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Aperture elongation of the femoral tunnel on the lateral cortex in anatomical double-bundle anterior cruciate ligament reconstruction using the outside-in technique

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Abstract

In anatomical anterior cruciate ligament reconstruction surgery using the outside-in technique, the aperture of the femoral lateral cortex may become elliptical.

Retrospective cross-sectional study

To evaluate the extent of elliptical eccentricity in lateral apertures relative to aperture positioning and clinical failure rate in anatomical anterior cruciate ligament double-bundle reconstruction using outside-in technique.

In 75 patients, the aperture elongation factor was defined as the ratio of the major axis of the elliptical aperture to the drill size. Using the lateral epicondyle as a reference point, the lateral femur was divided into sections by distance and angle, and the minimum area was evaluated to assess the relationship between the elongation factor and aperture position of the lateral cortex for each bundle. The incidence and associated clinical performance regarding cortical button migration were also investigated.

Aperture elongation factors were 120.2 ± 13.3% and 120.0 ± 16.3% on the anteromedial (AM) and posterolateral (PL) sides, respectively. Femoral tunnel elongation was smallest when the entry point axis were both between 30 to 60° and distance was between 10 to 20 mm and 0 to 10 mm on the AM and PL sides, respectively. During the postoperative follow-up period, intra-tunnel migration was confirmed in 4 of 75 cases (5.3%). Fixation failure neither affected clinical scores nor knee laxity.

Areas of minimum elongation for each bundle on both AM and PL sides were found anteroproximally to the lateral epicondyle and positioned near each other. Elongation did not directly affect the clinical outcome.

Level of evidence grade: prognostic level III

Abbreviations: ACL = anatomical anterior cruciate ligament, AM = anteromedial, CT = computer tomography, FAM = far anteromedial portal, OI = outside-in, PL = posterolateral.

Keywords: anterior cruciate ligament, elliptical elongation of aperture, femoral lateral cortex, outside-in technique, suspension device

1. Introduction

In recent years, anatomical anterior cruciate ligament (ACL) reconstruction has been becoming widely practiced due to its biomechanical[1–3] and clinical [4–10] benefits. It is important to create bone tunnels within the normal ACL insertion sites in order to obtain good results for this procedure. In accordance with these trends in anatomical reconstructive surgery, various surgical techniques have been reported.

Although the trans-tibial tunnel technique has been widely used for drilling the femoral tunnel, some reports have suggested that it is difficult to create the tunnel through the tibial tunnel within anatomical femoral ACL foot print.[11–13] As an alternative, new methods of bone tunnel construction have been proposed in order to easily construct anatomical femoral bone tunnels, including far anteromedial portal (FAM) and OI techniques. Both methods provide easy access to anatomical footprints without stipulating the position of the tibial tunnel[14–18]; however, the FAM technique risks inducing the shortening of bone tunnels, peroneal nerve injuries, and damages to the articular cartilage of the medial condyle,[19–21] while the OI technique requires additional incisions.[14,18,22]

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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In addition, unlike other techniques, the OI technique involves drilling the bone tunnel from an extra-articular into an intra-articular footprint, rendering the tunnel into a cylinder with entry and exit apertures of equal size; consequently, the apertures become elliptical, and in some circumstances, their major axes occasionally become greater or equal to the drill diameter, posing risks for creating apertures that are larger than originally intended. Although cortical suspension buttons are widely used for femoral fixation in ACL reconstruction,[23] there is a significantly higher risk for fixation failure when the tunnel aperture of the lateral femoral cortex is greater than half the 6 mm length of the cortical button[24] and the extent of tunnel aperture elliptical elongation is an important issue in cortical button fixation.

Although the elliptical elongation of the bone tunnel is thought to correspond to the position of the aperture, to the best of our knowledge, only Okazaki et al,[25] have investigated the relationship between elongation and aperture position. However, their report is a computer simulation study that presupposes a single-bundle reconstruction, and there are no reports of clinical cases involving a double-bundle reconstruction. Moreover, clinical results due to ovalization and its effects on fixation failure of suspension device have rarely been evaluated. The purpose of this study was to investigate the extent of lateral aperture elongation in relation to aperture positioning in anatomical ACL double bundle reconstruction using the OI technique. Based on immediate postoperative computer tomography (CT) imaging, we evaluated the following characteristics of the OI technique in anatomical double-bundle ACL reconstruction:

(1) the extent of elliptical major axis elongation in the aperture of the lateral cortex in relation to the actual drilling diameter and the percentage of bone tunnels with sizes exceeding 6 mm,
(2) the ideal aperture position with the least effect of elongation based on an examination of the relationship between aperture position of the lateral cortex and tunnel elongation,
(3) minimum clinical follow-up of 2 years and incidence of intra-tunnel cortical button migration.

2. Materials and methods

2.1. Patients

One hundred and twenty-three double-bundle ACL reconstruction surgeries performed from 2013 to 2016 with a minimum follow-up of 2 years (mean, 27.5 months, range, 24–54 months) were included in this study. The exclusion criteria for this study were as follows:

(1) re-operations,
(2) use of patellar tendon,
(3) drill size $>$ 6 mm,
(4) single-bundle reconstructions, and
(5) cases with femoral tunnels created within the non-anatomical foot print decided based on postoperative CT scan that is posterior to the resident's ridge and excludes the area surrounded by the posterior cartilage margin. Seventy-five cases remained after applying the exclusion criteria. Patients consisted of 32 males and 43 females with a mean age of 30.0 years (range, 13–55 years). The local institutional review board approved this study. All patients provided informed consent.

