Femoral Tunnel Apertures on the Lateral Cortex in Anterior Cruciate Ligament Reconstruction: An Analysis of Cortical Button Fixation

Ken Okazaki, M.D., Ph.D., Hirokazu Matsubara, M.D., Ph.D., Kanji Osaki, M.D., Yasutaka Tashiro, M.D., Ph.D., Hideki Mizu-uchi, M.D., Ph.D., Satoshi Hamai, M.D., Ph.D., Toshio Doi, M.D., Ph.D., and Yukihide Iwamoto, M.D., Ph.D.

Purpose: If the aperture of the oval-shaped femoral tunnel on the lateral cortex becomes bigger than half the size of the cortical button, the risk of fixation failure increases. This study investigated the effect of the location of the entry point and diameter of the femoral tunnel on the length of the major axis of the tunnel aperture in anterior cruciate ligament (ACL) reconstruction using an outside-in technique. **Methods:** Simulation of femoral tunnel drilling was performed on computed tomography (CT)-based 3-dimensional (3D) bone models obtained from 40 participants. The tunnel connected the center of the ACL footprint and various points on the lateral femoral surface. The diameter of the tunnel was set at 4.2 mm, 5.2 mm, or 6 mm, depending on the commercially available outside-in surgical systems (Arthrex, Naples, FL and Smith & Nephew, Andover, MA). The length of the major axis of the oval-shaped aperture on the lateral femoral surface was measured. **Results:** When the tunnel was introduced at 2 cm from the lateral epicondyle in a 45° anteroproximal direction, the major axis was lengthened to 130.7% ± 9.0% ($P < .001$) of the tunnel diameter, and it was more than 6.5 mm in 65% of participants in whom a 5.2-mm-diameter tunnel was drilled. When the entry point was 3 cm from the lateral epicondyle, 60% of participants had an oval-shaped aperture with a major axis of more than 6.5 mm, even though the diameter of the tunnel was only 4.2 mm. **Conclusions:** The risk of fixation failure of a cortical button increases if the entry point for drilling is 2 cm or further from the lateral epicondyle and the tunnel diameter is more than 5 mm. **Clinical Relevance:** This study indicates the potential risk of cortical button fixation failure caused by an oval tunnel aperture on the lateral femoral surface in ACL reconstruction using the outside-in technique.

Placement of grafts at an optimal position within the native attachment of the anterior cruciate ligament (ACL) is a crucial issue in anatomical ACL reconstruction. Because it is sometimes difficult to create a femoral tunnel at the anatomical ACL attachment using the conventional technique of femoral drilling through the tibial tunnel (the so-called transtibial drilling technique), alternative femoral drilling techniques have been advocated, e.g., the "transmedial portal technique" and the "outside-in technique."[1-6] The transmedial portal technique gives surgeons freedom in aiming the femoral ACL attachment when drilling. However, deep knee flexion and use of a low portal is required when drilling to avoid the risk of complications such as short femoral tunnels, posterior wall blowout, and injuries to the posterior cartilage or femoral nerve.[7-9]

The outside-in technique consists of targeting the femoral drilling site using an angle guide and a guide pin introduced from the lateral surface of the lateral femoral condyle. Although this technique requires another incision on the lateral side of the knee, it is relatively safe and easy to create femoral tunnels at the proper position because the surgeon can check the position of the guide pin both at the ACL attachment in the joint and at the lateral surface of the femoral condyle outside the joint while the knee is flexed at around 90°, which provides a familiar view for many surgeons.[1,10-12] Recently, several manufacturers have produced a retrograde reaming system, which allows

From Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan.

The authors report that they have no conflicts of interest in the authorship and publication of this article.

Received September 30, 2013; accepted March 6, 2014.

Address correspondence to Ken Okazaki, M.D., Ph.D., Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-0054, Japan. E-mail: okazaki@med.kyushu-u.ac.jp

