Three-Dimensional Fluoroscopic Navigation Guidance for Femoral Tunnel Creation in Revision Anterior Cruciate Ligament Reconstruction

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Abstract: Revision anterior cruciate ligament (ACL) reconstruction is accompanied by several technical challenges that must be addressed, such as a primary malpositioned bone tunnel, pre-existing hardware, or bone defects due to tunnel expansion. We describe a surgical technique used to create an anatomic femoral socket using a 3-dimensional (3D) fluoroscopy-based navigation system in technically demanding revision cases. After a reference frame is rigidly attached to the femur, an intraoperative image of the distal femur is obtained, which is transferred to a navigation system and reconstructed into a 3D image. A navigation computer helps the surgeon to visualize the whole image of the lateral wall of the femoral notch, even if the natural morphology of the intercondylar notch has been destroyed by the primary procedure. In addition, the surgeon can also confirm the position of the previous bone tunnel aperture, the previous exit of the femoral tunnel, and the presence of any pre-existing hardware on the navigation monitor. When a new femoral guidewire for the revision procedure is placed, the virtual femoral tunnel is overlaid on the reconstructed 3D image in real time. At our institution, 12 patients underwent 1-stage revision ACL procedures with the assistance of this computer navigation system, and the grafts were securely fixed in anatomically created tunnels in all cases. This technology can assist surgeons in creating anatomic femoral tunnels in technically challenging revision ACL reconstructions.

The anterior cruciate ligament (ACL) is frequently injured and is widely reconstructed, and failed reconstruction is becoming an issue.[1] With the increasing numbers of primary ACL reconstructions, revision ACL surgery is likely to become more frequent. Revision ACL reconstruction is accompanied by several technical challenges that need to be addressed, such as pre-existing hardware, bone tunnel defects, or primary tunnel malposition.[1,2] According to several authors, technical errors have been found to be a common cause of failure of primary reconstruction and, above all, femoral tunnel malposition has been the most common cause.[1] Thus it is frequently difficult to create a new femoral tunnel at an ideal position in revision ACL reconstructions because it may be impacted by the location of the previous femoral tunnel.

Since 2007, we have used a 3-dimensional (3D) fluoroscopy-based navigation system to position femoral sockets accurately and reproducibly in anatomic double-bundle ACL reconstruction using hamstring tendon grafts.[3,4] This system can also be applied in anatomic rectangular bone–patellar tendon–bone (BPTB) graft ACL reconstruction. This computer navigation is particularly useful for revision ACL reconstruction, because it enables visualization of the whole previous femoral tunnel or the pre-existing hardware inside the femoral bone, which is not visible

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arthroscopically. By use of this system, orientation of the lateral wall and the roof of the femoral intercondylar notch can be easily obtained, even if the natural morphology of the intercondylar notch was destroyed in the previous procedure. Thus the purpose of this article is to describe this surgical technique and to determine how successfully we could create properly placed femoral tunnels using the 3D fluoroscopy-based navigation system in revision ACL reconstruction.

TECHNIQUE

Principle for Graft Selection and Preoperative Technical Considerations

The BPTB graft is our current preference for revision ACL reconstruction because direct bone-to-bone healing is expected, resulting in secure and consistent fixation. The femoral bone plug is usually shaped 5 mm thick, 10 mm wide, and 15 mm long for a rectangular tunnel placement, except in cases with prior femoral aperture widening. Because the cross-sectional area of the tunnels required for rectangular ACL reconstruction is less than that for the round tunnel technique, this method is advantageous because it allows surgeons to consistently avoid overlap with tunnels from prior surgery.

It is essential to perform preoperative planning using 3D computed tomography (CT) images before every revision procedure. The previous femoral tunnel position can be classified into 3 types based on the 3D CT image depending on the location of the femoral tunnel relative to the lateral intercondylar ridge, as described by Magnussen et al.[5] The principle is to create a new femoral socket for a BPTB graft or 2 independent sockets for hamstring tendon grafts inside the anatomic footprint. In our experience, if the primary rectangular BPTB femoral or double hamstring tendon apertures were created anatomically, the revision could be performed in the same way as in a primary rectangular tunnel BPTB ACL reconstruction[6] without the assistance of a navigation system. In this case the prior anatomically placed aperture(s) could be easily expanded with a 5 × 10–mm dilator (Smith & Nephew Endoscopy, Andover, MA) into a single tunnel. If the previous tunnels on the femoral side were significantly improperly placed, a new femoral socket could be independently created anatomically in the same manner as in a primary ACL reconstruction with the assistance of computer navigation. Cases of a previous slightly malpositioned femoral tunnel or previously enlarged femoral tunnel aperture were the most technically challenging cases because overlap between the previous tunnel aperture and the newly created one was sometimes inevitable. In such cases a divergent tunnel could be created with the assistance of the navigation system, and a BPTB graft was usually selected for secure fixation. If a large femoral tunnel bone defect existed, a BPTB graft with trapezoidal bone block was used as a substitute for rectangular BPTB reconstruction.

