Incorrect bone tunnel position, particularly on the femoral side, is a frequent cause of failed anterior cruciate ligament reconstruction. Several studies have reported that drilling the femoral tunnel through the anteromedial portal allows a more anatomical placement on the lateral femoral condyle and higher knee stability than does transtibial reconstruction.

In the current study, the femoral tunnel was drilled with transtibial (n=6) and anteromedial (n=6) portal techniques in 12 cadaveric knees. With appropriate landmarks inserted into bone tunnels, the direction and length of the tunnels were determined on anteroposterior and lateral radiographs. Knee stability was evaluated with a KT1000 arthrometer (MEDmetric Corporation, San Diego, California) and pivot shift test, comparing the pre- and postoperative values of both techniques. Finally, all knees were dissected to enhance vision of the insertion of the reconstructed ligament. The anteromedial portal technique led to better placement of the femoral tunnel in the coronal and sagittal planes, with higher knee stability according to the pivot shift test but not the KT1000 arthrometer.

Anatomical and clinical results reported in the literature on transtibial and anteromedial portal techniques are controversial, but most of studies report better results with the anteromedial portal technique, especially regarding rotational stability. The current cadaveric study showed that the anteromedial portal technique provided better tunnel placement on the lateral femoral condyle in the coronal and sagittal planes, with an improvement in the rotational stability of the knee.
The femoral attachment of the anterior cruciate ligament (ACL) lies deep and low on the medial wall of the lateral femoral condyle. Correct placement of bone tunnels, especially on the femoral side, is important to prevent surgical failures. Femoral tunnel placement influences knee kinematics and graft length much more than tibial tunnel placement. Furthermore, the femoral tunnel is malpositioned more often than the tibial tunnel, and even small differences are important on the femoral side.

Anterior cruciate ligament reconstruction can be performed with different techniques. The most popular technique for femoral tunnel placement is the transtibial technique, but studies have reported that it did not provide an anatomical placement of the tunnel, resulting in rotational instability of the knee. Several studies have reported that the anteromedial portal technique allowed a more anatomical placement of the femoral tunnel on the lateral femoral condyle and led to better knee stability.

The purpose of the current study was to report femoral tunnel placement and knee stability in a cadaveric model, comparing transtibial and anteromedial portal techniques. The contribution of this study to the literature is the quantification of the different orientation of the femoral tunnel obtained through the anteromedial portal compared with the transtibial portal. This demonstrated difference in orientation, especially in the coronal and sagittal planes, is why it is possible to reach the appropriate location of the femoral tunnel through the anteromedial portal.

**Materials and Methods**

An a priori power analysis was performed to determine the appropriate number of specimens required to detect a difference in the position of each guide pin relative to the anatomical femoral ACL attachment. A difference greater that 10° was assumed to be clinically meaningful in the coronal and sagittal planes, and a standard deviation of 10° was assumed in the difference between the tunnel placements. With a repeated measures design and α=0.05, at least 12 specimens were needed to provide 80% power.

From a pool of 37 fresh-frozen cadaveric knees, 12 specimens (aged 68±14 years) met the criteria of having no prior surgery and no bony abnormalities, osteoarthritis, or other ligamentous injuries. The 12 specimens were thawed overnight. The thigh was secured on a jig and the leg was held by an assistant, allowing flexion and extension of the knee. A standard anterolateral viewing portal and a slight medial and low anteromedial portal were established in all knees. Hamstrings were harvested through an incision at the pes anserinus and prepared in a standard fashion as a 4-strand graft (diameter, 8-9 mm). The anteromedial portal should be slightly medial and low to prevent impingement of the aimer on the femoral condyle and to achieve a longer femoral tunnel.

Under arthroscopic control with a 30° or 70° optical device, the ACL was arthroscopically debrided. With the knee in 90° of flexion, a Kirschner wire was drilled into the tibia with a standard outside-in technique using a commercial tibial tunnel ACL guide (Arthrex, Naples, Florida) set at 55° in all the specimens. The starting point of the tibial tunnel encroached the anterior margin of the medial collateral ligament.