2.2. Surgical procedure and postoperative rehabilitation

Surgery was performed by 4 specialists belonging to the lower extremity group at our institution. We performed an anatomic double-bundle ACL reconstruction with an autologous semitendinosus tendon or a combination of a semitendinosus tendon and gracilis tendon. Two tendon grafts were each folded to prepare double- or quadruple-stranded grafts. Femoral and tibial bone tunnels were made using the OI technique. ACUFEX DIRECTOR Drill Guide (Smith and Nephew Endoscopy, Andover, MA) was used for drilling. Two femoral bone tunnels were created at an angle to avoid as much tunnel coalition as possible in the area surrounded by the posterior cartilage margin that is posterior to the resident's ridge. 2.4-mm guidewires were inserted from the lateral cortex of the femur, first for the anteromedial (AM) side and subsequently for the posterolateral (PL) side, and 2 femoral tunnels were created by over-drilling. The drill size was undersized by 0.5 mm in order to pass a sizing tube through a bone tunnel that provided a tight press-fit for the tendon graft. A tibial tunnel was created in the same manner with a drill guide system (Smith and Nephew Endoscopy, Andover, MA). The femoral side of the tendon was fixed using an EndoButton CL (Smith and Nephew Endoscopy, Andover, MA) and the tibial side of the tendon was fixed using a Double Spike Plate (Smith and Nephew Endoscopy, Andover, MA).

All patients received the same postoperative rehabilitation protocol. Isometric quadriceps exercises were started 2 to 3 days after surgery. Range-of-motion were started 1week after surgery and were continued. Partial weight bearing crutch gait was permitted postoperatively. Full weight bearing was allowed 4 weeks after surgery. Running was started 4 to 6months after surgery. Plyometric exercises, agility exercises, and sports-specific exercises was started 6 months after surgery. Return to previous sports activities was allowed 9 to 12 months after surgery.

2.3. CT protocol

CT scans were performed on all knees within 1 week after ACL reconstruction. A CT scanner (GE Quad slice CT scanner [SOMATOM Sensation 16; Siemens Medical Solutions, Erlangen, Germany]) was used for all examinations. The knee was placed in extension without a fixation device. The acquisition matrix was 512×512. Images were obtained with the following parameters: 1-mm thickness, approximately 5- to 10-second scan time, 0 mm skip between slices, and field of view of 140 mm. After extraction of Digital Imaging and Communications in Medicine data from the picture archiving and communication system, the data was imported into OsiriX imaging software (version 5.5; Pixmeo, Geneva, Switzerland). Two orthopedic surgeons performed all of the measurements.

2.4. The length of the major and minor axis of the elliptical aperture

Using 1 week postoperative CT, the length of the major and minor axis of the lateral femoral surface was assessed by the using the measuring for bone tunnel diameters as previously proposed by Lee et al.[26] Once the images were imported into OsiriX, they were converted into the multi-planar reconstruction mode which enables the re-arrangement of the orthographic view plane and view axis into any direction. On CT imaging using multi-planar reconstruction, a plane that is parallel to the direction of the

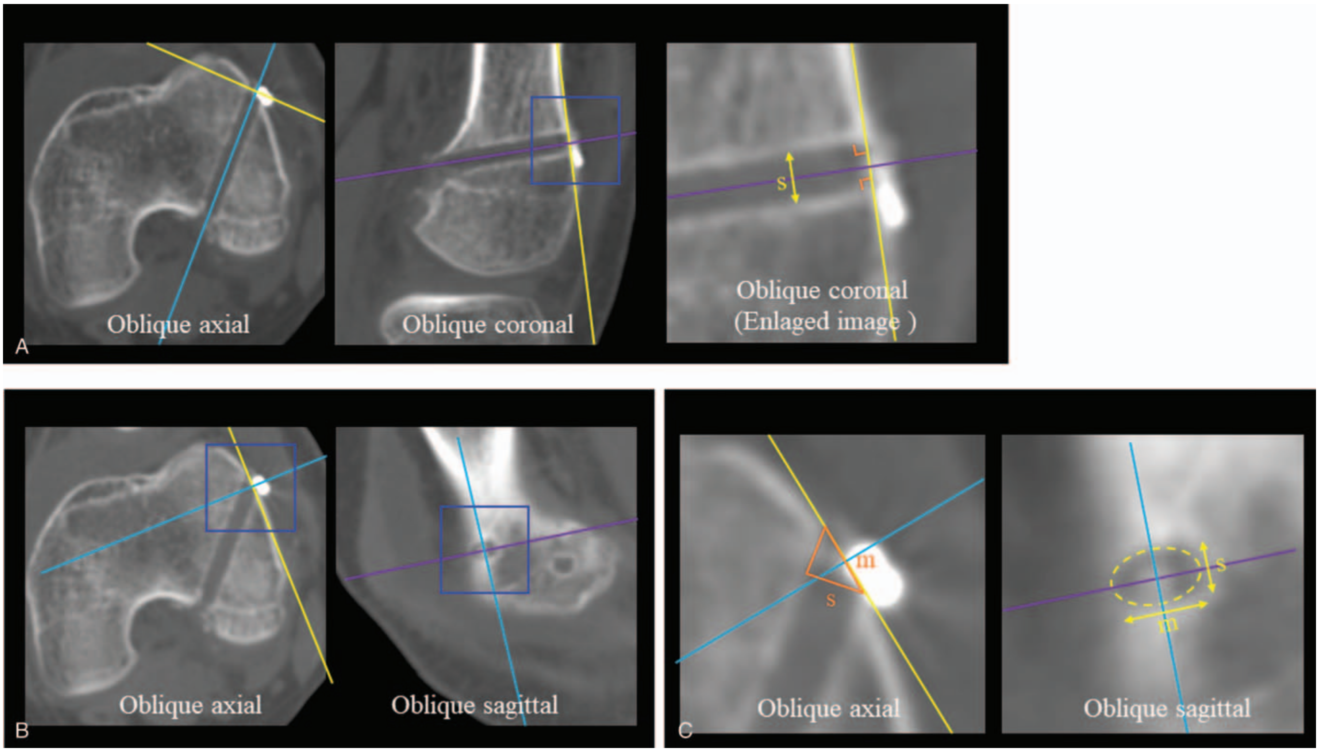

Figure 1. The measurement of the major and minor axis of the elliptical aperture. (A) Using multi-planar reconstruction, the oblique axial and oblique coronal planes were aligned to the direction of tunnel, and the plane wherein the entire periphery from the lateral aperture to the intra-articular aperture could be confirmed was identified. The cross bar was rotated on the oblique sagittal plane, and the plane in which the yellow bar of the oblique coronal plane makes contact with the lateral cortex, that is, a plane wherein the drill and resulting bone tunnel is positioned perpendicularly to lateral femoral cortex, was identified (the aperture and tunnel diameters are the same, s = short; minor axis of the tunnel aperture). At this point, the lateral aperture in the oblique axial plane that ran perpendicular to the oblique coronal plane defined the major axis of the ellipse. (B) The yellow bar was aligned to the lateral cortex on the oblique axial plane, and the oblique axial plane was confirmed as the major axis of the ellipse in the oblique sagittal plane. (C). Enlarged image of (B) Oblique axial plane corresponds to the major axis of ellipse, measuring m = major axis of the tunnel aperture. s = short; minor axis of the tunnel aperture. Light blue bar: oblique coronal plane line. Yellow bar: Oblique sagittal plane line. Purple bar: Oblique axial plane line.