0749-8063/13703/$36.00

http://dx.doi.org/10.1016/j.arthro.2014.03.004

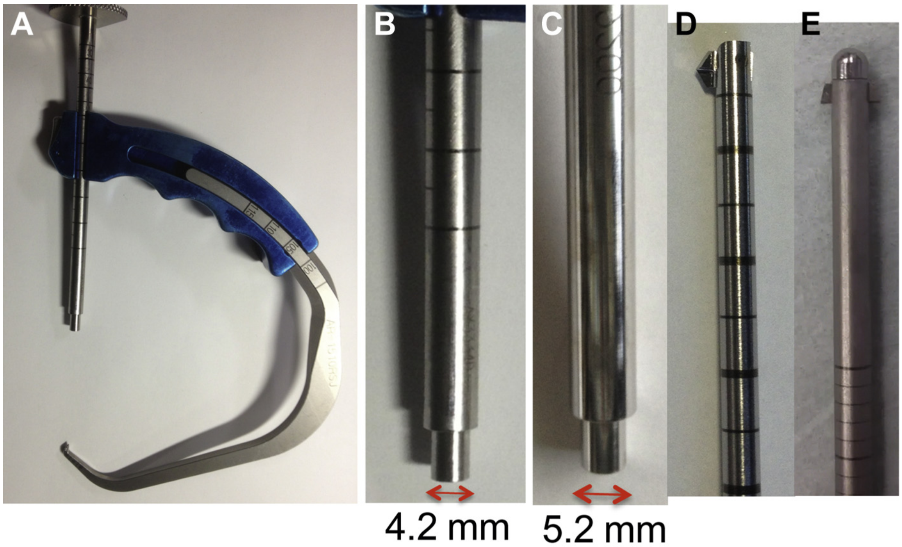

Fig 1. (A) The Arthrex surgical system for the outside-in drilling technique. A reaming guide for retrograde reaming is attached. (B) Magnified view of the tip of the reaming guide in the Arthrex system. The diameter of the tip that is introduced into the tunnel is 4.2 mm. (C) Magnified view of the tip of the reaming guide in a similar system by Smith & Nephew. The diameter of the tip is 5.2 mm. (D) The tip of the retrograde reamer of the Arthrex system (8 mm for the tip and 3.5 mm for the shaft). (E) The tip of the retrograde reamer of the Smith & Nephew system (8 mm for the tip and 4.5 mm for the shaft).

reaming of a large diameter tunnel through a narrow tunnel (e.g., FlipCutter [Arthrex, Naples, FL] and Endobutton retro drill [Smith & Nephew, Andover, MA]) (Fig 1). As a result, a cortical fixation button such as an Endobutton (Smith & Nephew) can be used with a minimal incision on the femoral side.

The development of these retrograde reaming systems has attracted more attention to the outside-in technique, especially from surgeons who use cortical buttons for fixation. However, we have encountered several cases in which one side of the cortical button had fallen into the tunnel. A computed tomographic image obtained a few weeks after the surgery showed that the tunnel aperture on the femoral lateral cortex was an oval larger than 7 mm on its major axis, whereas the button we used was 12 mm in length (Fig 2). Therefore, we considered that it poses a clinical risk to increase the major axis of the oval tunnel aperture by more than half the length of the fixation button when the tunnel is drilled at a low angle of incidence to the surface of the lateral femoral condyle, even though a retrograde reaming system was used.

The purpose of this study was to investigate the effect of the location of the femoral drilling entry point, using an outside-in technique, on the shape of the tunnel aperture on the lateral cortex of the femoral condyle. Our hypothesis was that the major axis of the oval-shaped aperture lengthens as the entry point of drilling in the outside-in technique moves away from the lateral epicondyle, and the length of the major axis can be more than half the length of cortical buttons.

Methods

Three-Dimensional Bone Model from Clinical CT Data

This study protocol was reviewed and approved by our institutional review board for the use of clinical CT data for reasons other than each patient's clinical requirements. CT data from 40 knees that underwent surgery in our hospital from 2008 to 2009 were used. The inclusion criteria were (1) age from 18 to 60 years and (2) no obvious osteoarthritis, fracture, deformity, or bone tumor on the femoral condyle. We included 23 men and 17 women with a mean age of 39.2 years (standard deviation, 11.6; range, 18-60 years). The participants were 166.2 ± 8.8 cm tall and weighed 64.0 ± 11.5 kg. All patients had intact femurs after epiphyseal arrest; their underlying diseases were vascular disorders (n = 3), fractures of the proximal tibia (n = 13) and patella (n = 4), ligament injuries (n = 6), tumorous diseases of the tibia (n = 9), degloving injury around the knee (n = 1), and healthy volunteers (n = 2). The 3-dimensional (3D) knee models were reconstructed from 0.67- to 1-mm slices of the CT data set, and the lateral half cross sections were obtained using 3D DICOM software, Mimics (Materialise, Leuven, Belgium).

Simulation of Femoral Tunnel Drilling Using the "Outside-In Technique"

At first, the point of the center of the femoral ACL attachment was determined. Because the CT model does not show the ACL itself, this point is determined by the bony morphologic features of the lateral intercondylar notch. The lateral intercondylar ridge (so-called resident's ridge)[13] and the lateral bifurcate ridge[14] and the ratio of the quadrant method[15,16] were used to determine the center of the ACL attachment. Next, to determine the entry points for drilling on the lateral femoral surface, 2 lines were drawn from the lateral epicondyle in an anteroproximal direction at 45° and 60° from the proximal-distal axis. The software enables us to point at the lateral epicondyle on the 3D bone model and draw lines on the projected lateral view. We can identify several points along this

