Femoral Tunnel Drilling Angles for Posteromedial Corner Reconstructions of the Knee

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Purpose: To determine the best angle to drill the femoral tunnels of the superficial medial collateral ligament (sMCL) and posterior oblique ligament (POL) with concomitant posterior cruciate ligament (PCL) reconstruction to avoid either short tunnels or tunnel collisions. **Methods:** Eight cadaveric knees were studied. Double-bundle PCL femoral tunnels were arthroscopically drilled. Drilling of the sMCL and POL tunnels was performed in 4 different combinations of 0° and 30° axial (anteriorly directed) and coronal (proximally directed) angulations. Specimens were scanned with computed tomography to document the relations of the sMCL and POL tunnels to the intercondylar notch and PCL tunnels. A minimum tunnel length of 25 mm was required. **Results:** When the sMCL femoral tunnel was drilled at 0° axial and 30° coronal (proximally directed) angulations or 30° axial (anteriorly directed) and 0° coronal angulations, the risk of tunnel collision with the PCL tunnels increased in comparison with the remaining evaluated angulations ($P < .001$). No POL tunnels collided with either PCL tunnel bundle with the exception of tunnels drilled at 0° axial and 30° coronal (proximally directed) angulations, which did so in 3 of 8 cases ($P < .001$). The minimum required tunnel length was obtained in all the sMCL and POL tunnels ($P < .001$ and $P = .02$, respectively). However, some of those angled at 0° on the axial plane violated the intercondylar notch. **Conclusions:** When one is performing posteromedial reconstructions with concomitant PCL procedures, the sMCL and POL femoral tunnels should be drilled anteriorly and proximally at both 30° axial and 30° coronal angulations. The POL femoral tunnel may also be angled 0° in the coronal plane. Tunnels at 0° axial angulations showed a shorter distance to the intercondylar notch and a higher risk of collision with the PCL tunnels. **Clinical Relevance:** Specific drilling angles are necessary to avoid short tunnels or collisions between the drilled tunnels when sMCL and POL femoral tunnels are placed with concomitant PCL reconstruction.

Most patients who sustain an injury to the superficial medial collateral ligament (sMCL) are restored to their preinjury level with nonoperative treatment.[1] However, persistent valgus instability places additional strain on a reconstructed anterior cruciate ligament or posterior cruciate ligament (PCL), which can contribute to late graft failure.[1-3] For this reason, a combined PCL and medial-side injury might be one indication for surgical reconstruction of the PCL, as well as the medial stabilizers of the knee.[1,3,4] Among the surgical techniques that address the posteromedial corner (PMC) of the knee is reconstruction of not only the sMCL but also the posterior oblique ligament (POL).[5,6]

When a surgeon must perform reconstruction of the sMCL and POL and a single- or double-bundle PCL reconstruction, the placement of the resulting 3 or 4 tunnels that have to be drilled in only 1 femoral condyle may be a challenge. It is crucial to determine the best angle for drilling to avoid tunnel collisions, insufficient tunnel length, or violation into the intercondylar notch, which may lead to graft rupture or to excessively short tunnels. A similar situation may be seen when the posterolateral corner is being reconstructed concomitantly with the anterior cruciate

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ligament, and this has been evaluated recently in some cadaveric studies.[7,8]

The purpose of this study was to determine the best angle to drill the femoral tunnels of the sMCL and POL with concomitant PCL reconstruction to avoid either short tunnels or tunnel collision. Because of the tunnel proximity and the anatomy of the intercondylar notch, our hypothesis was that the sMCL and POL tunnels should be drilled aiming anteriorly and proximally to ensure safe placement of their femoral tunnels.

