# How Accurate Are Anatomic Landmarks for Femoral Tunnel Positioning in Anterior Cruciate Ligament Reconstruction? An In Vivo Imaging Analysis Comparing Both Anteromedial Portal and Outside-In Techniques

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**Purpose:** To assess the ability of 2 independent surgical techniques, an inside-out technique and an outside-in technique, using bony landmarks on the femoral wall, to place the anterior cruciate ligament graft anatomically. **Methods:** A retrospective single-center study was conducted in 2012 and included patients who underwent anterior cruciate ligament reconstruction. Two techniques were used: The lateral condylar wall was visualized from the anterolateral portal and tunnels were drilled "outside-in" in one group, whereas viewing was performed from the anteromedial portal and retrograde drilling ("inside-out") was performed in the other group. The primary outcome measure was the placement of the tunnel center point on postoperative computed tomography scans with 3-dimensional reconstruction, according to the radiographic quadrant method of Bernard and Hertel. The measurements were compared with optimal placements according to Bird et al. Their reliability was assessed with Spearman (rho) and intraclass correlation coefficients. **Results:** Forty patients were included, with 20 in each group; the mean age was 29.8 ± 9.6 years, and there were 33 men and 7 women. The interobserver reliability and intraobserver reliability of measurements were good, with a Spearman ρ between 0.46 ($P = .002$) and 0.93 ($P < .001$) and an intraclass correlation coefficient between 0.44 ($P = .001$) and 0.86 ($P < .001$). The femoral tunnel positions of both techniques were close to the previously published anatomic placements, but there was a significant difference between our results and the theoretical position in proximal-distal measurements ($P = .01$). There was no difference in the anteroposterior measurements. There was no statistical difference in the accuracy of placement of the femoral tunnel center point between these 2 independent techniques. **Conclusions:** The direct arthroscopic visualization of bony landmarks seems sufficient for accurate positioning of the femoral tunnel whatever the drilling technique. This finding is clinically relevant because the routine use of direct measurement techniques or intraoperative radiographs may not be necessary to obtain anatomic tunnel placement. **Level of Evidence:** Level IV, case series.

Successful management of anterior cruciate ligament (ACL) deficiency is essential to prevent instability, risk of meniscal injury, and premature osteoarthritis.[1,2] Arthroscopic ACL reconstruction techniques are still evolving. Recently, the focus of ACL reconstruction has been anatomic reconstruction, which can be defined as placement of tunnels in the center of the native ACL insertion sites on the tibia and femur using either single- or double-bundle techniques.[3] Potential benefits of a more anatomic reconstruction are the re-creation of normal ligament stability and the graft-tension relation with restoration of near-normal kinematics. An anatomic reconstruction can potentially reduce the likelihood of graft failure, pain, instability, and early osteoarthritis. Small errors in femoral tunnel placement can produce large variations in graft-tension mismatch with elongation due to closer proximity to the rotational center of the knee compared with the tibial insertion site.[4] Incorrect femoral tunnel placement is a frequent cause of failed ACL reconstruction.[5]

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One of the most popular ACL reconstruction techniques in the past 2 decades has been single-bundle transtibial ACL reconstruction, with good results reported in the literature.[6] Lately, this method of reconstruction has been questioned because of the possible nonanatomic basis of tunnel drilling, which leads to a more vertical graft orientation that provides excellent anteroposterior stability but lacks rotational control, leading to recurrent pivot shift. It has been recommended to use an independent drilling technique for anatomic femoral tunnel placement.[6-11] Anatomic ACL reconstruction requires the accurate identification of the anatomy of the ACL and an attempt to reproduce normal graft forces by placing the graft in the center of the anatomic footprint and to apply appropriate tension to mimic the native ACL.[12] With these essential principles in mind, it is thus important to identify specific landmarks that will assist the surgeon in anatomic reconstruction. Some authors propose using the lateral intercondylar and bifurcate ridges to locate the native ACL femoral insertion site.[13,14] These bony landmarks have been shown to be accurate,[14] but the bifurcate ridge can be absent in 12% to 52% of cases.[13,15] To validate femoral tunnel position, Bird et al.[14] used 3-dimensional (3D) computed tomography (CT) postoperatively with the Bernard-Hertel radiographic quadrant method.[16] According to the mean coordinates previously published with this method,[17-22] Bird et al. determined the optimal position: 28% on the proximal-to-distal (PD) axis and 35% on the perpendicular axis.

