Validation of a New Technique to Determine Midbundle Femoral Tunnel Position in Anterior Cruciate Ligament Reconstruction Using 3-Dimensional Computed Tomography Analysis

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Purpose: The purpose of this study was to investigate and report on a new intraoperative measuring technique to place the anterior cruciate ligament (ACL) femoral tunnel in the center of the native ACL femoral insertion site. **Methods:** We investigated a novel measuring technique based on identifying the proximal border of the articular cartilage and using a specific ruler parallel to the femoral axis to locate the origin of the ACL. The accuracy of this technique was validated by measuring tunnel position on postoperative 3-dimensional computed tomography scans. Bony tunnels created by the ruler technique were compared with tunnels drilled by a traditional technique referenced from the back wall of the notch. **Results:** Fifty ACL reconstructions were performed by the novel measuring technique, with placement of the femoral tunnel at the center of the femoral insertion. The mean position for the center of the femoral tunnel measured by the ruler technique was 0.9 mm from the theoretic optimal center position but was a very distinct 5 mm from the mean position in the traditional tunnels. **Conclusions:** The ruler technique produced femoral tunnels comparable to published radiographic criteria used for tunnel placement and is reproducible and accurate. We recommend placement of the femoral tunnel at the midpoint of the lateral femoral condyle when using the anatomic single-bundle technique. **Level of Evidence:** Level IV, case series.

The ultimate goal of anterior cruciate ligament (ACL) reconstruction is the restoration of normal knee kinematics in patients with functionally unstable ACL-deficient knees. It has been hypothesized that abnormal knee kinematics is one of the primary causes of the development of osteoarthritis after ACL reconstruction.[1,2] It is hoped that a more anatomic ACL reconstruction will reduce the long-term incidence of osteoarthritis. The femoral tunnel has a major effect on the length-tension pattern of the reconstruction, and nonanatomic femoral tunnel placement is one of the most common causes of a failed ACL reconstruction.[3] Surgical techniques for placement of the femoral tunnel previously have been based on the concept of ACL graft isometry[4] or the use of offset femoral guides that reference the over-the-top position of the lateral femoral condyle. In the 1990s the transtibial technique was developed as a quick reproducible method; the femoral tunnel is drilled through the tibial tunnel by use of an offset femoral drill guide, and both tunnels are therefore effectively linked. Independent drilling methods can produce tunnels with superior function compared with tunnels produced by conven-

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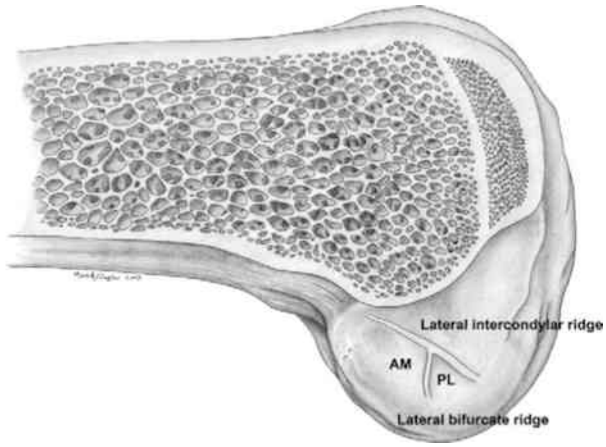

FIGURE 1. Lateral wall of intercondylar notch showing lateral intercondylar and lateral bifurcate ridges together with origins of anteromedial (AM) and posterolateral (PL) bundles. (Reprinted with permission.[10])

tional transtibial drilling methods.[5] Transtibial tunnel drilling has been shown to produce a high nonanatomic femoral tunnel that is located outside the native femoral ACL insertion site.[6,7] Recognition that transtibial tunnel drilling results in a nonanatomic vertically oriented femoral tunnel has led to increasing interest in surgical techniques that position the femoral tunnel within the footprint of the native ACL.[8-10]

The native ACL femoral insertion site is located along osseous landmarks on the posterior aspect of the medial wall of the lateral femoral condyle, that is, the lateral intercondylar and bifurcate ridges (Fig 1).[10] Identification of these ridges has been shown to be an accurate and reliable method to locate the native ACL femoral insertion site and the true entry point for the femoral tunnel.[9] The presence of these ridges is variable, however, and they may not be seen.[11] Identification of the lateral intercondylar ridge has been described in 100% of 60 knees at arthroscopy and the bifurcate ridge in 82% in one series[10] and 88% and 48%, respectively, in another.[12]

