomic position or posterior femoral condyle wall blowout tunnels.

Limitations

This study is not without limitations. Postoperative bone tunnel enlargement or following clinical

Table 4. Nonblowout Versus Blowout Tunnels

	Nonblowout (n = 87)	Blowout (n = 7)	P Value
Age, y	30.3 (13.4)	31.4 (14.5)	.84
Sex (male:female)	29:58	3:4	.61
Height, cm	163.4 (8.3)	165.7 (6.7)	.49
Weight, kg	60.4 (13.4)	64.1 (19.3)	.49
Joint laxity (0-7)	2.7 (1.9)	1.1 (0.6)	.07
Guidewire insertion angle			
Sagittal, °	39.7 (5.4)	35.9 (3.3)	.07
Coronal, °	53.4 (5.6)	50.0 (4.1)	.25
Sagittal, °	43.7 (5.8)	42 (2.3)	.45
Coronal, °	41.9 (4.3)	43 (3.6)	.52
Entry point			
AM, mm	9.9 (2.4)	10.3 (2.0)	.59
PL, mm	11.6 (1.8)	12.0 (2.1)	.57
Tibial posterior slope, °	10.3 (2.8)	10.5 (3.0)	.80
Tibial medial inclination, °	5 (2)	5.9 (1.0)	.28
Tunnel center			
AM tunnel (tibia)			
anterior-to-posterior, %	31.4 (3.6)	32.5 (3.7)	.42
medial-to-lateral, %	44.2 (1.8)	45 (1.2)	.42
PL tunnel (tibia)			
anterior-to-posterior, %	47.5 (3.9)	47.5 (3.0)	.98
medial-to-lateral, %	46.6 (1.8)	47.5 (2.8)	.24
AM tunnel (femur)			
posterior-to-anterior, %	23.4 (3.5)	17.7 (3.7)	.0001
proximal-to-distal, %	29.4 (5.7)	20.3 (3.6)	.00009
PL tunnel (femur)			
posterior-to-anterior, %	33.2 (4.6)	28.3 (3.2)	.01
proximal-to-distal, %	51.8 (4.8)	44 (4.5)	.00008

NOTE. Values are mean (standard deviation).

AM, anteromedial; PL, posterolateral.

outcomes with the overlapping tunnel apertures, which is a feature of the procedure, should be investigated. The clinical results between the optimal tunnel position group versus the nonoptimal group or among the diversity of the tunnel aperture configuration will be the succeeding study. From a technical perspective, the existence of 7.4% cases of the posterior wall blowout at the lateral femoral condyle and nonanatomic tunnel position should be considered as another issue to be resolved through technical improvement. Also, only one surgeon engaged all procedures in the series, verification of technical reproducibility for plural operators must be required.

Conclusions

Modified transtibial double-bundle ACL reconstruction is a reliable tunnel creation technique with anatomic placement in 92.6% of the cases. The modification required that partially superimposing configuration of the 2 tibial tunnel apertures. The nonanatomic tunnels were related to the heavier weight patients and lower tibial posterior sloped knees, whereas the posterior wall blowouts were related to the posterior and proximal PL bone tunnel positions.

Acknowledgments

The authors extend their gratitude to the team of physiotherapists in Kanto Rosai Hospital for collecting postoperative comprehensive clinical datasets and special language correction and support by Jessica Birdsong.

References

- Oh JY, Kim KT, Park YJ, et al. Biomechanical comparison of single-bundle versus double-bundle anterior cruciate ligament reconstruction: A meta-analysis. *Knee Surg Rel Res* 2020;32:1-11.
- Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. *Am J Sports Med* 2002;30:660-666.
- Zantop T, Herbort M, Raschke MJ, Fu FH, Petersen W. The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation. *Am J Sports Med* 2007;35:223-227.
- Sasaki S, Tsuda E, Hiraga Y, et al. Prospective randomized study of objective and subjective clinical results between double-bundle and single-bundle anterior cruciate ligament reconstruction. *Am J Sports Med* 2016;44:855-864.
- Chen H, Chen B, Tie K, Fu Z, Chen L. Single-bundle versus double-bundle autologous anterior cruciate

