

Evaluation and Comparison of Femoral Tunnel Placement During Anterior Cruciate Ligament Reconstruction Using 3-Dimensional Computed Tomography

Effect of Notchplasty on Transtibial and Medial Portal Drilling

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Background: Advocates of medial portal drilling claim that the transtibial technique results in a more vertical positioning of the graft, which could lead to subsequent failure and/or a residual pivot shift on postoperative examination. However, advocates of transtibial drilling state that with appropriate placement and adequate notchplasty, their technique places the graft in a more anatomically correct position on the wall, negating the resultant potential for pivot shift and early postoperative failure.

Hypothesis: Transtibial femoral drilling can adequately reproduce the femoral origin of the anterior cruciate ligament (ACL) and place the graft in an anatomical position equivalent to medial portal drilling.

Study Design: Controlled laboratory study.

Methods: Ten matched-pair cadaveric knees (N = 20) were scanned using computed tomography (CT), and 3-dimensional images of the native ACL origin were reconstructed. The matched pairs were then randomized into transtibial and medial portal groups. The femoral tunnel was drilled in each knee according to group. A bamboo skewer was placed in the femoral tunnel, and the knees underwent a second CT scan. Arthroscopic notchplasty was performed, and the femoral tunnels were redrilled. Radiographs confirmed placement, and the post-notchplasty tunnel was reamed with a 4-mm reamer. The knees underwent a third CT scan. CT scans compared femoral tunnel placement with the native ACL footprint before and after notchplasty.

Results: The post-notchplasty transtibial group revealed an average of 68.3% coverage of the native ACL femoral origin. The medial portal group revealed an average of 60.8% coverage, with 1 instance of perforation of the posterior cortex. There were no instances of perforation in the transtibial group.

Conclusion: Both drilling techniques place the graft in an anatomically correct position.

Clinical Relevance: Transtibial drilling of the femur can adequately place the entry tunnel at the origin of the ACL's native footprint.

Keywords: anterior cruciate ligament; femoral tunnel; medial portal; transtibial

Currently, there are 2 primary techniques, or philosophies, behind femoral tunnel placement during single-bundle anterior cruciate ligament (ACL) reconstruction: arthroscopic-assisted transtibial ACL reconstruction and arthroscopic-assisted ACL reconstruction using the medial portal for femoral tunnel placement. The transtibial

technique is currently the most commonly utilized.^{1-4,6-9,16} Proponents for the medial portal technique argue that the femoral tunnel cannot be placed independently inside the intercondylar notch because the tibial tunnel constrains the surgeon's ability to drill the femoral tunnel low on the wall of the notch at the anatomic origin. In addition, it has been shown that the angle and position of the tibial tunnel determines the angle and position of the femoral tunnel, which correlates to ultimate stability because femoral tunnel placement has a significant effect on the tensile behavior of the graft.⁶⁻⁹

Review of the literature has shown that ACL reconstruction alone leads to poor long-term outcomes in 11% to 30% of cases examined, and more important, the reconstruction can cause a persistent pivot shift in more than 15% of cases. The most common cause of failure and residual pivot shift is improper tunnel placement.^{1,13}

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Biomechanical data have shown that a more horizontal position on the clock face of the femoral tunnel (ie, 10 o'clock for a right knee) better controls anterior tibial translation and internal tibial rotation.^{5,11} In addition, this coronal graft positioning has been shown to decrease tension across the graft, increase motion, and decrease impingement on the posterior cruciate ligament (PCL).¹⁰ However, changing the coronal angle to a lower position on the lateral wall results in a shorter tunnel length.^{17,18} Golish et al⁶ showed that when femoral tunnels get more lateral than 10 o'clock, the tunnel length may be less than 20 mm. This can lead to perforation, or "blow out," of the posterior femoral cortex and problems with fixation in a short tunnel.

