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Research Paper

Material and structural tensile properties of the human medial patello-femoral ligament

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ABSTRACT

The medial patellofemoral ligament (MPFL) is considered the most important passive patellar stabilizer and acts 50–60% of the force of the medial soft-tissue which restrains the lateralization of the patella between 0° and 30°. In this work, 24 human knees have been tested to evaluate the material properties of MPFL and to determine the structural behavior of femur-MPFL-Patella complex (FMPC). Particular attention was given to maintain the anatomical orientation between the patella and MPFL and to the evaluation of the elongation during the mechanical tests. The ultimate stress of the isolated ligament was 16±11 MPa, the ultimate strain was 24.3±6.8%, the Young's Modulus was 116±95 MPa and the strain energy density was 2.97±1.69 MPa.

The ultimate load of the whole structure, FMPC, was 145±68 N, the ultimate elongation was 9.5±2.9 mm, the linear stiffness was 42.5±10.2 N/mm and the absorbed energy was 818.8±440.7 N mm. The evaluation of material and structural properties of MPFL is fundamental to understand its contribution as stabilizer and for the selection of repair and reconstruction methods.

1. Introduction

Patellar subluxation is a common disease. Annually, about 6 out of 100,000 in the general population suffers from primary patellar dislocation and more than 90% of the cases result in MPFL injury (Atkin et al., 2000; Fithian et al., 2004). After the first episode of dislocation there is a 17% probability of recurrence and, after the second episode, 49% of the patients will experience further recurrences (Fisher et al., 2010). Surgical treatment is usually indicated when conservative treatment fails or in those cases where repeated recurrent sublaxations occur (Servien et al., 2011).

The medial patello-femoral ligament (MPFL) seems to be the most important passive patellar stabilizer and it acts

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50–60% of the force of the medial soft-tissue which restrains the lateralization of the patella between 0° and 30° (Cash and Hughston, 1988; Cofield and Bryan, 1977; Hawkins et al., 1986; Larsen and Lauridsen, 1982; Mäenpää and Lehto, 1997; Mountney et al., 2005; Bicos et al., 2007; Conlan et al., 1993; Desio et al., 1998; Hautamaa et al., 1998).

Nevertheless, some authors in cadaveric studies were unable to locate this ligament in some of the anatomical specimens after dissection (Amis et al., 2003; Reider et al., 1981) creating further debate concerning the MPFL's function or its existence.

In 1979, Warren and Mashall, dissecting 154 anatomical specimens, observed that the anatomy of the structures located anteriorly to the superficial collateral medial ligament and medially to the medial edge of the patella is extremely variable (Warren and Marshall, 1979). Later studies have shown that the MPFL also varies in insertion, thickness and resistance. In the majority of cases it is palpable upon dissection and in a small percentage it is frail and thin (Nomura et al., 2005; Philippot et al., 2009; Baldwin, 2009).

The kinematics of the patello-femoral joint are sustained by static and dynamic factors that stabilize and center the patella within the trochlea. The static stabilizers do not change their size according to the movement phase. Dynamic stabilizers, however, adapt by varying their size and position according to the forces acting on the patella. Biomechanical studies have shown that the main medial static stabilizer of the patella is the MPFL which together with the medial patello-meniscal ligament, the medial patello-tibial ligament and the medial retinaculum prevents the external sublaxation of the patella (Panagiotopoulos et al., 2006). Indeed, The evaluation of mechanical behavior of the MPFL is fundamental to understand its contribution as stabilizer.

Burks et al. (1998) have examined the tensile behavior of the MPFL finding a mean failure load of 209 N at 25 mm of displacement for failure of the MPFL during lateral patellar dislocation. Similar results have been proposed by Mountney et al. (2005). Also Arendt et al. (2007) (Arendt, 2009) tested cadaveric specimens and they found that the ultimate load was 145.6 N. The differences between these results are related both to biologic variability and to experimental testing set up. From a biological point of view, Woo et al. (1999) demonstrated that the differences in specimen age, species, skeletal maturation, anatomic location, and exercise or immobilization can affect the biomechanical properties of ligaments (Woo et al., 1999). On the other side, experimental testing factors, such as specimen, orientation and geometry, status of the insertions, temperature of the specimen during testing, and strain rate can also affect the biomechanical properties of these tissues. In particular, Kim et al. demonstrated that the orientation of the specimen during tensile testing has a significant effect on stiffness and failure modes of the porcine FMPC (Kim et al., 2014).

The objective of this study is the evaluation of the tensile behavior of human MPFL distinguishing between material properties of ligament substance and structural ones of femur-MPFL-patella complex (FMPC).

To fulfill this objective we have to provide an experimental design which allows us to overcome the issues above explained. The mechanical properties of the MPFL substance will be determined through uniaxial tensile test of the isolated ligament with standardized size and with normalized velocity, to obtain a stress–strain relation. The anatomical orientation between the patella and ligament, which determines the correct load during the mechanical test on the FMPC, was guaranteed by a dedicated gripping system.

In both cases, particular attention was given to the method to evaluate the elongation, coupling data from the tensile testing device with optical measurements in case of MPFL characterization, and with measurements based on an infrared motion system in case of FMPC characterization.

2. Materials and methods

2.1. *Preparation of specimens*

A total of 24 human fresh frozen cadaveric knees from 6 women and 8 men with a mean age of 75±9 years were used in this experiment. None of these showed patellar instability, knee injuries, surgical procedures or arthritic deformations. The Nicola's Foundation Onlus Ethics Committee has given its approval for this study.

The cadavers were dissected after they have been stored for 24 h at 4 °C and then were preserved in a sterile gauze, sealed in a polyethylene bag, labeled and stored at −18 °C. They were thawed at a temperature of 4 °C when required.

Warren and Marshall's three-layer classification of the medial side of the knee was used to dissect the specimens (Warren and Marshall, 1979).

All dissections started with a midline incision of the skin detaching it from the subcutaneous fascia. The joint capsule was accessed extending through a lateral incision at the vastus lateralis muscle extending laterally at the parapatellar side and at the lateral compartment of the tibia which was cut proximally to distally. The femur was tipped up detaching the muscle bundles. The isolated single muscles of the quadriceps were left inserted in their distal insertions and used as landmarks. The patella was rotated and the posteromedial capsule was opened from the inside, detaching and isolating the synovial capsule in the 3rd layer from the 2nd one. The fibers of the MPFL were identified by palpation and direct vision.

After, we proceeded from the external side of the dissection at Layer 1, paying particular attention to not damage the ligament, with blunt and anatomical forceps, because of the extreme adhesion between these two layers.

Then, the next step was the identification of the Medial Epicondyle (E), the Adductors Tubercle (AT), the insertion of Medial Collateral Ligament (MCL), the Magnus Adductor Muscle (MAM) and the femoral insertion of MPFL (Placella et al., 2014).

Finally, The MPFL was isolated such that it was the only connection between the patella and the femur (Fig. 1). The MPFL was found in all the examined knees.

After dissection, the length, the thickness, the width and the cross-sectional areas of the MPFL at patellar insertion, mid-substance, and femoral insertion were measured using a digital caliper (accuracy of 0.02 mm and resolution of 0.01 mm) and a digital micrometer (accuracy of 0.01 mm