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Erratum to "The change in length of the medial and lateral collateral ligaments during in vivo knee flexion"

Sang Eun Park [a], Louis E. DeFrate [a,b], Jeremy F. Suggs [a,b], Thomas J. Gill [a], Harry E. Rubash [a], Guoan Li [a,*]

[a] Bioengineering Laboratory, Department of Orthopaedic Surgery, Massachusetts General Hospital/Harvard Medical School, 55 Fruit Street, GRJ 1215 Boston, MA 02114, United States
[b] Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02114, United States

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Abstract

The collateral ligaments of the knee are important in maintaining knee stability. However, little data has been reported on the in vivo function of the collateral ligaments. The objective of this study was to investigate the change in length of different fiber bundles of the medial collateral ligament (MCL), deep fibers of the MCL (DMCL) and the lateral collateral ligament (LCL) during in vivo knee flexion. The knees of five healthy subjects were scanned using magnetic resonance imaging. These images were used to create three-dimensional models of the tibia and femur, including the insertions of the collateral ligaments. The MCL, DMCL, and LCL were each divided into three equal portions: an anterior bundle, a middle bundle and a posterior bundle. Next, the subjects were imaged from two orthogonal directions using fluoroscopy while performing a quasi-static lunge from 0° to 90° of flexion. The models and fluoroscopic images were then used to reproduce the in vivo motion of the knee. From these models, the length of each bundle of each ligament was measured as a function of flexion. The length of the anterior bundle of the MCL did not change significantly with flexion. The length of the posterior bundle of the MCL consistently decreased with flexion ($p<0.05$). The change in length of the DMCL with flexion was similar to the trend observed for the MCL. The length of the anterior bundle of the LCL increased with flexion and the length of the posterior bundle decreased with flexion. These data indicate that the collateral ligaments do not elongate uniformly as the knee is flexed, with different bundles becoming taut and slack. These data may help to provide a better understanding of the in vivo function of the collateral ligaments and be used to improve surgical reconstructions of the collateral ligaments. Furthermore, the data suggest that the different roles of various portions of the collateral ligaments along the flexion path should be considered before releasing the collateral ligaments during knee arthroplasty.

Keywords: MCL; LCL; Deep MCL; MRI; 3D Modeling

1. Introduction

The collateral ligaments play an important role in maintaining knee stability. The medial collateral ligament (MCL) may be injured alone or in combination with the anterior cruciate ligament (ACL) [1–5]. Injury of the lateral collateral ligament (LCL) often accompanies rupture of the posterior cruciate ligament (PCL) [6,7]. During total knee arthroplasty (TKA), the collateral ligaments may be partially sectioned in order to balance the tension in the two ligaments [8–10]. For example, in varus knees, the MCL and deep MCL fibers may be released, while in valgus knees the LCL may be released [8].

Previous studies have investigated the biomechanics of the MCL and LCL under in vitro conditions [4,11–23]. In these studies, the MCL has been shown to resist valgus moments [15,19] and anterior loads beyond 60° of flexion [20]. The MCL has also been thought to stabilize the knee in response to anterior tibial loads after ACL injury [18,20].

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* Corresponding author. Tel.: +1 617 724 3246; fax: +1 617 724 4392.
E-mail address: gli1@partners.org (G. Li).

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The LCL is considered a component of the posterolateral complex and has been shown to restrain posterior tibial translation and external and varus tibial rotations especially after PCL injury [16,24].

The function of the MCL and LCL is usually investigated in separate studies [6,12,14,16,21,25–27]. Few studies have divided the MCL into superficial and deep fibers [3,28]. Furthermore, no data has been reported on the biomechanical role of the collateral ligaments during in vivo activities. Whether in vitro experimental data accurately represents in vivo collateral ligament function is unknown. Therefore, the objective of this paper was to investigate the in vivo elongation of the MCL, the deep fibers of the MCL, and the LCL as a function of flexion during a single leg lunge.

2. Materials and methods

Five knees (two left and three right) from five young and healthy volunteers (25 ± 5 years old) were imaged using a 1.5 Tesla magnet (GE, Milwaukee, WI) with a surface coil and a FIESTA (Fast Image Employing Steady-state Acquisition) sequence. The magnetic resonance (MR) scan spanned the medial and lateral extremes of the knee and enclosed a cubic volume of approximately 14 cm in each direction. Sagittal plane images at 0.7 mm intervals were acquired with a resolution of 512 × 512 pixels. A typical MR image is shown in Fig. 1a. These MR images were used to construct a 3D model of each knee using solid modeling software (Rhinoceros®, McNeel and Associates, Seattle, WA). These models included the bony geometry of the femur and tibia as well as the insertion areas of the collateral ligaments. Fig. 1b shows the tibiofemoral joint of one subject, including the insertion areas of the MCL, deep fibers of the MCL (DMCL), and LCL. These ligament insertion areas were further verified by comparing them to a classic anatomic study [29].