tunnel and verifiable in its entire circumference from the femoral lateral to intra-articular apertures was identified. A bone tunnel was drilled perpendicular to the lateral cortex of the femur whereby the oblique coronal plane was identified (Fig. 1A). Drilled perpendicular to the lateral cortex of the femur is the minor axis of the ellipse. At this point, the lateral aperture of the oblique axial plane, which is a plane perpendicular to the oblique coronal plane, becomes the major axis of the ellipse. For confirmation, we used the oblique sagittal plane, which is a plane along the lateral cortex of the oblique axial plane. Upon confirming that the aperture of the oblique axial plane is the major axis of the ellipse, we measured the major and minor axis (Figs. 1B and C). The ratio of the actual drill diameter to the major axis of the ellipse was defined as the aperture major elongation factor (aperture major elongation factor = major axis / drill size × 100). Similarly, the ratio of the actual drill diameter to the minor axis of the ellipse was defined as the aperture minor elongation factor (aperture minor elongation factor = minor axis / drill size × 100).

2.5. The exit position of the femoral tunnel

The femoral tunnel exit position was evaluated in terms of its relative position to the lateral femoral epicondyle as described by Okazaki et al,[25]. The lateral view of the femur was defined as the image where the medial and lateral femoral condyles overlap in a 3DCT image, and the 3D image of the distal femur was evaluated from the lateral view. The anatomical femoral axis was defined as a line connecting the point above the femoral condyle and the midpoint of the anteroposterior diameter 8 cm from the distal femur. A line parallel to the femoral axis was drawn through the lateral epicondyle, and using that lateral epicondylar line as a reference point, positive and negative deviations were defined as either anterior or posterior to the line. An angle formed between the lateral epicondyle and lateral aperture was measured (hereinafter referred to as entry point axis). Additionally, the distance between the lateral epicondyle and the center of the lateral aperture was measured (hereinafter referred to as entry point distance) (Fig. 2). The center of the lateral aperture is often hidden by buttons in 3DCT. When the bone tunnel could be identified, the center of the elliptical aperture was defined as the center of the lateral aperture. When the aperture was completely obfuscated with a button and the bone tunnel could not be identified, the button was removed on the OsiriX imaging software (version 5.5; Pixmeo, Geneva, Switzerland), and the exposed center of the elliptical aperture was subsequently defined as the center of the lateral aperture.

2.6. Evaluation

We examined the aperture major and minor elongation factor and percentage of major axes of tunnel apertures that exceeded 6 mm