In the absence of consistent intraoperative visualization, knee surgeons have used a variety of methods, such as preoperative and intraoperative radiographic images, computer navigation, and arthroscopic measuring devices with triangulation, to locate the native ACL femoral insertion site.[13-16] Radiological techniques use the Bernard-Hertel radiographic quadrant method on a true lateral image to define the insertion point of the ACL.[17] This requires an intraoperative true lateral view on an image intensifier; though accurate, this adds to the complexity and cost of the procedure, making its use potentially unpopular. Three-dimensional (3D) computed tomography (CT) has been used to validate femoral tunnel position postoperatively.[18-20] Kaseta et al.[21] noted that the center of the ACL was within 2 mm of an arthroscopic reference point located at the junction of a line drawn distally from the most proximal corner of the articular margin on the lateral wall of the notch and a perpendicular line drawn to the most posterior point of the condyle.

Double-bundle ACL reconstruction has been developed in an attempt to improve rotational stability and restore more normal kinematics to the knee. Biomechanical and some early clinical studies have shown promising results when double-bundle techniques have been compared with traditional techniques.[22-27] Notably, a recent review by van Eck et al.[22] has questioned how many double-bundle studies are truly anatomic. In addition, the double-bundle surgical technique is complex, as well as more time-consuming and technically difficult, precluding its widespread acceptance and adoption by ACL surgeons. In the smaller knee, double-bundle ACL reconstruction can even lead to a nonanatomic position.[28] On the basis of clinical studies, placement of a single-bundle graft in the midbundle position of the femoral footprint has been advocated.[29]

The purpose of this study was to investigate and report on a new intraoperative measuring technique to locate the center of the ACL femoral insertion site, as well as to validate the method by use of postoperative 3D CT scans comparing the tunnel position with published radiographic measurements and with our previous anteromedial (AM) portal surgical technique using an offset guide. Our hypothesis was that the midcondylar measuring technique would reproduce the midbundle position on the wall of the lateral femoral condyle and be an accurate method for placing an anatomic single-bundle femoral tunnel during ACL reconstruction.

METHODS

Fifty-five consecutive, functionally unstable, ACL-deficient patients underwent ACL reconstruction by use of a femoral tunnel in the anatomic position on the medial wall of the lateral femoral condyle with the described technique. CT scans were performed postoperatively, and reconstructive images were used to measure the tunnel position as referenced from the posterior aspect of the lateral femoral condyle and the roof of the intercondylar notch. The precise details of the anatomic technique and CT analysis are described later. These patients comprised the anatomic group.

CT analysis was performed in an additional 16 patients in whom the femoral tunnel had been located by use of a 5-mm offset jig referenced from the posterior wall of the notch, comprising the traditional group. This group consisted of patients who had undergone surgery more than 6 months previously with good clinical results and who were seen for routine follow-up or for unrelated reasons, thereby forming a representative sample for the determination of tunnel position in patients before the introduction of the new technique.

In both groups we prepared tunnels for insertion of the graft using an EndoButton fixation device (Smith & Nephew, Andover, MA) on the femur and an interference fit screw on the tibia applied with the use of a tensioner system (ExtraLok screw and SE tensioner; Linvatec, Largo, FL).

Anatomic Operative Technique

The patient is placed supine on the operating table. Ipsilateral semitendinosus and gracilis tendons are harvested and prepared into a 4-strand graft by use of a whip stitch.

Three arthroscopic portals are then made in the knee to allow optimal vision and instrumentation.[30] A high anterolateral (AL) portal is made at the level of the inferior pole of the patella, adjacent to the lateral border of the patellar tendon. A high AM visualization portal is inserted at the level of the inferior pole of the patella, adjacent to the medial border of the patellar tendon. Finally, an accessory anteromedial (AAM) portal is located inferior and medial to the AM portal, just above the level of the medial meniscus.[31] This portal is made under direct vision to avoid damage to the medial meniscus.

The notch is prepared by use of an arthroscopic shaver device to remove scar tissue and the remaining ACL stump, with care taken to preserve the bony anatomy (Fig 2A). A radiofrequency probe (MultiVac 50; ArthroCare, Austin, TX) is then used to remove the residual ACL stump and to identify the proximal margin of the articular cartilage as a specific reference point.