Over the past several years, there has been a trend toward more femoral tunnel drilling via the medial portal. Presenters and authors of these studies have reported improved positioning of their femoral tunnels with this technique, while discouraging transtibial drilling. At our institution, we have performed single-bundle ACL reconstruction using primarily transtibial drilling. It has been our "perception" that our technique has led to successful results clinically over a long period of time in a wide array of active patients. To date, we have not published these results, which are based on anecdotal evidence; however, having seen the recent interest in medial portal drilling, we set out to determine if we were, in fact, drilling our tunnels in an anatomic location via the transtibial technique and what, if any, differences were inherent to our technique versus others that have been reported. We began this process by asking several of our fellows if they felt that our technique differed substantially from what they had been exposed to in their residency. The most common answer they gave was that we typically performed a more generous notchplasty than they were accustomed to seeing. This led us to the current study, which assesses the influence of notchplasty on femoral tunnel position. In reviewing the existing literature, there do not appear to be any studies that address this issue as it pertains to the 2 drilling techniques.

The origin and insertion of the ACL have been recently described via high-resolution volume-rendering computed tomography (CT).^{14,16} The authors of the aforementioned studies determined that the origin of the ACL is bounded anteriorly by Resident's Ridge. They also mapped out the dimensions of the ACL in length, width, and distance from the articular cartilage.¹³ Proponents for medial portal drilling feel that it is not possible to place the ACL in its anatomic location on the lateral femoral condyle via the transtibial technique. The purpose of this study was to evaluate both medial portal and transtibial femoral tunnel techniques (with and without notchplasty) with respect to ACL graft positioning. Our hypothesis is that, with appropriate technique and adequate notchplasty, the anatomic origin of the ACL can be reapproximated via transtibial drilling.

MATERIALS AND METHODS

Ten matched-pair cadaveric knee specimens, midfemur to midtibia/fibula, were obtained and thawed to room temperature. The specimens were cemented in customized

wooden pots that allowed the knee to be maintained in a 90° flexed position with the patella anterior in the anatomical position during CT scanning. Potting the knees in this fashion helped standardize knee position for imaging purposes. Next, a superolateral intra-articular injection of 30 mL of air was performed using an 18-gauge needle to increase soft tissue resolution of the origin and insertion of the native ACL during CT scanning.¹⁶ Each knee was scanned on a GE LightSpeed VCT 64-slice computed tomography scanner (Fairfield, Connecticut, USA) at 0.625-mm slice thickness and 0 pitch. Images of the native ACL were reconstructed on an independent workstation using Vitrea 2 volume-rendering software (Vital Images, Inc, Minnetonka, Minnesota, USA).

The matched pairs of knees were randomized: 10 knees were placed in the transtibial group and 10 knees were placed in the medial portal group, with 1 knee from each matched pair in each group. Each knee was removed from its respective pot and mounted individually on an apparatus using a C-clamp with the knee in the "mounted" position: flexion to 90°, neutral varus/valgus, and neutral internal/external rotation. Although the knee was initially mounted at 90°, this apparatus allowed for a full range of knee flexion and extension. Prior to beginning arthroscopic evaluation, the skin was removed from the anterior aspect of the knee, and the surface anatomy was marked using a surgical marker (patella, tibial tubercle, patellar tendon, joint line) (Figure 1). The surgical procedures were performed by 2 fellowship-trained sports medicine subspecialty certified orthopaedic surgeons with assistance by a current orthopaedic sports medicine fellow.

For the transtibial group, a vertical portal lateral to the patellar tendon at the inferior pole of the patella was made with a No. 11 blade while the knee was in the mounted position. The arthroscope was inserted in the anterolateral portal, and the anteromedial portal was made under direct visualization with a No. 11 blade. An arthroscopic shaver placed through the medial portal was used to debride the native ACL from its tibial and femoral attachments without removing any bone from the notch. The Acuflex Director tip aiming ACL guide (Acuflex; Smith & Nephew, Andover, Massachusetts, USA) was set to 45° and placed in the center of the remaining tibial stump of the native ACL via the medial portal. The guide was adjusted in the coronal plane using a protractor and compass to place the bullet 30° off the central axis of the knee, level with the anterior crest of the tibial tubercle and just anterior to the anterior fibers of the superficial medial collateral ligament (MCL).² A 3/32-mm guide wire was then drilled through the guide under direct visualization, and the appropriate position was confirmed arthroscopically. The tibial guide was removed, and a 10-mm Acuflex acorn reamer was used to ream the tibial tunnel over the guide pin. The coronal angle of the tibial tunnel was measured and confirmed to be 30°. ^{3,6} An arthroscopic shaver was placed into the tibial tunnel to further debride the ACL insertion on the tibia. The arthroscopic Acuflex 7-mm transtibial over-the-top guide was placed into the knee through the tibial tunnel, and the 3/32-mm guide wire was drilled into the femur through the guide, with the guide set to the most horizontal position possible. The over-the-top guide

