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Analysis of forces of ACL reconstructions at the tunnel entrance: is tunnel enlargement a biomechanical problem?

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Abstract

Bone tunnel enlargement is a common phenomenon following reconstruction of the anterior cruciate ligament (ACL). Biomechanical and biological factors have been reported as potential causes of this problem. However, there is no analysis of forces between the graft and bone, as the graft changes direction at the bone tunnel entrance.

The purpose of this study was to study these 'redirecting forces'.

Magnetic resonance images of 10 patients with an ACL reconstruction (age: 26±6.8 years) were used to determine the angle between graft and drill holes. Vector analysis was used to calculate the direction and magnitude of the perpendicular component of the force between the bone tunnel and the graft at the entrance of the bone tunnel. Force components were projected into the radiographically important sagittal and coronal planes. Tension of ACL reconstructions was recorded during passive knee motion in 10 cadaveric knee experiments (age: 28.9±10.6 years) and the tension multiplied with the force component for each plane.

Results are reported for the coronal and sagittal planes, respectively: For -10° of extension, the percentages of graft tension were determined to be 17±7 (max: 26; min: 7%) and 26±9 (max: 39; min: 16%) for the tibia. They were 59±6 (max: 66; min: 48%) and 99±1 (max: 1.00; min: 99%) for the femur. Force components were 14.68±6.54 and 25.73±12.96 N for the tibial tunnel. For the femoral tunnel, they were 52.48±19.03 and 90.77±32.06 N.

Percentages of graft tension and force components were significantly higher for the femoral tunnel compared with the tibial tunnel. Moreover, in the sagittal direction, force components for the femoral tunnel were significantly higher compared with the coronal plane (Wilcoxon test, $p<0.01$).

The differences in force components calculated in this study corresponds with the amount of tunnel enlargement in the radiographic planes in the literature providing evidence that biomechanical forces play a key role in postoperative tunnel expansion.

Keywords: Knee; Anterior cruciate ligament; Bone tunnel enlargement; Hyperextension

1. Introduction

Bone tunnel enlargement has been observed following reconstruction of the anterior cruciate ligament (ACL) (Fink et al., 2001; Hoher et al., 1998; Jansson et al., 1999; Webster et al., 2001). The increase in tunnel diameter over time is greatest in between 4 and 6 months after surgery and then decreases at 1 and 2 years follow-up (Buelow et al., 2002; Webster et al., 2001).

A study that investigated bone tunnel healing in rabbits showed that drill holes without grafts heal from the outside to the surface of the joint creating a conical-shaped tunnel (Berg et al., 2001). However, this observation does not explain the differences in tunnel width that have been observed between the sagittal and anteroposterior planes (Clatworthy et al., 1999; Fink

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et al., 2001; Jansson et al., 1999; L'Insalata et al., 1997). Tunnel enlargement is more commonly found when pure tendon grafts are used compared with bone patellar tendon autografts (Clatworthy et al., 1999; Webster et al., 2001).

Numerous studies have conducted displacement (Beynnon et al., 1992) or tension (Goss et al., 1997; Markolf et al., 1990; Goss et al., 1997) measurements of the ACLs or ACL substitutes. However, no study used the data to determine the redirecting forces that are caused by the angulation of the graft at the entrance of the bone tunnels.

The purpose of this study is to investigate the magnitude of redirecting forces at the articular side of the tibial and femoral drill holes following a reconstruction of the ACL. The results are compared with the amount of tunnel expansion that others have observed following ACL reconstruction.

2. Material and methods

2.1. Patient selection and surgical technique

Ten patients having had ACL reconstructions using a semitendinosus/gracilis graft were examined in between 6 and 12 weeks (mean: 8.3 ± 2.4 weeks) after they had a primary ACL reconstruction. Patients who had associated grade 3 collateral ligament tears or associated lateral or posterior instability or partial resection of the meniscus were excluded. The group consisted of six female and four male patients, with an average age of 26 ± 6.8 years (range: 18–42 years) at the time of surgery.

All procedures were performed by a single surgeon (H.H.P.) using a doubled semitendinosus and gracilis graft. Graft diameter averaged 8.6 ± 0.7 mm (range: 7–10 mm). An endoscopic technique was used in all cases. The tibial tunnel was drilled with a drill guide (Richard Wolf GmbH, Knittlingen, Germany) with an angulation of 40–45°. The femoral tunnel was drilled through the anteromedial portal using a guide (Arthrex®, Naples, FL) with the knee flexed 120° in the 11 or 1 o'clock position in a region that has been determined being most isometric (Hefzy et al., 1989). Femoral fixation was performed using a bottle-like tunnel which enabled a press fit fixation (Paessler and Thermann, 2002). Tibial fixation of the graft was performed using Mersilene sutures no. 6 (Ethicon Inc., Somerville, NJ) and a bone bridge. All drill holes were in the regions recommended by Harner et al. (1994) for the location of the femoral and tibial tunnel.

2.2. Magnetic resonance imaging

Imaging was performed on a 0.18 T MR-unit (Artoscan®, ESAOTE BIOMEDICA, Genua, Italy). The low-field-strength MRI is equipped with a variable heel rest that enables the knee to fully extend. The knees were positioned at 0° of external rotation. Knee extension was increased stepwise. For each examination position, two independent observers assessed knee extension with a technique previously described with high accuracy ($R^2 = 0.83$; Jagodzinski et al., 2000b). Each step averaged approximately 2.5°. Images closest to each 10° increment of knee extension were subject to further analyses.

A three-dimensional (3D) T1-weighted flash sequence was chosen with a resolution of $256 \times 256 \times 128$ voxels. A field of view of 14–16 cm was used, depending on knee size. Imaging time was 2:56 min per sequence. Time to echo was 250 ms and repetition time was 560 ms, thus providing T1-weighted images. The coronal plane was aligned with the posterior outline of the femoral condyles with the knee fully extended. The femoral position was not changed during knee flexion. The images were then reconstructed in the coronal, sagittal and axial planes and transferred to a personal computer for further analysis. The procedure was repeated after increasing knee extension step by step.

2.3. Determination of graft tunnel angulation

Measurements of the angles between the ACL graft and the femoral and tibial tunnel were determined after importing the images into Auto-CAD (Auto-CAD, Autodesk Inc., San Rafael, CA 94903, USA). The image slices were superimposed and the outline of the femoral and tibial tunnels and the ACL graft were marked by 'eyeballing' the locations. The center of the drill holes and the graft was obtained using a midline function of the software (Fig. 1), creating a vector triplet in the sagittal, coronal and axial planes. Angle measurement function was used to determine the angles between the femoral and tibial tunnel and the graft in each plane. The procedure was repeated for the data of all knee extension angles.

2.4. Vector analysis

Vector analysis was used to calculate the direction and magnitude of the perpendicular component of the force between the bone tunnel and the graft at the entrance of the bone tunnel. This force was then projected into the sagittal and coronal planes to determine the percentage of graft tension and relative magnitude of this force that acts in the radiographic planes.

The axis of the bone tunnels and their articular connection lines create two pairs of intersecting lines that define a graft–drill hole angle (α, β). These were determined in the coronal (COR), sagittal (SAG) and axial (AX) planes (Fig. 2).They were transferred into