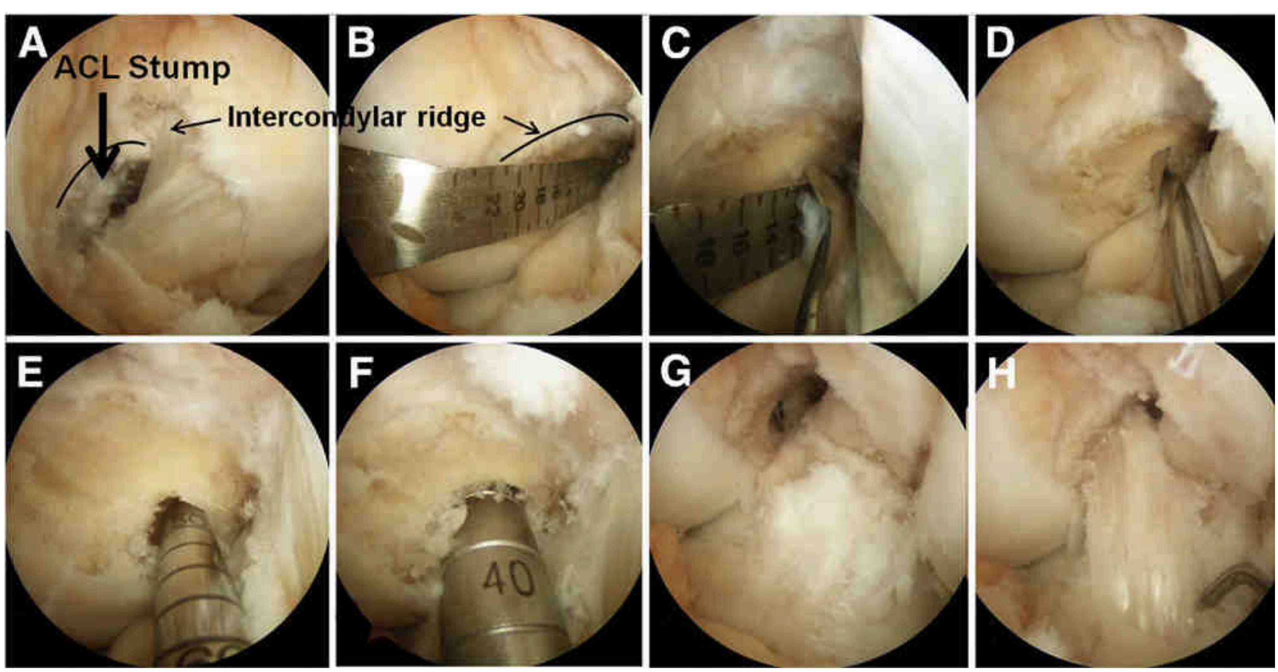

FIGURE 2. (A) Lateral wall of intercondylar notch viewed from AM portal. The main bulk of the ACL has been removed. Additional soft tissue has yet to be removed with the radiofrequency probe. (B) The ruler is positioned on the side wall of the notch with the end at the proximal border of the articular margin deep in the notch. The shallow/distal end of the ruler measures 22 mm. (C) A microfracture pick marks the midpoint of the side wall at 11 mm, on the visible bifurcate ridge and below and posterior to the intercondylar ridge. (D) The guidewire is positioned at the mark, before flexion of the knee to 120°. (E) The EndoButton drill is hooked onto the lateral wall of the femur measuring 50 mm, indicating that the true length of the tunnel is 40 mm. (F) The ACL reamer is drilled to 35 mm allowing for turning or flipping of the EndoButton when inserted. (G) The resultant femoral tunnel in midposition with the knee repositioned at 90° of knee flexion. (H) The final view of the ACL graft viewed through the AM portal.

A 6-mm-wide arthroscopic ruler (Smith & Nephew) curved to shape is inserted through the AL portal, placed against the lateral wall of the notch, and viewed through the high AM portal. Ensuring that the knee is flexed to 90°, the surgeon positions the tip of the ruler deep[32] in the notch at the identified and prepared junction of the proximal articular margin and the femur (Fig 2B). This is slightly lower on the arthroscopic view or more posterior anatomically than the "over-the-top" point. The length of the femoral condyle from deep in the notch to shallow (anatomically proximal to distal) is then measured on the "high" side of the ruler, and the midpoint is marked with a microfracture awl inserted through the AAM portal (Fig 2C). The height of the entry point is determined by the diameter of the tunnel. We aim to leave a 2-mm bridge of bone between the tunnel wall and the articular margin on the low (anatomically posterior) aspect of the notch. This usually corresponds to the top edge of the arthroscopic ruler. A drill-tip guidewire with an eye in the opposite end is inserted through the AAM portal and tapped 2 to 3 mm into the mark (Fig 2D); the knee is then flexed to 120°, and the guidewire is drilled out through the lateral condyle and skin. The wire is over-drilled with the 4.5-mm EndoButton drill and the length measured by hooking the drill part of the EndoButton drill on the lateral cortex and deducting 10 mm from the measurement viewed with the arthroscope (Fig 2E). An appropriately sized drill is then used to create the femoral tunnel, with care taken not to scuff the articular surface of the medial femoral condyle (Fig 2F). The resulting femoral tunnel can be visualized at the mid-bundle position with the knee repositioned at 90° of knee flexion. A lead suture is passed into the mouth of the tunnel (Fig 2G).

