The Relation Between Knee Flexion Angle and Anterior Cruciate Ligament Femoral Tunnel Characteristics: A Cadaveric Study Comparing a Standard and a Far Anteromedial Portal

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**Purpose:** The purpose of this study was to compare the anterior cruciate ligament (ACL) femoral tunnel characteristics between 2 common arthroscopic portals used for ACL reconstruction, a standard anteromedial portal and a far anteromedial portal.

**Methods:** Seven cadaveric knees were used. A 1.25-mm Kirschner wire was drilled through the center of the ACL femoral footprint and through the distal femur from the standard anteromedial and far anteromedial portals at knee flexion angles of 100°, 120°, and 140°. No formal tunnels were drilled. Each tunnel exit point was marked with a colored pin. After all tunnels were created, the specimens were digitized with a MicroScribe device (Revware, Raleigh, NC) to measure the tunnel length; distance to the posterior femoral cortical wall (posterior cortical margin); and tunnel orientation in the sagittal, coronal, and axial planes.

**Results:** The standard anteromedial portal resulted in a longer tunnel length, a less horizontal tunnel in the coronal plane, and a greater posterior cortical margin compared with the far anteromedial portal at all knee flexion angles. For both portal locations, the tunnel length and posterior cortical margin increased, and the tunnel position became more horizontal in the coronal plane, more anterior in the sagittal plane, and less horizontal in the transverse plane as knee flexion increased.

**Conclusions:** Portal position affects femoral tunnel characteristics, with results favoring the more laterally positioned standard anteromedial portal at all flexion angles. Increasing the knee flexion angle leads to a longer femoral tunnel length and posterior femoral cortical margin with either portal position.

**Clinical Relevance:** Understanding how portal positioning and knee flexion angle affect femoral tunnel orientation and characteristics may lead to improved surgical outcomes after ACL reconstruction.

Recently, there has been a push toward anatomic restoration of the anterior cruciate ligament (ACL) when performing reconstructions. Studies show that when reconstructing the ACL, anatomic placement leads to more native knee kinematics.\(^1\)\(^-\)\(^5\) Traditional methods of ACL reconstruction, such as the transtibial technique, lead to nonanatomic femoral tunnel placement.\(^6\)\(^-\)\(^8\) More recent technical changes to address this concern include independent drilling of the femoral tunnel through an anteromedial portal or far accessory anteromedial portal.\(^6\)\(^-\)\(^8\)

The independent drilling technique does have some drawbacks, however, including the possibility of damage to the medial femoral condyle articular cartilage, potential for damage to the common peroneal nerve and lateral collateral ligament, a shorter femoral tunnel, and the possibility of posterior cortex breach when drilling the femoral tunnel.\(^9\)\(^,\)\(^10\) When creating the femoral tunnel through the standard anteromedial portal, surgeons often place the knee at a high angle of knee flexion of 120° or greater to prevent posterior cortical wall blowout and short femoral tunnels, as well as to avoid soft tissues at the femoral tunnel outlet.\(^11\)\(^-\)\(^13\)

Many surgeons choose to drill the femoral tunnel using...
a far accessory portal more medial to the standard anteromedial portal to improve accessibility to the femoral footprint center in as orthogonal a position as possible, with the fundamental principle being that this most closely mimics the native insertional anatomy of the femoral ACL fibers.\textsuperscript{14,15} The more medial portal location allows for more perpendicular reaming and decreased tunnel aperture obliquity; however, it should not be placed so medial that it damages the articular cartilage of the medial femoral condyle.\textsuperscript{16,17}

Previous research has plotted the tunnel length with regard to a portal placed 10 to 15 mm medial to the patellar tendon and showed tunnel lengths that averaged 32.6 mm.\textsuperscript{18} Furthermore, Ilahi et al.\textsuperscript{16} found that a more medialized portal position gave a tunnel length approximately 3 mm longer than the more lateral portal. However, to our knowledge, no study has specifically examined the relation between knee flexion angle and portal placement with regard to their influence on femoral tunnel characteristics. The choice of most surgeons’ medial portal position is arbitrary when performed using an outside-in technique because this can vary the distance medial to lateral along the knee as well as proximal to distal to avoid the meniscus but still provide accessibility to the footprint. Therefore the purpose of this study was to compare the ACL femoral tunnel characteristics between 2 common arthroscopic portals used for ACL reconstruction, a standard anteromedial portal and a far anteromedial portal. We hypothesized that a far anteromedial portal placement would lead to a longer femoral intraosseous tunnel with increased obliquity in the coronal and sagittal planes, as well as a larger posterior cortical margin with increasing angles of knee flexion.