Methods

Eight frozen cadaveric knees from adult human volunteer donors were studied. The specimens were acquired from a university willed-body program. There were 5 male and 3 female donors (4 left and 4 right). Their ages ranged from 57 to 81 years (mean, 71.9 years). The specimens had been stored at −18°C. They were then thawed at room temperature for 24 to 36 hours before testing. Each specimen included the distal two-thirds of its corresponding femur and the proximal two-thirds of its corresponding tibia and fibula. None of the knees showed macroscopic signs of previous surgery. Knees with advanced degenerative changes were not included. Preoperative mobility, measured with a goniometer, showed minimum flexion of 135°. Full extension was still possible. The specimens were mounted on a knee holder (Sawbones Extremity Holder; Pacific Research Laboratories, Vashon, WA).

Arthroscopic Procedure

The surgical procedure was performed by the same author (P.E.G.), with 2 other authors (X.P. and J.C.M.) present and in agreement regarding tunnel placement. Only when the 3 experienced surgeons agreed on the tunnel placement was the tunnel drilled. The knees hung freely at 90° of flexion. A high anterolateral (AL) portal was established as the initial viewing portal. An anteromedial portal was also placed 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 place an AL bundle tunnel and a posteromedial (PM) bundle tunnel (Fig 1). They were placed with an outside-in technique. A specific outside-in aiming guide was used in all cases (ConMed Linvatec, Largo, FL). An 8-mm AL bundle tunnel was drilled by placing the aiming guide just anterior to the medial femoral epicondyle with an angulation of 50°. A 6-mm PM bundle tunnel was drilled by placing the aiming guide 10 mm more proximally with an angulation of 65°. These 2 divergent angulations allowed drilling proximal to the articular cartilage of the medial femoral condyle while minimizing the risk of collision between the PM and AL tunnels.

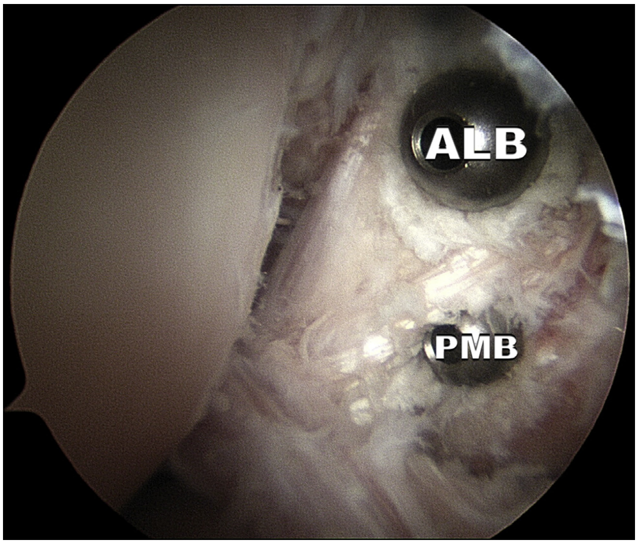

Fig 1. Arthroscopic view of a cadaveric right knee. The posterior cruciate ligament femoral tunnels were placed in the center of the femoral anterolateral bundle (ALB) and posteromedial bundle (PMB) footprints.

Dissection and PM Tunnel Drilling

The skin and subcutaneous tissue of the PM aspect of the knee were removed. The fascia was removed and the vastus medialis muscle was anteriorly retracted to facilitate assessment of the medial aspect of the femur. Careful dissection of the medial aspect of the knee was performed to identify the femoral insertion of the sMCL and POL. The sMCL femoral attachment is situated in a depression at an average of 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle.[9] The femoral insertion of the POL is located, on average, 7.7 mm distal and 6.4 mm posterior to the adductor tubercle, halfway between this tubercle and the medial epicondyle.[9] A 2.4-mm guidewire was drilled through the center of the femoral attachment of the sMCL and POL at 4 different guidewire orientations with the help of a manual goniometer in every specimen (Fig 2). On the basis of data reported in two similar studies,[7,8] additional orientations were excluded. The first orientation was 0° axial angulation with reference to the transepicondylar axis and 0° coronal angulation with reference to a line perpendicular to the femoral anatomic axis. A 0.8-mm metallic wire was inserted into the hole at the end of the guidewire. Then, each guidewire was pulled from the lateral side. The 0.8-mm metallic wire was left in the tunnel. The metallic wire later helped to facilitate recognition of the drilled tunnels during computed tomography (CT) assessment. At the same entry point and following the same steps as with the guidewire tunnel, additional metallic wires were consecutively left in the tunnels established at the femoral origin of both the sMCL and the POL at 0° axial angulation and 30° coronal angulation (directed