The exit point of the tibial tunnel into the knee is referenced from just anterior to the posterior rim of the anterior horn of the lateral meniscus, within the midpoint of the tibial footprint.[30,33] An increased jig angle of 50° may be required to produce a tibial tunnel that is adequate in length for the fixation screw. The lead suture is pulled down through the tibial tunnel, and the graft is passed through the knee and looped through an appropriate EndoButton (usually 15 mm). The graft is fixed in the tibia with the knee in extension by use of an interference screw (Fig 2H).

Traditional Operative Technique

In the traditional technique the center of the femoral tunnel is located by use of a 5-mm offset jig (Linvatec) inserted through the AM portal. The notch is cleared of soft tissue with a shaver, and the over-the-top position is identified deep in the notch. The 5-mm offset jig is positioned in this space and the knee bent to 120°. The guidewire is then inserted as dictated by the jig and the tunnel drilled while the surgeon is viewing from the AL portal at a 9:30 or 2:30 clock-face position.[34] A lead suture is passed in preparation for the ACL graft, and the knee is brought back to 0°.

Radiographic 3D CT Scan Analysis

Between 6 and 12 weeks after surgery, a 3D CT scan was obtained with a slice acquisition thickness of 1.25 mm. The scan was then oriented into a true lateral position so that both condyles were superimposed and the medial femoral condyle was removed. The center of the femoral tunnel was determined by use of the grid system described by Bernard and Hertel.[17] The grid was positioned so that the superior arm was against the roof of the notch corresponding to the Blumensaat line and the posterior section was against the posterior aspect of the lateral femoral condyle. The location of each tunnel on this grid was recorded and expressed as coordinates along the Blumensaat line from proximal to distal and

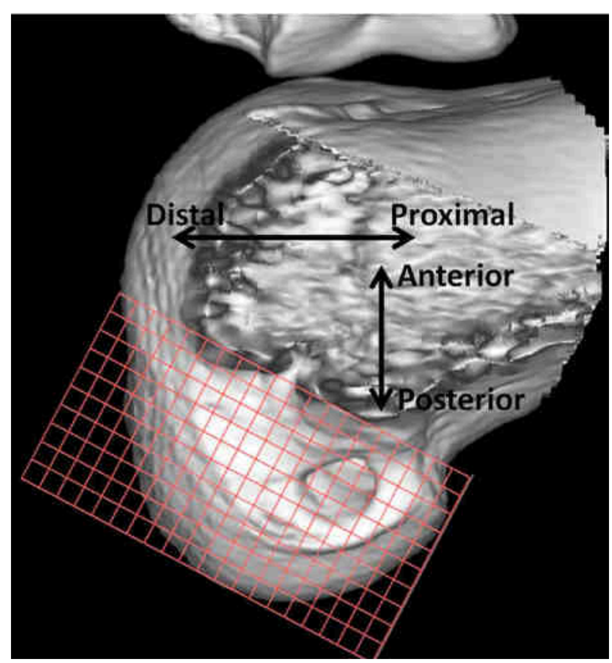

FIGURE 3. Sagittal section through the intercondylar notch showing the lateral wall to which the grid of Bernard and Hertel[17] has been applied.

along the opposite axis for anterior to posterior (Fig 3). The mean positions for the anatomic group and the traditional group were then calculated and related to the optimal position. We determined this optimal position by using the mean coordinates reported by previous authors (Table 1).[16,17,20,32,35,36] This put the mean midbundle position at a point at 28% on the proximal-to-distal axis and 35% on the perpendicular axis.

Statistical analysis of the distance from the center of the tunnel to the ideal literature point was performed with the Mann-Whitney *U* test for independent, continuous data and analyzed with SPSS software (SPSS, Chicago, IL).

