Femoral tunnel drilling angles for posteromedial corner reconstructions of the knee. Computed tomography evaluation in a cadaveric model.

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ABSTRACT

Purpose: To determine the best angle to drill the femoral tunnels of the superficial medial collateral ligament (sMCL) and posterior oblique ligament (POL) in concomitant posterior cruciate ligament (PCL) reconstructions as to avoid either short tunnels or tunnel collisions

Methods: Eight cadaveric knees were studied. Double bundle PCL femoral tunnels were arthroscopically drilled. sMCL and POL tunnels were performed at 0º and 30º axial and coronal angulations. They were scanned with computed tomography to document relationships of the sMCL and POL tunnels to the intercondylar notch and PCL tunnels. A minimum tunnel length of 25mm was required.

Results: When sMCL femoral tunnel was drilled either at 0º axial and 30º coronal angulation or 30º axial and 0º coronal angulation, there was an increased risk of tunnel collision with the AL bundle tunnel of the PCL ($p<.001$). None POL tunnels collided with either tunnel bundle of the PCL with the exception of tunnels drilled at 0º axial and 30º coronal angulations which in 3 out of eight cases did so with the AL bundle tunnel of the PCL ($p<.001$). All the sMCL and POL tunnels obtained the minimum required tunnel length ($p<.001$ and 0.02 respectively). However, some of those that were angled at 0º in the axial plane violated the intercondylar notch.

Conclusions: When performing posteromedial reconstructions in combination with concomitant PCL procedures, sMCL and POL femoral tunnels should be drilled at both 30º axial and coronal angulations. The POL femoral tunnel may also be drilled at 0º coronal angulation. Tunnels at 0º axial angulations showed a shorter distance to the intercondylar notch and a higher risk of collision with PCL tunnels.

Clinical Relevance: Specific drilling angles are necessary to avoid short tunnels or collision between the drilled tunnels when sMCL and POL femoral tunnels are performed with concomitant PCL reconstructions.

INTRODUCTION

Injury to the superficial medial collateral ligament (sMCL) is the most common knee ligament injury.[1-3] The sMCL is the primary static stabilizer preventing valgus translation and assist as an internal and external rotation restrain.[4,5] The majority of patients who sustain an injury to the sMCL restore their pre-injury level with non-operative treatment due to its high endogenous healing capacity. The posterior oblique ligament (POL) has also been reported as an important primary restrain to internal rotation and secondary restrain to valgus translation and external rotation.[1,3,4,6-8] A high frequency of combined sMCL and POL injuries have been reported in knees with acute or chronic valgus laxity, signifying the important role of the POL in providing static stabilization to the medial side.[1,9]. The majority of the most severe acute or the majority of the persistent chronic posteromedial knee instabilities occur concomitantly as part of a multiple-ligament injury. Recently, it has been experimentally demonstrated that reconstruction not only of the sMCL but also the POL better restore the posteromedial stability instead of addressing only the sMCL.[2,4] In addition, persistent valgus instability places additional strain on a reconstructed anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL), which can contribute to late graft failure.[3,10] For this reason, a combined PCL and medial side injury is considered one indication for surgical reconstruction of both the sMCL and POL.[3,7,10]

When a surgeon has to perform reconstruction of the sMCL, POL and a single or double bundle PCL, the placement of the resulting three or four tunnels that have to be drilled in only one femoral condyle may be a challenge. To determine the best angle for drilling so as to avoid tunnel collisions, which may lead to graft rupture or to excessively short tunnels, is crucial. Similar situation may be seen when a posterolateral corner is being reconstructed concomitantly with the ACL, and some recent studies have evaluated the feasibility of this multiple lateral femoral condyle drilling.[11,12] Conversely, no study has assessed the feasibility of combined single or double bundle posterior cruciate ligament with sMCL and POL femoral tunnels.

The purpose of this study was to determine the best angle to drill the femoral tunnels of the superficial medial collateral ligament and posterior oblique ligament when a posterior cruciate ligament reconstruction is concomitantly performed to avoid either short tunnels or tunnel collisions. Due to tunnel proximity and the anatomy of intercondylar notch, the hypothesis was that very specific sMCL and POL drilling angles would be necessary to assure safe placement of their femoral tunnels.