Methods

Seven fresh-frozen human knee specimens were stored at −20°C before use. The mean age was 69 years, with a range of 63 to 83 years. There were 5 right knees and 2 left knees. All specimens were from male donors. Each specimen was thawed for 24 hours before testing. The specimens were dissected, and all musculotendinous tissue was removed from the femoral and tibial metaphysis/diaphysis. The medial and lateral collateral ligaments were left intact. The extensor mechanism was left intact, and a Krackow stitch was placed into the proximal quadriceps tendon for loading before testing the specimens. A capsulectomy was performed to correctly identify and outline the ACL footprints. The ligaments and menisci were left intact. Each specimen was examined for ACL/posterior cruciate ligament deficiency, cartilage damage greater than Outerbridge grade III, meniscal pathology, varus or valgus deformity, or flexion contracture. Varus/valgus and flexion contracture deformities were evaluated by observing the angle between the long axis of the femoral shaft to the center of the patella and the long axis of the tibial shaft to the center of the patella, manually ranging the knee through the flexion/extension arc, and measuring the flexion angle with a goniometer. We did

![Fig 1.](image-url)
not observe any of the aforementioned findings in any specimen. The ACL was then transected, leaving 2 mm of residual fibers on the femoral footprint. The ACL footprint center was determined as the midpoint between the long axis at the widest portion and the short axis of the footprint measured with a digital caliper. This was marked with a microfracture awl.

The femoral shaft was secured in a custom-made knee testing jig with the epicondylar axis aligned with the baseplate of the testing system and the femur angled 10° above the horizontal. A threaded intramedullary rod was placed within the tibial shaft. A smaller-diameter pin was attached to the distal end of the threaded rod. The pin was then inserted through a guide secured to an arc and x-y translator at the base of the testing system used to control the knee flexion angle (Fig 1). The arthroscopic portals were simulated using a custom-fabricated metal portal guide with portal apertures 2 mm in diameter, spaced 20 mm apart, mounted to the anteromedial proximal tibial metaphysis (Fig 1B). This was placed approximately 1 mm above the medial meniscus so that the simulated standard anteromedial portal was directly adjacent to the patellar tendon and approximately 1 mm above the meniscus while the medial aperture within the mounted metal plate placed the far medial portal approximately 2 cm medial to the patellar tendon and 1 mm above the meniscus.

The specimen was loaded with 15 N on the extensor mechanism and locked into the set flexion angle. A low quadriceps load was used so that the knee could still be partially distracted and translated as in an arthroscopic situation. The specimens were tested at flexion angles of 100°, 120°, and 140° measured with a digital goniometer. A 1.25-mm × 150-mm Kirschner wire was used to create the femoral “tunnels.” No formal tunnels were drilled. A total of 6 holes were drilled for each specimen. All were drilled in the order previously listed, starting with 100° up to 140°. The Kirschner wire was positioned within each portal aperture, advanced and centered within the marked femoral footprint center, and then drilled into the lateral distal femoral condyle. The point at which the wire perforated the lateral cortex of the lateral femoral condyle was identified as the exit point. Color-coded tacks were used to mark the exit points on the lateral condyle (Fig 1C). This was repeated successively for all 3 flexion angles. The specimens were then disarticulated and mounted to a stable platform for digitization with a MicroScribe Digitizer (Revware, Raleigh, NC). The 3 dimension points from the MicroScribe Digitizer were recorded in an Excel worksheet (Microsoft, Redmond, WA) in which all calculations were performed.

