The role of navigation in ACL reconstruction

Eun-Kyoo Song, MD, Jong-Keun Seon, MD, Sang-Jin Park, MD, Young-Jin Kim, MD, Chang-Ick Hur, MD

Center for Joint Disease, Chonnam National University Hwasun Hospital, Jeonnam; Korea

Introduction

The last decade has seen many advancements in ACL reconstruction that have resulted from an improved knowledge of the biology and biomechanics of graft incorporation, new graft materials and graft fixation devices, and accelerated rehabilitation protocols. Current ACL reconstruction techniques are relatively successful at restoring stability to ACL- deficient knees and our review of the literature revealed that 85-95% of patients feel that they have a near normal knee. However some of them complain pivot shift sense postoperatively regardless of the reconstruction technique used. It means we still need to improve our ACL reconstruction technique.

The majority of revision surgeries after ACL reconstruction are because of technical errors, especially in tunnel placement. If a graft is incorrectly placed, it will undergo abnormal stresses and may impinge on adjacent structures and fail to control the combined rotational and translational stresses (9).

Computer aided navigation systems can provide enhanced precision in tunnel placement and may reduce the rate of revision surgery. Almost all systems allow the use of any graft choice or type of fixation and standard manual instruments to be used. Navigation systems provide useful information about the location of tunnels, isometry, and impingement data. They can also document movement in multiple planes, such as rotational stability as well as pure anterior-posterior stability.

Operation technique for Navigation assisted ACL reconstruction

We will describe the operation technique of ACL reconstruction using a navigation system (OrthoPilot ACL Version 2.0, B. Braun-Aesculap, Tuttlingen, Germany).

Transmitter placement and Registration

After confirming the rupture of the ACL by routine diagnostic arthroscopy, the femoral and tibial transmitters were firmly secured to the femur or tibia using a fixation instrument with two K-wires (Figure 1). Extra-articular anatomic landmarks such as the tip of the tibial tuberosity, the anterior tibial crest of the lower third of the tibia, medial and lateral points of the tibia plateau were registered (Figure 2). And then, the knee kinematics was registering between 0° to 90° flexion (Figure 3). This is followed by acquisition of intra-articular landmarks. The anterior portion of the posterior cruciate ligament(PCL) is lightly touched with the tip of the probe and registered, followed by the medial tibial eminence and anterior horn of the lateral meniscus. The anterior edge of the intercondylar notch is then sequentially palpated and registered. The instrument tracker is then attached to the hook probe, and the over-the-top position is palpated at 12 o'clock (Figure 4) and 1:30/10:30 with the tip of the instrument at the junction of the bone and soft tissue fringe. The ACL origin points are then acquired. Preoperative kinematic data are then acquired by placing the reduced knee at the desired angle(typically 30 degrees) and applying an anterior and posterior

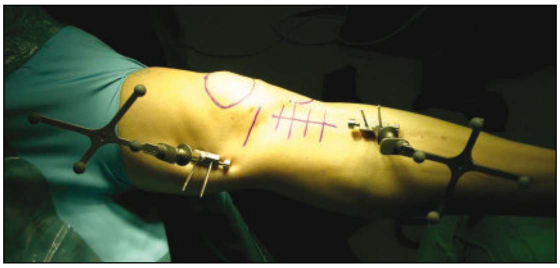

Figure 1 : Navigation set-up showing the secured fixation of the femoral and tibial transmitters with two K-wires.

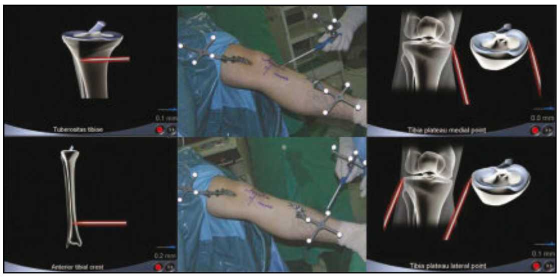

Figure 2 : Registration of extra-articular anatomic landmarks such as the tip of the tibial tuberosity, the anterior tibial crest of the lower third of the tibia, medial and lateral points of the tibia plateau.