METHODS

Eight fresh cadaveric knees from adult human volunteer donors were studied. There were five male and three female donors (4 left, 4 right). Their ages ranged from 57 to 81 years (mean, 71.9). The specimens had been stored at -18ºC. They were then thawed at room temperature for 24 to 36 hours before testing. None of the knees showed macroscopic signs of previous surgery. Only knees with none or mild degenerative changes were included. Preoperative mobility, measured with the goniometer, gave minimum flexion of 135º. Full extension was still possible. The specimens were mounted on a knee holder (Extremity Holder, Sawbones, Sweden).

Arthroscopic procedure

The surgery was performed with two other authors present and in agreement with tunnel placement. Only when the three experienced surgeons agreed on the tunnel placement was it drilled. The knees hung freely at a 90º of flexion. A high anterolateral portal was established as the initial viewing portal. An anteromedial portal was also performed as a working portal to resect the fat pad so that the lateral wall of the medial condyle could be clearly seen. The PCL was left intact and helped as a guide to perform an anterolateral (AL) bundle and a posteromedial (PM) bundle tunnels (**Figure 1**). They were performed with an outside-in technique. A specific outside-in aiming guide was used in all cases (ConMed Linvatec, Largo, FL, USA). A 8mm AL bundle tunnel was performed with by placing the aiming guide just anterior to the medial femoral epicondyle and with an angulation of 50º. A 6mm PM bundle tunnel was drilled by placing the aiming guide 10mm more proximal and with an angulation of 65º.

Dissection and Posteromedial Tunnel Drilling

The skin and subcutaneous tissue of the posteromedial aspect of the knee were removed. The fascia was removed and the vastus medialis muscle was anteriorly retracted to more easily assess the medial aspect of the femur. Careful dissection of the medial aspect of the knees was performed to identify the femoral insertion of the sMCL and POL. A 2.4mm guide-wire was drilled through the center of the femoral attachment of the sMCL and POL at four different guide-wire orientations with the help of a manual goniometer in every specimen (**Figure 2**). Due to data inferred from two similar studies,[11,12] additional orientations were excluded.

- 0º of axial angulation in reference to the transepicondylar axis, and 0º of coronal angulation in reference to a line perpendicular to the femoral anatomic axis.

A 0.8mm metallic wire was pulled from the lateral side with the guide-wire and left in place. The metallic wire later helped to more easily recognize the drilled tunnels in the computed tomography assessment. Consecutively, at the same entry point and following the same steps than with the guide-wire tunnel, others metallic wires were left in tunnels (**Figure 3**) performed at both the femoral origin of the sMCL and POL with:

- 0º of axial angulation and 30º of coronal angulation
- 30º of axial angulation and 0º of coronal angulation
- 30º of axial angulation and 30º of coronal angulations.

Overdrilling the sMCL and POL tunnels in every specimen to those performed in the clinical setting would have been impractical in the design. Thus, in order to determine the safety of each drilling tunnel, a 7mm tunnel was the theoretical diameter to be overdrilled in the clinical setting. Then, an additional 2.3mm-wide has to be considered. This comes from the difference of half of the 2.4mm drilled tunnel (1.2mm) and of the supposed 7mm clinical tunnel (3.5mm). A minimum of 2.5mm was finally chosen as the minimum safe distance.

A minimum tunnel length of 25 mm for proper graft-tunnel healing is usually recommended.[13] Thus, in order to evaluate the role of the sMCL and POL tunnel depth as a possible cause of tunnel collision, a 25mm of tunnel was a requirement in considering a safe drilling angle.

CT Scanning

All knees were placed in full extension and imaged on multiple planes on a LightSpeed VCT Pro 5-Beat Cardiac with AW VolumeShare (GE Healthcare, Waukesha, WI, USA) to generate multiplanar reconstructions of axial, sagittal and coronal plane CT images. Volume-rendering 3D CT reconstructions were also performed. With the OsiriX Medical Imaging Software Version 5.9 32-bit, an open-source software for navigating in multidimensional DICOM images,[14] different quantitative parameters were evaluated.

