Clinical Biomechanics 33 (2016) 20–25

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Biomechanical evaluation of a novel dynamic posterior cruciate ligament brace

Christian H. Heinrichs [a], Werner Schmoelz [a,*], Raul Mayr [a], Alexander Keiler [a], Philip B. Schöttle [b], René Attal [a]

[a] Department of Trauma Surgery, Medical University of Innsbruck, Anichstrasse 35, 6020 Innsbruck, Austria
[b] Department of Orthopaedic and Trauma Surgery, Isar Medical Center, Sonnenstrasse 24, 80331 Munich, Germany

ARTICLE INFO

Article history:
Received 20 August 2015
Accepted 1 February 2016

Keywords:
Posterior cruciate ligament
Brace
Orthopedic biomechanics
Posterior tibial translation
Stress radiographs
PCL reconstruction

ABSTRACT

Background: Use of a rigid brace or cast immobilization is recommended in conservative treatment or postoperative rehabilitation after a posterior cruciate ligament injury. To prevent the loss of knee joint function and muscle activity often associated with this, a flexible knee brace has been developed that allows an adjustable anteriorly directed force to be applied to the calf in order to prevent posterior tibial translation. The purpose of this biomechanical study was to evaluate the impact of this novel dynamic brace on posterior tibial translation after posterior cruciate ligament injury and reconstruction.
Methods: A Telos stress device was used to provoke posterior tibial translation in seven human lower limb specimens, and stress radiographs were taken at 90° of knee flexion. Posterior tibial translation was measured in the native knees with an intact posterior cruciate ligament; after arthroscopic posterior cruciate ligament dissection with and without a brace; and after posterior cruciate ligament reconstruction with and without a brace. The force applied with the brace was measured using a pressure sensor.
Findings: Posterior tibial translation was significantly reduced ($P = 0.032$) after application of the brace with an anteriorly directed force of 50 N to the knees with the dissected posterior cruciate ligament. The brace also significantly reduced posterior tibial translation after posterior cruciate ligament reconstruction in comparison with reconstructed knees without a brace ($P = 0.005$).
Interpretation: Posterior tibial translation was reduced to physiological values using this dynamic brace system that allows an anteriorly directed force to be applied to the calf.

1. Introduction

The incidence of posterior cruciate ligament (PCL) ruptures reported in the literature is 5–20% of all acute knee ligament injuries with almost 50% of PCL injuries being isolated (Kowalczuk et al., 2015; Schulz et al., 2003). The PCL acts as the primary stabilizer preventing posterior translation of the tibia relative to the femur (Butler et al., 1980). Gravity and dynamic loads caused by the hamstring muscles provoke posterior tibial translation (PTT) when the PCL is insufficient and the patient is lying in a supine position (Lopez-Vidriero et al., 2010; Strobel et al., 2002). It is therefore recommended that PTT should be kept to a minimum or at the pre-injury level during the ligament healing phase after PCL injury and during the graft incorporation phase after PCL reconstruction (Pierce et al., 2013). To achieve this position, the recommended treatment algorithm uses a rigid brace or cast immobilization with a posterior tibial splint for the first 5–8 weeks (Edson et al., 2010; Jung et al., 2008; Kim et al., 2013), since applying an anteriorly directed force to the tibia during PCL healing has been reported to improve the clinical outcome (Strobel et al., 2002; Ahn et al., 2011; Jacobi et al., 2010). After this initial healing period, a 6- to 8-week period follows with a second brace that allows an adjustable range of motion (Edson et al., 2010; Jung et al., 2008; Yoon et al., 2013). Initial prolonged rigid brace or cast immobilization during the healing period can cause knee joint stiffness, reduce muscle strength, and result in impairment of knee joint function. This can prolong the rehabilitation process and delay the patient's return to work, thereby increasing costs to the healthcare system.

To overcome these limitations, a novel flexible PCL brace has been developed that makes it possible to apply an adjustable anteriorly directed force to the calf in order to reduce PTT after PCL injury, or to prevent PTT after PCL reconstruction. The novel flexible PCL brace is intended to allow conservative treatment or postoperative rehabilitation using a single brace, with a potential for early mobilization in the knee joint. Currently, none of the available PCL braces has been evaluated biomechanically in relation to whether or not they are able to prevent or reduce PTT

* Corresponding author at: Department of Trauma Surgery, Medical University of Innsbruck, Innsbruck, Austria. Tel.: +43 512 504 22413; fax: +43 512 504 25743.
E-mail addresses: christian.heinrichs@i-med.ac.at (C.H. Heinrichs), werner.schmoelz@tirol-kliniken.at (W. Schmoelz), raul.mayr@tirol-kliniken.at (R. Mayr), alexander.keiler@tirol-kliniken.at (A. Keiler), p_schoettle@web.de (P.B. Schöttle), rene.attal@tirol-kliniken.at (R. Attal).

http://dx.doi.org/10.1016/j.clinbiomech.2016.02.001
0268-0033/

(Jansson et al., 2013). In addition, the amount of anteriorly directed force that needs to be applied to the calf is still unknown.

