The Knee xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

The Knee

journal homepage: www.elsevier.com/locate/

The effects of graft size and insertion site location during anterior cruciate ligament reconstruction on intercondylar notch impingement

Alexander D. Orsi [a], Paul K. Canavan [b], Askhan Vaziri [a], Ruben Goebel [c], Onaly A. Kapasi [d], Hamid Nayeb-Hashemi [a,*]

[a] Biomechanics Research Group, Northeastern University, 360 Huntington Avenue, Boston, MA, United States
[b] Department of Rehabilitation, UMass Memorial Hospital, Worcester, MA, United States
[c] Sports Science Program, Qatar University, Doha, Qatar
[d] Department of Orthopaedic Surgery, Brigham and Women's Faulkner Hospital, Boston, MA, United States

ARTICLE INFO

Article history:
Received 7 December 2016
Received in revised form 28 January 2017
Accepted 28 February 2017
Available online xxxx

Keywords:
Anterior cruciate ligament
Impingement
Insertion site
Graft size
Notchplasty

ABSTRACT

Background: Intercondylar notch impingement is detrimental to the anterior cruciate ligament (ACL). Notchplasty is a preventative remodeling procedure performed on the intercondylar notch during ACL reconstruction (ACLR). This study investigates how ACL graft geometry and both tibial and femoral insertion site location may affect ACL-intercondylar notch interactions post ACLR. A range of ACL graft sizes are reported during ACLR, from six millimeters to 11 mm in diameter. Variability of three millimeters in ACL insertion site location is reported during ACLR. This study aims to determine the post-operative effects of minor variations in graft size and insertion location on intercondylar notch impingement.

Methods: Several 3D finite element knee joint models were constructed using three ACL graft sizes and polar arrays of tibial and femoral insertion locations. Each model was subjected to flexion, tibial external rotation, and valgus motion. Impingement force and contact area between the ACL and intercondylar notch compared well with experimental cadaver data from literature.

Results: A three millimeter anterior–lateral tibial insertion site shift of the maximum size ACL increased impingement force by 242.9%. A three millimeter anterior–proximal femoral insertion site shift of the maximum size ACL increased impingement by 346.2%. Simulated notchplasty of five millimeters eliminated all impingement for the simulation with the greatest impingement. For the kinematics applied, small differences in graft size and insertion site location led to large increases in impingement force and contact area.

Conclusions: Minor surgical variations may increase ACL impingement. The results indicate that notchplasty reduces impingement during ACLR. Notchplasty may help to improve ACLR success rates.

1. Introduction

The anterior cruciate ligament (ACL) acts as a major motion stabilizer for the knee joint by preventing anterior tibial displacement and providing torsional stability [1–6]. The ACL is the most commonly injured ligament within the knee [7–9].

* Corresponding author.
E-mail address: hamid@coe.neu.edu (H. Nayeb-Hashemi).

http://dx.doi.org/10.1016/j.knee.2017.02.010
0968-0160/© 2017 Elsevier B.V. All rights reserved.

These painful injuries occur upwards of 400,000 times annually in the United States [8,10,11]. ACL reconstruction (ACLR) and rehabilitation are costly, and represent an annual $1 billion expense in the United States [10–12]. This cost is expected to rise with the anticipated increase in ACLR performed annually [13].

Up to 90% of ACL injured patients elect to have ACLR. ACLR can be performed with either an autograft or allograft. Allografts are not as common due to the risks of infection and host rejection. Autografts are common, and can be performed using a bone-patellar tendon–bone (BPTB) graft, or with a hamstring graft using the semitendinosus in either a single or anatomical double bundle technique. Several review papers have reported that no significant benefit exists between the various techniques, and recommend the use of a single bundle BPTB graft [14–16].

Reinjury may be more likely for athletes who have undergone ACLR [17,18]. Wright et al. reported that six percent of patients who underwent ACLR had a reinjury within two years [19]. Salmon et al. reported that 12% of patients with an ACLR had a reinjury within a five year follow-up window [20]. In this same patient population, in a 15 year follow-up window, Leys et al. reported up to a 34% reinjury rate [21].