The femoral tunnel with anteromedial portal technique was performed as previously described. Briefly, a special endoscopic aimer (Arthrex) with an appropriate offset depending on graft size was inserted in the anteromedial portal and placed against the medial side of the lateral femoral condyle at the 10-o’clock (left knee) or 2-o’clock position (right knee) on the medial wall of the lateral femoral condyle, holding the knee at 90° of flexion. The knee was subsequently flexed at 120° and a K-wire was advanced through the aimer into the femoral condyle (Figure 1). The width of the lateral femoral condyle was measured with the graduated scale reported on the K-wire.

Anteroposterior and lateral radiographs were obtained with an image intensifier, and the angle between the K-wire placed into the tibia and the K-wire placed into the femur with the anteromedial portal technique was measured. The femoral tunnel with the transtibial technique was assumed to be coaxial to the transtibial K-wire. The transtibial K-wire was not advanced into the femur because it would have prevented angle measurements with knee flexion and extension.

The ACL was reconstructed with the transtibial technique in 6 knees. In these specimens, the tibial tunnel was reamed over the K-wire with the knee in 90° of flexion. An endoscopic aimer with an appropriate offset depending on graft size was inserted into the tibial tunnel and placed against the medial side of the lateral femoral condyle. A K-wire was advanced into the femur, and a standard 25-mm femoral tunnel was reamed.

The ACL was reconstructed with the anteromedial portal technique in 6 knees. The tibial tunnel was reamed as described with the transtibial technique. The femoral tunnel was reamed over the K-wire inserted through the anteromedial portal,
and its length was measured on the graduated scale impressed on the reamer. For both techniques, a standard hamstring autograft was fixed with the TransFix system (Arthrex) on the femoral side and with a BioComposite Interference Screw (Arthrex) on the tibial side.

Knee stability was evaluated with a KT1000 arthrometer (MEDmetric Corporation, San Diego, California) set at 134 N and a manual pivot shift test. The pivot shift test was performed by applying torque to the lower third of the leg just before the ankle joint that was not present because of previous amputation. These tests were performed before ACL sectioning and after reconstruction to evaluate whether these 2 surgical procedures were able to restore normal values of knee stability. In all cases, the pivot shift test was performed by the same author and classified according to the International Knee Documentation Committee (IKDC) scoring system as: normal (same anterior tibial translation as before ACL sectioning), nearly normal (glide), abnormal (clunk), and severely abnormal (gross instability). With the KT1000 arthrometer, anterior tibial translation was expressed as mean±SD of the difference between pre- and postoperative values.

Finally, the knees were dissected and the medial femoral condyle was removed to enhance vision of the insertion of the reconstructed ligament. A line was drawn tangent to the intercondylar shelf (Blumensaat line), and the distance between this line with the cortices of the condyle was measured (distance A-C). A second line was drawn perpendicular to the first on the anterior margin of the femoral tunnel. The intersection between these 2 lines was marked as B. Femoral tunnel placement was expressed as the ratio AB:AC (Figure 2).

The primary endpoint of the study was tunnel placement on the lateral femoral condyle in the coronal and sagittal planes. Secondary endpoints were the KT1000 and pivot shift test measurements. The null hypothesis was that no differences would exist between the 2 techniques.

Statistical analyses were performed with SPSS version 15 software (SPSS Inc, Chicago, Illinois). A P value less than .05 was considered statistically significant.

The study conformed to the Helsinki Declaration, and approval was obtained from the Ethics Committee at the authors’ institution before beginning experimental work.

RESULTS

Mean angle between transtibial portal and anteromedial portal femoral tunnels was 25° (range, 22°-28°) and 60° (range, 55°-65°) on anteroposterior and lateral radiographs, respectively (Figures 3, 4). A statistically significant difference existed in tunnel direction between the 2 techniques in both views (P=.04).

Manual pivot shift test was rated normal in all cases before ACL sectioning and after ACL reconstruction with the anteromedial portal technique. After transtibial technique reconstruction, a glide was present in all cases, and all knees were classified as nearly normal.

With the KT1000 arthrometer, the difference in pre- and postoperative anterior tibial translation was 4±1 mm after transtibial reconstruction and 3±1 mm after anteromedial portal reconstruction. This difference was not statistically significant (P=.08) (Table 1).
After dissection of the knees, mean AB:AC ratio was 0.52 (range, 0.50-0.57) for the transtibial technique and 0.60 (range, 0.55-0.65) for the anteromedial portal technique. A statistically significant difference existed in transtibial and anteromedial portal technique ratios \((P<.002)\). Insertion of the reconstructed ACL on the lateral femoral condyle with the anteromedial portal technique was closer to the anatomical insertion of the ACL, in a better position than that with a transtibial approach (Figure 5; Table 1). Femoral tunnel length in the anteromedial portal group ranged from 38 to 52 mm.