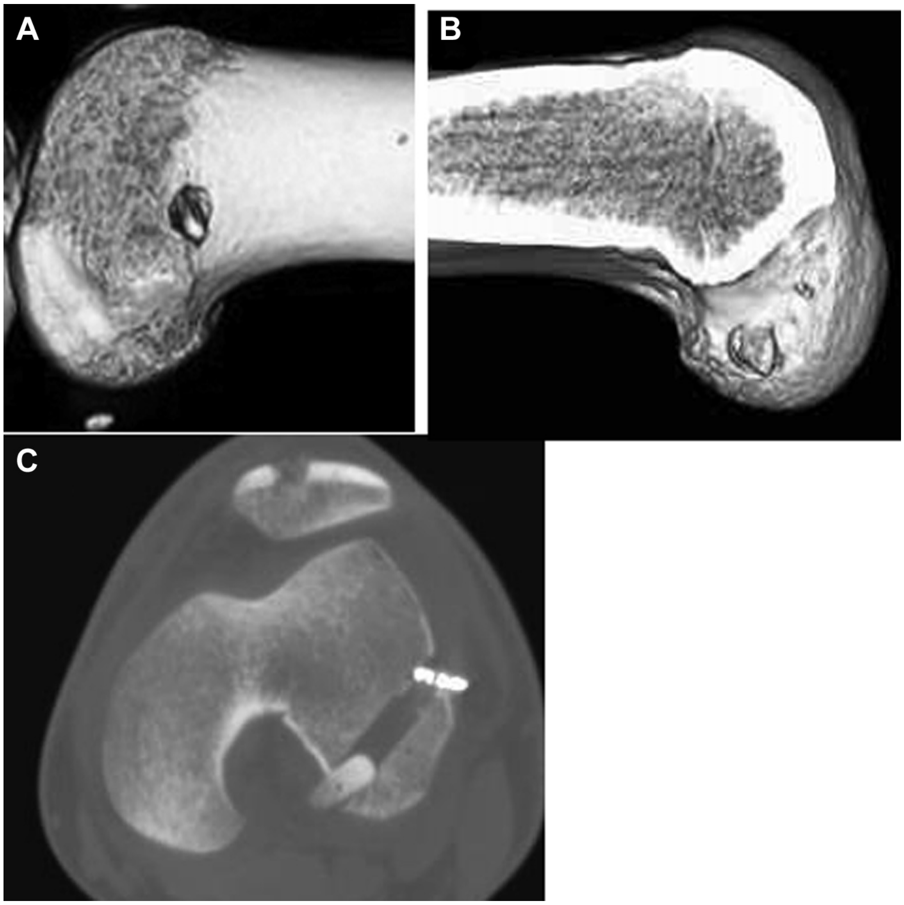

Fig 2. CT images of a patient who underwent ACL reconstruction with a 10-mm bone—patellar tendon—bone graft using the outside-in drilling technique with the Smith & Nephew system. (A) View of the lateral femur showing the oval-shaped tunnel aperture and that one end of the Endobutton had fallen into the tunnel. (B) View of ACL attachment. The tunnel is at the center of the attachment. (C) Transverse view showing that one end of the button had fallen into the tunnel. As a result, the graft had migrated into the joint.

projected line on the lateral femoral condyle of the 3D bone model. Three points were determined on each line apart from the lateral epicondyle as 1, 2, and 3 cm, respectively (Fig 3). To simulate drilling, we then connected the point within the ACL attachment and each point on the lateral surface of the femoral condyle with a cylinder to represent the drilled tunnel. The reason we used 45° and 60° from the proximal-distal axis is that our previous study showed that the area from 0° to 45° is covered with the attachment of the lateral head of the gastrocnemius and is not a suitable area for the cortical fixation.[17] The area from 60° to 90° was difficult to target in a clinical setting.

The diameter of drilling was determined according to the manufacturer's system. In these systems, tunnels are initially drilled with a relatively narrow reamer, which is 4.5 mm in the Smith & Nephew system and 3.5 mm in the Arthrex system. However, both systems require insertion of the reaming guide into the narrow tunnel for the subsequent retrograde reaming. The Smith & Nephew system uses a 5.2-mm-diameter reaming guide, and the Arthrex system uses a 4.2-mm-diameter reaming guide (Fig 1). Therefore, a cylinder of 5.2-mm diameter or 4.2-mm diameter was placed into the 3D bone model to simulate the aperture of tunnels on the lateral femoral surface made with a Smith & Nephew system or an Arthrex system, respectively. In addition, a 6-mm tunnel was also tested because some surgeons perform double-bundle ACL reconstruction using the outside-in technique with antegrade reaming systems for tunnels up to 6 mm diameter.[18] The aperture of the tunnel outlet on the lateral femoral surface is examined by measuring the major axis and minor axis on the femoral surface.

Drilling on the SawBone Model

To confirm the actual results obtained by the simulation on our 3D bone model, drilling was also performed in a similar setting on a SawBone (Orthofix, Lewisville, TX) model using the manufacturer's system. Three entry points at 1, 2, and 3 cm from the lateral epicondyle were determined at 45°. According to the system provided by Arthrex or Smith & Nephew, a reaming guide with a 4.2-mm or 5.2-mm diameter was introduced into the tunnels drilled with the 3.5-mm or 4.5-mm reamer, respectively. Because the shape of each SawBone is identical, one SawBone for each system was tested. The major axis of the oval-shaped aperture of the tunnel outlet on the lateral femoral surface was measured using a digital caliper, which has an accuracy of one decimal millimeter.