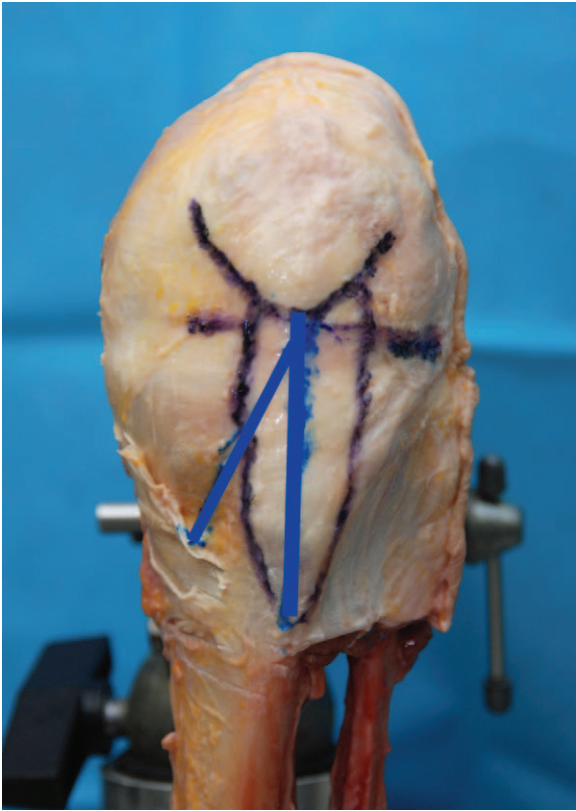


Figure 1. Anterior surface anatomy of mounted knees at 90° of flexion, neutral varus/valgus, and neutral internal/external rotation.

was removed. Anteroposterior (AP) and lateral radiographs (Integris V4000; Philips Medical Services, Andover, Massachusetts, USA) were performed to confirm correct guide wire positioning and to show it was contained within bone and had not penetrated the posterior cortex. Using a cannulated 4-mm EndoButton reamer (Smith & Nephew), a 4-mm tunnel was made over the 3/32-mm guide wire to a depth of 30 mm. The guide wire was removed, and a 3.5-mm bamboo skewer was placed in the reamed tunnel. Bamboo was used because it is radiolucent and would allow one to see the placement of the tunnel on CT without metal artifact. CT scans were performed in the potted position.

Following CT scanning, the bamboo skewer was removed, and a notchplasty was performed with an arthroscopic shaver and burr through the medial portal to remove “Resident’s Ridge” (Figure 2), changing the configuration of the posterior notch to resemble a smooth, inverted “U” rather than an A-notch, which allows one to visualize the back wall and properly position the over-the-top guide. An arthroscopic shaver was used to “score” the bone at the starting point via the medial portal. A size 7-mm Acuflex over-the-top guide was again placed through the tibial tunnel, and the 3/32-mm guide wire was again drilled into the femur through the guide. A second AP and lateral radiograph were performed after notchplasty to confirm correct positioning. A cannulated 4-mm reamer was placed over the guide wire and advanced to a depth of 30 mm. The guide wire was removed

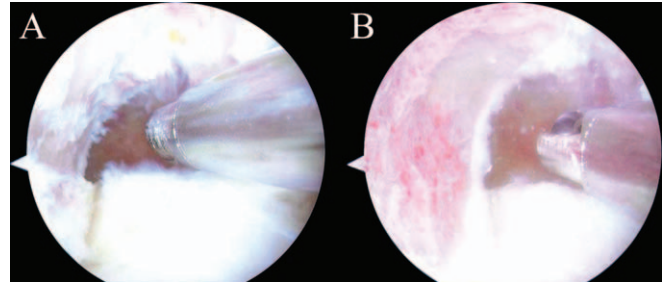


Figure 2. Arthroscopy of the intercondylar notch of a right knee both (A) before and (B) after notchplasty.

and replaced by a 3.5-mm bamboo skewer. The knee was repotted, and a third CT scan was performed.