Image Data Acquisition and Reconstruction

The reference frame (Orthopaedic Frame HC; Medtronic, Louisville, CO) was attached rigidly to the femur with 2 half-pins at the beginning of surgery. Intraoperative 3D images were acquired with the C-arm of the Arcadis Orbic 3D device (Siemens AG, Erlangen, Germany).[3] The C-arm of the image intensifier was equipped with a wireless tracker (Stealth Active wireless tracker S/N 130; Medtronic) for navigation registration. The acquired image data were downloaded to the navigation computer (StealthStation TRIA plus; Medtronic), and a 3D image of the distal femur was reconstructed on the computer screen. The medial half of the 3D reconstructed distal femur was deleted by use of computer software for a better view of the lateral wall and the roof of the femoral intercondylar notch.

Computer Navigation–Assisted Femoral Tunnel Preparation

Any metal hardware inside or outside the femur was removed in case it might interfere with the creation of the new anatomic femoral socket(s). The placement of guidewires for the femoral socket was performed with a femoral guide equipped with a tracker (SureTrak2 Universal Tracker, Large Passive Fighter; Medtronic). With an arthroscope introduced through a medial portal, the tip of the femoral guide could be placed arthroscopically through a far anteromedial portal at the designated location. The image-interactive navigation enabled the surgeon to confirm the position of the tip of the femoral guide on the 3D reconstructed image in real time (Fig 1).

With the femoral guide tip being kept inside the femoral footprint, the knee was fully flexed. On the navigation computer screen, the surgeon could then identify the whole image of the lateral wall of the femoral notch (Figs 2A and 3A). In addition, the surgeon was able to monitor any apertures of previous tunnels on the navigation, even when the arthroscopic visualization of the lateral wall of the intercondylar notch was disturbed because of an impeding fat pad or limited flow across the

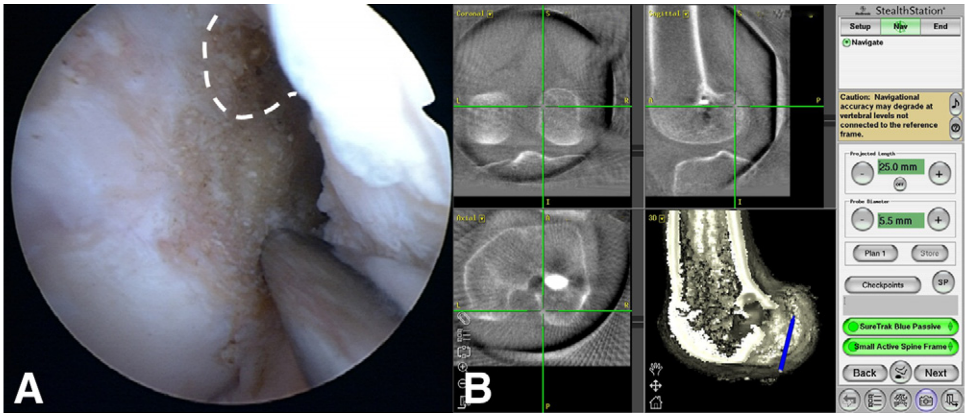

FIGURE 1. (A) Arthroscopic view of the lateral wall of the femoral intercondylar notch from the anteromedial portal in a right knee. The knee was at 90° of flexion. The tip of the femoral guide was placed inside the anatomic femoral footprint through a far anteromedial portal. The dashed line shows the nonanatomic previous femoral socket. (B) Navigation view of the lateral wall and the roof of the femoral intercondylar notch on the 3D reconstructed image. The previous bone tunnel and the retained metal hardware can be observed on the axial, coronal, and sagittal 2-dimensional images.