The main purpose of this study was to assess the ability of 2 independent surgical techniques, an inside-out technique and an outside-in (OI) technique, using bony landmarks on the femoral wall, to place the ACL graft anatomically. Our hypothesis was that with accurate identification of the bony landmarks and subsequent femoral tunnel placement, graft occupation of the anatomic femoral insertion site can be achieved, using 2 independent operative techniques.

## Methods

This retrospective, single-center study was conducted with institutional approval of our local ethical committee. Patients were included after a postoperative consultation during June and July 2012. All patients were operated on after June 2011 and underwent ACL reconstruction using an anatomic position on the medial wall of the lateral femoral condyle according to 2 independent techniques, either an OI technique or an inside-out technique drilling through the anteromedial (AM) portal. One surgeon exclusively used the OI technique (M.F.) and the other used the AM technique (G.V.) in all their patients.

### Anatomic Outside-In Operative Technique

Two arthroscopic portals are made in the knee to allow optimal vision and instrumentation. A high anterolateral (AL) portal is placed at the level of the inferior pole of the patella, adjacent to the lateral border of the patellar tendon. An AM portal is made at the same level as the AL portal, between the medial border of the patellar tendon and medial femoral condyle. After diagnostic arthroscopy, an arthroscopic shaver device is used to remove scar tissue and some of the remaining ACL tibial stump. A radiofrequency probe is then used to remove the ACL femoral stump to preserve the bony anatomy and to identify the proximal margin of the articular cartilage as a specific reference point (Fig 1). With the knee flexed at 90°, the lateral intercondylar ridge and the bifurcate ridge are visualized. The midpoint of the femoral tunnel is marked with a microfracture awl inserted through the AM portal just posteriorly to the bifurcate ridge.[23] The height of the entry point is chosen according to the data of Bird et al.[14] and 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 aspect of the notch. The portals are then switched. The arthroscope is placed in the medial portal, and the medial wall of the lateral femoral condyle is observed. The correct position of the midpoint of the femoral tunnel is assessed (Fig 2). A FlipCutter ACL femoral guide (Arthrex, Naples, FL) is placed through the AL portal. The center of the guide is placed over the mark made by the awl, with the concavity anterior to the articular cartilage and the tip at the "over-the-top"

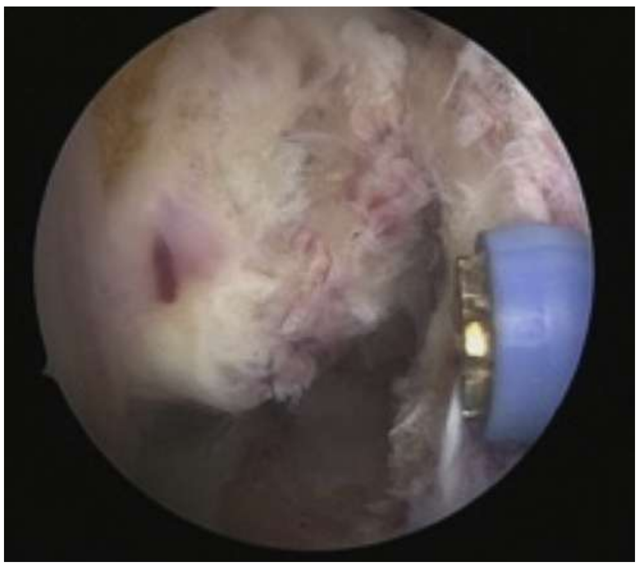

**Fig 1.** A radiofrequency probe is used to remove the anterior cruciate ligament femoral stump to preserve the bony anatomy and to identify the proximal margin of the articular cartilage as a specific reference point.