The ACL reinjury rate reportedly varies depending on the reconstruction technique [22–24]. Several studies have compared autograft vs allograft techniques for ACL reconstruction. Ellis et al. reported that 35% of patients who underwent allograft BPTB replacement required revision surgery within one year, compared to three percent for patients who had autograft replacement [22]. Vishal et al. reported that with a mean follow-up of 49 months, 0.7% of patients who had an autograft BPTB replacement required revision surgery compared to 9.7% for patients who had an allograft BPTB replacement [23].

Differences have been reported regarding the reinjury rate of ACLR patients [17,19,20]. However the reinjury rate has been reported as high as six times greater than healthy patients [17]. Because of these high surgical revision rates, it is important to understand the potential factors contributing to reinjury. Inaccurate placement of the ACL insertion sites during ACLR has been reported in 10% to 40% of ACL tunnel placements [25,26]. Up to three millimeters of variation in graft placement from the anatomical insertion site has been reported with experienced surgeons [27]. A range of ACL graft sizes have also been reported for use during ACLR [28–31]. Wilson et al. reported an average BPTB graft diameter of 9.9 mm and an average cross section of 44.6 mm^2, with a 2.2 mm standard deviation for the diameter, and a 23.1 mm^2 standard deviation for the cross sectional area [29]. Magnussen et al. reported graft sizes between seven millimeters and nine millimeters in diameter [28]. Tuman et al. reported that in a group of 106 patients, the average graft size was 7.7 mm in diameter, with two percent having grafts six millimeters in diameter, and one percent having grafts 10 mm in diameter or larger [30].

Several investigations have reported impingement between the ACL and the intercondylar notch during knee joint motion [7,32,33]. Park et al. performed a study which evaluated a three-dimensional (3D) finite element (FE) model of ACL impingement within the femoral intercondylar notch [7]. Park et al. validated their model with experimental data collected from an instrumented cadaver [7]. Knee flexion, external tibial rotation, and valgus motion were applied to the cadaver, and the contact area and impingement force data were collected. The same kinematic data were applied to the FE model. The contact area and impingement force results predicted in the FE model were in close agreement with the cadaver experiment, validating the FE model as a useful tool for predicting ACL impingement.

Femoral notchplasty is a surgical procedure in which the intercondylar femoral notch is widened during ACLR to prevent ACL impingement with the femoral intercondylar notch. Intercondylar notch impingement is thought to be a leading cause of ACL injury [8,12,34]. Notchplasty is commonly performed during ACLR; however a standard protocol has not been well defined. There is no recommended amount of bone removal during notchplasty, and different studies suggest varying amounts of notchplasty [35–37].

The purpose of the present study is to understand how surgical variations affect ACL-intercondylar notch interactions post ACLR. This is important because ACL-intercondylar notch impingement may lead to ACL injury [7,8,12,32-34,38]. The results of this study have the potential to improve ACLR success rates. Furthermore, as this study provides a method to quantify the amount of notchplasty to be performed during ACLR, the results may support the use of surgical notchplasty to reduce the risk of ACL reinjury.

2. Methods

A subject-specific 3D FE model of a male left knee was created from sagittal view magnetic resonance images (MRI) using the method provided by Homyk et al., Yang et al., Orsi et al. and Haut Donohue et al. [39–43]. The model is seen in Figure 1a. Details of the MR data acquisition can be found in our previous work [39–42]. The MRIs were converted into 3D solid structures using solid modeling software packages Rhinoceros (Robert McNeel & Associates, Seattle, WA) and SolidWorks (Dassault Systemes, France). The solid structures were imported into the FE software package ABAQUS (Dassault Systemes, France) and converted to an FE mesh for use in kinematic FE simulations.

A free meshing technique was used for the cartilage and meniscus using four-node linear tetrahedral elements. The ACL was meshed using hexahedral elements. Details justifying these element types and any volumetric locking effects rising from using these elements are provided in Orsi et al. [41].

Bone was modeled rigid as it is much stiffer than the soft tissue it interacts with [39–43]. The articular cartilage was modeled as isotropic linear elastic and the meniscus was modeled as transversely isotropic linear elastic with the material properties shown in Table 1. The menisci were attached to the tibial plateau with linear spring elements. The transverse ligament was modeled as a single spring element which connected the anterior horns of the medial and lateral meniscus.

Please cite this article as: A. Orsi et al., The effects of graft size and insertion site location during anterior cruciate ligament reconstruction on intercondylar notch impingement, The Knee (2017), http://dx.doi.org/10.1016/j.knee.2017.02.010