Two expert musculoskeletal imaging radiologists performed all measurements and then averaged them. Both radiologists were blinded to the subject and purpose of the study. The radiologists followed a previously described method.[12] They first confirmed that the actual tunnel angles

drilled for the sMCL and POL matched approximately the author's intended angles. Then, the shortest distance to every tunnel and to the intercondylar notch was measured. Any possible intersection between the sMCL and POL tunnels was also studied. Superposition of the axial, coronal and sagittal views was done and only the shortest distance observed in any of the three different planes was the final measure considered for data purposes. Each measurement was performed from the distal border of the corresponding 2.4mm tunnel to the nearest point of the cortex of the cruciate femoral tunnels or to the intercondylar notch. All the following measurements were performed in 0.1-millimeter interval:

- Minimum distance to the tunnels of both bundles of the PCL.
- Minimum distance to either bundle tunnel of the PCL.
- Tunnels drilled through the intercondylar notch.
- Tunnel lengths from the entry point to the intercondylar notch.
- Tunnels not drilled through the intercondylar notch which had at least 2.5mm of bone-wall between them.

Statistical analysis

Categorical variables are presented as percentages and frequencies. Mean and standard deviation as well as median, minimum and maximum were calculated for each continuous variable. Quartiles were not calculated due to the small number of cases.
The analysis of variance (ANOVA) with repeated measures was used for multiple comparisons of the mean values of each different drilling angle. The Greenhouse-Geisser test was used to avoid any possible violation of the sphericity assumption.
Interobserver agreement was analyzed using the intraclass correlation coefficient (ICC) in the case of a quantitative variable. In those relevant cases, a 95% confidence interval was also calculated. In cases of categorical variables, the interobserver agreement was estimated with the kappa coefficient.
Statistical analysis was performed using SPSS 19 (SPSS Inc., Chicago, Illinois, USA). Statistical significance was set at 0.05.

RESULTS

Relationship to PCL tunnels

When the sMCL femoral tunnel was drilled either at 0º axial and 30º coronal angulation or at 30º axial and 0º coronal angulation, there was an increased risk of tunnel collision with the AL bundle tunnel of the PCL ($p < .001$) (**Table 1**). There was no risk of tunnel collision of the sMCL with the PM bundle tunnel of the PCL in any of the studies angulations.

None POL tunnels collided with either tunnel bundle of the PCL with the exception of the tunnels drilled at 0 degrees axial and 30 degrees coronal angulations that in 3 out of 8 cases did so with the AL bundle tunnel of the PCL (**Table 1**) ($p < .001$).

Intercondylar notch and tunnel length

A variable percentage of sMCL and POL tunnels angled at 0º at the axial plane violated the intercondylar notch (**Figure 4**). However, all the sMCL and POL tunnels drilled at any angulation obtained the minimum required tunnel length ($p<.001$ and 0.02 respectively) (**Table2**).

Optimal sMCL and POL tunnel angulations

Considering all the studied variables, the safest sMCL tunnels were obtained in the group of 30º on both the axial and coronal planes. Relative to the POL tunnels, the safest combination was observed when it was drilled at 30º on the axial plane and at 0º or 30º on the coronal plane.

Evaluation of the experimental design

The actual angles of the drilled tunnels were in a range of ± 4.8º to the intended angles in all cases. In addition, no intersection between the sMCL and POL tunnels were observed in any of the studied angulations. Finally, the obtained ICC was considered excellent (0.94).[15] The high calculated kappa coefficient (0.91) also revealed excellent agreement between observers.

DISCUSSION

The current study confirmed the high risk of short tunnels or collision between tunnels when the sMCL and POL of the knee are being reconstructed concomitantly with a single or double bundle posterior cruciate ligament. However, our study found that such complications could be avoided by directing the sMCL tunnel anteriorly with an axial angulation of 30º and proximally with an angulation of 30º of coronal angulation and by also directing the POL tunnel with 30º of axial angulation.