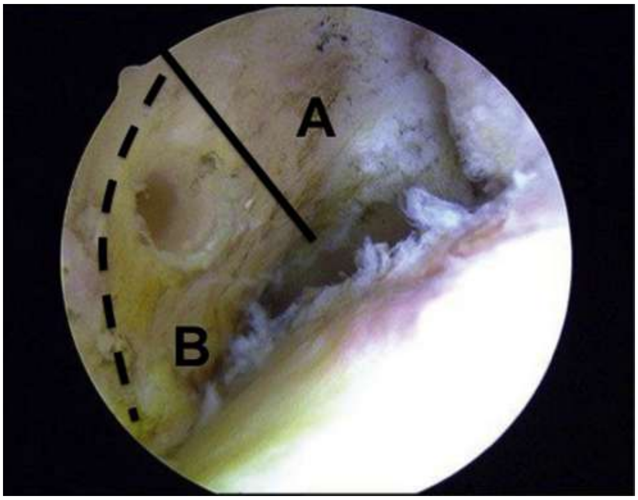


**Fig 2.** The lateral intercondylar ridge (A) and the bifurcate ridge (B) are visualized from the anterolateral portal view. The midpoint of the femoral tunnel is marked with a microfracture awl inserted through the anteromedial portal just posteriorly to the bifurcate ridge.[23] The height of the entry point follows the steps as performed according to Bird et al.[14]

position (Fig 3). A FlipCutter matching the diameter of the prepared graft is drilled from outside into the joint through a small incision over the lateral femoral cortex. The correct entrance point of the drill above the concavity of the guide is visualized from the AM portal. After removal of the guide, the arthroscope is then switched to the AL portal and retrograde drilling of a blind socket is performed in the femur to the desired depth after flipping the FlipCutter from the articular side of the lateral femoral condyle.

### Anatomic Inside-Out Operative Technique

Two arthroscopic portals are made in the knee to allow optimal vision and placement of instrumentation. A high AL portal is placed at the level of the inferior pole of the patella, adjacent to the lateral border of the patellar tendon. An AM portal is made under direct vision just above the level of the medial meniscus, in the inferomedial corner of the patellar tendon and tibial plateau junction.

The notch is prepared by use of an arthroscopic shaver device to remove scar tissue and the remaining ACL tibial stump. A radiofrequency probe is then used to remove the ACL femoral stump to preserve the bony anatomy and to identify the proximal margin of the articular cartilage as a specific reference point. With the knee flexed at 90°, the lateral intercondylar ridge and the bifurcate ridge are visualized from the AL portal view. The midpoint of the femoral tunnel is marked with a microfracture awl inserted through the AM portal just posteriorly to the bifurcate ridge.[23]

The height of the entry point is determined by the diameter of the tunnel according Bird et al.[14] 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.

### Radiographic 3D CT Analysis Protocol

Only the technique of femoral tunnel placement was evaluated in this study. CT scans were performed postoperatively, and 3D reconstructions 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. Two orthopaedic trauma surgeons (E.P., G.V.), with similar amounts of experience, independently viewed the CT scan on 2 separate occasions at a mean of 2 weeks apart. Scans were anonymized. An independent biostatistician (S.K.) performed the statistical analysis.

Between 3 weeks and 1 year after surgery, a 3D CT scan was obtained with a slice acquisition thickness of 1 mm. The scans were performed with a Toshiba Aquilion 64 CT scanner (Tokyo, Japan), and Aquilion software was used for analysis (version V3.20 ER 003). The scan was oriented into a true lateral position so that both condyles were superimposed and the medial femoral condyle was removed.[14] The center of the femoral tunnel was determined by use of the grid system described by Bernard and Hertel.[18] The grid was positioned so that the superior arm was against the roof of the notch corresponding to the Blumensaat line and the posterior edge was aligned with the posterior aspect of the lateral femoral condyle (Fig 4). The position of the tunnels was then calculated with coordinates from