The purpose of this biomechanical study was to evaluate the impact of a novel dynamic brace with free degrees of flexion on PTT after PCL injury and reconstruction. It was hypothesized that the brace, which applies an anteriorly directed force to the calf, can reduce PTT after PCL injury and prevent PTT after PCL reconstruction. It was also evaluated whether increasing the anteriorly directed force to the calf can further affect PTT.

2. Methods

2.1. Specimen preparation

Seven fresh frozen lower limb specimens from four female donors (average age = 75, range = 52–88 years) were used for testing. Quantitative computed tomography scans (qCT; Lightspeed VCT 64, General Electric, Milwaukee, WI, USA) were performed for each specimen to rule out any relevant pathology, such as previous fractures. The lower limbs were cut in the middle of the femur. Soft tissues and muscles were retained. The specimens were kept frozen at −20 °C, thawed 24 h before testing at 4 °C, and prepared at room temperature prior to testing. After thawing, diagnostic arthroscopy was performed to ensure that central stabilizers such as cruciate ligaments and menisci were intact. Brass rods (diameter 4 mm, length 50 mm) were implanted in a standardized fashion under fluoroscopic control into the tibia and femur at 90° of knee flexion so that they were axially aligned to each other in order to serve as radiological landmarks for measuring PTT.

2.2. Brace

The novel dynamic knee brace (M4PCL knee brace, medi GmbH, Bayreuth, Germany) is composed of a femoral and a tibial leg frame (Fig. 1a). Polycentric physiological hinge joints connect the two frames, using the principle of four-chain linkage, and allow constrained or free flexion and extension movements. An anteriorly directed force can be applied to the calf from a posterior pressure pad attached to the tibial frame. The amount of force applied by the posterior pressure pad is variable and can be adjusted using a wire traction wheel (Fig. 1b).

Fig. 1. (a) The M4PCL knee brace. (b) A variable anteriorly directed force can be applied to the calf by turning the wire traction wheel on the posterior pressure pad.

2.3. Posterior tibial translation measurements

A Telos stress device (Metax GmbH, Hungen-Obbornhofen, Germany) was used to provoke PTT by applying a standardized posteriorly directed force of 150 N at 90° of knee flexion (Schulz et al., 2003; Jung et al., 2006; Schulz et al., 2005; Shelbourne et al., 1999). After two preloading cycles in which the knee was moved between 0° and 90° of flexion, the specimens were positioned in the stress device at 90° of knee flexion, as recommended by the manufacturer. The proximal end of the femur and the ankle of the specimen were fixed to the stress device in order to standardize knee positioning in the device and minimize rotational error. Lateral stress radiographs (Siremobil 2000, Siemens Healthcare, Erlangen, Germany) were taken in five states per specimen:

1) Native knee with an intact PCL (native)
2) After arthroscopic total dissection of the PCL (dPCL) without a brace
3) After arthroscopic total dissection of the PCL (dPCL) with a brace applied
4) After arthroscopic reconstruction of the PCL (rPCL) without a brace
5) After arthroscopic reconstruction of the PCL (rPCL) with a brace applied

The distance between the radiation source and the fixed knee in the stress device was kept at a constant maximum. Care was taken to ensure that the center of the knee was located in the center of the image intensifier, to minimize measurement errors in the repeated measurements of each specimen.

In the first part of the biomechanical tests, the brace was applied with an anteriorly directed force of 50 N, representing approximately the lower leg mass of a person weighing 80 kg. For quantification of the anteriorly directed force, a pressure sensor (Sensor 5101, Tekscan Inc., South Boston, MA, USA) was positioned in a standardized fashion between the calf and the posterior pressure pad. The pressure sensor, 0.102 mm thick, has a matrix dimension of 112 × 112 mm, which is larger than the surface of the pressure pad. The total number of sensels is 1963, resulting in a spatial resolution of 15.5 sensels per square centimeter. The net force between the calf and the pressure pad was calculated as the sum of each sensel force. The pressure pad's wire traction wheel was turned until the pressure sensor measured a net force of 50 N before testing started.

In the second part of the biomechanical tests, the anteriorly directed force was further increased by turning the pressure pad's wire traction wheel by one full turn and two full turns (360°, 720°) in order to examine whether increasing the anteriorly directed force alters PTT further. Maximum force values from the pressure sensor were documented after the wire traction wheel was turned before testing started.

PTT was measured using an image processing program (Gimp 2.8.4, GNU) and consisted of three steps (Fig. 2):

- The long axis of the tibial and femoral brass rods was marked.
- At the proximal end of the tibial brass rod, a line was drawn perpendicular to the long axis of the tibial brass rod.