For the medial portal group, a No. 11 blade was used to make a vertical anterolateral viewing portal placed adjacent to the inferolateral border of the patella above the joint line. The arthroscope was inserted. The anteromedial portal was placed 1 cm medial to the medial border of the patellar tendon under direct visualization, with the portal placed at the upper surface of the meniscus to create the lowest possible entry point. An arthroscopic shaver placed through the medial portal was used to debride the native ACL from its tibial and femoral attachments without removing bone from the notch. Using a DePuy Mitek 7.5-mm anteromedial femoral aiming over-the-top guide (Raynham, Massachusetts, USA), a 3/32-mm guide wire was drilled into the femur from the medial portal with the knee hyperflexed. AP and lateral radiographs were taken to confirm appropriate positioning of the guide wire. A cannulated 4-mm reamer was placed over the guide wire, and the femoral tunnel was reamed from the medial portal. The guide wire was removed, replaced with a bamboo skewer, repotted, and a CT scan performed. A notchplasty was performed with a shaver and burr through the medial portal in the same manner as was done in the transtibial group. Next, a small, curved curette was used to remove the posterior capsular tissue from the back wall to confirm the over-the-top position. Using the anteromedial portal over-the-top guide, a 3/32-mm guide wire was drilled into the femur from the medial portal with the knee hyperflexed. A cannulated 4-mm reamer was placed over the guide wire, and a second femoral tunnel was reamed from the medial portal. The reamer and guide pin were removed, and the guide pin was replaced by a 3.5-mm bamboo skewer. The knee was then repotted, and a third CT scan was performed.

Once 3-dimensional reconstructions were created, these images were evaluated to determine the anatomic location of the ACL origin. The values were mapped out (Figure 3A) according to prior values stated in the literature.¹⁶ Using a mathematic ratio, the size of the tunnel after reaming (4.5 mm) was extrapolated to resemble the oval, which would be produced by a 10-mm reamer used intraoperatively. The percentage contact of the entrance oval along the native ACL was determined before and after notchplasty. Also, the tunnel length for each specimen was calculated (Figure 3, B and C). Paired *t* tests with an alpha level of .05 were used to determine if there were any statistical differences between the 2 techniques.

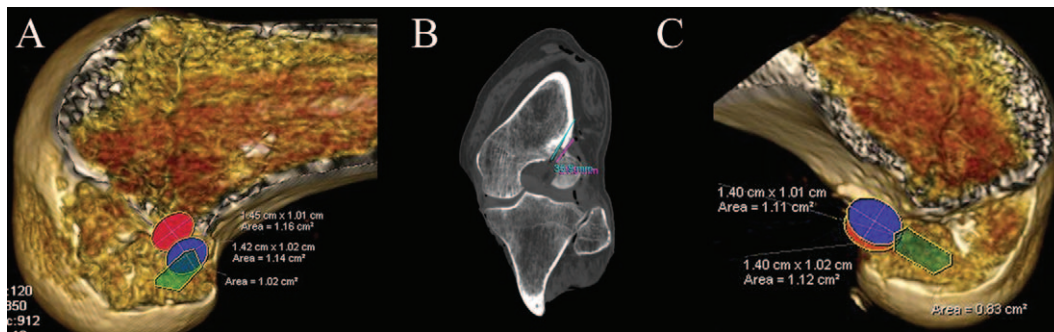


Figure 3. (A) Sagittal 3-dimensional computed tomography (CT) reconstruction of a right femur along its long axis. Looking at the medial aspect of the lateral femoral condyle, the native anterior cruciate ligament (ACL) origin is depicted in green. The red oval shows the entrance tunnel a 10-mm reamer would make via the transtibial technique before notchplasty. The blue oval corresponds to the entrance tunnel post-notchplasty using a 10-mm reamer. (B) Coronal 2-dimensional CT through the notch showing length of tunnel (purple), which may have led to posterior cortical compromise. (C) Three-dimensional CT reconstruction of the contralateral knee shown in (A). Because of the short tunnel length, the posterior cortex was compromised and the tunnels were not placed in the anatomic position of the origin of the ACL (green).