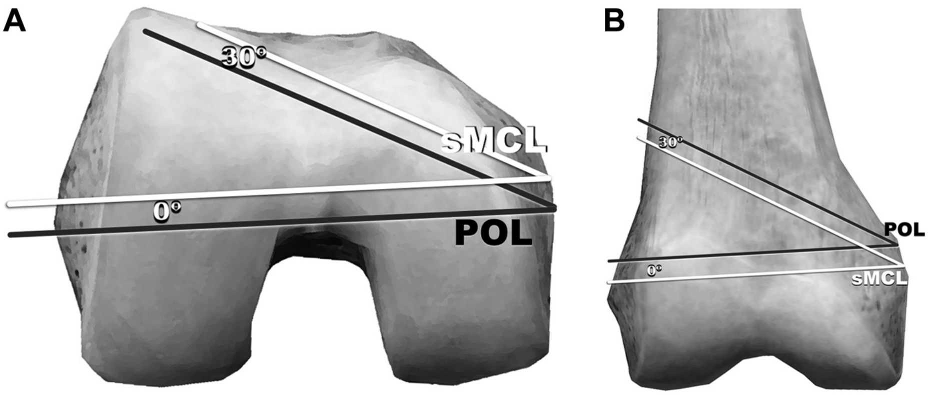

Fig 2. Drilling angles in a right knee. In both the (A) axial and (B) coronal planes, superficial medial collateral ligament (sMCL) and posterior oblique ligament (POL) tunnels were created at 0° and 30°. The neutral position (0°, 0°) was considered when the guidewire was placed parallel to the transepicondylar axis and perpendicular to the femoral anatomic axis.

proximally), at 30° axial angulation (directed anteriorly) and 0° coronal angulation, and at 30° axial angulation (directed anteriorly) and 30° coronal angulation (directed proximally).

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

A minimum tunnel length of 20 mm is usually recommended for proper graft-tunnel healing.[10] However, in the clinical setting, some extra millimeters in tunnel length are sometimes needed to effectively place the graft under the desired tension while pulling from its end. Thus a tunnel length of 25 mm was a requirement in considering a safe drilling angle to evaluate the role of the sMCL and POL tunnel depth as a possible cause of tunnel collision.

CT Scanning

All knees were placed in full extension and imaged in multiple planes on a LightSpeed VCT Pro 5-Beat Cardiac system with AW VolumeShare (GE Healthcare, Waukesha, WI) to generate multiplanar reconstructions of axial-, sagittal-, and coronal-plane CT images. Volume-rendering 3-dimensional CT reconstructions were also performed. Different quantitative parameters were evaluated with OsiriX medical imaging software, version 5.9, which is a 32-bit, open-source software program for navigating multidimensional DICOM (Digital Imaging and Communications in Medicine) images.[11]

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.[8] They first confirmed that the actual tunnel angles drilled for the sMCL and POL approximately matched our intended angles. Then, the shortest distance to every tunnel and to the intercondylar notch was measured. Any possible collision between the sMCL and POL tunnels was also studied. Superpositioning of the axial, coronal, and sagittal views was performed, and only the shortest distance observed in any of the 3 different planes was used as the final measure considered for data purposes. Each measurement was performed from the distal border of the corresponding 2.4-mm tunnel to the nearest point of the cortex of the cruciate femoral tunnels or to the intercondylar notch. The following assessments were also performed:

