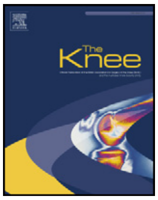
The Knee 21 (2014) 1160–1165

Contents lists available at ScienceDirect

The Knee



Notchplasty in anterior cruciate ligament reconstruction in the setting of passive anterior tibial subluxation

Hendrik A. Zuiderbaan [a,*], Saker Khamaisy [a], Danyal H. Nawabi [a], Ran Thein [a], Joseph T. Nguyen [a], Joseph D. Lipman [b], Andrew D. Pearle [a]

[a] Sports Medicine and Shoulder Service, Department of Orthopaedic Surgery, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY, United States
[b] Department of Biomechanics and Implant Design, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY, United States

ARTICLE INFO

Article history:
Received 30 May 2014
Accepted 13 August 2014

Keywords:
Notchplasty
Anterior cruciate ligament reconstruction
Revision
Anterior tibial translation
Anterior cruciate ligament

ABSTRACT

Purpose: In an effort to minimize graft impingement among various ACL deficient states, we sought to quantitatively determine requirements for bone resection during notchplasty with respect to both volumetric amount and location.

Methods: A validated method was used to evaluate Magnetic Resonance Imaging scans. We measured the ATT of the medial and lateral compartments in the following four states: intact ACL (27 patients), acute ACL disruption; <2 months post-injury (76 patients), chronic ACL disruption; 12 months post-injury (42 patients) and failed ACL reconstruction (75 patients). Subsequently, 11 cadaveric knees underwent Computed Tomography (CT) scanning. Specialized software allowed virtual anterior translation of the tibia according to the average ATT measured on MRI. Impingement volume was analyzed by performing virtual ACLRs onto the various associated CT scans. Location was analyzed by overlaying an on-screen protractor. The center of the notch was defined as 0°.

Results: Average impingement volume changed significantly in the various groups compared to the intact ACL group (acute 577 ± 200 mm^3, chronic 615 ± 199 mm^3, failed ACLR 678 ± 210 mm^3, $p = 0.0001$). The location of the required notchplasty of the distal femoral wall border did not change significantly. The proximal femoral border moved significantly towards the center of the notch (acute 8.6° ± 4.8°, chronic 7.8° ± 4.2° ($p = 0.013$), failed ACLR 5.1° ± 5.9° ($p = 0.002$)).

Conclusion: Our data suggests that attention should be paid peri-operatively to the required volume and location of notchplasty among the various ACL deficient states to minimize graft impingement.

1. Introduction

The Anterior Cruciate Ligament (ACL) is among the most commonly injured ligaments, with an estimated 200,000 ruptures per year and 100,000 primary ACL reconstructions (ACLR) performed per year in the United States [1]. ACL deficiency leads to altered joint kinematics and symptoms of instability due to anterolateral subluxation of the tibia relative to the femur.

Improved surgical techniques have led to restoration of joint kinematics in 80–95% of patients following ACLR [2–4]. However, clinical failure rates between 3.6% and 15% have been reported [5–7]. Various reports show that technical errors, such as incorrect tunnel placement and graft impingement, account for a substantial portion of graft failures [8,9]. Notch roof impingement occurs when there is premature impaction of the ACL graft on the notch during knee extension [10]. This leads to graft attenuation and deterioration as well as the development of cyclops lesions that may impair range of motion. Therefore, the avoidance of graft impingement is an important surgical consideration in reconstructive ACL procedures. Several authors have suggested that posterior tibial tunnel placement and a generous notchplasty are the solutions for graft impingement [10–14].