joint in deep flexion of the knee. Next, the 3D image was rotated 90° on the navigation screen, and the risk of a back-wall blowout could be evaluated (Fig 2B). Finally, the 3D image was rotated 180° to show the lateral aspect of the distal femur on the navigation screen. Visualization of the virtual exit of the femoral tunnel on the monitor enabled the surgeon to avoid communication between the primary and revision tunnel exits on the lateral cortex (Fig 2C). The total length of the femoral tunnel could be evaluated at the same time. During these procedures, the axial, coronal, and sagittal 2-dimensional image of any point could also be referred to. These views are a powerful tool allowing the surgeon to create a new femoral socket without any interference with the previous bone tunnel or the retained hardware (Fig 1B, Video 1).

CASE SUMMARY

From July 2008 to December 2011, we treated 12 patients with failed ACL reconstruction using a 3D fluoroscopy-based navigation system to position the femoral socket. Previous femoral tunnel positions were classified into 3 types as described previously.[5] Regardless of the presence of hardware or the location of a previous femoral tunnel, single-stage arthroscopic

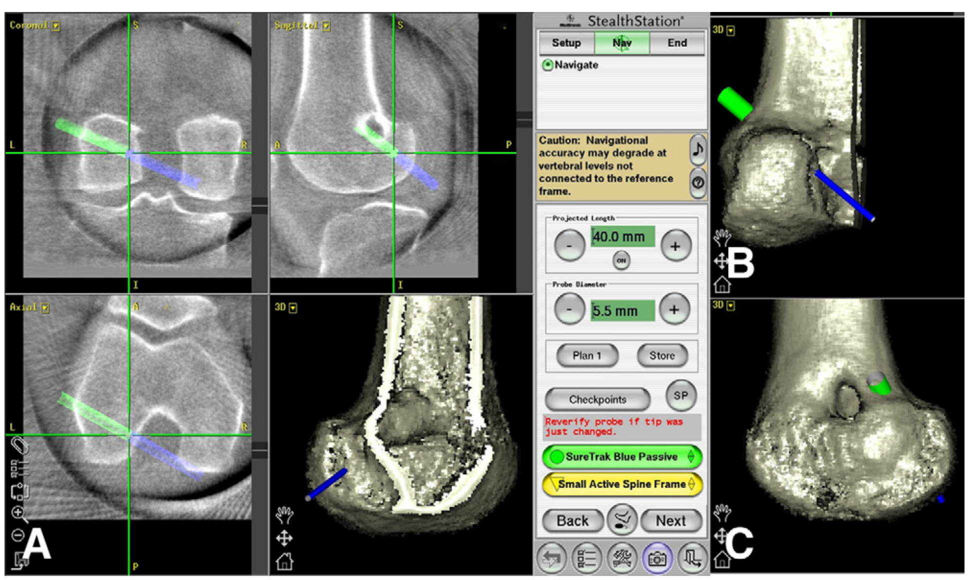

FIGURE 2. Navigation views of left knee. (A) The surface of the lateral wall of the intercondylar notch is shown in an orthogonal projection on the navigation computer screen. (B) The 3D image was rotated 90° on the navigation screen, and the risk of a back-wall blowout could be evaluated. (C) The image was rotated 180° to show the lateral aspect of the distal femur. The virtual exit of the femoral tunnel on the monitor enabled the surgeon to avoid any communication between the primary and revision tunnel exits on the lateral cortex.