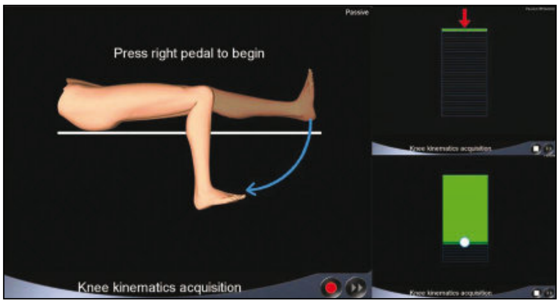

Figure 3 : Registering the knee kinematics between 0° to 90° flexion, after registration of the surface landmarks.

Figure 4 : Palpation of the over the top position (Blumensaat's line).

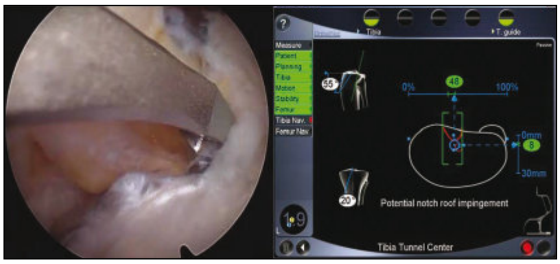

Figure 5: Tibial tunneling was performed with navigational assistance. Navigation displays the tunnel in 55 degrees of sagittal angle and 20 degrees of coronal angle, 48% from medial tibial plateau and 8mm anterior from PCL insertion.

force. The rotational laxity of the tibia with respect to the femur is also registered by internally and externally rotating the tibia.

Tibial Tunnel Mapping

The tibial drill guide is then placed intra-articularly, and an approximate position for the tibial tunnel is chosen. The instrument tracker is attached to the drill guide, and the relationship of the proposed tunnel to intra- and extra- articular landmarks is seen on the navigation screen. Information provided includes the location of the intercondylar notch with the knee in full extension projected onto the tibial plateau; the distance from the PCL, and the location of the medial tibial eminence and the anterior horn of the lateral meniscus. The amount and location of any impingement are also shown. The percentage of the medial-lateral distance is calculated. The coronal and sagittal angle of the tibial tunnel with respect to the tibia is also shown, which aids in aiming the tunnel to the appropriate position on the femur (Figure 5). Taking the provided information into account, the surgeon chooses a tunnel location, and a guidewire is drilled into the elbow of the guide. The tunnel location is then registered using the foot pedal.

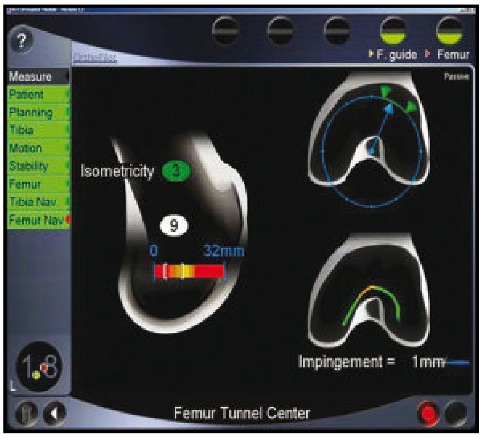

Figure 6 : Femoral tunnel was created at the most isometric point (as 3mm of isometricity) displayed by navigation.

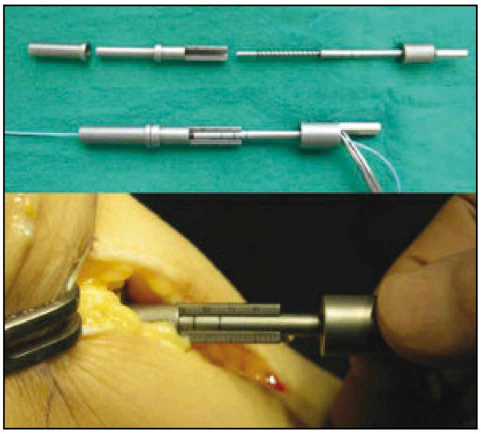

Figure 7 : Isometer, specially designed device for the measurement of isometricity. It was composed by tibial tunnel guide, body marked with line per millimeter, indicator which maintains a tension during passive range-of-motion. After passing the suture material to simulate ACL graft, tibial tunnel guide is inserted to tibial tunnel. And then the isometricity can be measured manually during full range of motion of the knee.

