Title: A biomechanical study of the meniscofemoral ligaments and their contribution to contact pressure reduction in the knee

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Authors: Hippolite O Amadi PhD[1], Chinmay M Gupte FRCS(Orth)[2], Denny T T Lie FRCS(Edin)[3], Ian D McDermott FRCS(Orth)[4], Andrew A Amis DSc[5], Anthony M J Bull PhD[6]

[1] Department of Bioengineering, Imperial College, London SW7 2AZ.
[2.] Specialist registrar, St. Mary's Hospital, Praed Street, Paddington.
[3] Consultant Orthopaedic Surgeon, Sports service, Singapore General Hospital, Outram Road, Singapore 169608
[4] Consultant Orthopaedic Surgeon and Honorary Professor Associate Brunel University School of Sport and Education, The Northwood Orthopaedic Clinic, c/o Bishops Wood Hospital, Rickmansworth Road, Northwood, Middlesex. HA6 2JW
[5] Professor of Orthopaedic Biomechanics, Departments of Mechanical Engineering and Musculoskeletal Surgery, Imperial College London SW7 2AZ.
[6] Reader in Musculoskeletal Mechanics, Department of Bioengineering, Imperial College London SW7 2AZ.

Corresponding Author:
Anthony MJ Bull PhD CEng FIMechE,
Department of Bioengineering,
Imperial College London
Room B436 Bessemer Building
South Kensington Campus
London SW7 2AZ.
Tel: +44 20 7594 5186
Fax: +44 20 7584 6897
E-mail: a.bull@imperial.ac.uk

Abstract

The aim of this study was to test the hypothesis that the meniscofemoral ligaments (MFLs) of the human knee assist the lateral meniscal function in reducing tibiofemoral contact pressure.

Five human cadaveric knee joints were loaded in compression in extension using a 4-degree of freedom rig in a universal materials testing machine. Contact pressures pre- and post-sectioning of the MFLs were measured using pressure sensitive film.

Sectioning the MFLs increased the contact pressure in the joints for two of the four measures.

In addition to their known function in assisting the posterior cruciate ligament (PCL) to resist tibiofemoral posterior drawer, the MFLs also have a significant role in reducing contact stresses in the lateral compartment. Their retention in PCL and meniscal surgery is therefore to be advised.

Keywords: ligament of Wrisberg, ligament of Humphrey, lateral meniscus, knee joint, osteoarthritis

Introduction

The meniscofemoral ligaments (MFLs) connect the posterior horn of the lateral meniscus to the lateral intercondylar aspect of the medial femoral condyle. One passes anterior (aMFL) to the posterior cruciate ligament (PCL), and the other passes posterior (pMFL) to the PCL. Their anatomical prevalence is 74% and 69%, respectively, with both being present in 50% of knees [7]. These structures have material properties similar to the PCL, and mechanical strength similar to the postero-medial bundle of the PCL [6]. Their prevalence and strength have led to many hypotheses regarding their function in the intact and PCL deficient knee [5, 10]. The first study to assess the mechanical effects of the MFLs showed that the hypothesis of Radoïévitch [13], that they act as a 'third cruciate', is, at least in part, true, and that they do act as secondary restraints to posterior drawer, particularly in the PCL-deficient knee [8]. The second main hypothesis about the function of these ligaments is related to their attachment to the lateral meniscus, suggesting that they may assist in the primary role of the meniscus, which is as a distributor of the tibiofemoral contact force [15]. This has not been tested in human knees.

The aim of this study was to test the hypothesis that loss of function of the MFLs would cause an increase in contact pressure in the lateral compartment of the tibiofemoral joint.

Materials and Methods

Cadaveric knee joints had their tibiofemoral contact pressures measured by placing pressure-sensitive films between the bone ends and applying axial compression loads. This was repeated after cutting the MFLs.