TABLE 1
Summary of Data^a

	Transtibial	Medial Portal (n = 10)	Medial Portal, Specimens 5c and 6c Removed (n = 9)
% Area covered pre-NP	0.2 ± 0.6	29.5 ± 0.4	
% Area covered post-NP	68.3 ± 0.2	60.8 ± 0.3	67.6 ± 0.3
<i>P</i> value (paired <i>t</i> test: pre- vs post-NP)	.000 ^b	.008 ^b	
<i>P</i> value (paired <i>t</i> test: TT vs MP post-NP)		.3	.5
Tunnel length, mm	26.1 ± 5.6	24.5 ± 5.4	24.8 ± 5.6
<i>P</i> value (paired <i>t</i> test)		.4	.6

^aValues are expressed as mean ± standard deviation. MP, medial portal; NP, notchplasty; TT, transtibial.

^bStatistically significant difference ($P < .05$).

RESULTS

Descriptive statistics and paired *t* tests results are presented in Table 1. During this study, there was 1 case of perforation, or “blow out” (Figure 3C), in the posterior cortex of the femur in the medial portal group (sample 6). Therefore, statistics are also presented for a subset of the population, which excluded that matched pair (numbers 5 and 6). For the pre-notchplasty measurements of percent area covered, there were 2 samples (11 and 17) that had a pre/post overlap, meaning that the ovals covered the native ACL origin before notchplasty. These were the only 2 specimens in which this was the case out of the 20 specimens in the study.

In each of the transtibial specimens, the addition of a notchplasty in the transtibial group allowed one to get to a more posterior and inferior position on the medial surface of the lateral femoral condyle. The individual images of 2 sample-matched pairs are shown in Figure 4.

The percentage area of coverage the extrapolated 10-mm entrance oval placed on the origin of ACL on the femur averaged 68.3% ± 0.23% in the transtibial group and 60.8% ± 0.25% in the medial portal group ($P = .34$). Individual calculations of the area of coverage are listed in Table 2. Deflation of the percentage covered by the medial

portal group was drastically affected by the 6c specimen (seen in Figure 3C) that “blew out” the posterior cortex of the femur. If specimens 5c and 6c are discounted, leaving 9 pairs of specimens in the group, the average percent coverage in the medial portal group was 67.6%. With specimens 5c and 6c removed, there was no statistical difference between the 2 groups ($P = .49$) for area of the native ACL covered after notchplasty.

Calculation of the length of the femoral tunnel was performed by measuring the tunnel on the coronal view of the CT scan, which showed the notch in its entirety. The lengths of the tunnels are listed in Table 3. In the medial portal group, the mean tunnel length (not including specimen 6c) was 24.5 ± 5.4 mm (range, 16.3-33.8 mm), whereas the mean tunnel length in the transtibial group was 26.1 ± 5.6 mm (range, 18.4-35.9 mm). There were no statistically significant differences between the values ($P = .57$) (Table 1).

DISCUSSION

Our results showed that the post-notchplasty transtibial group and medial portal group revealed comparable coverage of the native ACL femoral origin, indicating that both