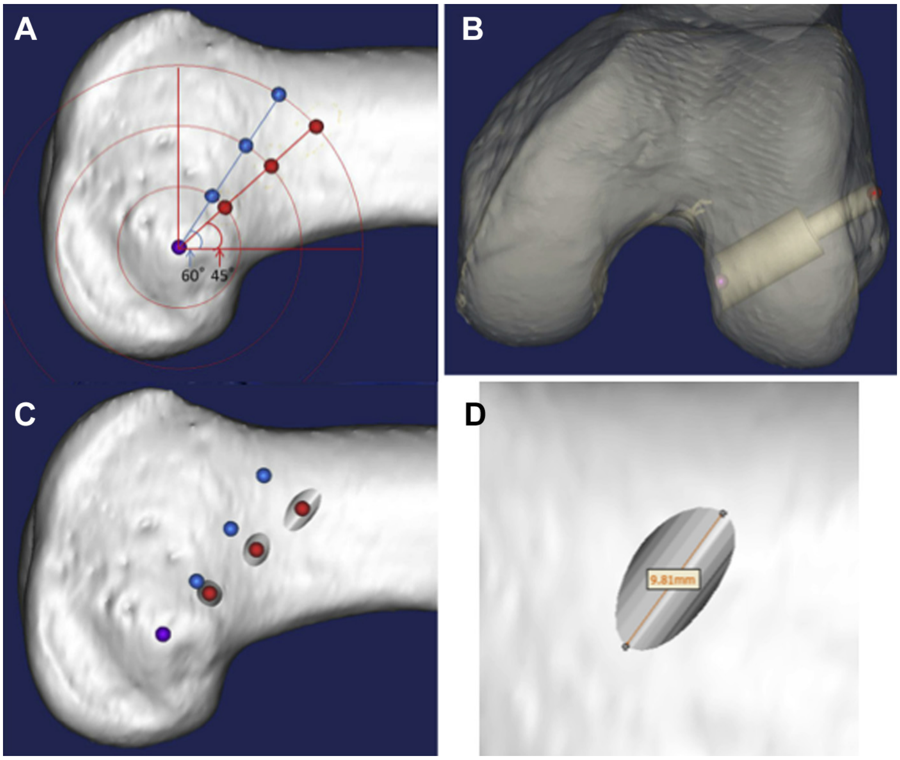

Fig 3. Simulated drilling on a CT-based 3-dimensional (3D) bone model. (A) Two lines are drawn from the lateral epicondyle in an anteroproximal direction in 45° and 60° from the proximal-distal axis to determine the entry points for drilling on the lateral femoral surface. Three points were then located on each line at a distance of 1, 2, and 3 cm from the lateral epicondyle. (B) A virtual tunnel can be created by connecting the ACL attachment and the entry point on the lateral condyle with a cylinder. The narrow cylinder represents the initial tunnel and the wider cylinder represents the retrograde reaming. (C) Apertures for a tunnel 4.2 mm diameter at the entry point on the 45° line are shown. The apertures are oval-shaped when the tunnel entry points are at 2 cm and 3 cm from the lateral epicondyle. (D) The software allows measurement of the length of the major axis of the oval-shaped aperture on the 3D bone model.

Statistical Analysis

The differences for the long axis of the oval-shaped aperture between the entry points were analyzed using the paired *t* test module of JMP 9.0 software (SAS Institute, Cary, NC).

Results

Simulation on 3D Bone Models

The increase in the major axis of the tunnel aperture on the lateral femoral surface was smallest at a point 1 cm away from the lateral epicondyle on either line at 45° or 60° (106.7% ± 2.8% and 107.2% ± 3.1%, respectively) (Fig 4). It significantly increased as the distance from the lateral epicondyle increased on either line ($P < .001$). When the point of drilling was 2 cm from the lateral epicondyle, the mean axis length increased by 130.7% and 128.1% on the line at 45° and 60°, respectively; both apertures increased, and the 5.2 mm diameter tunnel became more than 6.5 mm (line a on Fig 4; Table 1). If the major axis of the tunnel aperture becomes more than half the size of the cortical button, the risk of fixation failure increases. Because the length of the cortical fixation button is 12 mm for the Smith & Nephew device and 12.9 mm for the Arthrex device, the risk for the length of the major axis becoming more than 6.5 mm was evaluated. There were many participants in whom the major axis was longer than 6.5 mm after simulation of a 5.2-mm-diameter tunnel (Fig 5). When the drilling point was set at 3 cm away from the epicondyle, elongation of the major axis was more significant, especially at the 45° line (Fig 4A), and became more than 6.5 mm even after simulation of a 4.2-mm diameter (line b on Fig 4). It was more than 6.5 mm in 60% of participants with a 4.2-mm tunnel simulation at the 3-cm point on the 45° line (Fig 5). When 6-mm-diameter tunnels were simulated, the risk of the major axis becoming more than 6.5 mm was high at any drilling entry point (Fig 5). There was no difference between the minor axis of the aperture and the diameter of the tunnel for any of the tunnels.