- Minimum distance to either bundle tunnel of the PCL
- Tunnels drilled through the intercondylar notch or at a distance shorter than 2.5 mm
- Tunnel lengths from the entry point to the intercondylar notch in those cases in which the drilled tunnel went across the intercondylar notch or to the nearest point to the intercondylar notch in those cases in which the drilled tunnel did not go across the intercondylar notch
- Tunnels not drilled through the intercondylar notch that had at least 2.5 mm of bone wall between them

Statistical Analysis

Categorical variables are presented as percentages and frequencies. Mean and standard deviation, as well as minimum and maximum, were calculated for each continuous variable. Quartiles were not calculated because of the small number of cases.

Analysis of variance 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.

Table 1. Distances From sMCL and POL Tunnels to PCL Tunnels

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

NOTE. Unless otherwise indicated, data are expressed as minimum (mean ± standard deviation); number of cases with distance shorter than 2.5 mm. ALB, anterolateral bundle; PCL, posterior cruciate ligament; PMB, posteromedial bundle; POL, posterior oblique ligament; sMCL, superficial medial collateral ligament.

Interobserver agreement was analyzed using the intraclass correlation coefficient in the case of a quantitative variable.[12] In those relevant cases, a 95% confidence interval (CI) was also calculated. In cases of categorical variables, the interobserver agreement was estimated with the κ coefficient. Statistical analysis was performed using SPSS software (version 19; SPSS, Chicago, IL). Statistical significance was set at .05.

Results

Relation to PCL Tunnels

When the sMCL femoral tunnel was drilled either at 0° axial and 30° coronal angulations or at 30° axial and 0° coronal angulations, there was an increased risk of tunnel collision with the AL bundle tunnel of the PCL ($P < .001$) (Table 1, Fig 3). There was no risk of tunnel collision of the sMCL with the PM bundle tunnel of the PCL for any of the studied angulations. No POL tunnels collided with either PCL tunnel bundle with the exception of the tunnels drilled at 0° axial and 30° coronal angulations, which did so with the AL bundle tunnel of the PCL in 3 of 8 cases (Table 1) ($P < .001$).

Intercondylar Notch and Tunnel Length

A variable percentage of sMCL and POL tunnels angled at 0° on the axial plane violated the intercondylar notch (Fig 4). However, all the sMCL and POL tunnels drilled at any angulation—except for the POL tunnels drilled at 0° axial and 0° coronal angulations—obtained the minimum required tunnel length (Table 2).

Optimal sMCL and POL Tunnel Angulations

Considering all the studied variables, we found that the safest sMCL tunnels were obtained in the group drilled at 30° in both the axial (anteriorly directed) and coronal (proximally directed) planes. Relative to the POL tunnels, the safest combination was observed when drilling was performed at 30° in the axial plane (anteriorly directed) and at 0° or 30° (proximally directed) in the coronal plane (Fig 5).

Evaluation of Experimental Design

The actual angles of the drilled tunnels were in the range of ±4.8° of the intended angles in all cases. In addition, no collision between the sMCL and POL tunnels was observed for any of the studied