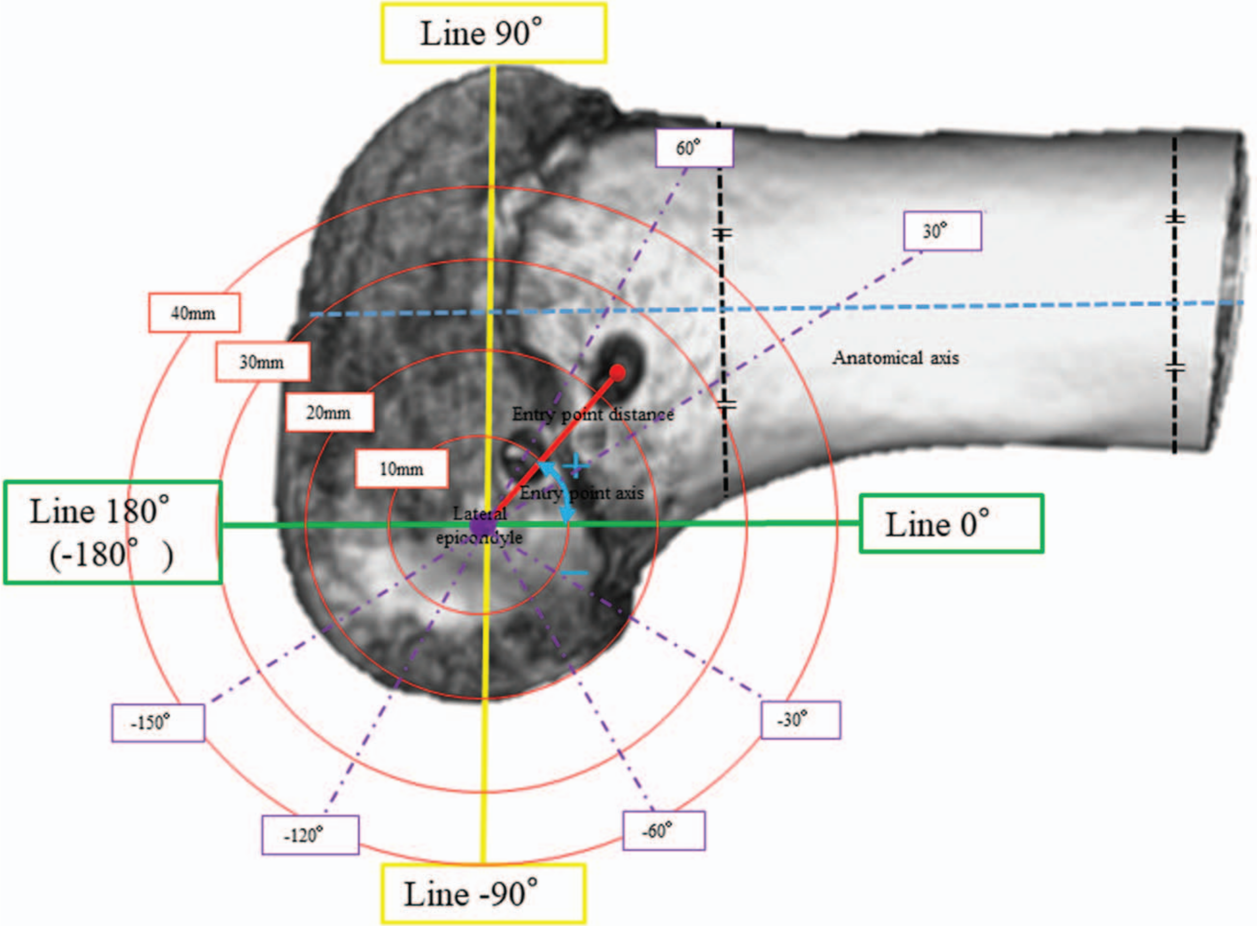

Figure 2. Position of tunnel aperture of femur and lateral epicondyle. 3DCT of lateral femoral condyle; lateral image. Anatomical axis: a line connecting the point above the femoral condyle and the midpoint of the anteroposterior diameter 8 cm from the distal femur. Entry point distance: the distance between the lateral epicondyle and the center of the lateral aperture (distance between purple and red points). Entry point axis: a line parallel to the femoral axis (green line) is drawn through the lateral epicondyle (purple dot), and using that lateral epicondylar line as a reference point, positive and negative deviations are defined as either anterior or posterior to the line; the angle formed between the lateral epicondyle and lateral aperture is the entry point axis. Purple dot: lateral epicondyle. Red dot: center of the lateral aperture. Red Circle: line indicating every 10 mm from lateral epicondyle. Purple dot line: line indicating every 30° from lateral epicondyle as the origin.

that corresponded to both their entirety and each drill size on the AM and PL sides. The positional relationship of the femoral tunnel aperture of the lateral cortex was divided into areas bounded by the entry point axis and entry point distance at 30° and 10 mm intervals from the lateral epicondyle, respectively, and the area of minimum major axis of elongation was compared to other areas.

Postoperative radiographic evaluations were conducted periodically and compared to their immediate postoperative images. When a button failure was suspected, CT imaging was performed for assessment. We divided our patients into 2 groups, either with major axes of their elliptical apertures greater than 6 mm (> 6 mm group) or less than 6 mm (< 6 mm group), and failure rates were compared between the 2 groups. For clinical evaluation, the difference in the Lyshlom score and knee laxity between the affected and unaffected sides were evaluated at final postoperative follow-up using the KT-1000 arthrometer, and a comparison was made between cases with and without failure.

2.7. Statistical analysis

The intraclass and interclass correlation coefficients of the measurements were randomly selected from 25 patients, the major and minor axes of the ellipse were measured, and the bone tunnel elongation factors were verified. On both the AM and PL sides, the bone tunnel elongation factor was evaluated using the unpaired *t* test, while the percentage wherein the major axis of the tunnel aperture exceeded 6 mm was verified using the Chi-squared test. The area of minimum elongation was compared to other areas for the AM and PL elongation of apertures using the unpaired *t* test. The failure rate of the 2 groups were evaluated with a cut-off value of 6 mm using the Chi-squared test, and the clinical results of the failure and non-failure groups were evaluated using the unpaired *t* test. We defined statistical significance as $P < .05$. A minimum sample size of 33 knees was required for an α value of 0.05 and β value of 0.8, while considering a clinical difference of 5% for the aperture elongation factor and a standard deviation of 10%. All analyses were performed with commercially available software (Stat Flex version 5.0, Artech, Inc., Osaka, Japan).

3. Results

ICC for the aperture elongation factor was 0.88 for intra-rater reliability and 0.82 for inter-rater reliability, indicating a good

Table 1

The aperture major and minor axis elongation factor.

	major axis factor	minor axis factor	*P* Value
AM	120.2±13.3%	102.3±1.8%	<.001
PL	120.0±16.3%	103.0±2.1%	<.001

AM=anteromedial, PL=posteolateral.

agreement between observers. The aperture major axis elongation factor was 120.2±13.3% on the AM side and 120.0±16.3% on the PL side. The aperture minor axis elongation factor was 102.3±1.8% on the AM side and 103.0±2.1% on the PL side. Significant difference was found in both the AM and PL sides between the major and minor elongation factor (<.001) (Table 1). The percentage of bone tunnels created for each drill size with a major axis of the ellipse that exceeded half the length of the cortical button (6 mm) were 56% on the AM side. On the PL side, the corresponding percentages of cases exceeding 6 mm were 30.7% (*P*=.002). When the drill diameter was 4.5 mm or less on the AM side, the major axis of the tunnel aperture did not exceed 6.0 mm, and cases exceeding 6.0 mm were found when the drill size exceeded 5.0 mm (Table 2). On the PL side, there were cases where the major axis of the tunnel aperture exceeded 6.0 mm even when the drill size was 4.0 mm (Table 3). On the AM side, the femoral tunnel elongation factor was smallest at 113.8±8.1% when the entry point axis was between 30°and 60°and the entry point distance was between 10 mm and 20 mm (Table 4, Fig. 3). On the PL side, the femoral tunnel elongation was the smallest at 107.5±5.0% when the entry point axis was between 30° to 60° and the entry point distance was between 0 to 10 mm (Table 5, Fig. 4).

During the postoperative follow-up period, intra-tunnel cortical button migration was confirmed in 4 out of 75 patients (5.3%). One failure was confirmed 5 days after surgery, and 3 other failures were confirmed 3 months after surgery. A surgical operation was performed on 1 patient who exhibited early failure (Fig. 5). In terms of the failure rate, although there were no cases of failure in the 85 tunnels (AM: 33, PL: 52) of the <6 mm group, there was a significantly higher incidence of failure in the 65 tunnels (AM: 42, PL: 23) of the > 6 mm group at 6.2% (4/65 cases) (*P*=.03). There was no significant difference between the clinical results of failure and non-failure cases at final follow-up in terms of their clinical scores (96.3±4.8 and 96.2±4.7, respectively; *P*=.97) and knee laxity (–0.33±2.51 and 0.68±1.84, respectively; *P*=.36).