The accuracy and repeatability of the MicroScribe Digitizer are both less than 0.3 mm. An anatomic coordinate system was defined on the femur to align the coronal, sagittal, and transverse planes. The origin was defined as the midpoint of the medial condyle in line with the long axis of the femur. The anterior direction was then defined as the midpoint of the lateral condyle in line with the axis of the femur. Both medial and lateral condyle points and 4 points around the femoral shaft were digitized with the MicroScribe 3DLX (Revware). The anatomic coordinate system was then defined as the origin point on the medial condyle. The x-direction was defined toward the lateral condyle. The y-direction was then defined as the perpendicular vector to the x-direction in the direction of the center of the femoral shaft calculated from the 4 points digitized around the femoral shaft. Finally, the anterior direction was defined to be orthogonal to the first 2 axes (Fig 2).

The notch clock-face positions; the ACL periphery; the ACL center point, which defined the entry point of each tunnel; the exit point of each tunnel; and the posterior femoral condylar cortex were then digitized. The coronal, sagittal, and axial plane angles of the femoral tunnels were calculated from the entrance and exit points.
points as angles projected to each plane (Fig 3). The tunnel lengths were calculated as the total distance from the entrance and exit points. The distances of the tunnel exiting points to the posterior femoral condylar cortex were also calculated to assess which tunnel was located most closely to the posterior cortex.

Statistical analysis was performed with a paired t test to compare the data between portal locations. A repeated-measures analysis of variance was used to compare the effect of flexion angle on femoral tunnel characteristics. If a significant difference was detected, a Tukey post hoc test was used to statistically compare between each flexion angle. $P < .05$ was considered statistically significant.

**Results**

For all specimens, we did not observe any of the following: ACL/posterior cruciate ligament deficiency, cartilage damage greater than Outerbridge grade III, meniscal pathology, varus or valgus deformity, or flexion contracture.

The standard anteromedial portal resulted in a significantly longer tunnel length, a less horizontal tunnel in the coronal plane, and a greater posterior cortical margin compared with the far anteromedial portal at all knee flexion angles (Table 1). All 3 tunnel lengths were significantly longer using the standard anteromedial portal for flexion angles of $100^\circ$ ($P = .021$), $120^\circ$ ($P = .017$), and $140^\circ$ ($P = .014$). Individual data results are shown in Table 1. All tunnels were of adequate length for standard graft preparations with the average minimum tunnel length being $33.2 \text{ mm}$ with the far anteromedial portal at $100^\circ$ of knee flexion. The changes in the sagittal plane and transverse plane angles were less consistent between the 2 portal locations. For the far anteromedial portal, the sagittal plane angle was significantly greater than that for the standard anteromedial portal at $120^\circ$ of knee flexion ($P = .028$) and the transverse plane angle was significantly less than

![Fig 3](image_url). Plots of (A) coronal plane depicting measurement of coronal angle, (B) transverse plane depicting measurement of transverse angle, and (C) sagittal plane depicting measurement of sagittal angle. All tunnels begin at the center of the ACL footprint with the exit point at the end of the tracing point. (AM, anteromedial.)
that for the standard anteromedial portal at 140° of knee flexion ($P = .003$).

The tunnel length and posterior cortical margin increased as knee flexion increased for both the standard anteromedial portal ($P < .02$ for 100° v 140° of knee flexion) and far anteromedial portal ($P < .02$ for 100° v 120° and 100° v 140° of knee flexion) (Figs 4 and 5). As the knee flexion angle increased, the tunnel position became more horizontal in the coronal plane. There was a significant difference among all 3 flexion angles for the far anteromedial portal ($P < .03$), whereas for the standard anteromedial portal, the coronal plane angle at 140° of knee flexion was significantly less than that at 100° ($P = .002$) and 120° ($P = .003$) of knee flexion. The tunnel position also became more anterior in the sagittal plane and less horizontal in the transverse plane with increasing knee flexion for both portal locations with increasing knee flexion angle ($P < .003$).

### Discussion

The results of this study show that adequate femoral tunnel length, back wall cortical margin, and accessibility to the footprint are all attainable using either a standard anteromedial portal or a far accessory medial portal through a range of knee flexion from 100° to 140°. However, there was a trend that showed the back wall cortical margin was decreasing at lower flexion angles especially with the far anteromedial portal. When applying this finding to the clinical realm, surgeons performing independent femoral tunnel drilling techniques may be advised to maintain high flexion angles at all times especially when using the far anteromedial portal.