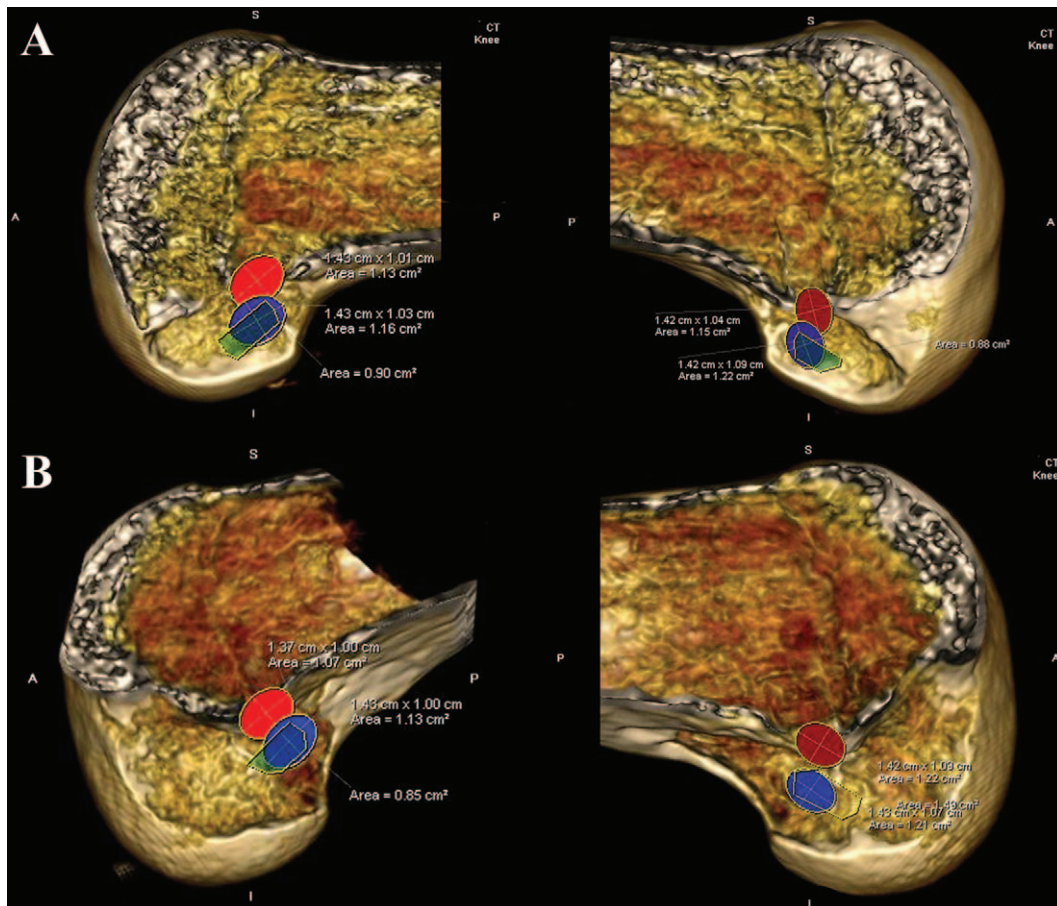


Figure 4. Insertion of anterior cruciate ligament (ACL) and femoral tunnels: (A) right knee transtibial, (B) left knee medial portal. The green trapezoid represents the area of insertion of the native ACL in each specimen. The red oval represents the oval entrance to a tunnel created with a 10-mm reamer before a notchplasty was performed. The blue oval represents the oval entrance to a tunnel created with a 10-mm reamer after a notchplasty was performed. Note that in each matched pair (both transtibial and medial portal specimens), the blue oval more completely covers the native ACL origin than does the red oval.

drilling techniques can reproducibly place the graft in an anatomically correct position, and further that transtibial drilling of the femur can adequately place the entry tunnel at the origin of the ACL's native footprint. Recent work by others has shown similar femoral tunnel aperture areas between accessory medial portal and transtibial drilling, although medial portal drilling was shown to create a tunnel that was more anterior and horizontal than the transtibial tunnels.¹⁹ A cadaveric study has revealed that it is possible to create anatomical femoral tunnels using transtibial drilling with notchplasty as long as care is taken when choosing the proximal tibial starting location.¹⁵ Biomechanical research in a large animal model has shown that notchplasty had a detrimental effect on knee biomechanics under anterior tibial translational loading; however, this study did not address the effect of notchplasty on different tunnel placements.¹² No human studies are currently available that specifically investigate the biomechanical effect of notchplasty on femoral tunnel placement.

In our study, the age and concurrent diagnoses present in the cadaveric knees were not known. Ideally, young knees

without meniscal pathology, arthritic changes, or instability would be used in this study. However, limitations inherent in procuring and obtaining matched-pair cadaveric knees prevented us from having control over the age, sex, or medical conditions of the donors. We had no instances of any insertional pathology of the native ACL or bony morphology that would alter the results of the study.