Table 2

The major axis of the tunnel aperture and drill-bit diameter; AM side (n=75).

	Over 6 mm case	
Drilling size (mm) (n)	(n)	(%)
4.0 mm (n=8)	0/8	0
4.5 mm (n=9)	0/9	0
5.0 mm (n=28)	14/28	50.0
5.5 mm (n=16)	14/16	87.5
6.0 mm (n=14)	14/14	100.0
Total	42/75	56.0

AM=anteromedial.

Table 3

The major axis of the tunnel aperture and drill-bit diameter; PL side (n=75).

	Over 6 mm case	
Drilling size (mm) (n)	(n)	(%)
4.0 mm (n=19)	2/19	10.5
4.5 mm (n=25)	6/25	24.0
5.0 mm (n=18)	6/18	33.3
5.5 mm (n=9)	5/9	55.6
6.0 mm (n=4)	4/4	100
Total	23/75	30.7

PL=posteolateral.

4. Discussion

In this study, we investigated the elongation in the aperture of the lateral cortex when using the OI technique, and the major axis of the lateral aperture was on average expanded by 120% in both the AM and PL sides. The percentage of bone tunnels created for each drill size with a major axis of the ellipse that exceeded 6 mm were 56% on the AM side and 30.7% on the PL side. The aperture elongation was minimized on both the AM and PL sides when the apertures were created in near proximity to the anteroproximal side of the lateral epicondyle (Fig. 6). For both the AM and PL sides, the femoral tunnel elongation factor tended to increase when the entry point axis was smaller and the entry point distance was greater. In the minimum 2-year follow-up, intra-tunnel migration was observed in 4 out of 75 patients (5.3%) with a significantly higher incidence in the > 6 mm group, although no effects on its clinical outcome and stability were found. To the best of our knowledge, there are no reports that examine the frequency, extent, and influencing factors of ovalization using the OI method, and evaluate the effect of aperture elongation on the clinical failure rate.

OI technique requires an extra-articular drilling of the bone tunnel, the bone tunnel becomes cylindrical with elliptical entry and exit apertures of equal size. This elliptical elongation of the lateral aperture may pose a problem when a cortical suspension button is used to fixate the graft to the femur. In a study using porcine femur, Herbort et al reported that more than half of the bone tunnels between 5 and 9 mm that were fixated with a suspension device had caused penetration, and that an increase in the tunnel diameter resulted in a gradual decrease in survived cycles of the loading protocol.[24] In this study, the percentage of bone tunnels created for each drill size with a major axis of the ellipse that exceeded half the length of the cortical button (6 mm) were 56% on the AM side and 30.7% on the PL side. From these results, we believe that there is a potential risk for penetration of the lateral cortex.

Although studies on femoral bone tunnel construction using the OI method have been increasing in recent years,[1,5,11,12] there are very few reports on the angle and inlet/outlet positioning during bone tunnel construction. Lubowitz et al,[27] and Matsubara et al,[28] reported on the inlet position of the lateral femoral surface for covering the morphology of the anatomical ACL femoral foot print. On the other hand, only Okazaki et al[25] have reported an examination of factors that affect the elliptical eccentricity of the lateral aperture. They describe an increased elongation factor when the lateral aperture is positioned further away from the lateral epicondyle, and the elongation factor was

Table 4

The major axis of the oval-shaped aperture of tunnels on the lateral femoral surface (%, mean±SD) AM side.

		Entry point distance (mm)				
		0–10mm	10–20mm	20–30mm	30–40mm	40–50mm
Entry Point Axis (°)	60°–90°		126.6 (n=1)	117.1±11.8 (n=4)	116.9±9.7 (n=2)	
	30°–60°	122.4 (n=1)	113.8* ±8.1 (n=28)	122.1** ±11.5 (n=28)	135.2** ±13.9 (n=3)	141.8 (n=1)
	0°–30°		114.0±0.32 (n=2)	144.8** ±22.2 (n=4)		
	−30°–0°		126.5 (n=1)			

AM=anteromedial, SD=standard deviation.

* The femoral tunnel elongation factor was smallest at 113.8±8.1% when the entry point axis was between 30°and 60°and the entry point distance was between 10 mm and 20 mm.