Our data show that a more laterally positioned portal allows for slightly longer femoral tunnels, as well as an increased posterior cortical wall margin, although all tunnels were of adequate length for clinical utility. This contradicts our hypothesis that a more medial portal location would lead to improved tunnel metrics. Theoretically, this increased margin means that there is less likelihood of back wall blowout when drilling the femoral tunnel through a more standard anteromedial portal. However, additional studies are needed to confirm this in the clinical setting. The exact dimensions for optimum tunnel length and posterior back wall are imprecisely defined. However, studies have shown that

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**Table 1. ACL Femoral Tunnel Characteristics for Standard Anteromedial and Far Anteromedial Arthroscopic Portals**

<table>
<thead>
<tr>
<th>Knee Flexion Angle</th>
<th>Tunnel Length</th>
<th>Distance to Posterior Cortex</th>
<th>Coronal Plane Angle</th>
<th>Sagittal Plane Angle</th>
<th>Transverse Plane Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°</td>
<td>37.4 mm (5.8 mm)</td>
<td>18.9 mm (12.6 mm)</td>
<td>57.9° (5.4°)</td>
<td>−6.6° (10.3°)</td>
<td>−10.1° (16.1°)</td>
</tr>
<tr>
<td>120°</td>
<td>39.3 mm (4.9 mm)</td>
<td>23.6 mm (9.7 mm)</td>
<td>57.6° (5.5°)</td>
<td>6.8° (7.0°)</td>
<td>11.3° (11.2°)</td>
</tr>
<tr>
<td>140°</td>
<td>40.5 mm (5.9 mm)</td>
<td>31.0 mm (8.4 mm)</td>
<td>52.0° (6.1°)</td>
<td>29.1° (8.4°)</td>
<td>35.8° (12.6°)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Far anteromedial portal*</th>
<th>Tunnel Length</th>
<th>Distance to Posterior Cortex</th>
<th>Coronal Plane Angle</th>
<th>Sagittal Plane Angle</th>
<th>Transverse Plane Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°</td>
<td>33.2 mm (2.6 mm)</td>
<td>12.0 mm (11.1 mm)</td>
<td>40.8° (3.8°)</td>
<td>−6.2° (13.7°)</td>
<td>−5.0° (11.6°)</td>
</tr>
<tr>
<td>120°</td>
<td>35.4 mm (2.5 mm)</td>
<td>18.3 mm (9.1 mm)</td>
<td>37.3° (4.3°)</td>
<td>15.3° (10.7°)</td>
<td>11.9° (8.7°)</td>
</tr>
<tr>
<td>140°</td>
<td>35.9 mm (3.1 mm)</td>
<td>23.7 mm (7.3 mm)</td>
<td>33.2° (6.1°)</td>
<td>34.3° (10.3°)</td>
<td>24.2° (7.5°)</td>
</tr>
</tbody>
</table>

*Data are shown as mean (standard deviation) of 7 specimens.

| $P$ value for standard anteromedial portal v far anteromedial portal |
|--------------------------|--------------------------|--------------------------|
| 100°                     | .021                     | .019                     | <.0001                  | .81                     | .09                    |
| 120°                     | .017                     | .007                     | <.0001                  | .028                    | .85                    |
| 140°                     | .014                     | .0003                    | <.0001                  | .11                     | .003                   |

$\ast$ $P < .05$ for comparison of standard and far anteromedial portals.

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![Fig 4. ACL femoral tunnel characteristics for standard anteromedial portal at each flexion angle ($P < .05$ v 100° knee flexion angle [asterisks], $P < .05$ v 120° knee flexion angle [plus signs]).](image4.png)

![Fig 5. ACL femoral tunnel characteristics for far anteromedial portal at each flexion angle ($P < .05$ v 100° knee flexion angle [asterisks], $P < .05$ v 120° knee flexion angle [plus signs]).](image5.png)
a minimum of 30 mm and a 1- to 2-mm back wall are sufficient for most graft dimensions and fixation methods. Research is beginning to show medium-term follow-up for ACL reconstructions performed using an anteromedial portal technique. A recent Level II study out of Denmark showed an increased rate of revision ACL reconstruction with an anteromedial femoral tunnel drilling technique when compared with a transitiabil technique, whereas other studies have reported an increased risk of repeat surgery with a transitiabil technique compared with an anteromedial technique or no difference in the Lysholm and International Knee Documentation Committee scores. Further studies must continue to illustrate the outcomes once long-term data become available using this technique.