According to the study data, the null hypothesis was rejected; the 2 techniques provided different tunnel placement in the coronal and sagittal planes and pivot shift test results. Anterior tibial translation according to the KT1000 arthrometer was comparable between the anteromedial and transtibial techniques.

The anteromedial portal technique provided a more anatomical placement of the femoral tunnel and better knee stability, especially in rotational control as measured with the pivot shift test.

**DISCUSSION**

Several attempts have been made to achieve better tunnel placement on the lateral femoral condyle during ACL reconstruction. The limitations of the transtibial technique were recognized, and new surgical procedures were developed for drilling the femoral tunnel.

The most important limitation of the transtibial technique is the dependency between bone tunnels. Using the transtibial technique, surgeons can place tunnels in the center of femoral and tibial attachments, but the tibial tunnel will be short and start close (14 mm) to the tibial articular surface, with subsequent fixation problems. To avoid this problem, surgeons tend to start the tibial tunnel more distally, thus leading to a nonanatomical anterior and vertically oriented femoral tunnel. In several biomechanical studies, tunnels placed at the 11-o’clock position restored anterior tibial stability under anterior tibial loads but failed to control rotational instability. A femoral tunnel placed too far anteriorly could result in a vertically oriented graft, which is different from the oblique orientation of the native ACL.不禁 might provide inadequate restraint to the increased internal rotation and medial tibial translation observed in patients with ACL deficiency. Furthermore, the clinical results of anteriorly placed femoral tunnels are poor, and notch impingement or graft stretching may occur. To avoid a vertically oriented femoral tunnel, several authors have suggested drilling a more horizontal tibial tunnel that encroaches the anterior border of the medial collateral ligament.

In the current study, results in the transtibial group were satisfactory, even if a glide was always present in the specimens at the pivot shift test. To improve results in the transtibial group, the tibial tunnel was drilled starting medial, just anterior to the distal insertion of the medial collateral ligament, to reconstruct a crossed ACL. Despite that, the rotational stability of the knee was unable to be completely restored.

To overcome the problems of the transtibial technique, surgeons began drilling the femoral tunnel through the anteromedial portal; however, the anatomical results of this technique in terms of femoral tunnel placement are controversial. Several studies reported that independent femoral tunnel placement led to a more anatomical position on the coronal and sagittal planes, but other studies reported no differences between the 2 techniques. Rue et al. reported that an anatomical placement of the femoral tunnel could be obtained with a transtibial approach, and Musahl et al. reported that tunnel placement between the anatomical origin of the ACL and the most isometric position fully restored knee kinematics, but anatomic graft placement resulted in kinematics similar to the normal knee joint.

The results of the current study showed that, with the anteromedial por-
The anteromedial portal technique has some theoretical advantages, 27, 55 limitations, and risks 26, 55, 56 (Table 2). The most important risk of the anteromedial portal technique is a short tunnel length. Several authors suggested knee hyperflexion to reduce the risk of a short femoral tunnel. 57, 58 Bedi et al 55 reported that knee hyperflexion is associated with an increased risk of a critically short tunnel (less than 25 mm), but their results are biased by the use of a conventional transtibial offset guide. Knee hyperflexion was also reported to be protective against peroneal nerve injury. 58, 59

In the current study, with the knee hyperflexed at 120°, the femoral tunnel was long enough (38-52 mm) for secure fixation and was always in the middle of the lateral face of the femoral condyle on the sagittal plane. The only problem in some cases was related to the insufficient amount of water for capsule distention due to the hyperflexed position. The position of the femoral tunnel drilled through the anteromedial portal was satisfactory in the specimens, even if the medial femoral condyle prevented true anatomical ACL insertion.