The posterior cruciate ligament has two functional bundles, the AL and the PM bundles.[16,17] Most surgeons agree that when the PCL is being reconstructed with a single bundle technique, the single graft should be placed at the AL bundle femoral footprint. In case of a double bundle procedure, a second graft is additionally placed at the femoral PM bundle footprint. While a double bundle reconstruction has shown some biomechanical advantages in experimental studies,[18,19] not proven clinical advantage has been shown over isolated reconstruction of the stronger AL bundle.[17,20] Be that as it may, some surgeon still preferred to reconstruct the PCL with a single bundle technique while others prefer a double bundle technique. In the present study, femoral tunnel of both bundles of the PCL were performed and analyzed separately. Thus, a representation of both a single or double bundle PCL reconstruction was provided.

Posteromedial corner reconstructions are performed in different clinical situations. Most of the PMC injuries are addressed with cruciate ligament reconstructions. A combined PCL and medial side injury is considered one indication for surgical reconstruction of both the sMCL and POL. [3,7,10]. Awareness of the need to understand and treat persistent medial side instability has increased because untreated PMC injuries might lead to failure of PCL reconstructions.[8,10] When a PCL is being concomitantly reconstructed, drilling its one or two tunnels with the additional femoral POL and sMCL tunnels may represent a challenge to fit them all in the medial femoral condyle. Interestingly enough, no detailed information with regard to the orientation of the femoral tunnels of both ligaments has been reported. While some investigation provided no information by any means ,[2,5,9,21,22] others vaguely described to aim the tunnels “anterolaterally”.[4] In the present study, it was seen that the femoral tunnel of the sMCL should always be angled 30º anteriorly on the axial plane and 30º proximally on the coronal plane. This orientation proved to avoid short tunnels of the sMCL itself and also to avoid compromising the AL bundle of the PCL grafts that are placed inside their corresponding tunnels. Although the sMCL tunnels angled 0º on

both the axial and the coronal plane were just above the minimum acceptable required length (i.e. 25mm) and the minimum safe distance (i.e. 2.5mm), it seems logical to better prefer the 30º/30º configuration, which showed considerable higher measures. On the other hand, when the femoral tunnel of the posterior oblique ligament is being reconstructed, some wider range of safe angle drillings was observed. The POL tunnel may be angled at either 0º or 30º in the coronal plane but it should always be drilled 30º anteriorly on the axial plane.

The posteromedial aspect of the knee has a complex anatomy. This anatomy has been largely described several decades ago.[23-28] Recently, more detailed and quantitative descriptions have better defined the exact locations of the sMCL and POL.[29-30] Determination of the radiographic placement of both structures was also described.[31] Proper knowledge of distances to surrounding bony structures and radiographic standardization of bone attachments provide crucial information in the clinical setting as the normal anatomy is frequently distorted in injured knees. However, in the current study the femoral insertions of the sMCL and POL were easily found, as the specimens had no injury of the posteromedial corner. In addition, all the combinations of drilling angles for both the sMCL and POL were drilled in each specimen preventing any concern for anthropometric differences.

The angulations of the evaluated tunnels were assessed during the procedure only with a manual goniometer. Although this device might provide low accuracy and it might be seen as a limitation of the study, it was chosen to more closely reproduce a clinical situation. In addition, the CT scan evaluation demonstrated that the tunnels were performed around the intended drilled angle. With regard to the evaluation of tunnel placement and its relationships, computed tomography is currently considered the gold standard for assessing tunnel relationships in reconstructions of the knee-ligaments.[33,34] Recent studies also showed the reliability of multiplanar reconstructions of CT views and volume-rendering 3D CT images with a study design similar to that used in the current study.[11,12]

Controversy exist regarding how much tunnel length is necessary for safe graft to bone-tunnel healing. Although there is no consistent scientific data supporting a specific tunnel length, authors usually recommend tunnels of at least 20mm[32] or 25mm[12,33] in length, which was also the minimum length considered in the current investigation.