Drilling on SawBone Models

Three entry points for drilling were determined on the lateral surface of the femoral condyle at 1, 2, and 3 cm apart from the lateral epicondyle to 45° in the anteroproximal direction (Fig 6). The angle of incidence for the drilling guide to the lateral surface of the femoral condyle decreased as the entry points became further from the lateral epicondyle (Fig 6A-C). Consequently, the major axis of the oval-shaped tunnel aperture became longer (Fig 6D and E). The length of the major axis to the diameter of the drilling guide increased by 127% at the entry point 2 cm from the lateral epicondyle and by approximately 150% at 3 cm from the epicondyle (Table 2). These results were consistent with those found after simulation with 3D bone models. The Smith & Nephew system created an oval-shaped tunnel aperture with a major axis more than 6.5 mm when an

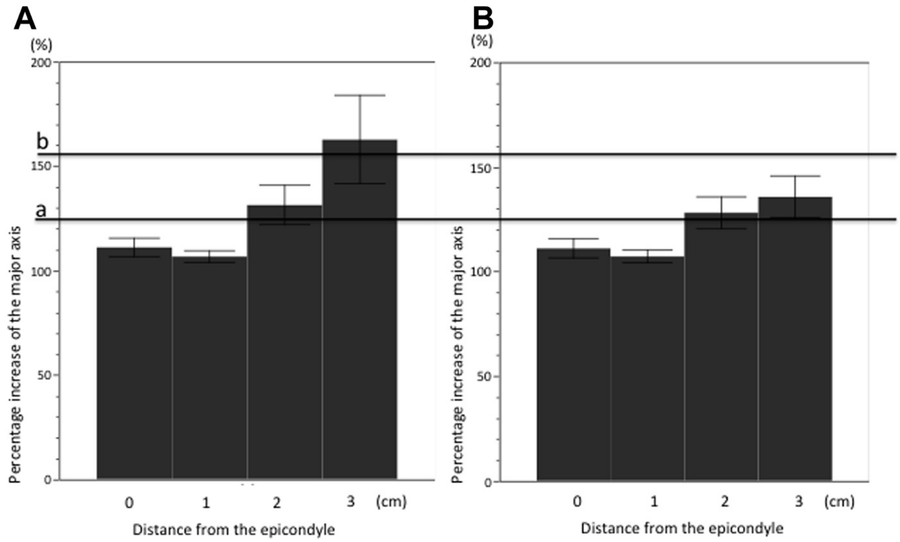

Fig 4. Lengthening of the major axis of the oval-shaped aperture on the lateral femoral surface (major axis/diameter of tunnel ×100). (A) Results for the entry points on the 45° line. (B) Results for entry points on the 60° line. Line "a" shows 125% lengthening of the major axis of the oval-shaped aperture to 6.5 mm for the 5.2-mm-diameter tunnel. Line "b" shows 155% lengthening of the major axis of the oval-shaped aperture to 6.5 mm for the 4.2-mm-diameter tunnel.

entry point of 2 cm from the lateral epicondyle was used, whereas the Arthrex system created a tunnel aperture major axis of more than 6.5 mm with an entry point 3 cm from the epicondyle.

Discussion

This study found that the aperture of the ACL reconstruction tunnel on the lateral surface of the femoral condyle will be oval-shaped. As the tunnel entry point in the outside-in femoral drilling technique moves away from the lateral epicondyle, the angle of incidence to the femoral surface becomes smaller and the major axis of the oval-shaped aperture becomes longer. If the major axis becomes longer than half the size of the cortical fixation button, the risk of fixation failure from the button falling into the tunnel increases (Fig 2). If a surgeon uses a button 12 to 13 mm length (Fig 6F), 6.5 mm is the critical length of the major axis for this risk. When the entry point is 2 cm away from the lateral epicondyle, the major axis of the aperture becomes more than 25% longer than the diameter of tunnel. In this situation, the major axis of the oval aperture of a tunnel with a 5.2-mm diameter will be more than 6.5 mm, which is longer than half the size of cortical fixation buttons 12 to 13 mm length. The risk for the major axis becoming longer than 6.5 mm when using the 5.2-mm-diameter tunnel was 0% at 1 cm, 67.2% at 2 cm, and 100% at 3 cm on the 45° line.

One of the advantages of the outside-in drilling technique compared with the transmedial portal drilling technique is that it allows surgeons more freedom in setting the location of the tunnel outlet, not only at the ACL attachment inside the joint but also at the lateral surface of the femoral condyle outside the joint, whereas it is difficult to control the location of tunnel outlet on the lateral femoral surface using the transmedial portal drilling technique. The posterior area of the lateral surface of the femoral condyle is covered with the attachment of the lateral head of the gastrocnemius or lateral collateral ligament.[19] A soft tissue interposition between the button and femoral cortex is another complication related to the use of cortical buttons.[17] Additionally, the tunnel length would be short when the tunnel outlet is located at the posterior area of the femoral condyle.[9,20] Therefore, surgeons may attempt to place the entry point for drilling for the outside-in technique in a more anterior region to avoid a short tunnel or placing the fixation button at the thick muscle of the lateral head of the gastrocnemius. Furthermore, Lubowitz et al.[21] recently reported that drilling with an entrance angle of 60° to a line perpendicular to the femoral anatomical axis, combined with an angle of 20° to the transepicondylar axis, resulted in optimal reconstruction of the normal human anatomical ACL femoral footprint length, width, area, and angular orientation. With this information,

Table 1. The Major Axis of the Oval-Shaped Aperture of Tunnels on the Lateral Femoral Surface (mm, mean ± SD)

	Distance from the Lateral Epicondyle						
		Line at 45°			Line at 60°		
Diameter of Tunnel	0 cm	1 cm	2 cm	3 cm	1 cm	2 cm	3 cm
4.2 mm	4.7 ± 0.2	4.5 ± 0.1	5.5 ± 0.4	6.7 ± 0.8	4.5 ± 0.1	5.4 ± 0.3	5.7 ± 0.4
5.2 mm	5.8 ± 0.2	5.5 ± 0.1	6.8 ± 0.4	8.3 ± 1.0	5.6 ± 0.2	6.7 ± 0.4	7.1 ± 0.5
6.0 mm	6.7 ± 0.3	6.4 ± 0.2	7.8 ± 0.5	9.6 ± 1.2	6.4 ± 0.2	7.7 ± 0.5	8.2 ± 0.6

SD, standard deviation.