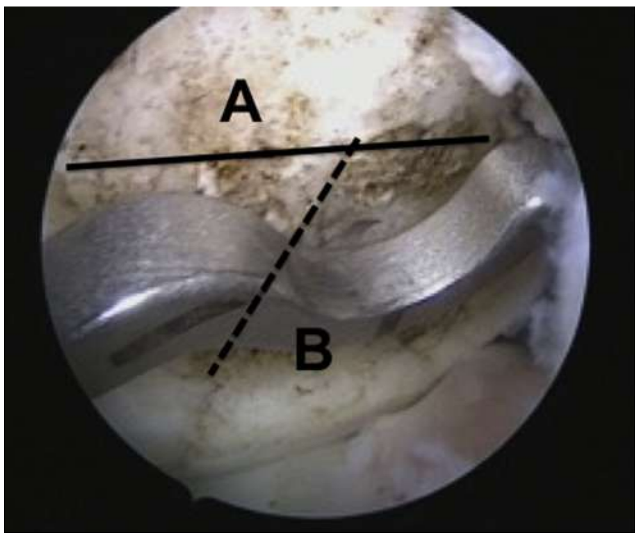


**Fig 3.** The correct position of the midpoint of the femoral tunnel is assessed from the anteromedial portal view, and an anterior cruciate ligament femoral guide is placed through the anterolateral portal, with the concavity anterior to the articular cartilage and the tip at the over-the-top position. The lateral intercondylar ridge (A) and bifurcate ridge (B) are shown.

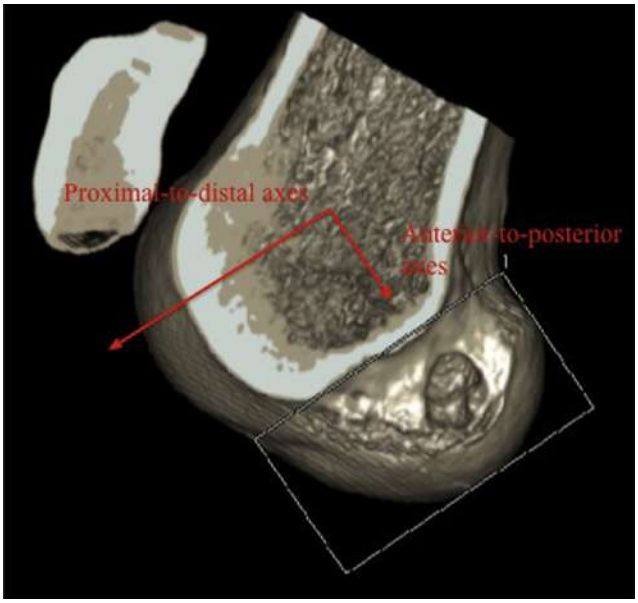


**Fig 4.** Sagittal section through the intercondylar notch showing the lateral wall to which the quadrant method of Bernard and Hertel[18] has been applied.

the center of the tunnel (Figs 5 and 6) and was represented by a percentage on the superior and posterior axis.

## Evaluation Criteria

The main evaluation criterion was the placement of the tunnel center point on postoperative CT scans with 3D reconstruction, according to the radiographic quadrant method of Bernard and Hertel,[18] which describes the centrum as a percent distance along the Blumensaat line (from proximal and posterior to distal and anterior) and a percent distance along a line perpendicular to the Blumensaat line (from proximal and anterior to distal and posterior). The coordinate positions for each patient from the 2 groups were compared with the optimal position defined by Bird et al.[14] and previous authors.[17-22] Their mean bundle position was found to be at 28% of the PD axis and at 35% of the anterior-to-posterior (AP) axis.