There are very few studies evaluating tunnel collision in knee surgery. More specifically and to our knowledge, this is the first study that has evaluated different angulations of any of both, sMCL and POL femoral tunnels, when they are performed concomitantly with anatomic single or double bundle PCL reconstructions. This might be of critical clinical relevance as tunnel collisions may lead to graft rupture or to excessively short tunnels.

There are some limitations to the present study: First, only four different drilling angulations were evaluated in the study. However, due to the data reported in two investigations with similar study design,[11,12] additional orientations were excluded. In one of those previous studies[11], only differences between those tunnels performed at 0º of axial and coronal angulations with those performed at 20º or 40º of axial and coronal angulations were found. In the other study,[12] and similar to the current investigation, only 0º and an intermediate tunnel at 30º were chosen. Another important limitation was that not only the PCL was performed with only one specific technique, but also that this technique might offer some variations. For instance, different placement or different degree at which the aiming guide may be set on the medial aspect of the medial femoral condyle determine different PCL femoral tunnel multiplanar situation. This might limit the generalization of the results observed in this investigation. In the same way, although the chosen diameters of the drilled tunnels were intended to be similar to that performed in a clinical situation, others tunnel diameters were not evaluated. Although some surgeons prefer to drill a10mm tunnel, in our experience with cadaveric studies, the specimens that we are used to working with are usually smaller than those in average people. Thus, we had thought that a bigger tunnel might involve too much of the medial condyle. Also, fixation of the graft with an interference screw is commonly performed in the clinical setting. This screw may lead to some degree of tunnel distortion, which was not evaluated in the investigation. Finally, the fact that the wires were left in situ may have subtly affected the trajectory of the subsequent drilled wires.

Regarding the aforementioned limitations, this study showed that specific drilling angles are necessary to avoid short tunnels or collision between the drilled tunnels when sMCL and POL femoral tunnels are performed with concomitant PCL reconstructions.

CONCLUSIONS

When performing posteromedial reconstructions in combination with concomitant single or double bundle PCL procedures, sMCL and POL femoral tunnels should be drilled at both 30º axial and coronal angulations. The POL femoral tunnel may also be drilled at 0º coronal angulation. Tunnels at 0º axial angulations showed a shorter distance to the intercondylar notch and a higher risk of collision with PCL tunnels.

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FIGURE LEGENDS

Figure 1. Arthroscopic view of one cadaveric right knee. The PCL femoral tunnels were placed in the center of its femoral anterolateral bundle (ALB) and posteromedial bundle (PMB) footprints.