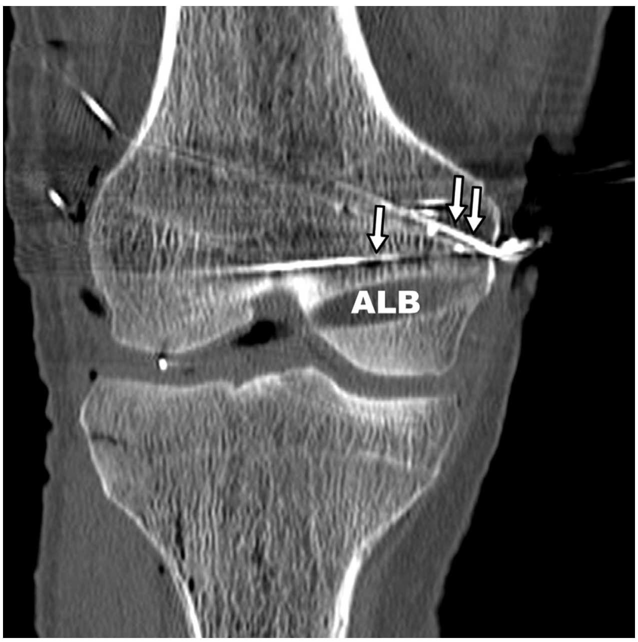

Fig 3. Computed tomography view of a right knee. The superficial medial collateral ligament (sMCL) tunnels drilled at 0° axial angulation were in excessively close proximity to the drilled tunnels of the anterolateral bundle (ALB) of the posterior cruciate ligament in several cases. In this coronal view, the sMCL at 0° axial angulation (single arrow) passed 1.8 mm from the ALB of the posterior cruciate ligament whereas the sMCL drilled at 30° axial angulation (double arrows) did not.

Fig 4. Coronal computed tomography view of a left knee. While the tunnel of the posterior oblique ligament drilled at 0° in reference to the transepicondylar axis passed through the intercondylar notch (single arrow), the tunnel drilled at 30° did not (double arrows).

angulations. Finally, the intraclass correlation coefficient obtained was considered excellent (0.94; 95% CI, 0.81 to 0.97), and the high calculated κ coefficient (0.91; 95% CI, 0.79 to 0.95) showed excellent agreement between observers.

Discussion

This study confirmed the risk of collision between tunnels or violation of the intercondylar notch when the sMCL and POL of the knee are being reconstructed concomitantly with a single- or double-bundle PCL reconstruction. However, our study found that such complications could be avoided by directing the sMCL tunnel anteriorly with an axial angulation of 30° and proximally with a coronal angulation of 30° and directing the POL tunnel with a 30° axial angulation.

PMC reconstructions are performed in different clinical situations. Most of the combined PMC injuries are addressed with cruciate ligament reconstructions. A combined PCL and grade III medial-side injury is considered one indication for surgical reconstruction of both the sMCL and POL by some authors.[1,3,4] Awareness of the need to treat persistent medial-side instability has increased because untreated PMC injuries may lead to failure of PCL reconstruction.[3,13] When the PCL is being concomitantly reconstructed, drilling its 1 or 2 tunnels with the additional femoral POL and sMCL tunnels may present a challenge in terms of fitting them all in the medial femoral condyle. Interestingly, no detailed information regarding the orientation of the femoral tunnels of either ligament has been reported. Whereas some investigation have not provided any information at all,[5,14-17] others have vaguely described aiming the tunnels "anterolaterally."[6] In our study it was seen that the femoral tunnel of the sMCL should always be angled 30° anteriorly in the axial plane and 30° proximally in the coronal plane. This orientation proved to prevent short tunnels of the sMCL itself and to avoid compromising the AL bundle of the PCL grafts that were placed inside their corresponding tunnels. Although the sMCL tunnels angled at 0° in both the axial and the coronal planes were just above the minimum required length (i.e., 25 mm) and the minimum safe distance (i.e., 2.5 mm), it seems logical to prefer the 30°-30° configuration more, which showed considerably higher measures. On the other hand, when the femoral tunnel of the POL was being reconstructed, a