- ligament reconstruction: A meta-analysis of randomized controlled trials at 5-year minimum follow-up. *J Orthop Surg Res* 2018;13:50.
6. Xiang X, Qu Z, Sun H, et al. Single-tunnel anatomic double-bundle anterior cruciate ligament reconstruction has the same effectiveness as double femoral, double tibial tunnel. A prospective randomized study. *Medicine (Baltimore)* 2019;98:e14851.
 7. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 cases with 3- to 5-year follow-up. *Am J Sports Med* 2012;40:512-520.
 8. Zhang Y, Xu C, Dong S, et al. Systemic review of anatomic single- versus double-bundle anterior cruciate ligament reconstruction: Does femoral tunnel drilling technique matter? *Arthroscopy* 2016;32:1887-1904.
 9. Järvelä S, Kiekara T, Suomalainen P, Järvelä T. Double-bundle versus single-bundle anterior cruciate ligament reconstruction. A prospective randomized study with 10-year results. *Am J Sports Med* 2017;45:2578-2585.
 10. Steiner ME, Battaglia TC, Heming JF, Rand JD, Festa A, Baria M. Independent drilling outperforms conventional transtibial drilling in anterior cruciate ligament reconstruction. *Am J Sports Med* 2009;37:1912-1919.
 11. Giron F, Cuomo P, Edwards A, Bull AM, Amis AA, Aglietti P. Double-bundle "anatomic" anterior cruciate ligament reconstruction: A cadaveric study of tunnel positioning with a transtibial technique. *Arthroscopy* 2007;23:7-13.
 12. Strauss EJ, Barker JU, McGill K, Cole BJ, Bach BR Jr, Verma NN. Can anatomic femoral tunnel placement be achieved using a transtibial technique for hamstring anterior cruciate ligament reconstruction? *Am J Sports Med* 2011;39:1263-1269.
 13. Silva A, Sampaio R, Pinto E. Placement of femoral tunnel between the AM and PL bundles using a transtibial technique in single-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2010;18:1245-1251.
 14. Kim NK, Kim JM. The three techniques for femoral tunnel placement in anterior cruciate ligament reconstruction: Transtibial, anteromedial portal, and outside-in techniques. *Arthrosc Orthop Sports Med* 2015;2:77-85.
 15. Rahr-Wagner L, Thillemann TM, Pedersen AB, Lind MC. Increase risk of revision after anteromedial compared with transtibial drilling of the femoral tunnel during primary anterior cruciate ligament reconstruction: Results from the Danish Knee Ligament Reconstruction Register. *Arthroscopy* 2013;29:98-105.
 16. Clatworthy M, Sauer S, Roberts T. Transportal central femoral tunnel placement has a significantly higher revision rate than transtibial AM femoral tunnel placement in hamstring ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2019;27:124-129.
 17. Wang JH, Kim JG, Lee DK, Lim HC. Comparison of femoral graft bending angle and tunnel length between transtibial technique and transportal technique in anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2012;20:1584-1593.
 18. Tashiro Y, Irrarázaval S, Osaki K, Iwamoto Y, Fu FH. Comparison of graft bending angle during knee motion after outside-in, trans-portal, trans-tibial anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2017;25:129-137.
 19. Bae JY, Kim GH, Seon JK, Joen I. Finite element study on the anatomic transtibial technique for single-bundle anterior cruciate ligament reconstruction. *Med Biol Eng Comput* 2016;54:811-820.
 20. Saito M, Nakajima A, Sonobe M, et al. Superior graft maturation after anatomical double-bundle anterior cruciate ligament reconstruction using the transtibial drilling technique compared to the transportal technique. *Knee Surg Sports Traumatol Arthrosc* 2019;27:2468-2477.
 21. Muahl V. A modified transtibial technique was similar to an anteromedial portal technique for anterior cruciate ligament reconstruction. *J Bone Joint Surg Am* 2015;97:1373.
 22. Youm YS, Cho SD, Lee SH, Young CH. Modified transtibial versus anteromedial portal technique in anatomic single-bundle anterior cruciate ligament reconstruction: Comparison of femoral tunnel position and clinical results. *Am J Sports Med* 2014;42:2941-2947.
 23. Parkar AP, Draensen MEAPM, Vindfeldt S, Solheim E. The anatomic centers of the femoral and tibial insertions of the anterior cruciate ligament: A systematic review of imaging and cadaveric studies reporting normal center locations. *Am J Sports Med* 2017;45:2180-2188.
 24. Bernard M, Hertel P, Hornung H, Cierpinski T. Femoral insertion of the ACL: Radiographic quadrant method. *Am J Knee Surg* 1997;10:14-22.
 25. Kopf S, Forsythe B, Wong AW, Irrgang JJ, Fu FH. Transtibial ACL reconstruction technique fails to position drill tunnels anatomically in vivo 3D CT study. *Knee Surg Sports Traumatol Arthrosc* 2012;20:2200-2207.
 26. Lorenz S, Elser F, Mitterer M, Obst T, Imhoff AB. Radiologic evaluation of the insertion sites of the 2 functional bundles of the anterior cruciate ligament using 3-dimensional computed tomography. *Am J Sports Med* 2009;37:2368-2376.
 27. Tsukada H, Ishibashi Y, Tsuda E, Fukuda A, Toh S. Anatomical analysis of the anterior cruciate ligament femoral and tibial footprints. *J Orthop Sci* 2008;13:122-129.
 28. Yamamoto Y, Hsu WH, Woo SL, Van Scyoc AH, Takakura Y, Debski RE. Knee stability and graft function after anterior cruciate ligament reconstruction: A comparison of a lateral and an anatomical femoral tunnel placement. *Am J Sports Med* 2004;32:1825-1832.
 29. Zantop T, Wellmann M, Fu FH, Petersen W. Tunnel position of anteromedial and posterolateral bundles in anatomic anterior cruciate ligament reconstruction: Anatomic and radiographic findings. *Am J Sports Med* 2008;36:65-72.
 30. Sabzevari S, Shailh H, Marshall B, et al. The femoral posterior fan-like extension of the ACL insertion increases the failure load. *Knee Surg Sports Traumatol Arthrosc* 2020;28:1113-1118.
 31. Sasaki N, Ishibashi Y, Tsuda E, et al. The femoral insertion of the anterior cruciate ligament: Discrepancy between