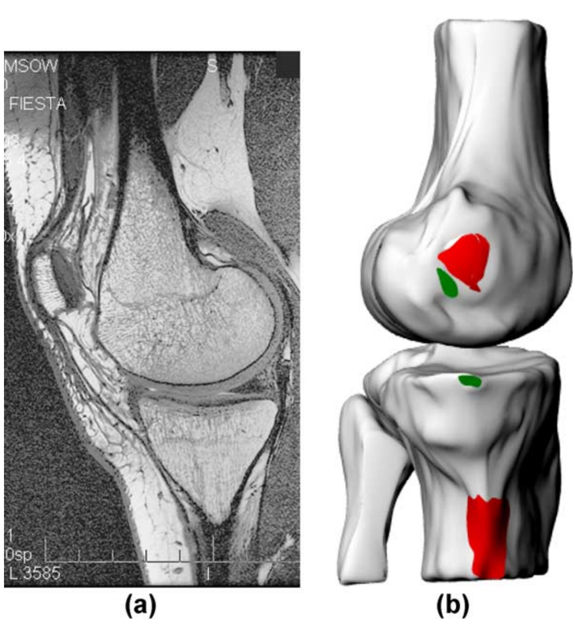

Fig. 1. A 3D knee model of a typical specimen (b) created from sagittal plane MR images (a). The insertion areas of the MCL are shown by the shaded regions on the tibia and femur.

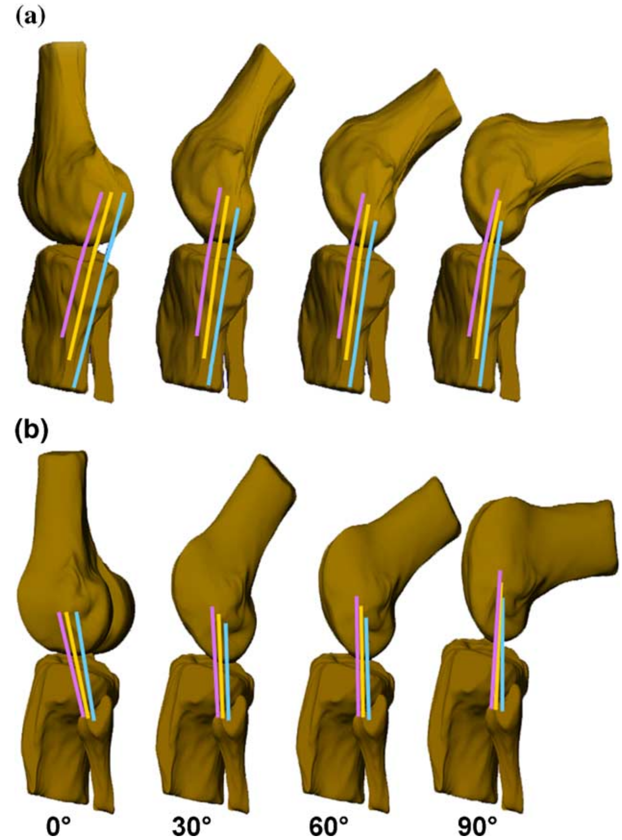

Fig. 2. Medial (a) and lateral (b) views of a typical knee model at different flexion angles. The lengths of the MCL and LCL bundles changed with flexion.

Next, each subject performed a quasi-static single-leg lunge to 0°, 30°, 60° and 90° of flexion as a 3D fluoroscope (SIREMOBIL Iso-C^{3D}, Siemens, Germany) was used to acquire two images of the knee from orthogonal directions. These images were recorded from the anteromedial and anterolateral directions. Flexion angle was verified with a goniometer as subjects stood upright on a platform with the C-arm of the fluoroscope positioned in the horizontal plane. Capturing the two orthogonal images at each flexion angle took less than 4 s [30]. This protocol was approved by the Institutional Review Board at Massachusetts General Hospital.

These orthogonal images were used to recreate the in vivo knee positions at each of the targeted flexion angles. The fluoroscopic images were imported into the solid modeling software and placed in two orthogonal planes, based on the positions of the C-arm during image acquisition. Two virtual cameras were created to simulate the position of the X-ray source from these two orthogonal directions. The 3D knee model was then imported into the