RESULTS

There were 55 patients in the anatomic group operated on between September 2009 and April 2010. Five patients in this group did not attend their CT scan appointments and so were excluded. This left a total of 50 patients. Sixteen patients undergoing ACL reconstruction by the traditional technique were also evaluated. The mean patient age at surgery was 30 years (range, 16 to 66 years) in the anatomic group and 33 years (range, 21 to 62 years) in the traditional group. There were 38 male and 12 female patients in the anatomic group and 15 men and 1 woman in the traditional group. Overall, there were 28 right and 22 left knees in the anatomic group and 11 right and 5 left knees in the traditional group.

The positions of the femoral tunnels in the anatomic group are shown in Fig 4, and the positions in the traditional group are shown in Fig 5. The mean position of the femoral tunnel in each group is shown in Fig 6.

Table 1. *Coordinates of Ideal Position of ACL Insertion on Grid of Bernard and Hertel[17] Reported in Literature*

	Depth			Height		
	AMB	PLB	Mean	AMB	PLB	Mean
Study						
Colombet et al.[36]	26.4	32.3	29.35	25.3	47.6	36.45
Zantop et al.[32]	18.5	29.3	23.9	22.3	53.6	37.95
Tsukada et al.[16]	25.9	34.8	30.35	17.8	42.1	29.95
Yamamoto et al.[35]	25	29	27	16	42	29
Bernard and Hertel[17]			24.8			28.5
Forsythe et al.[20]	21.7	35.1	28.4	33.2	55.3	44.25
Mean across studies			27.3			34.35

NOTE. Data represent percentage by depth (deep to shallow) and lateral wall height (high to low) measured on the grid.

Abbreviations: AMB, anteromedial bundle; PLB, posterolateral bundle.

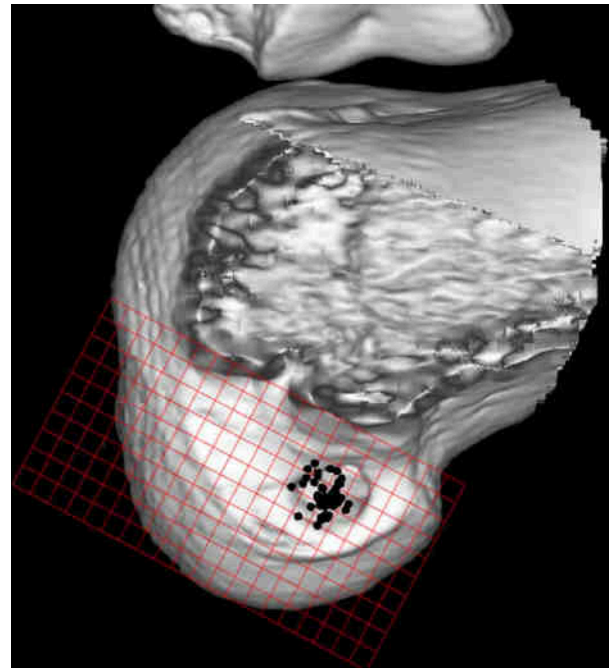

Figure 4. Distribution of midtunnel points of femoral tunnels with anatomic technique.

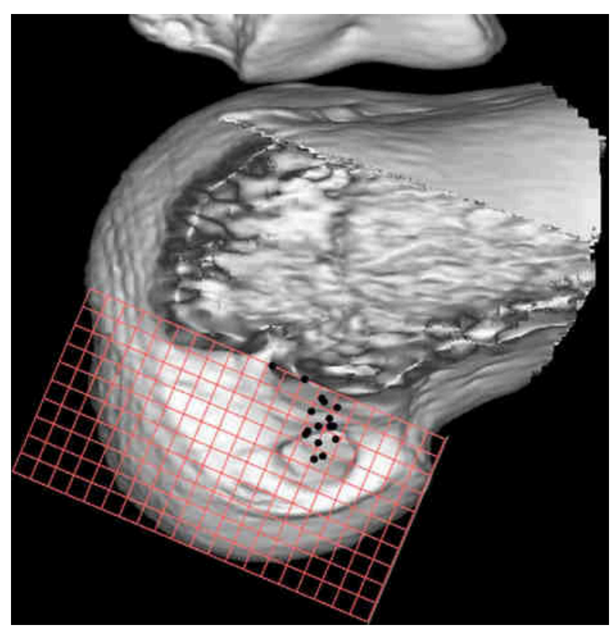

Figure 5. Distribution of midtunnel points of femoral tunnels with traditional method.