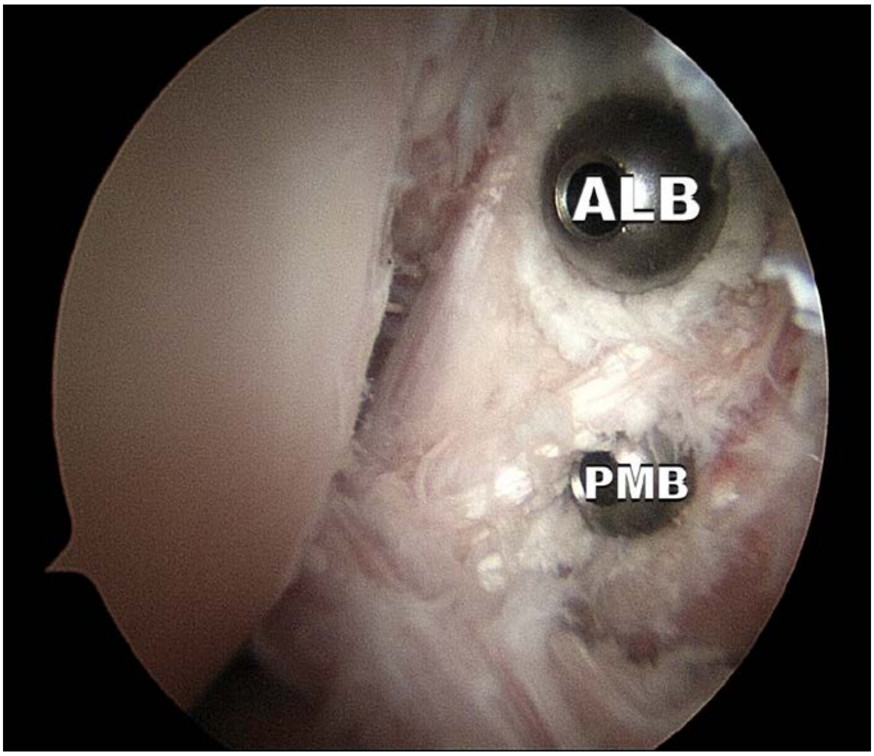


Figure 2. In both the axial (a) and coronal (b) planes, superficial medial collateral ligament and posterior oblique ligament tunnels were created at 0º and 30º. The neutral position (0,0) was considered when the guide wire was placed parallel to the transepicondylar axis and perpendicular to the femoral anatomic axis, respectively.

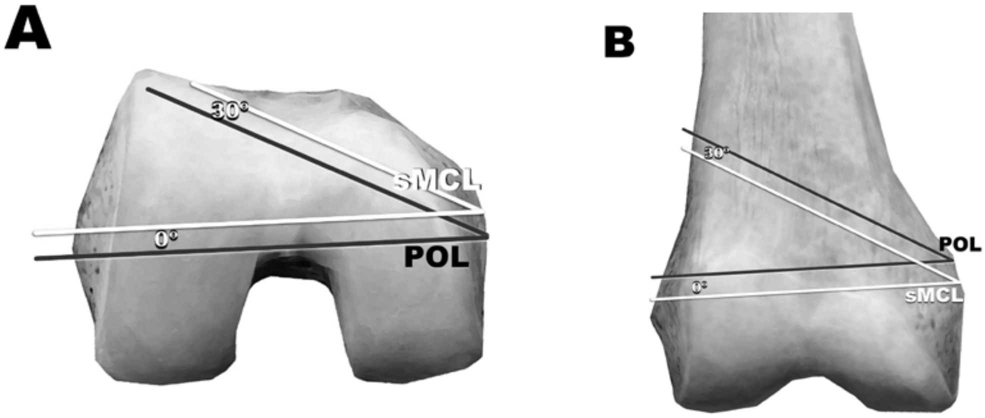


Figure 3. Four tunnels with the four tested angulations were drilled from the same entry point corresponding to the superficial medial collateral ligament (sMCL) and posterior oblique

ligament (POL) femoral origins. A 0.8mm metallic wire was left inside of each of the 8 evaluated tunnels for easier recognition in the following computed tomography evaluation. The outer exits of the tunnels corresponding to the anterolateral bundle of the posterior cruciate ligament (AL-PCL) and to the posteromedial bundle of the posterior cruciate ligament (PM-PCL) are also shown.

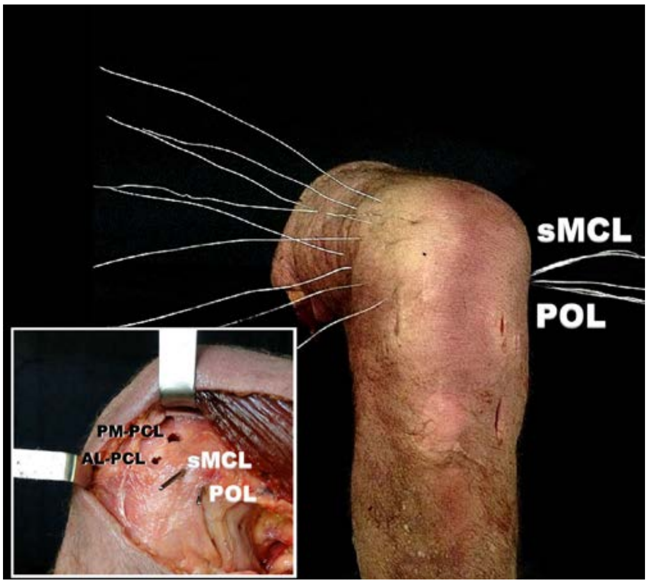


Figure 4. The superficial medial collateral ligament (sMCL) tunnels drilled at 0º axial angulation where in several cases in an excessively close proximity to the drilled tunnels of the anterolateral bundle (ALB) of the posterior cruciate ligament (PCL). In this coronal CT view, the sMCL at 0º of axial angulation (arrow) passed at 1.8mm from the ALB of the PCL, whereas the sMCL drilled at 30º of axial angulation (double arrow) did not.