Many surgeons trust that the anteromedial portal technique creates a more horizontal femoral tunnel in all cases and is a safe and reproducible procedure; however, in 1 study, the anteromedial portal technique was not protective against poor femoral tunnel placement, 53 indicating that the anteromedial portal technique should be performed only by expert surgeons. These conflicting results demonstrate the debate that exists about the best technique to drill the femoral tunnel during ACL reconstruction. Further studies are needed to clarify differences between these techniques.

The clinical results of transtibial and anteromedial portal techniques are controversial. A recent literature review revealed that patients in which the femoral tunnel was drilled with the anteromedial portal technique began running significantly earlier and had significantly greater range of motion and anteroposterior knee stability at short-term follow-up, but these differences were not evident at mid- and long-term follow-ups. 60 In contrast, patients undergoing a transtibial reconstruction had a greater activity level at mid- and long-term follow-up and a lower graft failure rate. 60 The authors found no difference in terms of clinical function between the 2 groups and concluded that there is no evidence that 1 technique is superior to the other. 60 However, their study was based on indirect comparison of data from non-homogeneous studies, and the reported results should be considered with caution.

Subsequently, Alentorn-Geli et al 61 published the first study that, to the current authors’ knowledge, directly compared the clinical results of 2 groups of patients undergoing ACL reconstruction in which the femoral tunnel was drilled with a transtibial or anteromedial portal technique. The authors concluded that the anteromedial portal group had significantly improved anteroposterior and rotational knee stability, IKDC scores, and surgery recovery time, but no differences were found in visual analog scale scores for satisfaction with surgery and Lysholm, Tegner, and 12-Item Short Form Health Survey scores between groups. 61 However, despite the less anatomical placement and poor clinical outcomes reported, the transtibial approach is easier to perform and is the technique favored by most surgeons performing ACL reconstruction. In 2009, eighty-five percent of members of the American Academy of Orthopaedic Surgeons drilled the femoral tunnel with a transtibial approach, and 15% used an anteromedial portal. 58 However, although the anteromedial portal technique is more demanding, the experimental and clinical results of improved stability may increase its use.

The current cadaveric study showed that drilling the femoral tunnel through the anteromedial portal led to better placement on the lateral femoral condyle in the coronal and sagittal planes (P<.05). The more anatomical placement of the femoral tunnel with the anteromedial portal technique was associated with significantly higher knee stability according to the pivot shift test (P<.05) but not the KT1000 arthrometer.

### Table 2

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate independent femoral and tibial tunnel placement</td>
<td>Short tunnel length</td>
</tr>
<tr>
<td>Preservation of anteromedial or posterolateral bundle in augmentation cases</td>
<td>Posterior wall blow-out</td>
</tr>
<tr>
<td>Single- or double-bundle reconstructions in primary or revision settings</td>
<td>Not protective against incorrect tunnel placement: expert surgeons</td>
</tr>
<tr>
<td>Compatible with any graft choice or fixation device</td>
<td>Limited tunnel visualization</td>
</tr>
<tr>
<td>Parallel placement of interference screw fixation through same medial portal as that used for tunnel creation</td>
<td>Excessive sagittal angulation (70° optical device)</td>
</tr>
<tr>
<td>Decreased tunnel widening</td>
<td>Peroneal nerve injury</td>
</tr>
</tbody>
</table>
This study had limitations. It was performed on cadavers of older individuals, with transtibial and anteromedial portal techniques performed in the same knee. However, every effort was made to make the surgery as realistic as possible. Pivot shift was manually tested, thus introducing a subjective evaluation that could lead to methodological bias, but manual pivot shift is what surgeons usually perform to evaluate patients after ACL reconstruction. Entire lower limbs were not used for the study; this could alter the equilibrium of the muscles and the results of the experiment.62 This study also had strengths. A repeated measures design was used in which tunnel placement with the anteromedial and transtibial techniques were compared in the same cadaveric knee, limiting variability within specimens. Femoral tunnel length was measured in anteromedial portal group because it is one of the most important concerns for surgeons performing the anteromedial technique. Collected data confirmed that reaming the femoral tunnel at 120° of flexion can obtain sufficient femoral tunnel length.

CONCLUSION
This cadaveric study showed that drilling the femoral tunnel through the anteromedial portal led to a better placement on the lateral femoral condyle in the coronal and sagittal planes. Stability improved with both techniques, but better rotational stability, as evaluated with the pivot shift test, was achieved with the anteromedial portal.

REFERENCES