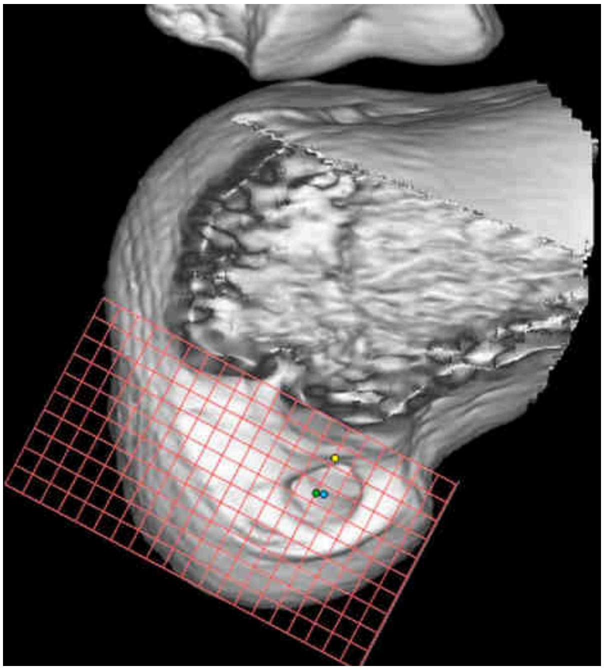

FIGURE 6. Mean positions of femoral tunnels with both the anatomic (green 30,35) and traditional (yellow 30,17) methods compared with the optimal mean position from the literature (blue 28,35). These coordinates represent the percentage depth of AP depth and lateral wall height.

The distance between the anatomic tunnels (5.95 units) was significantly closer to the ideal literature point than in the traditional group (16.17 units) ($P <$ .001).

Although we have not measured this in each patient, the distance from the mean position in the anatomic group to the optimal position (Table 1) was 0.9 mm compared with 5 mm in the traditional group in a male patient with an average-sized femur.

DISCUSSION

We have described a new technique to reliably position the femoral tunnel in the midbundle position of the ACL insertion on the lateral wall of the intercondylar notch. An arthroscopic ruler is used to measure the depth of the lateral wall, and the tunnel is drilled at the midpoint of this line. Quantification of the center of the resulting tunnel on specific 3D CT scan reconstructions has shown that the technique reproducibly places the tunnel close to the anatomic center of the insertion as defined radiographically[18-20] by use of the grid method popularized by Bernard and Hertel.[17] When we compared this anatomic position with the position determined using a 5-mm offset guide inserted through the AM portal and into the over-the-top position, there was a substantial difference in tunnel location.

The anatomic insertion of the anteromedial and posterolateral bundles of the ACL on the femur is now well-defined. Fibers attach posterior to the intercondylar ridge, and the 2 bundles are separated by the bifurcate ridge in most, but not all, patients. This places the center of the insertion lower or anatomically more distal and anterior than previously thought. The philosophy of ACL reconstruction has recently been restated to emphasize the requirement to reproduce as much of the anatomic native insertion as possible, thereby restoring anatomy.[37,38] Double-bundle reconstruction techniques have shown improved anterior laxity[26] and improved pivot-shift testing[23,24] in addition to improved biomechanical outcome.[25] In addition, double-bundle reconstruction by use of an anatomic posterolateral bundle has been shown to more closely restore normal knee kinematics.[27] Recently, anatomic single-bundle reconstruction techniques have shown similar kinematic control of knee rotation and anterior displacement to double-bundle techniques.[39,40] This simpler single-bundle technique has a strong appeal over more complicated techniques for double-bundle reconstruction.

Various methods of locating the anatomic footprint of the ACL have been described. Radiographically, the grid method has been extensively used, and we based our reference target point on the mean of 6 articles quantifying the bundle position in varying numbers of cadaveric knees[16,17,20,32,35,36] (Table 1). Though developed as quantification for tunnel position on radiographs, the grid method can also be applied intraoperatively with fluoroscopy,[15] but this may not be considered practical in some institutions. Other authors have described arthroscopic measurements to describe the drilling points for the ACL bundles, of which the Watanabe technique has been considered the best (Fig 7).[16,41] In this technique arthroscopic reference points are established at the over-the-top position and the anterior notch outlet point, and the center of the 2 bundles is defined as a proportion of the distance between these points along a line parallel to the femoral axis. Bedi and Altchek[29] described the footprint technique of placing the guide pin in the center of the femoral footprint after dissection, but unfortunately, their tunnel positions are not fully defined. The reference points seem to rely on being able to identify the footprint accurately, which may not be clear in the long-standing ACL-deficient knee.[29]