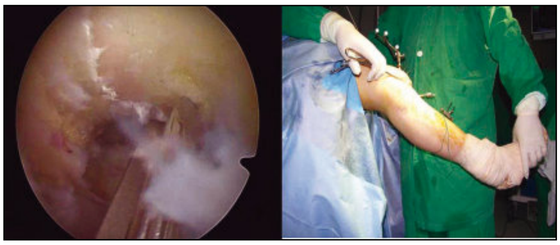

Figure 8 : The arthroscopic picture shows the point measured by 5mm off set manual guide (Arthrex®) for the conventional manual femoral tunnel. We passed a guide wire with an attached No 5 Ethibond, to simulate ACL graft, through this point. We then measured the isometricity by isometer.

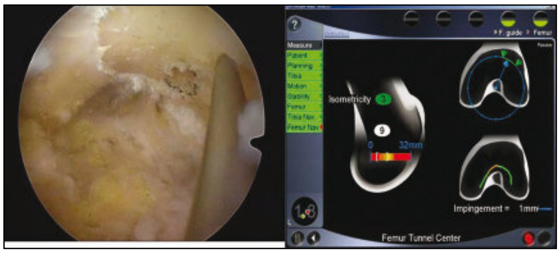

Figure 9 : Femoral tunnel was created at the most isometric point as 3mm of isometricity displayed by navigation, and re-evaluated the isometricity in similar fashion.

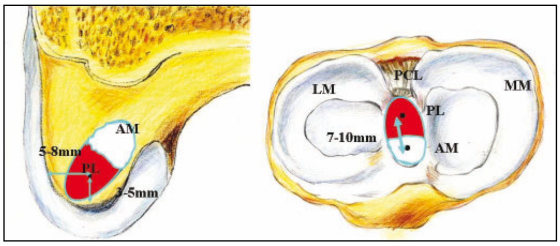

Figure 10 : Schematic drawing of the AM tunnel and PL tunnel at tibia and femur.

Femoral Tunnel Mapping

With the instrument tracker attached to the femoral probe, a femoral tunnel was then created through the tibial tunnel at the best isometric point displayed by the navigation system. The femoral navigation screen (Figure 6) provides real-time information on the distance to the over-the-top position, graft isometry, location on the clock face, and the location and amount of any potential impingement. Using this information the surgeon can decide on and register an appropriate starting point. The guidewire is then drilled into this point and the reamer is used to create the femoral tunnel.

The advantage of navigation systems for ACL reconstruction

Tunnel Placement

Recently, a navigation system has been introduced in the ACL reconstruction for improvement of tunnel placement (3,7,8,12,15). There is a report that computer assisted fluoroscopic navigation systems improve accuracy and decrease the dispersion of the tibial tunnel placement around the Blumensaat's line in single bundle ACL reconstruction (5). There is a report that the navigational tibial tunnel placement was more accurate when compared by plain radiograph with distance between the projection of the Blumensaat line on the tibial plateau and the anterior edge of the tibial tunnel (15). Another report described that computer overlays resulted in additional significant reductions in tibial and femoral tunnel placement variability (8). This innovative device decreases the problem of skeletal variation among patients. Another report demonstrated that navigation technique produced more accurate tibial tunnel placement. It is suggested that this would reduce impingement and improve graft longevity (14).

Isometricity

The isometric point is defined as the point at which the distance between the femoral and tibial attachment sites do not change as the knee is flexed (2). Tendons are stretched irreversibly when exposed to cyclic strains that increase their length beyond 4%. The consequences of malplacement include graft tightening, blocking knee motion, graft slackening elsewhere in the arc of knee flexion, knee instability, and graft failure due to excessive tension (1).