Table 2. Distances From sMCL and POL Tunnels to Intercondylar Notch

		Tunnel Length—Intercondylar Notch, mm	
	Intercondylar Notch	Minimum	Mean ± SD
sMCL tunnel			
0° axial/0° coronal	37.5% of cases	26.6	31.8 ± 3.8
0° axial/30° coronal	25% of cases	30.3	34.7 ± 4.7
30° axial/0° coronal	0% of cases; minimum, 10.5 mm (mean ± SD, 17.7 ± 3.8 mm)	28.9	32.2 ± 2.8
30° axial/30° coronal	0% of cases; minimum, 10 mm (mean ± SD, 17.3 ± 4 mm)	26.9	31.8 ± 3.2
POL tunnel			
0° axial/0° coronal	12.5% of cases	23.8	32.3 ± 4.9
0° axial/30° coronal	75% of cases	25.6	31.9 ± 3.5
30° axial/0° coronal	0% of cases; minimum, 6.3 mm (mean ± SD, 16.3 ± 5.7 mm)	29.5	33 ± 2.7
30° axial/30° coronal	0% of cases; minimum, 11.2 mm (mean ± SD, 19.3 ± 4.6 mm)	27.8	32.3 ± 3

NOTE. The intercondylar notch is the distance to the intercondylar notch in those cases in which the tunnel was not drilled through it. The intercondylar notch data are expressed as the percentage of cases with tunnels shorter than 25 mm. The tunnel length—intercondylar notch is the length of the drilled tunnel from the entry point to its end at the intercondylar notch or to the nearest point to it.

POL, posterior oblique ligament; sMCL, superficial medial collateral ligament.

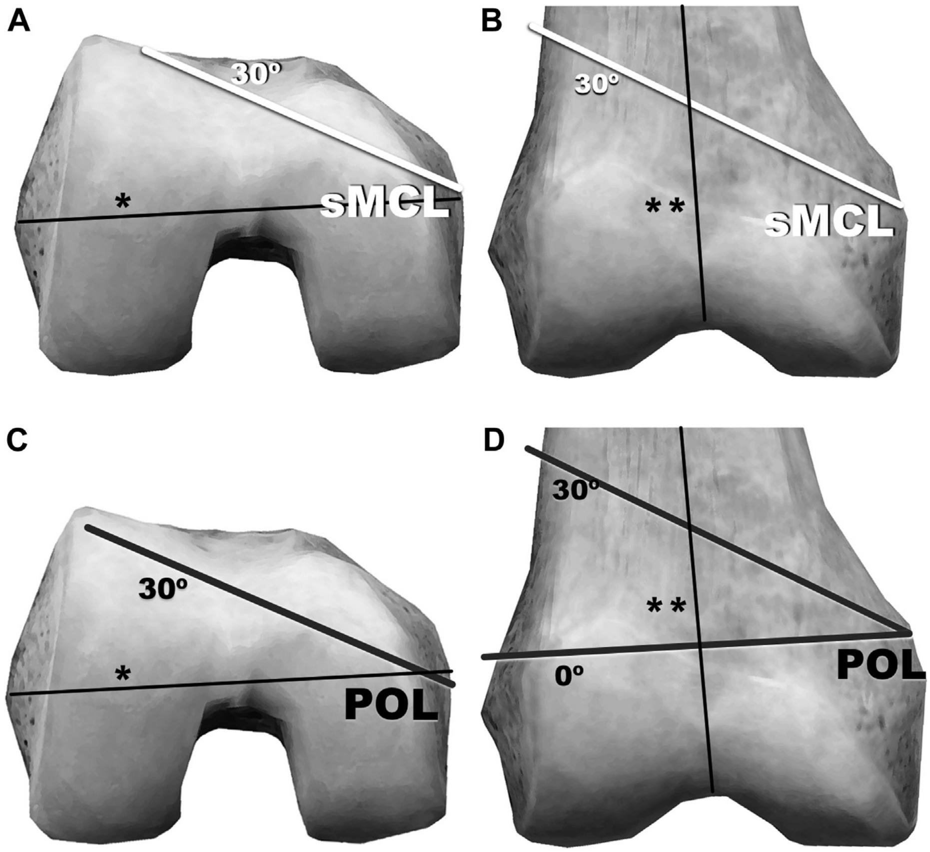

Fig 5. Recommended drilling angles in a right knee. (A) The superficial medial collateral ligament (sMCL) should be drilled at 30° axial angulation in reference to the transepicondylar axis (asterisk). (B) In the coronal plane, the sMCL should be angled at 30° in reference to a line perpendicular to the femoral anatomic axis (double asterisk). (C) The posterior oblique ligament (POL) should be drilled at 30° axial angulation in reference to the transepicondylar axis (asterisk). (D) In the coronal plane, the POL may be angled at either 0° or 30° in reference to a line perpendicular to the femoral anatomic axis (double asterisk).