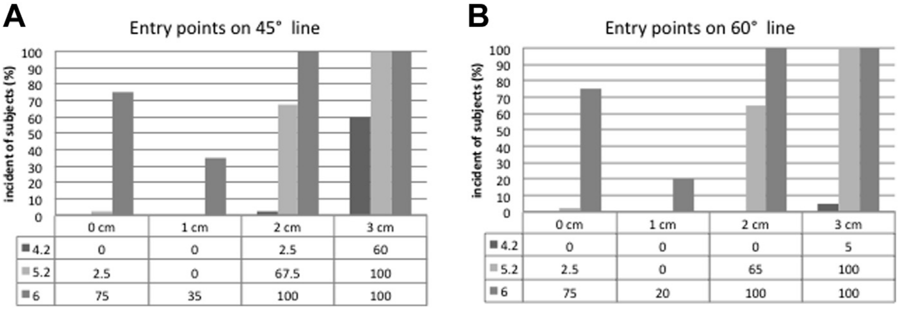

Fig 5. Incidence of participants in whom the major axis of the oval aperture is more than 6.5 mm (%, n = 40). Results for drilling with 4.2-mm, 5.2-mm, and 6-mm-diameter holes on the 4 entry points on the (A) 45° line or on the (B) 60° line.

surgeons might try to place the drilling entry point anteriorly and proximally. However, surgeons should also be aware that excessive angulation of drilling toward the surface of the femur will result in excessive length of the major axis of the oval-shaped tunnel aperture on the surface of the femur, increasing the risk of button fixation failure.

Both the diameter of the tunnel and the size of the fixation button affect the risk of fixation failure because of an increase in tunnel aperture size. Some surgeons use antegrade drilling up to 6 mm in diameter for double-bundle ACL reconstruction with the outside-in technique.[11,18] Although a 6-mm diameter is half the size of an Endobutton, surgeons should recognize that the tunnel aperture will be oval-shaped and its major axis will easily be longer than half the size of an Endobutton when using a 6-mm-diameter tunnel. The development of a retrograde reaming system has enabled the use of cortical button fixation for any diameter tunnel in either single-bundle or double-bundle reconstruction when using the outside-in technique. The Smith & Nephew system uses a