** Significantly different from minimum area (*P*<.01).

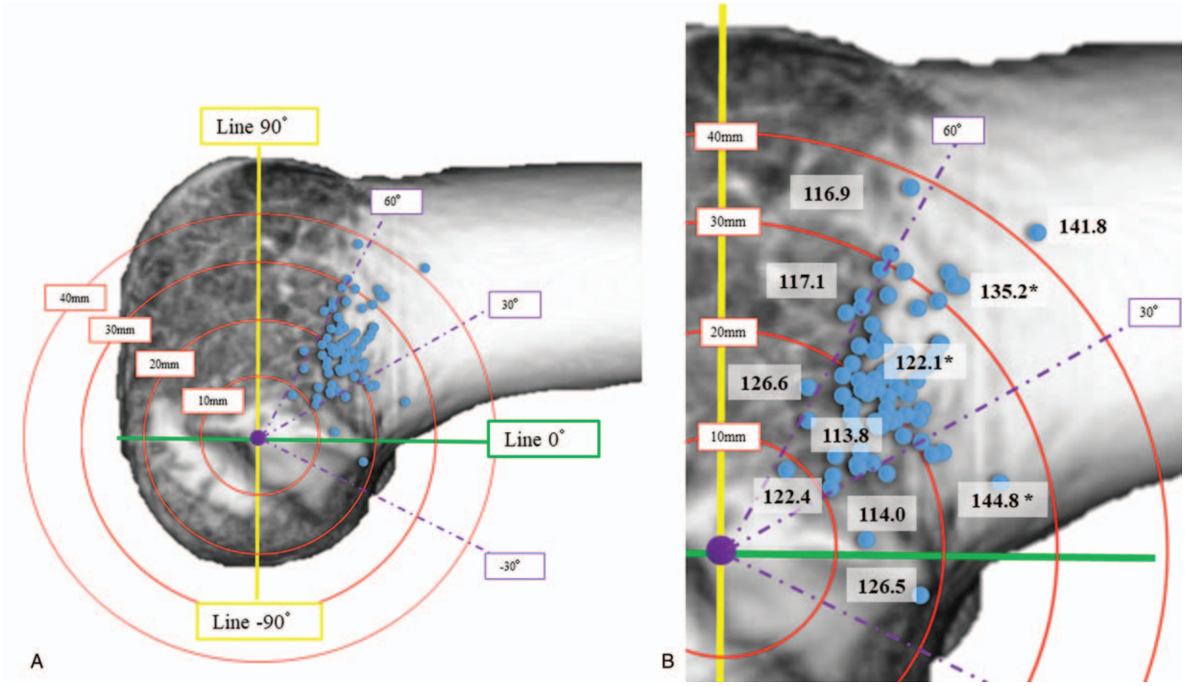

Figure 3. The femoral tunnel exit position; anteromedial (AM) side. (A). The positional relationship of the lateral aperture (blue dot) and lateral epicondyle (purple dot) on the AM side. With the exception of one case, the lateral apertures were created anteroproximally to the lateral epicondyle. Entry point axis: a line parallel to the femoral axis (green line) was drawn, and using the lateral epicondyle (purple dot) as a reference point, positive and negative deviations were defined as either anterior or posterior to the line (purple line), further divided in areas created by 30° intervals. Entry point distance: the distance between the lateral epicondyle and the center of the lateral aperture were divided in 10 mm increments (red circle with purple dot as center). (B). The average aperture elongation factor for each area; AM side. (A) was enlarged, and the average elongation factor was recorded for each area. The elongation factor was 113.8% when the entry point axis was from 30° to 60° and the entry point distance was from 10 to 20 mm, creating a minimum area. *Significantly different from minimum area (*P*<.01).

Table 5

The major axis of the oval-shaped aperture of tunnels on the lateral femoral surface (%, mean±SD) PL side.

		Entry point distance (mm)		
		0–10mm	10–20mm	20–30mm
Entry Point Axis (°)	60°–90°	107.8 (n=1)		
	30°–60°	107.5* ±5.0 (n=8)	111.6±7.9 (n=15)	101.0 (n=1)
	0°–30°	119.7** ±8.6 (n=10)	113.3** ±7.7 (n=16)	
	−30°–0°	133.2** ±20.3 (n=6)	156.4** ±35.8 (n=2)	
	−30°–−60°	142.1** ±12.5 (n=4)	123.7** ±8.6 (n=3)	
	−60°–−90°	143.4** ±7.7 (n=4)		
	−90°–−120°	132.0** ±22.3 (n=2)	139.2 (n=1)	
	−120°–−150°			
	−150°–−180°	131.4** ±7.8 (n=2)		

PL=posteolateral, SD=standard deviation.

* The femoral tunnel elongation factor was the smallest at 107.5±5.0% when the entry point axis was between 30° to 60° and the entry point distance was between 0 to 10 mm.

** Significantly different from minimum area (*P*<.01).

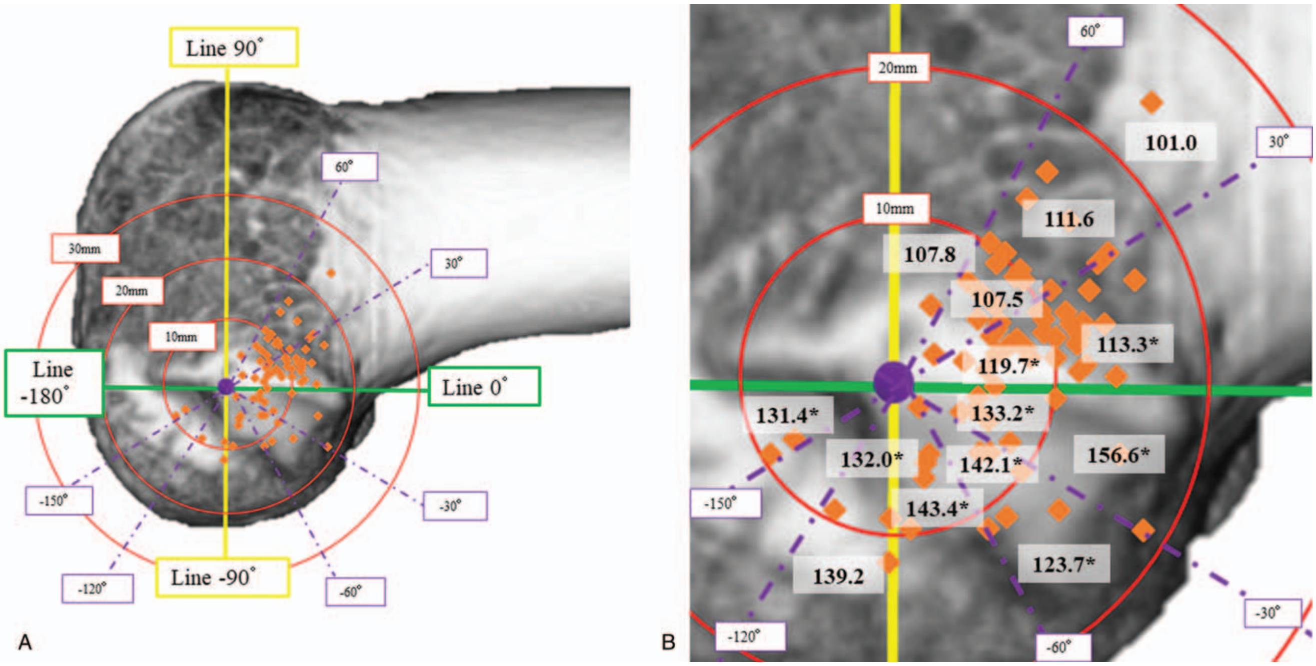

Figure 4. The femoral tunnel exit position; posterolateral (PL) side. (A). The positional relationship of the lateral aperture (orange dot) and lateral epicondyle (purple dot); PL side. The lateral apertures were created in varying positions, excepting anterodistally to the lateral epicondyle. Entry point axis: a line parallel to the femoral axis (green line) was drawn, and using the lateral epicondyle (purple dot) as a reference point, positive and negative deviations were defined as either anterior or posterior to the line (purple line), further divided in areas created by 30° intervals. Entry point distance: the distance between the lateral epicondyle and the center of the lateral aperture were divided in 10 mm increments (red circle with purple dot as center). (B) The average aperture elongation factor for each area; PL side. (A) was enlarged, and the average elongation factor was recorded for each area. The aperture elongation factor was 107.5% when the entry point axis was from 30° to 60° and the entry point distance was from 0 to 10 mm, creating a minimum area. * Significantly different from minimum area (*P* < .01).