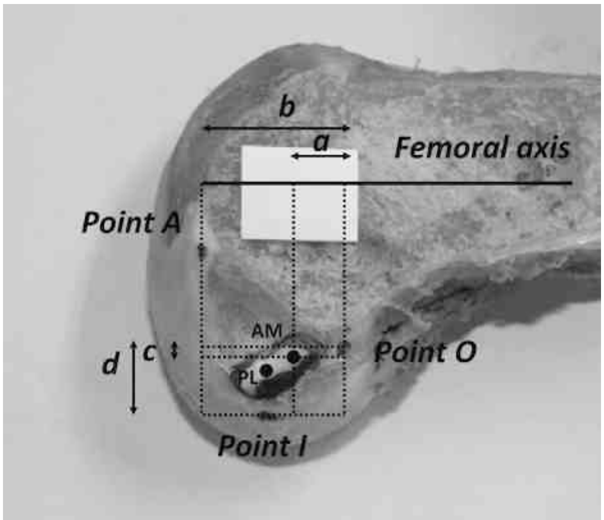

FIGURE 7. Watanabe method for determining tunnel position. The position is expressed as a proportion of lateral wall depth from point A to point O and lateral wall height from point I to point O. (PL, posterolateral.) (Reprinted with permission.[16])

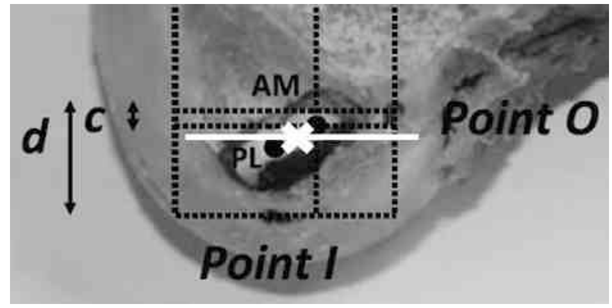

FIGURE 9. Close-up of cadaveric specimen reported by Watanabe et al.[41] showing anatomic landmarks on lateral wall of notch including origin of AM and posterolateral (PL) bundles. The white line and cross represent the application of the ruler based on the junction of the articular margin proximally and the articular cartilage distally. Positioning at 50% along this line puts the tunnel in the midbundle position. (Reprinted with permission.[16])

In choosing a technique to locate where to place the guidewire for drilling the femoral tunnel, the true ideal method may be to accurately delineate the intercondylar and bifurcate ridges, but the process of ablating the tissue is time-consuming and the ridges can sometimes be difficult to visualize.[11] Our technique is based on the observation reported by Kaseta et al.[21] in their study on the difficulty of reaching the anatomic center of the femoral insertion by drilling through the tibial tunnel. The anatomic center was reported to be 2 mm from an arthroscopic reference point, defined as the intersection of a line drawn distally from the most proximal border of the articular cartilage on the lateral wall of the notch and a perpendicular line drawn to the most posterior point of the condyle.[21] When the center of the femoral insertion of the ACL is marked in a cadaver where the femur has been split in the mid–sagittal plane and a ruler laid over the sidewall, simulating the arthroscopic measurement with the knee at 90° of flexion, then the midbundle position is clearly seen to lie at the 50% mark along the measurement from proximal to distal (Fig 8).

If a white line representing the ruler is superimposed on the photograph of the cadaveric specimen reported by Watanabe et al.[41] showing the anatomic landmarks on the lateral wall of the notch, then positioning at 50% along this line puts the tunnel in the midbundle position (Fig 9).

The advantage of the currently reported technique is that it produces an accurate midfootprint placement of the femoral tunnel. The technique is readily teachable and reproducible with a close grouping of the measured points on the overall grid placed on the cutaway 3D reconstruction scan image.