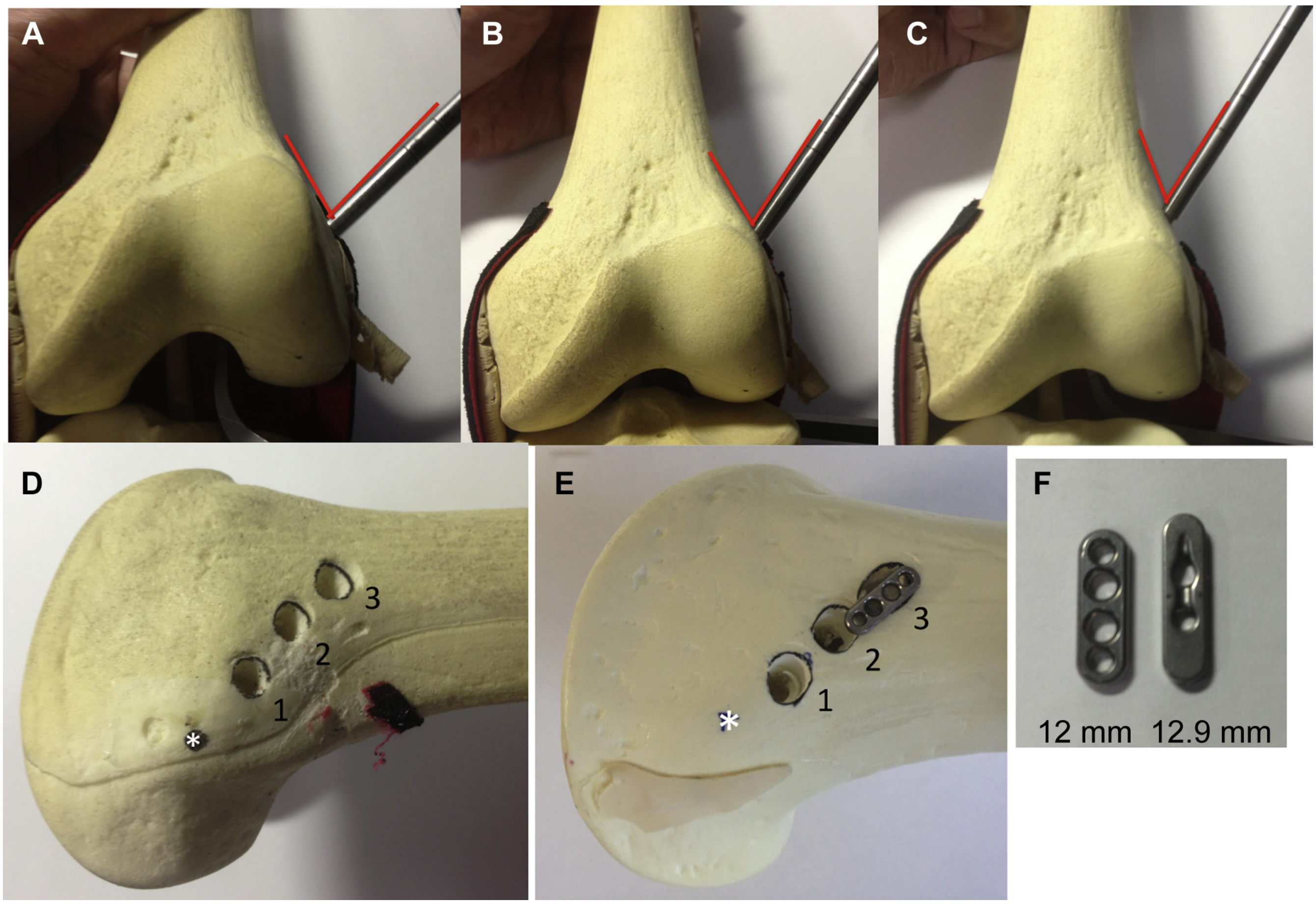

Fig 6. Drilling on the SawBone models. A drilling guide is introduced at the (A) 1-cm, (B) 2-cm, and (C) 3-cm entry points. The angle of incidence is decreased when the entry point is moved further away from the epicondyle. (D and E) The tunnel created at the entry points 1, 2, and 3 cm away from the epicondyle in an anteroproximal direction at 45°. D shows the 4.2-mm diameter. E shows the 5.2-mm diameter (F) Fixation buttons from Smith & Nephew (left) and Arthrex (right).

Table 2. Length of the Major Axis and Its Percentage Increase in the SawBone Model Drilling

Diameter of Tunnel	Distance from the Lateral Epicondyle 1 cm	2 cm	3 cm
4.2 mm			
Length of major axis	4.5 mm	5.3 mm	6.5 mm
Percentage increase (%)	107	127	155
5.2 mm			
Length of major axis	5.7 mm	6.6 mm	7.6 mm
Percentage increase (%)	110	127	146

5.2-mm-diameter reaming guide after 4.5-mm-diameter drilling, whereas the Arthrex system uses a 4.2-mm-diameter reaming guide after 3.5-mm-diameter drilling. Surgeons should be aware that although a tunnel is drilled with a relatively narrow reamer, such as 4.5 mm or 3.5 mm, the diameter of the reaming guide that is introduced at the entry point on the lateral surface is wider at 5.2 mm and 4.2 mm, respectively. The current study indicates that a 4.2-mm-diameter tunnel had a low risk of having an oval-shaped aperture with a major axis in excess of 6.5 mm when the entry point was set within 2 cm from the epicondyle. Moreover, the length of button of Smith & Nephew is 12 mm, whereas that of the Arthrex system is 12.9 mm (Fig 6F). Therefore, the Arthrex system should theoretically have less risk of button fixation failure caused by increased tunnel aperture diameter at low angles of incidence. There are many other cortical fixation systems available. Surgeons should be aware of the size of the cortical button and the diameter of tunnels on the lateral cortex for whatever surgical system they use.

The major axis of the oval-shaped tunnel aperture on the lateral surface of the femoral condyle lengthens as femoral drilling using the outside-in technique is introduced at points further from the lateral epicondyle as the angle of incidence to the femoral surface becomes shallower. If the surgical system requires a tunnel diameter to be more than 5 mm, there is considerable risk of the long axis being longer than half the size of the fixation button when drilling is started at 2 cm or further from the lateral epicondyle. It is recommended that the entry point of drilling be retained within 2 cm from the lateral epicondyle, especially when creating a tunnel of more than 5-mm diameter. It may also be recommended that the direction of the long axis of buttons be perpendicular to the major axis of the oval-shaped aperture because the minor axis of the tunnel aperture did not lengthen in our study.

Limitations

First, the results from simulated drilling on a 3D-bone model may not be the same as those of actual drilling. However, by comparing the model with other methods, such as the use of a cadaver, the simulation allows comparison of multiple settings and diameters under the same conditions for many samples. The utility of the results was confirmed by the actual drilling on a SawBone model. Second, different entry points may yield different results. We did not assess the area less than 45° from the proximal-distal axis because this area is covered by attachment of the lateral head of the gastrocnemius and is not suitable for cortical fixation. An area of more than 60° is not practical in a clinical setting. However, the fact that drilling at an oblique angle to the femoral surface increases the major axis of the oval-shaped tunnel aperture would not change. Third, the center of the ACL attachment was determined based on the bony morphologic features of the intercondylar notch and may not be correct. Nevertheless, surgeons are likely to determine the point in a similar manner in cases of ACL reconstruction in a clinical setting. Finally, we defined the entry point by the distance from the epicondyle. Some surgeons may prefer to determine the entry point by the angle of the guide in reference to the femoral axis.[21] When we measured the angle of the tunnel in this study, the point 2 cm apart from the lateral epicondyle on the 45° line was 44.8° ± 7.2° (range, 26.0° to 60.1°) to a line perpendicular to the femoral axis and 54.9° ± 3.1° (range, 47.5° to 62.1°) to the epicondylar axis. The angles varied depending on the morphologic features of the condyle. It could be difficult to measure accurately a distance on the femoral condyle in a small incision during the operation. However, our clinical message is to maintain the distance within 2 cm, which is feasible during the operation.