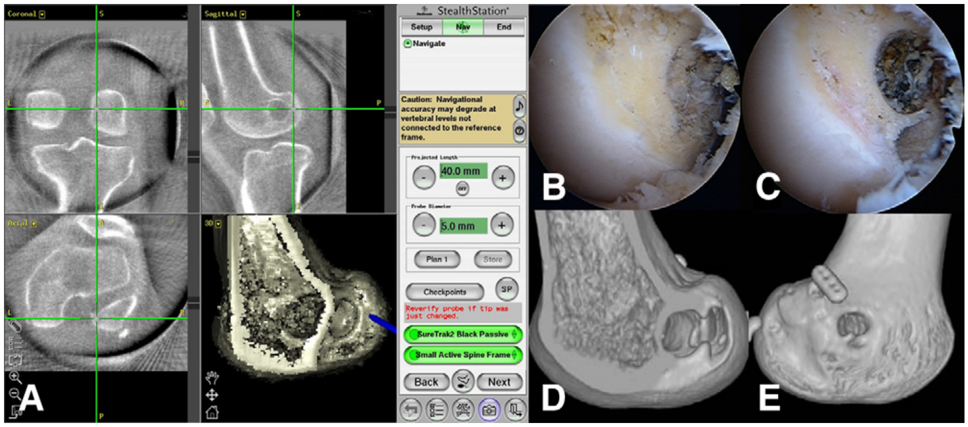

FIGURE 3. An illustrative case (right knee) with previous nonanatomic placement of the femoral socket. (A) On the navigation computer screen, the surgeon can identify the whole image of the lateral wall of the femoral notch during surgery, whereas the natural morphology of the lateral wall of the intercondylar notch was destroyed by the previous reconstructive surgery. (B) Arthroscopic view of the lateral wall of the femoral notch with the previous non–anatomically placed femoral socket from the anteromedial portal. The knee was at 90° of flexion. (C) Arthroscopic view of the newly created rectangular femoral socket (the same way as in B). (D) Medial view of a 3D CT reconstruction of a right distal femur at 1 week after revision shows the previous nonanatomic femoral socket (anterior), the newly created rectangular socket (posterior) for the BPTB graft with a slight overlap with the aperture of the previous one, and the bone plug. (E) Lateral view of a 3D CT scan shows the new femoral tunnel (proximal) with no interference with the previous bone tunnel (distal) and the EndoButton.

revision ACL reconstruction could be successfully performed in all cases. All grafts could be securely fixed with an EndoButton (Smith & Nephew Endoscopy) at the exit of the femoral sockets without any additional exposure of the lateral femur (Fig 3E). Three-dimensional CT imaging of the operated knee for evaluation of the tunnel location was performed a week after surgery in all patients. This showed that the femoral socket apertures were placed anatomically in all cases (Fig 3D). The patients and their families were informed that data from their cases would be submitted for publication, and all gave their consent.

DISCUSSION

Recently, computer-assisted surgery has been introduced to improve the accuracy and reproducibility of socket placement in ACL reconstruction.[7-10] We have used a 3D fluoroscopy-based navigation system to place femoral sockets accurately and reproducibly through a far anteromedial portal.[3,4] Using this system, surgeons can identify the lateral intercondylar ridge, which is an important landmark of ACL femoral insertion[11-13] not only arthroscopically but also on 3D images on the navigation system in primary ACL reconstruction.[3,4] In revision ACL settings, an arthroscopic image alone is not sufficient to evaluate tunnel placements because the natural morphology of the lateral wall of the intercondylar notch has often been destroyed by the previous procedure. Specifically, in our cases, although the lateral intercondylar ridge could not be identified in most patients, this system allowed the surgeon to recognize the orientation of the lateral wall and the roof of the femoral intercondylar notch. As a result, the femoral socket apertures could be reproducibly placed anatomically, which was confirmed on postoperative 3D CT taken a week after surgery (data not shown). In this series, regardless of the presence of hardware or the location of a previous femoral tunnel, the anatomic femoral sockets were created through a far anteromedial portal with an inside-out technique and with no complications. In cases with slightly malpositioned apertures, it was possible to create a new divergent tunnel and avoid overlap between the exit of the previous femoral tunnel and the new one. It should also be noted that surgeons should always suspect that it may not be possible to securely attach a graft with a suspension device in revision ACL reconstruction and should prepare alternative hardware in case it is required. If a suspension device is not appropriate, we do not hesitate to add an accessory incision and alternatively fix the graft to a femoral post with a screw.

The navigation system that we used has some disadvantages. In this system a reference frame must be fixed to the lateral femur with 2 half-pins, which necessitates additional skin incisions and drill holes in the femoral bone. However, no complications were encountered associated with pin insertion in our experience. The other disadvantages include radiation exposure of the patient and medical staff at the beginning of the procedure and the extra medical cost.

In summary, we used a 3D fluoroscopy-based navigation system for revision ACL reconstruction in 12 patients, the early clinical results of which are encouraging. We believe that this new technology could assist surgeons in performing more accurate and safe revision ACL reconstructions and may be reflected in improvements in patient outcome.

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