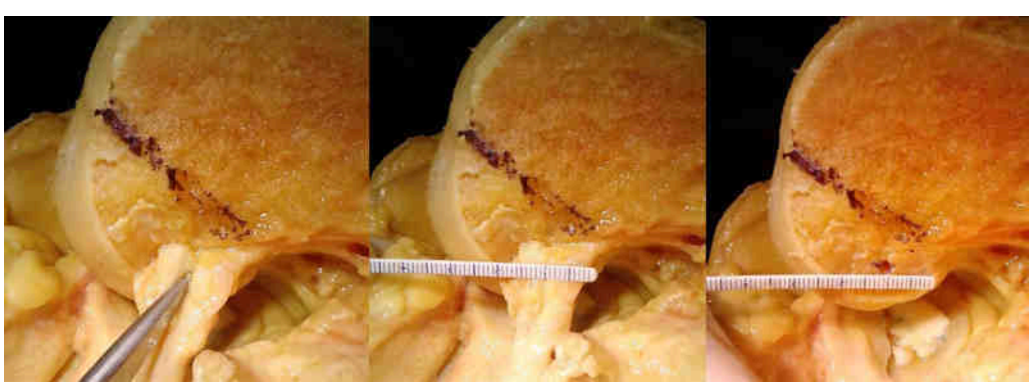

FIGURE 8. Application of measurement method to lateral wall of a cadaveric specimen. The midposition of the lateral femoral condyle corresponds to the middle of the ACL insertion with the knee at 90° of flexion.

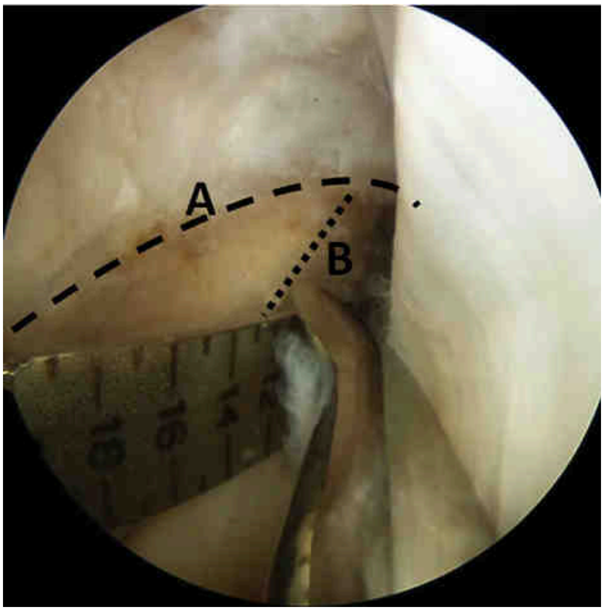

Figure 10. AM portal view of lateral wall showing intercondylar ridge (A) and bifurcate ridge (B). The microfracture pick hole at the midportion of the lateral condyle lies on the bifurcate ridge.

The disadvantage of the method is that, like all new techniques, there is a learning curve. The first difficulty is related to visualization through the high AM portal and drilling through a low AAM portal. The technical difficulties of this AM portal drilling approach have been well-discussed.[42,43] Use of 2 AM portals and 1 AL portal requires the help of a skilled assistant or scrub nurse. For marking the drill position, a microfracture pick is inserted through the AAM portal while the ruler is inserted through the AL portal, with visualization through the arthroscope in the high AM portal.[30] Instrument crowding can be a significant issue, and we advocate appropriate positioning of the patient on the operating table and use of wide arthroscopic portals to allow unobstructed passage of instruments. The ruler accurately measures the proximal/distal position of the guide pin but does not determine the posterior/anterior position. The ruler that we use is 6 mm wide, which allows easy passage into the knee without obstructing the view of the proximal border of the articular cartilage margin, which is the proximal reference point. Provided that there is approximately 2 mm of bone showing on the sidewall of the notch below the ruler with the knee at 90°, the position is likely to be correct (Fig 10).

Another criticism is that in this study we routinely cleared the sidewall of the notch of soft tissue by radiofrequency coblation to try to accurately identify the anatomic landmarks. This may have an effect on functional outcome because retaining soft tissue has been shown to be relevant for post-reconstruction proprioception.[44,45] Careful exposure of the articular margin of the lateral condyle may only be required in future reconstructions preserving proprioceptive soft tissues.

We have described a reproducible, precise, and accurate method of anatomic single–femoral tunnel placement on the wall of the lateral femoral condyle. This technique is readily teachable and easily learned. We believe that this method optimizes tunnel placement, conferring the biomechanical advantages of anatomic single-bundle placement without the technical difficulties of the double-bundle technique. The results in terms of clinical outcomes are awaited.

CONCLUSIONS

The ruler technique produced femoral tunnels comparable to published radiographic criteria used for tunnel placement and is reproducible and accurate. We recommend placement of the femoral tunnel at the midpoint of the lateral femoral condyle when using the anatomic single-bundle technique.

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