Conclusions

The risk of fixation failure of a cortical button increases if the entry point for drilling is 2 cm or further from the lateral epicondyle and the tunnel diameter is more than 5 mm.

References

1. Logan JS, Elliot RR, Wilson AJ. TransLateral ACL reconstruction: A technique for anatomic anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2012;20:1289-1292.
2. 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.
3. Golish SR, Baumfeld JA, Schoderbek RJ, Miller MD. The effect of femoral tunnel starting position on tunnel length in anterior cruciate ligament reconstruction: A cadaveric study. *Arthroscopy* 2007;23:1187-1192.
4. Kaseta MK, DeFrate LE, Charnock BL, Sullivan RT, Garrett WE Jr. Reconstruction technique affects femoral tunnel placement in ACL reconstruction. *Clin Orthop Relat Res* 2008;466:1467-1474.
5. 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.
6. Gadikota HR, Sim JA, Hosseini A, Gill TJ, Li G. The relationship between femoral tunnels created by the transtibial, anteromedial portal, and outside-in techniques and the anterior cruciate ligament footprint. *Am J Sports Med* 2012;40:882-888.
7. Lubowitz JH. Anteromedial portal technique for the anterior cruciate ligament femoral socket: Pitfalls and solutions. *Arthroscopy* 2009;25:95-101.
8. Ilahi OA, Ventura NJ, Qadeer AA. Femoral tunnel length: Accessory anteromedial portal drilling versus transtibial drilling. *Arthroscopy* 2012;28:486-491.
9. Basdekis G, Abisafi C, Christel P. Effect of knee flexion angle on length and orientation of posterolateral femoral tunnel drilled through anteromedial portal during anatomic double-bundle anterior cruciate ligament reconstruction. *Arthroscopy* 2009;25:1108-1114.
10. Lubowitz JH, Konicek J. Anterior cruciate ligament femoral tunnel length: Cadaveric analysis comparing anteromedial portal versus outside-in technique. *Arthroscopy* 2010;26:1357-1362.
11. Lee YS, Sim JA, Kwak JH, Nam SW, Kim KH, Lee BK. Comparative analysis of femoral tunnels between outside-in and transtibial double-bundle anterior cruciate ligament reconstruction: A 3-dimensional computed tomography study. *Arthroscopy* 2012;28:1417-1423.
12. Arnold MP, Duthon V, Neyret P, Hirschmann MT. Double incision iso-anatomical ACL reconstruction: The freedom to place the femoral tunnel within the anatomical attachment site without exception. *Int Orthop* 2013;37:247-251.
13. Shino K, Suzuki T, Iwahashi T, et al. The resident's ridge as an arthroscopic landmark for anatomical femoral tunnel drilling in ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2010;18:1164-1168.
14. Ferretti M, Ekdahl M, Shen W, Fu FH. Osseous landmarks of the femoral attachment of the anterior cruciate ligament: an anatomic study. *Arthroscopy* 2007;23:1218-1225.
15. Bernard M, Hertel P, Hornung H, Cierpinski T. Femoral insertion of the ACL. Radiographic quadrant method. *Am J Knee Surg* 1997;10:14-21; discussion 21-22.
16. Forsythe B, Kopf S, Wong AK, et al. The location of femoral and tibial tunnels in anatomic double-bundle anterior cruciate ligament reconstruction analyzed by three-dimensional computed tomography models. *J Bone Joint Surg Am* 2010;92:1418-1426.
17. Osaki K, Okazaki K, Tashiro Y, Matsubara H, Iwamoto Y. Influences of knee flexion angle and portal position on the location of femoral tunnel outlet in anterior cruciate ligament reconstruction with anteromedial portal technique. *Knee Surg Sports Traumatol Arthrosc* October 9, 2013 [Epub ahead print].
18. Mae T, Shino K, Matsumoto N, Yoneda K, Yoshikawa H, Nakata K. Immediate postoperative anterior knee stability: Double- versus triple-bundle anterior cruciate ligament reconstructions. *Arthroscopy* 2013;29:213-219.
19. Farrow LD, Parker RD. The relationship of lateral anatomic structures to exiting guide pins during femoral tunnel preparation utilizing an accessory medial portal. *Knee Surg Sports Traumatol Arthrosc* 2010;18:747-753.
20. Kim JG, Wang JH, Ahn JH, Kim HJ, Lim HC. Comparison of femoral tunnel length between transportal and retrograde reaming outside-in techniques in anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2013;21:830-838.
21. Lubowitz JH, Akhavan S, Waterman BR, Aalami-Harandi A, Konicek J. Technique for creating the anterior cruciate ligament femoral socket: Optimizing femoral footprint anatomic restoration using outside-in drilling. *Arthroscopy* 2013;29:522-528.