- macroscopic and histological observation. *Arthroscopy* 2012;28:1135-1146.
32. Iwasaki T, Shino K, Nakata K, et al. Direct anterior cruciate ligament insertion to the femur assessed by histology and 3-demansional volume-rendered computed tomography. *Arthroscopy* 2010;26:13-20.
 33. Tsuda E, Ishibashi Y, Fukuda A, Tsukada H, Ono S. Tunnel position and relationship to postoperative knee laxity after double-bundle anterior cruciate ligament reconstruction with a transtibial technique. *Am J Sports Med* 2010;38:698-706.
 34. Bedi A, Volker MV, Steuber V. Transtibial versus anteromedial portal reaming in anterior cruciate ligament reconstruction: An anatomic and biomechanical evaluation of surgical technique. *Arthroscopy* 2011;37:380-390.
 35. Kawaguchi Y, Kondo E, Onodera J, et al. Tunnel enlargement and coalition after anatomic double-bundle anterior cruciate ligament reconstruction with hamstring tendon autografts. A computed tomography study. *Orthop J Sports Med* 2013;1:2325967113486441.
 36. Drews BH, Seitz AM, Huth J, et al. ACL double-bundle reconstruction with one tibial tunnel provides equal stability compared to two tibial tunnels. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1646-1652.
 37. Ichiba A, Tokuyama F, Makuya K, Oda K. Graft quality and clinical outcomes of intraoperative bone tunnel communication in anatomic double-bundle anterior cruciate ligament reconstruction. *Asia Pac J Sports Med Arthrosc Rehabil Technol* 2016;3:6-12.
 38. Nukuto K, Hoshino Y, Yamamoto T, et al. Anatomic double-bundle anterior cruciate ligament reconstruction could no achieve sufficient control of pivot-shift when accompanying tibial tunnel coalition. *Knee Surg Sports Traumatol Arthrosc* 2021;29:3743-3750.
 39. Ziegler CG, Pietrini SD, Westerhaus BD, et al. Arthroscopically pertinent landmarks for tunnel positioning in single-bundle and double-bundle anterior cruciate ligament reconstructions. *Am J Sports Med* 2011;39:743-752.