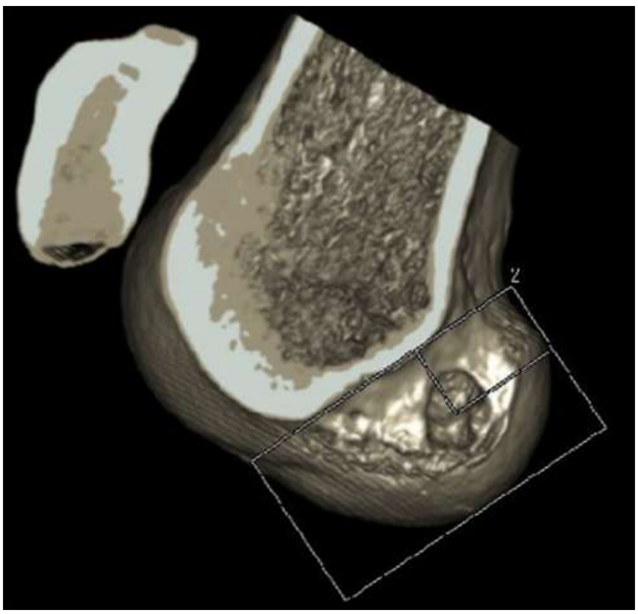


**Fig 5.** The center of the femoral tunnel is determined using the quadrant method.

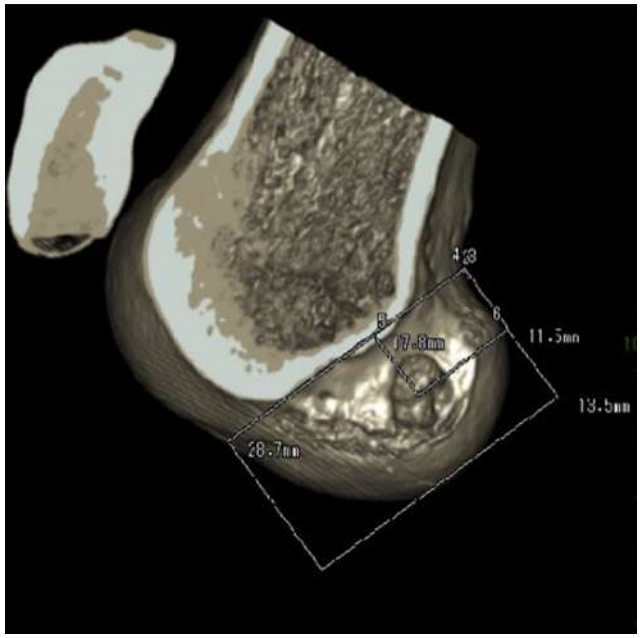


**Fig 6.** The location of each tunnel on this grid is recorded and expressed as coordinates along the Blumensaat line from proximal to distal and along the opposite axis for anterior to posterior. Our software calculates the measurements.

## Statistical Analysis

Given the lack of previous data in the literature, the number of patients was set empirically to 20 by technique. The positions of the femoral tunnels in the 2 groups, in the AP axis and in the PD axis, were the mean of all measurements performed by the 2 observers. Tunnel placement relative to the ideal position was compared among all the patients and between the 2 techniques. Statistical analyses were performed using Stata/IC, version 10.0 (StataCorp, College Station, TX). Nonparametric tests were used, based on the type and distribution of the data, including the Mann-Whitney test and the paired Wilcoxon test for quantitative parameters. The relation between the 2 measurements of each observer and between observers was measured using Spearman correlation coefficients, which were classified as strong (>0.5), medium (from 0.3 to 0.5), small (from 0.1 to 0.3), or none (<0.1).[24] The intraobserver reliability and interobserver reliability were evaluated by intraclass correlation coefficients (ICCs), which were classified as excellent (ICC >0.75), good

(ICC from 0.40 to 0.75), or poor (ICC <0.40).[25] All correlations were tested for statistical significance using the $P$ value. $P < .05$ was considered to be significant.

## Results

A total of 40 patients (mean age, 29.8 ± 9.6 years; age range, 15 to 48 years) underwent ACL reconstruction using an anatomic position on the medial wall of the lateral femoral condyle according to 2 independent techniques: the OI technique in 20 patients (mean age, 30 ± 8.8 years; age range, 15 to 48 years) and the AM technique in 20 patients (mean age, 29.7 ± 10.5 years; age range, 15 to 48 years). There were 16 male and 4 female patients in the OI group and 17 male and 3 female patients in the AM group. There were 11 right and 9 left knees in the OI group and 14 right and 6 left knees in the AM group. CT scans were performed after a mean postoperative follow-up period of 3 ± 3 months (range, 3 weeks to 12 months).

For intraobserver reliability, the test-retest correlation was strong for all measurements, with a Spearman ρ ranging from 0.79 to 0.93 ($P < .001$). Physicians' agreement between their initial scoring and rerating of the same patient was good or excellent, with an ICC ranging from 0.70 to 0.86 ($P < .001$). For interobserver reliability, the correlation was medium to strong, with a Spearman ρ varying between 0.46 ($P = .002$) and 0.69 ($P < .001$). The agreement between physicians' ratings of patients was medium, with an ICC ranging from 0.44 ($P = .001$) to 0.70 ($P = .01$).

The mean positions of the femoral tunnels in the OI group were 34.8% ± 9% (range, 16% to 53%) in the AP axes and 31% ± 5% (range, 22% to 40%) in the PD axes. In the AM group the mean results were 30% ± 8% (range, 12% to 41%) and 30% ± 6% (range, 21% to 42%), respectively. The mean positions of all our patients were 32.3% ± 9% (range, 12% to 53%) and 30.4% ± 5% (range, 21% to 42%), respectively. About half of the patients had values from 30% to 39% in the AP axes (ideal position, 35%) and 23% to 32% in the PD axes (ideal position, 28%) (Fig 7).