Our data corroborate the findings of Basdekis et al., who previously reported that as the knee flexion angle increases, the sagittal and coronal plane angles of the tunnels become more horizontal. Conversely, in the axial or transverse plane, the tunnels increase in angulation anteriorly. It is unknown how this tunnel orientation will affect graft strength and survivorship, and additional research is needed to clarify how this angulation affects the graft both biomechanically and clinically. Scopp et al. were able to show in a cadaveric model that a more oblique (i.e., horizontal in the coronal plane) orientation of the femoral tunnel leads to a more normal restoration of native knee kinematics. At least 1 study has shown that a more oblique tunnel can also lead to a higher likelihood of critically short (<25 mm) femoral tunnels; however, even in female patients, this likelihood is still small (1:200). A more oblique tunnel has implications for both graft selection and fixation techniques (i.e., cortical suspensory techniques).

Our findings corroborated previous findings reported by Dave et al., who found that the femoral tunnel distance to the posterior femoral cortex increased when knee flexion was increased. They also showed that increasing the knee flexion angle from 90° to 120° led to longer femoral tunnels. An interesting finding of our study was that the more lateral or standard anteromedial portal had, on average, a longer femoral tunnel length, as well as an increased posterior cortical margin. Conversely, Ilahi et al. compared their more medial portal location and average tunnel lengths with those reported by another group of authors who used a slightly more lateral portal position and showed shorter femoral tunnel lengths. However, these comparisons are difficult to interpret because they are not comparing portal placements in the same knee and in different patient populations. An in-depth knowledge of the dynamic relation between knee flexion and portal location gives the surgeon further options intraoperatively to maneuver and control tunnel length and orientation simply by portal selection and intraoperative knee flexion. This becomes especially important in patients in whom adequate tunnel length is an issue, such as those with smaller distal femurs, or in certain types of grafts (e.g., bone–patellar tendon–bone) or fixation methods (i.e., cortical suspensory fixation).

**Limitations**

Several limitations must be taken into account when interpreting the results. These include the potential selection bias of the cadaveric specimens used. There is limited availability of young cadaveric knees, which more closely resemble the clinical scenario of the ACL-reconstructed patient. Furthermore, this was a cadaveric study, and a large percentage of surrounding musculature and capsular tissue was excised during dissection, which may affect the tibial position; however, the quadriceps was loaded to provide a compressive force across the joint but to allow some manipulation of the tibia. Nonetheless, the ability to accurately demarcate the anatomic center of the femoral footprint was greatly facilitated and led to a more precise wire start point on the femoral footprint. The possibility of rotational subluxation with knee motion could distort the planar position of the wires both before advancement and after advancement into the femur. Kirschner wires were used to serve as a proxy for the femoral tunnels. No tunnels were drilled, and therefore extrapolation regarding the likelihood of posterior wall breach is difficult. This also means that one cannot evaluate tunnel aperture or proximity to the medial femoral condyle articular cartilage. It is possible that the pins were misdirected away from their actual straight-line trajectory by the cancellous and cortical bone of the posterior lateral femoral condyle or that the trajectory was influenced by a previously drilled wire. Randomization of the drilling order would have minimized bias based on the drilling order; however, none of the wires exited at the same point, indicating that the wires did not follow the same path. In addition, the proximity of the tunnels to the lateral collateral ligament and peroneal nerve between 2 portals at various flexion angles was not tested and may be an interesting topic for further investigation. Finally, the ideal study would be a prospective, randomized clinical trial comparing the 2 portal positions to examine whether the theoretically increased likelihood of back wall blowout is increased with the far anteromedial portal, as well as to examine any functional outcome differences, if they exist, between the 2.

**Conclusions**

Our hypothesis that a more medial portal location would lead to improved tunnel metrics was contradicted in this study. Portal position affects femoral tunnel characteristics, with results favoring the more
laterally positioned standard anteromedial portal at all flexion angles. Increasing the knee flexion angle leads to a longer femoral tunnel length and posterior femoral cortical margin with either portal position.

References


