Navigated Anterior Cruciate Ligament Reconstruction: Radiographic Validation of a Nonimage-based System

JEAN-YVES JENNY, MD; LAMINE ABANE, MD

abstract

The authors compared the intraoperative navigated measurements of the location of the tibial and femoral tunnels during arthroscopic-assisted anterior cruciate ligament reconstruction to the postoperative measurements performed on standard plain radiographs in 56 patients. The position of the center of the tibial and femoral tunnels was measured intraoperatively with the OrthoPilot (B. Braun Aesculap, Tuttlingen, Germany) and postoperatively on plain anteroposterior and lateral radiographs.

The center of the tibial tunnel was located at 43% of the mediolateral tibial dimension intraoperatively and at 41% of the mediolateral tibial dimension postoperatively (P=.14). The center of the tibial tunnel tibial was located at 40% of the anteroposterior tibial dimension intraoperatively and at 35% of the anteroposterior tibial dimension postoperatively (P=.01). The center of the femoral tunnel was located at 85% of the anteroposterior femoral dimension intraoperatively and at 76% of the anteroposterior femoral dimension postoperatively (P<.001). A significant correlation was found between intraoperative navigated and postoperative radiographic measurements only at the femur. Good agreement existed between all navigated and radiographic measurements. The OrthoPilot navigation system allows an accurate measurement of the location of the tibial and femoral tunnels during anterior cruciate ligament reconstruction.

Drs Jenny and Abane are from the Orthopedic Surgery and Hand Center, University Hospital Strasbourg, Illkirch-Graffenstaden, France.

Drs Jenny and Abane have no relevant financial relationships to disclose.

Correspondence should be addressed to: Jean-Yves Jenny, MD, Orthopedic Surgery and Hand Center, University Hospital Strasbourg, 10 Avenue Baumann, F-67400 Illkirch-Graffenstaden, France (jean-yves.jenny@chru-strasbourg.fr).

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The precise positioning of the tibial and femoral tunnels is important during anterior cruciate ligament (ACL) reconstruction.\textsuperscript{1,2} Tunnel misplacement is the primary reason for ACL reconstruction failure and revision.\textsuperscript{1,3} Despite all intraoperative controls, it has been demonstrated that a significant deviation from the desired tunnel location may occur, even for experienced surgeons.\textsuperscript{4,5} A navigation system may allow for more accurate positioning.\textsuperscript{6,7} The current authors previously performed an experimental validation of a new system\textsuperscript{8} and sought to perform a validation in a clinical setting.

The goal of this study was to compare the intraoperative navigated measurements of the location of the tibial and femoral tunnels during arthroscopic-assisted ACL reconstruction with the postoperative measurements performed on standard plain radiographs.

**Materials and Methods**

All patients undergoing arthroscopic-assisted ACL reconstruction at the authors’ institution between January 2008 and December 2009 were included in the study. No exclusion criteria existed. The study was approved by the local institutional review board, and all patients gave informed consent to participate in the study.

Preoperative calibrated anteroposterior and lateral knee radiographs were obtained, and the following measurements were performed to implement the intraoperative navigated data: anteroposterior and mediolateral dimension of the tibia plateau and anteroposterior dimension of Blumensaat’s line. All surgeries were performed by a single surgeon (J.Y.J.) with an arthroscopic-assisted bone–patellar tendon–bone or hamstring graft according to the patient’s or surgeon’s preference. All procedures were performed with the help of an image-free navigation system (OrthoPilot; B. Braun Aesculap, Tuttingen, Germany).\textsuperscript{7,9} Rigid trackers were pinned to the distal femur and the proximal tibia. Several intra-articular landmarks were palpated with a navigated stylus: the medial and lateral borders of the tibial plateau, anterior horn of the lateral meniscus, medial tibial spine, tibial attachment of the posterior cruciate ligament, anterior opening of the femoral intercondylar notch, and most posterior point of Blumensaat’s line.

For tibial tunnel preparation, the tip of the navigated aimer was placed into the joint according to the surgeon’s judgment of the optimal location of the tibial tunnel on the tibial plateau. A transtibial K-wire was set with the aimer when the position was considered optimal, and the tunnel was reamed over this wire. The position of the tip of the aimer (ie, the center of the tibial tunnel) was recorded by the system with reference to the mediolateral and anteroposterior dimensions of the tibial plateau.

For femoral tunnel preparation, the tip of the navigated aimer was placed into the joint according to the surgeon’s judgment of the optimal location of the femoral tunnel on the lateral wall of the intercondylar notch. A transfemoral K-wire was set with the aimer when the position was considered optimal, and the tunnel was reamed over this wire. The position of tip of the aimer (ie, the center of the femoral tunnel) was recorded by the system with reference to the anteroposterior dimension of Blumensaat’s line.

Postoperatively, anteroposterior and lateral knee radiographs were obtained. All measurements were performed by a unique observer (L.A.), who was not the operating surgeon. The position of the center of the tibial tunnel was defined by the intersection of the tibial plateau line with the longitudinal axis of the metallic interference screw on anteroposterior and lateral views. The position of the center of the femoral tunnel was defined by the position of the tip of the metallic interference screw on the lateral view. The following measurements (in mm) were recorded:

- The mediolateral dimension of the tibial plateau and distance between the medial tibial border and the center of the tibial tunnel.
- The anteroposterior dimension of the tibial plateau and distance between the anterior tibial border and the center of the tibial tunnel.
- The anteroposterior dimension of Blumensaat’s line and the distance between the posterior femoral border of Blumensaat’s line and the center of the femoral tunnel.