To our knowledge, there are few reports that compared the isometricity between conventional and navigational technique. We compared isometricity between two techniques for 22 ACL reconstructions using an isometer (specially designed device) (Figure 7). After tibial tunnel preparation, the conventional manual femoral tunnel site was marked using 5mm off-set manual guide (Arthrex®). The guide wire was passed with suture material attatched, to simulate an ACL graft through this point. Isometricity was then measured using an isometer (Figure 8). Next, we identified the most isometric point displayed by navigation and re-evaluated the isometricity in similar fashion (Figure 9). As a result, the mean isometricity of femoral tunnels by the conventional technique was 4.59 mm, whereas by the navigational technique this was 3.00 mm ($P < 0.05$). And femoral tunnel position guided by navigation was placed of slight anterolateral aspect (1.5 mm) compared to that of conventional technique. The in vivo isometric test demonstrated that the navigation technique provided better isometricity during ACL reconstruction than the conventional technique.

Information for Stability and Postoperative Laxity

Navigation is a very useful tool for evaluation of knee stability before and after surgery. Pearle et al. (14) reported that an image-free infrared optical navigation system can reliably register and collect multiplanar knee kinematics during knee stability examination when coupled knee motions were determined by a robotic testing system and by an image-free navigation system in 6 cadaveric knees.

There is another report about stability that the clinical result in terms of laxity by the use of computer-assisted navigation is more reliable. In the report, laxity compared by Telos® device was less than 2 mm in 96.7% of the navigated group and 83% of the conventional group. The variability of laxity in the navigated group was significantly less than in the conventional group with the standard deviation of the navigated group being smaller than that in the conventional (15).

Double-Bundle ACL Reconstruction Techniques

Navigation can be used not only for single bundle ACL reconstruction, but also double bundle reconstruction which attempts to reproduce the anteromedial(AM) and posterolateral(PL) bundles.

In our report concerning comparison of in vivo stability between single- and double-bundle reconstructions in different groups (16), we found that a double-bundle ACL reconstruction tended to be more stable than a single-bundle reconstruction in both total AP translation and tibial rotation. The operation technique of the tunnel placement is as follows. The PL tibial tunnel was located at the center of the PLB footprint on the tibia (5 mm anterior to the PCL) using a tibial drill guide set at an inclination angle of 55° and 45° from the sagittal plane. The AM tunnel was positioned in a more anteromedial position on the tibial footprint (7 mm anterior and 5 mm medial to the PL tunnel) using a tibial drill guide set at an inclination angle of 45° and 20° from the saggital plane. The AM femoral tunnel through the AM portal was prepared at the 1:00 o'clock position on the left or at the 11:00 o'clock position on the right. The PL femoral tunnel was determined as follows; at 5 to 8mm from the anterior lateral femoral condyle cartilage, and 3 to 5mm from the inferior lateral femoral condyle cartilage with the knee in 90° of flexion and prepared through the accessory AM portal (Figure 10). Although the aim of this study is different, during the double bundle reconstruction, we have been supported by navigation which presented the 3-dimentional information related to each tunnel. Thus, we can also use the navigation in other ways compared to those presented by the original software.

Teaching Tool and Reducing the Learning Curve

There is a small attachment area which is isometric under a range of loading conditions in the intact knee, at the furthest posterior extremity of the femoral intercondylar notch, close to the over-the-top position. Unfortunately, the natural tendency is to migrate into the field of clear vision, i.e., towards the surgeon. This error was made by experienced arthroscopic surgeons (10) and leads to a graft that is stretched by knee flexion. Pannisset et al. (13) evaluated tunnel placement by surgeons at different points along the learning curve in an attempt to prove the reliability of computer aided navigation for ACL reconstruction. They concluded that computer aided procedures are reliable for this purpose and suggested that navigation can help less experienced surgeons to avoid errors when placing the tunnels. Computer navigation and virtual ligament reconstruction are good arthroscopic surgery teaching tools. These techniques enable residents and less experienced surgeons to control positioning and limit the complications caused by tunnel misplacement.

Summary

Navigation provides real time information about location, rotation, translation, impingement and isometry. Thus during ACL reconstruction, navigation improves accuracy of tunnel placement with prevention of the impingement, leading to superior results in isometricity and stability. And we can also do the double bundle reconstruction with the 3-dimentional information presented by navigation, although this is not presented by the original software. Navigation allows documentation of rotation and translation, which is otherwise very difficult. With these data, the surgeon can correct his/her faults besides in using it as a learning tool.

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