wider range of safe drilling angles was observed. The POL tunnel may be angled at either 0° or 30° in the coronal plane but should always be drilled 30° anteriorly in the axial plane.

Regarding the evaluation of tunnel placement and its relations, CT is currently considered the gold standard for assessing tunnel relations in reconstructions of the knee ligaments.[18,19] Moreover, recent studies have shown the reliability of multiplanar reconstructions of CT views and volume-rendering 3-dimensional CT images with a design similar to that used in our study.[7,8] In addition, the CT scan evaluation showed that the tunnels were placed around the intended drilling angle.

Very few studies have evaluated tunnel collision when different ligaments are being reconstructed in knee surgery. More specifically, our investigation addresses a knowledge gap regarding the proper angulations of both the sMCL and POL femoral tunnels when they are placed concomitantly with anatomic single- or double-bundle PCL reconstruction. It shows that specific drilling angles are necessary to prevent short tunnels or collisions between the drilled tunnels when the sMCL and POL femoral tunnels are placed with concomitant PCL reconstruction. This finding might be of critical clinical relevance because tunnel collisions may lead to graft rupture or to excessively short tunnels.

Limitations

There are some limitations to our study. First, some of the non—statistically significant differences observed might be because of the small number of specimens included. An a priori sample assessment was not performed. Besides, only 4 different drilling angulations were evaluated in the study. However, additional orientations were excluded based on the data reported in two investigations with a similar study design.[7,8] In one of these previous studies, differences were only found between tunnels placed at 0° axial and coronal angulations and those placed at 20° or 40° axial and coronal angulations.[7] In the other study, and similar to our investigation, only 0° and an intermediate tunnel at 30° were chosen.[8] In addition, no actual tunnels of any diameter were drilled. The only solution found to assess different tunnel orientations in the same medial femoral condyle was to drill thinner tunnels. However, the calculations were performed considering that the drilled tunnels had the diameters of tunnels used in the clinical setting.

Another important limitation is that the PCL reconstruction was performed with only one specific technique; moreover, this technique might also offer some variations. For instance, performing placement at a different location or setting the aiming guide at a different degree on the medial aspect of the medial femoral condyle could yield different PCL femoral tunnels in multiplanar situations. This might limit generalization of the results observed in this investigation. In the same way, other tunnel diameters were not evaluated, although the chosen diameters of the drilled tunnels were intended to be similar to those used in a clinical situation. Although some surgeons prefer to drill a 10-mm tunnel, in our experience with cadaveric studies, the specimens that we are used to working with are usually smaller than the knees of average patients. Thus we thought that a larger tunnel might involve too much of the medial condyle. Moreover, 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 our investigation. The angulations of the evaluated tunnels were assessed during the procedure with only a manual goniometer. Although this device might provide low accuracy and might be considered another limitation of the study, it was chosen to more closely reproduce the clinical situation. Finally, the fact that the wires were left in situ may have subtly affected the trajectory of the subsequently drilled wires.

Conclusions

When one is performing PM reconstructions with concomitant PCL procedures, the sMCL and POL femoral tunnels should be drilled anteriorly and proximally at both 30° axial and 30° coronal angulations. The POL femoral tunnel may also be angled 0° in the coronal plane. Tunnels at 0° axial angulations showed a shorter distance to the intercondylar notch and a higher risk of collision with the PCL tunnels.

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