The measurements of the tunnel positions were expressed as a percentage of the respective bone dimension to allow comparability with navigated measurements.

Navigated and radiographic measurements of the tunnel positions were compared for each patient with paired Student’s $t$ test at a 5% limit of significance. The correlation between navigated and radiographic measurements was assessed by a correlation test at a 5% limit of significance. Agreement between navigated and radiographic measurements was assessed according to the Bland-Altman technique; agreement was considered good if a poor correlation existed between the mean and difference of both measurements for each specimen ($R^2<0.4$).

**Results**

Sixty patients were eligible for the study. Four patients were excluded because of missing data (poor quality postoperative radiographs). Therefore, 56 patients (37 men and 19 women; mean age, 30.3±10.2 years [range, 15-56 years]) were analyzed.

The center of the tibial tunnel was located at 43%±4% (range, 35% to 50%) of the mediolateral tibial dimension intraoperatively and at 41%±8% (range, 25% to 57%) of the mediolateral tibial dimension postoperatively ($P=.14$). No correlation ($R^2=0.02; P=.27$) (Figure 1) and good agreement ($R^2=0.31$) existed between the 2 measurements.

The center of the tibial tunnel was located at 40%±8% (range, 18%-57%) of the...
anteroposterior tibial dimension intraoperatively and at 35%±9% (range, 12%-52%) of the anteroposterior tibial dimension postoperatively (P=.01). No correlation (R²=0.01; P=.48) (Figure 2) and good agreement (R²=0.05) existed between the 2 measurements.

The center of the femoral tunnel was located at 85%±15% (range, 71%-100%) of the anteroposterior femoral dimension intraoperatively and at 76%±13% (range, 52%-100%) of the anteroposterior femoral dimension postoperatively (P=.25). No correlation (R²=.34; P=.12) (Figure 3) and good agreement (R²=0.17) existed between the 2 measurements.

**DISCUSSION**

No significant difference was observed between intraoperative navigated and postoperative radiographic measurements of the location of the femoral and tibial tunnels. Good agreement existed between the 2 measurement techniques, but no correlation existed between navigated and radiographic measurements.

Quality control is desirable after any orthopedic procedure to assess precision and accuracy. In a previous experimental study, the current authors demonstrated that, in a laboratory setting, it was possible to use plain radiographs to accurately locate the footprint of the native ACL compared with the anatomic measurement. Accordingly, plain radiographs may be used for quality control after ACL reconstruction. Such techniques have been extensively used in previous studies. However, only indirect measurement of tunnel placement may be performed on plain radiographs because the intra-articular tunnel opening is difficult to accurately define on plain radiographs, especially on the femoral side. Furthermore, the relative measurement of the location of the tunnel opening may be flawed by an inadequate position of the knee, especially in rotation, or poor beam orientation. Computed tomography or magnetic resonance imaging may be more accurate but are not routinely used for postoperative assessment of ACL reconstruction and would involve additional costs. Furthermore, these imaging techniques may be disturbed by the presence of metallic fixation devices. Quality control of ACL reconstruction should be performed by a direct measurement of tunnel location with a 3-dimensional imaging technique.

Navigation has the potential to allow direct measurement of tunnel location. The precision and accuracy of navigation has been previously evaluated for applications other than ACL reconstruction, in both in vitro and in vivo settings, to be less than 1 mm for distance measurements and less than 1° for angular measurements. These results may also be applied for ACL reconstruction. In an experimental study, the current authors demonstrated that the navigation system used allowed accurate measurement of the anatomic location of the ACL footprint of gross specimens, with a mean variation of 3% compared with the tibial or femoral size. The position of the intra-articular tunnel opening may be palpated by the navigation tool, and no risk exists of distortion due to mal-

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**Figure 1:** Scatter plot of the results of the mediolateral position of the tibial tunnel.

**Figure 2:** Scatter plot of the results of the anteroposterior position of the tibial tunnel.

**Figure 3:** Scatter plot of the results of the anteroposterior position of the femoral tunnel.
positioning of the joint. Navigation may theoretically overcome the limitations of currently used imaging systems.

The current study demonstrated that the navigation system used was able to provide accurate data compared with radiographs. It has been previously demonstrated in total knee arthroplasty that navigated measurements were more accurate than radiographic measurements when analyzing prosthetic orientation. Consequently, the differences observed in the current study may be in favor of the navigation system because of the direct measurement technique. However, this assumption has not been validated.

This study had some limitations. Only 1 navigation system was analyzed, and the results may not be reproduced by other systems. Only 1 surgeon was involved in the study, and the results may represent only his experience. The intraoperative navigated measurements were performed by the operating surgeon, with a possible bias. No reference 3-dimensional measurement, such as those taken with computed tomography or magnetic resonance imaging, was used to differentiate the respective accuracy of both measurements techniques.

However, the number of included cases was large, the navigated technique was experimentally validated prior to the study, and all radiographic measurements were performed by a unique observer different from the operating surgeon.

CONCLUSION

The OrthoPilot navigation system allows an accurate measurement of the location of the tibial and femoral tunnels during ACL reconstruction. The accuracy of this technique may be higher than standard radiographic measurements. The usefulness of postoperative radiographic assessment of tunnel position after ACL reconstruction is questionable when the reconstruction is performed under navigation control.

REFERENCES