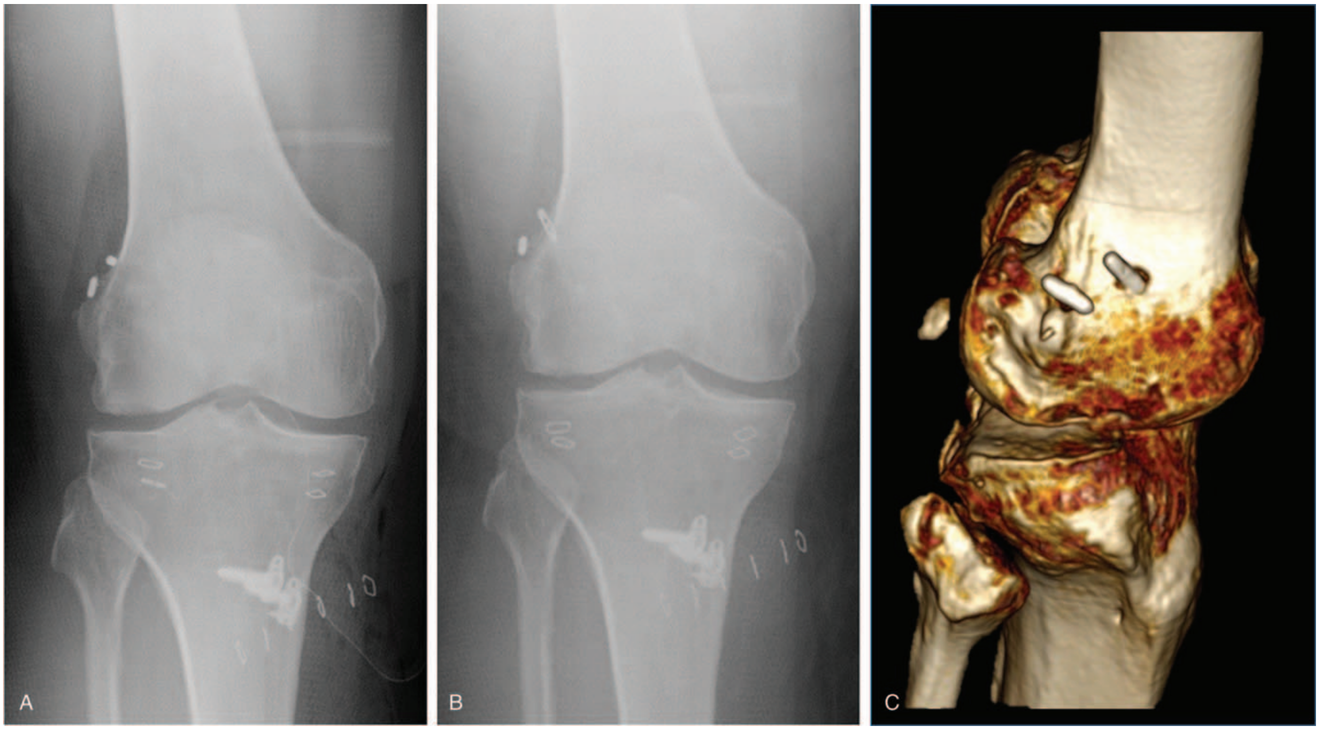

Figure 5. A case of intratunnel migration of cortical button. (A) was immediate postoperative anteroposterior radiograph. Secure fixation of the cortical button on the lateral femoral cortex was reconfirmed in the postoperative radiographs. (B)Five days postoperative anteroposterior radiograph. The cortical button of the anteromedial graft appears to have migrated within the bone (compared with the immediate postoperative radiographs). (C). One-week postoperative Computed tomography. Three-dimensional Computed tomography images show migration of the anteromedial cortical button.