There was a difference in femoral tunnel placement between our series and the ideal position in the PD axis ($P = .01$) but not in the AP axis ($P = .13$). There were no differences between the 2 techniques ($P = .09$ for AP axis and $P = .36$ for PD axis).

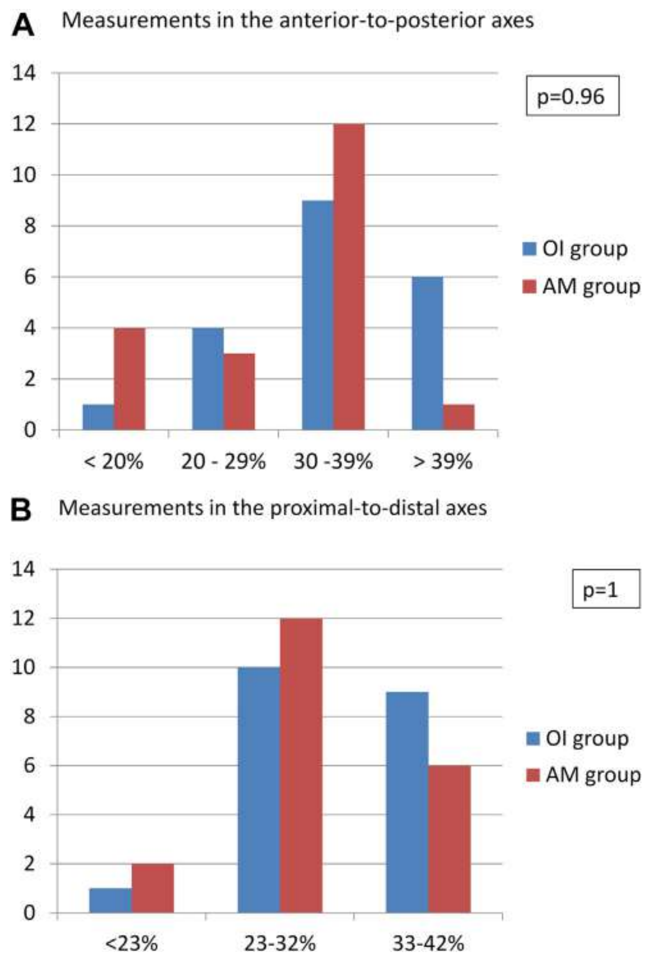


**Fig 7.** The mean positions of the femoral tunnels in the (A) anterior-to-posterior axes and (B) proximal-to-distal axes by group. (AM, anteromedial; OI, outside in.)

## Discussion

The philosophy of ACL reconstruction is to perform an anatomic reconstruction, which can be defined as placement of the tunnels in the center of the native ACL insertion sites on the tibia and femur, using either single- or double-bundle techniques.[3] Some authors have questioned the need for a double-bundle reconstruction and found that the posterolateral graft can occasionally fail during tests with internal torque or anterior tibial force.[26] Recently, Ho et al.[27] showed that an anatomic single-bundle reconstruction can restore the same kinematic control of knee rotation and anterior displacement as the double-bundle technique. Moreover, the single-bundle technique is less complicated and presents a shorter learning curve than a double-bundle reconstruction.[14]

We choose to use the bony landmarks defining the ACL footprint location as described by Ferretti et al.[13] and corroborated by arthroscopic and CT data[28,29]: The femoral footprint is identified posterior to the lateral intercondylar ridge, and the 2 bundles are separated by the bifurcate ridge.[14] The lateral intercondylar ridge is constant, but the bifurcate ridge is present in 48% to 88% of cases,[9,13,15] which can explain our difference in the PD axis. In a cadaveric study, Ziegler et al.[23] showed that the bifurcate ridge is harder to locate arthroscopically and can correspond to a change in slope. We have not used the roof of the intercondylar notch as a reference because it is reported to be imprecise.[28,30] Lubowitz[28] proposed using the posterior articular cartilage as a landmark, but his technique does not account for the variability in each patient. Some authors have proposed using the remnant femoral stump of the ACL as a soft-tissue landmark.[9,31,32] This technique is attractive in that, by retaining the soft tissue, it may improve post-reconstruction proprioception.[33] However, in chronic long-standing ACL-deficient knees, it may be difficult to observe this remnant ACL.[31,34] The Watanabe technique, using 3 reference points (the over-the-top position, the anterior-notch outlet point, and the most inferior point of the interface between bone and cartilage), is considered to be accurate but requires the use of a navigation system.[17]