Recently, Tanaka et al. introduced a new concept of anterior tibial translation (ATT) in the various ACL deficient states of the knee [15]. The authors found that passive anterior tibial translation varies significantly among the various ACL deficient states. They reported that the ATT is greater in failed ACLR patients than in patients who sustained an acute ACL disruption. This is of considerable importance since various reports show that ACLR is not capable to restore ATT following surgery [16–20]. Since the tibiofemoral relation is chronically altered, even after surgery, additional intraoperative techniques should be used to optimize the position of the graft and minimize impingement. Notchplasty is one of the additional techniques which can be used to optimize the position and integrity of the graft. Therefore the purpose of the current study was to quantify the volume and location of the notchplasty

---

* Corresponding author at: Hospital for Special Surgery, 535 E. 70th Street, New York, NY 10021, United States. Tel.: +1 646 714 1641; fax: +1 646 797 8222.
E-mail addresses: hazuiderbaanmd@gmail.com (H.A. Zuiderbaan), khamaisys@hss.edu (S. Khamaisy), nawabid@hss.edu (D.H. Nawabi), theinr@hss.edu (R. Thein), nguyenj@hss.edu (J.T. Nguyen), lipmanj@hss.edu (J.D. Lipman), pearlea@hss.edu (A.D. Pearle).

http://dx.doi.org/10.1016/j.knee.2014.08.011
0968-0160/© 2014 Elsevier B.V. All rights reserved.

required in acute ACL deficiency, chronic ACL deficiency and after failed ACLR state. We hypothesized that the volume and location of the performed notchplasty varies significantly among the various ACL deficient states when fixed tunnel positions are used in performing ACLR.

2. Materials and methods

After Institutional Review Board approval was obtained, an electronic database search was performed for patients who sustained a complete ACL disruption between the 1st of July 2007 and 1st of March 2013. Patients with a history of previous knee surgery were excluded. ACL ruptures were confirmed by an experienced musculoskeletal radiologist on magnetic resonance imaging (MRI) and clinically by an orthopedic surgeon with extensive experience in ACLR. The data extraction resulted in 322 eligible subjects. They were divided in three groups; (1) acute ACL disruption (76 patients), (2) chronic ACL disruption (42 patients) and (3) failed ACLR (75 patients). Twenty-seven healthy subjects were included in the control group and formed the baseline to which all measurements in the study groups were compared. They had an intact ACL, without other pathologic MRI findings.

An acute ACL disruption was defined as a complete disruption of all ACL fibers within two months of traumatic injury. A chronic ACL disruption was defined as a complete disruption of all ACL fibers at least 12 months following traumatic injury. A failed ACLR was defined as a complete disruption of all graft fibers following primary ACLR. The three groups were compared to MRIs of healthy individuals with an intact ACL. One hundred and two patients with MR imaging between two and 12 months post ACL injury were excluded. Patients with an associated meniscal tear were not excluded since it has no proven effect on the ATT [17,19].

The study consisted of two phases. First, the MRIs from patients were analyzed for ATT in the various ACL deficient states. Subsequently the volume of graft impingement and its location in the femoral notch were calculated and analyzed on a cadaveric study where tibial position was changed based on the mean values for our MRI measurements.

2.1. MR analysis — radiographic study

A standardized MRI was performed for each patient. The knee was brought into 0° of flexion and extension. To minimize any motion artifact, the lower extremity was fixed with a sponge in a tight fitting extremity coil (8 channel knee, Medrad). A previously validated method described by Iwaki [21] and Tanaka [15] was used to evaluate the amount of ATT. In the medial compartment, ATT was measured on the sagittal MRI slice where the insertion of the medial head of the gastronemius muscle onto the femur was visible. In the lateral compartment, ATT was measured on the sagittal slice where the most medial aspect of the fibula was visible. Once these sagittal MR planes had been identified, a best fit circle was drawn over the subchondral line of the posterior condyle. A perpendicular line to the tibial plateau was drawn over the posterior border of this circle. Subsequently a second line, also perpendicular to the tibial plateau, was drawn at the posterior border of the tibial plateau. The measured difference between the two perpendicular lines represented the position of the tibia with respect to the femur (Fig. 1). All measurements were performed by the same author (***). Previous studies show the measurement to be reliable and reproducible [15].