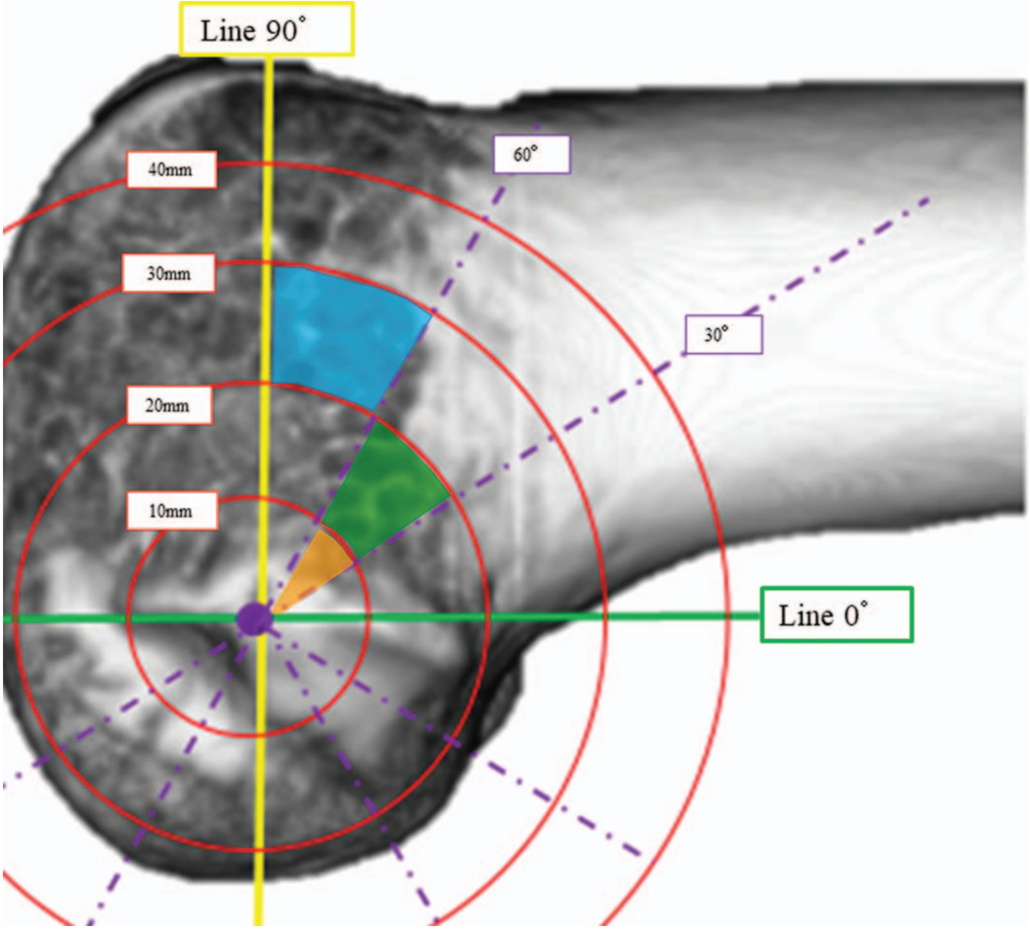

Figure 6. The minimum area of the anteromedial (AM) and posterolateral (PL) tunnels and their relationship to safe zones (compared within an area where n=4 or n>4). The ovalization is minimized in the area from 30° to 60°and 10 to 20 mm on the AM side (green area). Furthermore, the area from 60° to 90°and 20 to 30 mm (blue area) will not be significantly larger than the minimum area; thus, this area defines the area with minimal ovalization on the AM side (green and blue area). The ovalization is minimized in the area from 30° to 60°and 0 to 10 mm on the PL side (orange area). Furthermore, the area from 30° to 60°and 10 to 20 mm (green area) will not be significantly larger than the minimum area; thus, this area defines the area with minimal ovalization on the PL side (green and orange area). These minimum areas for both the AM and PL sides and their respective areas are in close proximity to each other (green area).

increased to 130.7% when introduced at 2 cm from the lateral epicondyle in a 45° anteroproximal direction. However, this report is based on computer simulation with ACL single bundle reconstruction and may be unsuitable for clinical cases that present greater variability. In our study using actual clinical cases, the aperture elongation factor was at minimum value in an area bounded by an entry point axis ranging from 30° to 60° and entry point distance between 10 and 20 mm on the AM side. On the PL side, the minimum area was bounded by an entry point axis from 30° to 60° and entry point distance between 0and 10 mm.

There have been several reports in the literature on the fixation failure of suspension devices.[29,30] However, the causes of failure have been largely unverified. This study suggested that postoperative failure within the bone tunnel may be affected by an unintended elongation of tunnel apertures for diameters exceeding 6 mm using the OI method. In addition, our study confirmed that an elongation exceeding 6 mm occurred even when a 4 mm drill was used. This poses 2 problems: first, even when using the recommended retrograde drill for the OI method, elongation cannot be completely prevented, since commercially available drill sleeves are generally larger than 4 mm, such as the common 4.2 (Arthrex, Naples, FL) or 5.2 mm (Smith & Nephew, Andover, MA) sleeves [31,32]; second, depending on the position of the aperture on the lateral femoral cortex under the commonly performed transtibial or FAM methods, there is risk for apertures to exceed 6 mm whereby the strength of fixation is decreased. Therefore, surgeons should bear in mind these aforementioned problems before using suspension devices.

5. Limitations

There are several limitations to this current study. Firstly, the morphology and size of the femoral condyles may differ by individual body types, race, and sex. The results in our study could possibly yield different results according to groups with differing race or body type. Secondly, the evaluation of button failure in this study was performed by CT when translation was suspected during routine radiographic evaluation. Because radiography alone may not have been sufficient, we believe that performing CT imaging of all cases during a certain prescribed period may have enabled a more accurate assessment of button failures. However, CT evaluations were not performed on all cases due to concerns regarding radiation exposure and cost, and CT imaging was only performed when button failure was suspected during routine radiographic evaluation. Thirdly, problems that arise from a normal anatomical ACL insertion site should be considered. There are numerous studies in the literature in terms of the position and morphology of normal ACL foot print[7,33–38] and each study describes contrasting views. As a result, the tunnel positioning differs according to the particular views of the surgeon. In this study, the targeted tunnel position was placed posterior to the resident's ridge and within an area surrounded by the posterior cartilage margin, and to the best of our ability, 2 bone tunnels were angled to prevent tunnel coalition in the above-mentioned area. However, differing targets for the anatomical tunnel position may produce contrasting results. Finally, causes of tunnel elongation immediately after surgery are not limited to the geometrical issues mentioned in this study, but can also be attributed to multifaceted problems involving the drilling itself, including the drill tip, sharpness of the drill, speed of drilling, quality of bone, and many others. However, in this study, the elongation factor for the major axis was approximately 120%, while the elongation factor for the minor axis was on average 102.3% or 103.0%. Elongation of the minor axis may be affected by factors other than geometrical issues, but the degree of elongation is small compared to the elongation of the major axis and does not significantly affect the results of this research. In other words, the elongation of the major axis on the lateral side can be largely attributed to geometrical issues.

6. Conclusion

The major axis elongated by approximately 120%, and the diameter of the aperture exceeded 6 mm at a frequency of 56% for AM and 30.7% for PL. The relative positional relationship with the lateral epicondyle affected the elongation (ovalization). Elongation did not directly affect the clinical outcome, but in all cases exhibiting intratunnel migration, the aperture exceeded 6 mm. Although a retrograde drill is recommended in all cases using the OI method, the diameter of the aperture on the lateral cortex cannot be completely controlled with its use. Even if another method is used, surgeons should recognize that depending on the position of the aperture, there is a risk for the aperture to exceed 6 mm, causing the button to fail.

Author contributions

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