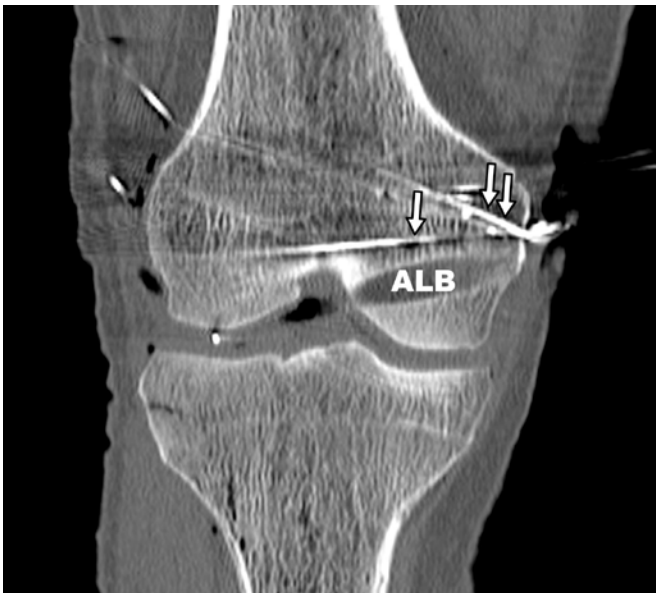


Figure 5: Coronal computed tomography view of a left knee. While the tunnel of the posterior oblique ligament drilled at 0º in reference to the transepicondylar axis pass through the intercondylar notch (arrow), the tunnel drilled at 30º did not (double arrow).

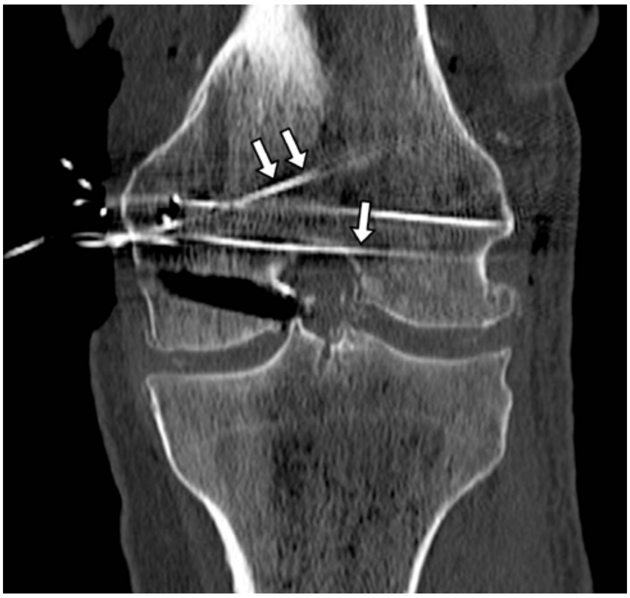
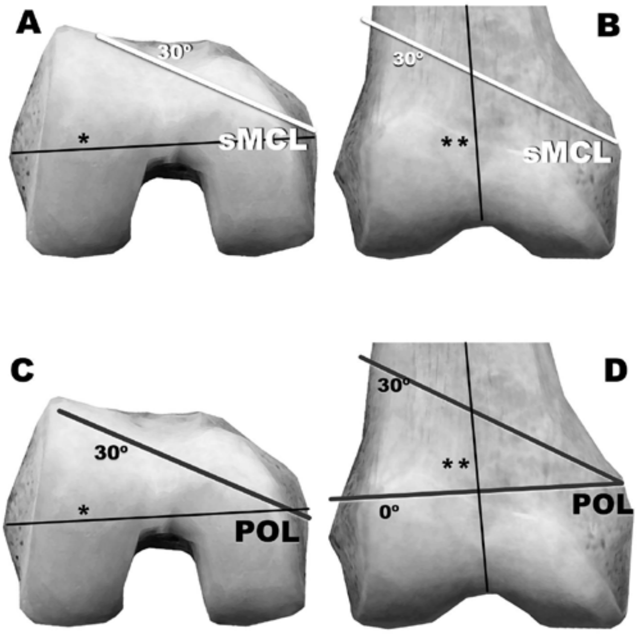