Our results show that the direct arthroscopic visualization of bony landmarks to determine femoral tunnel placement is clinically reproducible using 2 independent techniques. Using the lateral intercondylar ridge and the bifurcate ridge, there is no difference in the placement of our femoral tunnel between the OI and AM techniques. The use of these landmarks appears to be reproducible. However, our global results present a significant difference in the PD axis compared with the ideal position described by Bird et al.[14] To avoid this difference, some authors have proposed using a ruler to measure the depth of the lateral wall and drilling the tunnel at the midpoint to place it in the midbundle position.[14] We have not used this technique because our hypothesis was that bony landmarks are sufficient, especially in the PD axis.[28] Moreover, in a recent review of the literature, Lubowitz[28] suggested that the anatomic center of the ACL footprint is 43% of the PD length of the lateral wall. Both independent techniques present a difference regarding the ideal point, but for the OI technique, the difference is in the PD axis, and for the AM technique, it is in the AP axis. These results could suggest that each technique presents advantages and disadvantages according to the visualization angle of the medial wall of the lateral condyle for the placement of the femoral tunnel and for the visualization of the bony landmarks. In the OI technique, a narrow notch dimension may decrease visibility of the lateral condyle wall.[15] Some authors have proposed that this problem can be avoided by performing a notchplasty or by viewing from an accessory AM portal or an OI technique.[15] A more medial high portal, which passes through the patellar tendon, also can be used.

The use of intraoperative computer navigation or radiographic correlation is suggested. These devices assist the surgeon in creating the femoral tunnel in the anatomic footprint and avoiding potential complications.[35] However, with navigation, any unexpected movement of the reference frame can occur and resolution of the C-arm needs improvement.[35] The quadrant method is useful for evaluating the intraoperative tunnel position,[17] but it requires an intraoperative true lateral view.[18] Despite the findings of Chitnavis et al.,[36] who showed that radiation doses administered during fluoroscopically assisted ACL reconstruction were safe, this method remains unpopular because of the complexity and cost of the procedure.[14]

### Limitations

There are some limitations in our study. First, 2 separate surgeons, each exclusively using 1 technique, performed the operations. This could introduce some bias, but both surgeons are experienced in performing anatomic ACL reconstructions. Second, the use of a 3D CT scan can introduce some inaccuracies. The acquisition of the true lateral view of the medial side of the lateral femoral condyle, the positioning of the quadrant, and the choice of the center of the tunnel, which is not a true circle, are observer and operator dependent. This could introduce human error. Other authors have proposed using bilateral 3D magnetic resonance imaging to compare the femoral tunnel placement with the contralateral ACL femoral attachment[6] because the soft tissue cannot been seen with a 3D CT scan. However, 3D CT has already been validated to assess the position of the femoral tunnel postoperatively,[11,21,37] and the quadrant method has been used by many authors to locate the femoral tunnel position.[14,17-22] Third, we chose to compare our placement according to previously published data,[14] and articles of merit may have been excluded.[28] Another limitation of these data is that they were obtained in cadaveric analyses[14] and ACL patients are generally of a younger age and may have different anatomy.[28] Fourth, the delay in the 3D CT scans performed after surgery is an important bias: CT scans obtained after a longer delay may shown larger tunnels,[38] and we do not know if expansion is equal in all directions, which could affect the location of the tunnel center. Tunnel diameters were been measured. Finally, we did not perform a sample size calculation given the lack of previous data in the literature. In the future, these initial data will help us to design a prospective study with good power.

## Conclusions

The direct arthroscopic visualization of bony landmarks seems sufficient for accurate positioning of the femoral tunnel whatever the drilling technique. This finding is clinically relevant because the routine use of direct measurement techniques or intraoperative radiographs may not be necessary to obtain anatomic tunnel placement.

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