The Knee 23 (2016) 813–819

Contents lists available at ScienceDirect

The Knee

Arthroscopically blind anatomical anterior cruciate ligament reconstruction using only navigation guidance: a cadaveric study

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A R T I C L E   I N F O

Article history:
Received 21 August 2015
Received in revised form 24 February 2016
Accepted 28 February 2016

Keywords:
Navigation
Anterior cruciate ligament reconstruction
Computed tomography

A B S T R A C T

Background: To develop a preoperative planning and navigation system for anatomic anterior cruciate ligament (ACL) reconstruction and to evaluate the accuracy and the efficacy of anatomical ACL reconstruction using only navigation guidance.

Methods: A three-dimensional (3D) preoperative planning and navigation system was developed from open source libraries. Twenty knees from 10 fresh-frozen human cadavers underwent navigation-only guided double-bundle ACL reconstruction using the transportal technique. A computed tomography (CT) scan was performed after ACL reconstruction to create a 3D surface model of the distal femur. We evaluated the tunnel position by Bernard's quadrant method, the tunnel orientation by measuring the tunnel angle in three projected planes, and the incidence of posterior cortical damage. Then, we compared preoperative planning with the post-operative results.

Results: The difference in tunnel position between preoperative planning and the postoperative results was a mean of 2.50 ± 1.75 mm (range, 0.77 to 5.85 mm) in the anteromedial (AM) tunnel and a mean of 3.53 ± 2.20 mm (range, 0.39 to 7.92 mm) in the posterolateral (PL) tunnel. The difference in tunnel orientation was a mean of 6.74 ± 6.70° (range, 0.35 to 25.6°) in the AM tunnel and a mean of 5.73 ± 3.51° (range, 1.58 to 15.04°) in the PL tunnel. No statically significant difference was observed. Posterior cortical damage developed in seven cases (35%).

Conclusions: Our navigation-only guided ACL reconstruction produced consistent femoral tunnel position and orientation results. The accuracy and consistency of femoral tunneling were improved by using the preoperative planning and navigation system.

1. Introduction

The anterior cruciate ligament (ACL) reconstruction procedure is usually performed using an arthroscopic technique. The procedure includes an arthroscopic examination, forming a tunnel by drilling bone, graft passage, and fixation. The transtibial tunnel technique has traditionally been used to form the femoral tunnel. However, recent studies reported that it is difficult to form an anatomically correct tunnel using the conventional transtibial technique [1–7]. The importance of anatomical position has been emphasized [8,9], and the transportal or outside–in technique is now considered proper. However, it remains difficult to determine the exact position during arthroscopic surgery. In particular, an inexperienced surgeon may make a mistake while forming the femoral tunnel because synovial and scar tissues cover the original ACL footprint, making it difficult to find.

Computer-assisted orthopedic surgery has been developed in sports medicine to improve the accuracy and reproducibility of surgical procedures [10–13]. Preoperative planning and a navigation system could be useful for anatomical ACL reconstruction surgery. Computer-assisted surgery benefits surgeons by providing feedback on the positions of instrument and bony anatomy inside the surgical field; and preoperative surgical planning and a navigation system provide good results for tunnel position and orientation in accuracy and reproducibility.

There have been many studies that used a navigation system for anatomical ACL reconstruction. However, as we know, there has been no study about anatomical ACL reconstruction using only navigation guidance. If navigation-only guided ACL reconstruction is performed,

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http://dx.doi.org/10.1016/j.knee.2016.02.020
0968-0160/

the number of portals decreases, and the tunnel procedure can be performed more precisely because the hand that grabs and moves the scope is free.

The purpose of this study was to develop preoperative planning and to make a navigation system for anatomical ACL reconstruction using only navigation guidance and to evaluate the accuracy of the system and the efficacy of anatomic ACL reconstruction using only navigation guidance.

2. Materials and methods

2.1. Three-dimensional preoperative planning

We developed three-dimensional (3D) preoperative planning software for arthroscopic ACL reconstruction. This software was created using the open source libraries called the Visualization Tool Kit (VTK; Kitware, Clifton Park, NY, USA), and the DICOM Tool Kit (DCMTK; OFFIS, Berlin, Germany). A cadaver underwent a preoperative computed tomography (CT) scan. The CT scan data was loaded using DCMTK, and 3D and sectional images were reconstructed using VTK (Figure 1).

We used the radiographic quadrant method to determine the femoral insertion position for the ACL graft [14]. The opacity of the femur model was adjusted to show Blumensaat's line and the intercondylar notch. A quadrant plane was fitted to Blumensaat's line and the femoral condyle contour by adjusting four control points of the quadrant plane (Figure 2). The insertion point was projected onto the femoral model. Once the insertion position was determined, the imaginary tunneling pathway was displayed, and tunnel information, including tunnel length, distance between the tunnel and the posterior cortex, and the distance between the two tunnels were calculated. Furthermore, we obtained the mesh model after tunneling (Figure 3).