Figure 6. (A) The superficial medial collateral ligament (sMCL) should be drilled with 30º of axial angulation in reference to the transepicondylar axis (*). (B) In the coronal plane, the sMCL should be angled at 30º in reference to a line perpendicular to the femoral anatomic axis (**). (B) The posterior oblique ligament (POL) should also be drilled with 30º of axial angulation in reference to the transepicondylar axis (*). (D) In the coronal plane, the POL may be angled at either 0º or 30º in reference to a line perpendicular to the femoral anatomic axis (**).



TABLES

Table 1. Distances from the Superficial Medial Collateral Ligament and Posterior Oblique Ligament Tunnels to the Posterior Cruciate Ligament Tunnels.

	ALB PCL tunnel	**PMB PCL tunnel**
a. sMCL tunnel		
0º axial/0º coronal	2.8 (6±2.7); 0/8	3.4 (12.4±4.5); 0/8
0º axial/30º coronal	2 (8±3.6); 1/8	6.1 (12.8±4.8); 0/8
30º axial/0º coronal	1.8 (7.1±3.6); 2/8	7.3 (15.2±4.8); 0/8
30º axial/30º coronal	2.9 (12.3±7.8); 0/8	5.8 (19.3±7.7); 0/8
P	<.001	<.001
b. POL tunnel		
0º axial/0º coronal	9.5 (13.1±3.2); 0/8	9.1(15.8±4.3); 0/8
0º axial/30º coronal	0.5 (5.3±3.6); 3/8	4.2 (9.1±5.1); 0/8
30º axial/0º coronal	6.4 (12.2±4.5); 0/8	8.3 (16.8±5.3); 0/8
30º axial/30º coronal	7.7 (12±5.7); 0/8	10.4 (19.4±7.2); 0/8
P	<.001	<.001

All data is expressed in millimeters as minimum (mean ± standard deviation); number of cases at shorter distance than 2.5mm.

sMCL, superficial medial collateral ligament; POL, posterior oblique ligament; ALB, anterolateral bundle; PMB, posteromedial bundle.

Table 2. Distances from the Superficial Medial Collateral Ligament and Posterior Oblique Ligament Tunnels to the Intercondylar Notch.

	Intercondylar Notch	**Tunnel length-ICN**
a. sMCL tunnel		
0º axial/0º coronal	37.5% of cases	26.6 (31.8±3.8)
0º axial/30º coronal	25% of cases	30.3 (34.7±4.7)
30º axial/0º coronal	10.5 (17.7±3.8)	28.9 (32.2±2.8)
30º axial/30º coronal	10 (17.3±4)	26.9 (31.8±3.2)
P	0.04	<.001
b. POL tunnel		
0º axial/0º coronal	12.5% of cases	23.8 (32.3±4.9)
0º axial/30º coronal	75% of cases	25.6 (31.9±3.5)
30º axial/0º coronal	6.3 (16.3±5.7)	29.5 (33±2.7)
30º axial/30º coronal	11.2 (19.3±4.6)	27.8 (32.3±3)
P	0.02	0.002

All data is expressed in millimeters as minimum (mean ± standard deviation); number of cases with tunnels shorter than 25mm.

Intercondylar Notch: distance to the intercondylar notch in those cases that the tunnel was not drilled through it; Tunnel length-ICN: length of the drilled tunnel from the entry point to its end at the intercondylar notch. sMCL, superficial medial collateral ligament; POL, posterior oblique ligament; ALB, anterolateral bundle; PMB, posteromedial bundle.