One shortcoming to our study was that the amount of notchplasty was not quantified. This is an issue that is logistically being worked on at the moment, and because of the fact that it is a complex curved surface, we are unable to quantify that particular value at present. However, the purpose of this study was not to quantify the notchplasty but rather to demonstrate that notchplasty materially affects the position of the femoral tunnel and to quantify the amount of the native origin of the ACL covered by the tunnels created with the various techniques with and without notchplasty.

Another issue was the extrapolation of the entrance oval from a 4.5-mm reamer to a 10-mm reamer. Mathematically, this was a solid calculation and was carefully transcribed

TABLE 2
Percentage Area Covered by the Entrance Tunnel
on the ACL Origin^a

Specimen ^b	Side	Technique	Area Covered, %	
			Pre-NP	Post-NP
5c	Right	Transtibial	0	40
6c	Left	Medial portal	0	0 (out)
7c	Right	Medial portal	85	100
8c	Left	Transtibial	2	83
9c	Right	Medial portal	0	23
10c	Left	Transtibial	0	42
11c	Left	Medial portal	100 (pre/post overlap)	100
12c	Right	Transtibial	0	100
13c	Right	Transtibial	0	93
14c	Left	Medial portal	13	78
15c	Right	Medial portal	0	69
16c	Left	Transtibial	0	60
17c	Right	Medial portal	70 (pre/post overlap)	70
18c	Left	Transtibial	0	88
19c	Right	Transtibial	0	82
20c	Left	Medial portal	0	67
21c	Right	Medial portal	18	39
22c	Left	Transtibial	0	54
23c	Right	Transtibial	0	41
24c	Left	Medial portal	9	62

^aACL, anterior cruciate ligament; NP, notchplasty.

^bc = after notchplasty.

TABLE 3
Length of Femoral Tunnel After Notchplasty

Specimen ^a	Side	Technique	Length of Tunnel, mm
5c	Right	Transtibial	27.0
6c	Left	Medial portal	21.9
7c	Right	Medial portal	29.8
8c	Left	Transtibial	35.9
9c	Right	Medial portal	25.7
10c	Left	Transtibial	23.8
11c	Left	Medial portal	30.0
12c	Right	Transtibial	20.4
13c	Right	Transtibial	27.1
14c	Left	Medial portal	19.1
15c	Right	Medial portal	22.7
16c	Left	Transtibial	30.9
17c	Right	Medial portal	33.8
18c	Left	Transtibial	30.6
19c	Right	Transtibial	27.3
20c	Left	Medial portal	21.8
21c	Right	Medial portal	16.3
22c	Left	Transtibial	18.4
23c	Right	Transtibial	20.0
24c	Left	Medial portal	24.1

^ac = after notchplasty.

into the volume-rendering software. Unfortunately, there was no other way to get around using a 4.5-mm reamer because if a larger reamer had been used, the 2 entrance ovals prior to notchplasty would "cave in" after notchplasty.

Therefore, we chose to design this study in such a manner and felt confident in the calculation.

This study helps suggest that transtibial drilling can place the femoral tunnel in an equivalent anatomical position to medial portal drilling. Another reported issue with medial portal drilling is short tunnel length, which can compromise graft fixation with posterior cortical compromise. In our study, tunnel length was not significantly different between the 2 technique groups.

In summary, notchplasty materially affects the position of the femoral tunnel on the medial wall of the lateral femoral condyle at the time of ACL reconstruction. In doing so, it also materially affects the coverage of the native ACL origin with the drilled tunnel, and subsequently, the graft material. This study also demonstrates that transtibial drilling of the femoral tunnel can consistently place the entrance oval in the anatomic proximity of the ACL origin on the femur, similar to medial portal drilling. Thus, we provide evidence that transtibial drilling with an adequate notchplasty is an effective, consistent, and anatomically sound way to reconstruct the ACL. Existing and future literature on this topic should take into account the effect of notchplasty on tunnel placement.

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