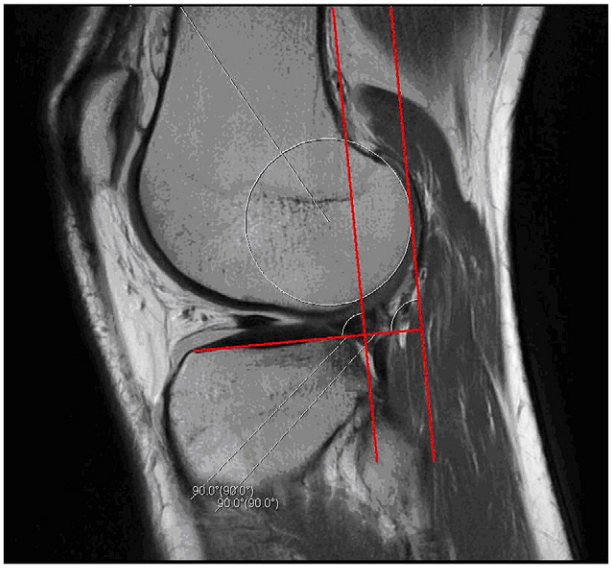


Fig. 1. The figure shows the amount of ATT in the lateral compartment. The distance between the two vertical lines represents the ATT in millimeters.

2.2. Impingement volume analysis — cadaveric study

Eleven cadaveric knees (mean age 52.5 years; range 29–65) underwent computed tomography (CT) scanning. Any cadaver with evidence of bony deformity, osteoarthritis or an existing ACL deficiency was excluded. The knees were then mounted to a 6° of freedom robot (ZX165U; Kawasaki, Tokyo, Japan) which simulated knee flexion based on a least resistance path. Physical digitizations were performed with reference markers fixed to each cadaveric specimen which are tracked during robotic testing. The markers are CT dense, allowing us to link the virtually constructed joint to the physical experiment and thus permit the determination of the 3D virtual flexion path of the knee. Eleven three-dimensional models, one for each individual cadaveric knee, were generated from the CT (Mimics, Materialise Inc. Leuven, Belgium). The centers of the femoral and tibial footprints were then selected by one of the authors experienced in ACLR, mimicking anatomic ACL tunnel positions. Using sagittal slices of the CT scan we were able to define the outline of the native ACL. The tibial footprint was segmented into two halves on the sagittal section. We then identified the medial and lateral tibial spines on the coronal slices and located the halfway point. The point which corresponded to the half way mark on both the sagittal and coronal slices was used as the center of the tibial footprint. Subsequently, the center of the femoral footprint was located by identifying the lateral intercondylar ridge on 3D CT reconstruction. This was segmented into two halves. A perpendicular line from the midpoint of the lateral intercondylar ridge was then dropped towards the posterior articular cartilage. The midpoint of this perpendicular line represented the center of the femoral footprint.

Impingement volume analysis was performed using 3D modeling software (Geomagic Studio 2013, Geomagic Inc. Rock Hill, United States). A 9 millimeter cylinder was placed between the femoral and tibial tunnel positions, simulating an ACL graft. Impingement was calculated as the amount of volume overlap between the femur and the graft using a Boolean operation. Subsequently the location of femoral notch impingement was analyzed using a protractor overlay (Fig. 2). The center of the protractor was placed in the middle of the femoral condyles. Two lines were then drawn from the center of the protractor to the two outside borders of the area of femoral wall impingement. Border A represents the most proximal (or high) border towards the center of the femoral roof whereas border B is the most distal (or low) located. The locations of the borders were analyzed in amount of degrees that they were located from the center of the femoral roof. For each of our three study groups, using the same 3D modeling software, the medial and lateral parts of the tibia were subluxed anteriorly according to the mean measurements from the MRI ATT analysis (Fig. 3). Impingement volumes and areas were then measured for each state of tibial subluxation (Fig. 4).