2.2. Surgical technique

We utilized 20 fresh-frozen human knees for this study. Each specimen was transected at mid-femur and mid-tibia. Each knee specimen underwent arthroscopic double-bundle ACL reconstruction using the transportal technique by a single experienced operator. We created the femoral tunnel using only navigation guidance with no arthroscopic viewing.

Two threaded pins were placed in the distal portion of the femur and the proximal portion of the tibia to track the position of the cadaver knee during the procedure, and rigid bodies with reflective markers were attached (Figure 4). Tracking was done using an optical measurement system (Polaris Spectra®, Northern Digital Inc., Waterloo, ONT, CAN). The intra-articular aspects were registered by the system using straight and curved pointers with markers. The intra-articular landmarks included the anterior edge of the posterior cruciate ligament insertion site for the medial femoral condyle (MFC), the suprapatellar pouch, the medial and lateral walls of the femur in the gutter, the notch wall of the femur, the ACL insertion area on the femur, and the over-the-top position. Then, the extra-articular landmarks were pointed and coincidence image with cadaver was confirmed. The extra-articular landmarks included the medial and lateral epicondyle of the distal femur and the anterior cortex of the femoral shaft. The exact location of the femoral tunnel was selected using a special aimer with attached markers based on real-time information on the femoral condyle as seen on the navigation system. Then, the femoral tunnel was made using only navigation guidance.

A femoral guide with attached marker was inserted through the accessory anteromedial (AAM) portal following navigation guidance, and a 2.4 mm guide pin was advanced two to three millimeters to stably engage through the guide to the center of the anteromedial (AM) bundle femoral footprint that was determined in preoperative planning. Then, the knee joint was bent fully and the pin was advanced until it passed the cortex and skin. Following guide pin, a Sentinel cannulated reamer (ConMed Linvatec, Largo, FL, USA) was inserted, and the femoral tunnel was drilled to a 27 mm depth cannulated reamer. The same procedure was performed in making the posterolateral (PL) bundle.

2.3. Measuring tunnel position and tunnel angle using 3D-CT

CT scans were performed on all knees after ACL reconstruction. A Somaris/7 Syngo CT scanner (Siemens AG, Berlin, Germany) was used for all examinations. The knee was placed in full extension. Digital Imaging and Communications in Medicine (DICOM) data were extracted

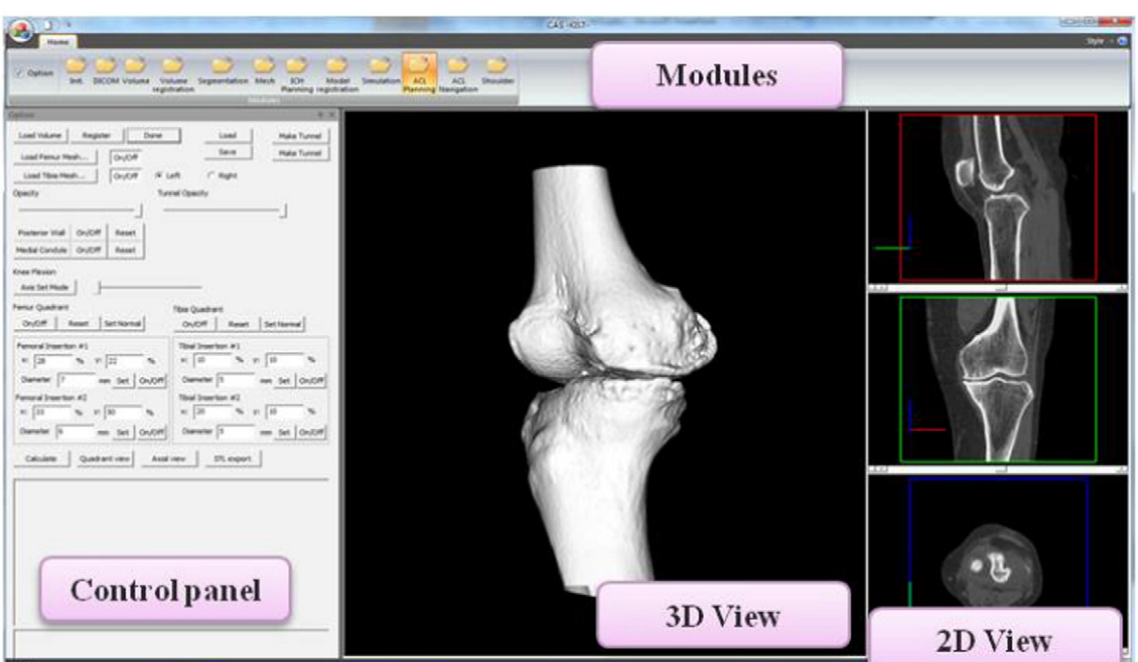

Figure 1. Three-dimensional (3D) preoperative planning software. We developed 3D preoperative planning software for arthroscopic anterior cruciate ligament (ACL) reconstruction. This software was created using open source libraries, such as the Visualization Tool Kit (Kitware, Clifton Park, NY, USA) and the DICOM Tool Kit (OFFIS, Berlin, Germany).