Apparatus

Fuji Prescale Film (Fuji Photo Company, 26-30 Nishiazabu 2-Chome, Minato-Ku Tokyo 106-8620, Japan) has been used widely to quantify contact pressure in joints [4]. Its primary purpose is to measure pressure, pressure distribution and contact area between two surfaces in contact. A template was designed in the shape of the tibial lateral plateau [11] so that Prescale films could be cut and prepared for specimen testing.

A 4-degree of freedom loading rig was designed to apply physiological contact forces across the tibiofemoral joint [11]. The crosshead of an Instron 1122 Materials testing machine (Instron; High Wycombe, Bucks, UK) used for loading the joints provided axial compression of the knee, which was the test control motion. Hence, of the six degrees of freedom of motion of the knee, flexion-extension was fixed, proximal-distal was controlled to provide axial compression and freedom was allowed to the remaining four secondary motions (Figure 1).

Specimens

Five cadaveric human specimens (age range 66 – 80 years) were obtained with informed consent under a research ethics committee approval within 48 hours post mortem and frozen at –20°C in sealed polyethylene bags. Specimens were thawed overnight before dissection. A lateral parapatellar incision was made for the identification and isolation of the anterior cruciate ligament (ACL) and aMFL while a posterior approach involving a midline capsulotomy was used to identify and isolate the PCL and the pMFL [7]. Access for the submeniscal insertion of the Fuji film into the lateral compartment was made possible by a 20 mm incision along the anterior edge of the lateral meniscus to divide it from the anterior edge of the lateral tibial plateau.

The knees were denuded of muscle to expose the proximal femoral bone and the distal tibia and fibula respectively. The bones were cast into steel pots using PMMA bone cement for mounting the specimen in the test rig (Figure 1).

Protocol

In order to calibrate the Fuji film, the Instron machine was used to apply axial compressive loads of 50 N to 1800 N in 50 N increments on paddles of Low and Super Low Prescale ranges, covering a pressure range of 0.28 MPa to 10 MPa. Each of the A and C layers of the paddles were separated after the load applications and two out of the four impressions per paddle were selected and arranged on a sheet of paper ready for scanning. The scanning was done with EPSON Scanner at 72dpi. Each set of the scanned images, Low and Super Low, were analysed using Scion Image computer software package to obtain the mean pixel densities corresponding to each of the applied pressure loads. The best graph of mean pixel density against applied load was plotted with the software package to produce the standard working relation as a third order polynomial, with a coefficient of correlation of 0.9977.

The Fuji film was made into test paddles that were assemblies of one set of each of the Low and Super-Low Prescale films, which were separated immediately after each test for scanning and digitization. By sandwiching together two grades of film, the pressure range was extended; this is an accepted method [1]. The test paddle was inserted submeniscally into the tibiofemoral lateral compartment and a 700N vertical force was applied axially through the centre of the joint at full extension for 10 seconds and the paddle removed for image analysis and quantification of contact pressure (4 DOF test). A 5 Nm internal moment was applied to the tibia and then the rotation was locked in order to load the MFLs maximally (3 DOF test). After cutting the MFLs, the full testing sequence was repeated. Full extension was chosen because joint loading is highest at heel strike in the gait cycle, which occurs near knee joint extension [12]. Between each test the pressure paddles were inspected visually. A deep stain with a clear margin was taken as evidence of shear and these paddles were rejected and the test repeated.

Analysis

The stain densities on the calibration films corresponding to the known applied pressures were digitised and a correlation analysis was made to obtain a mathematical relation between the two. A correlation coefficient of 0.9977 was obtained for these calibrated stain intensities.

Mean and peak pressures were determined for intact and MFL divided specimens. The hypothesis that sectioning of the MFLs increased contact pressures in the lateral compartment of the joint was tested using one-tail paired t-tests.

Results

All knees had at least one MFL. All five knees had an aMFL, four knees also had a pMFL.

Contact pressure data are summarised in Table 1. The peak pressure with unrestricted four DOF increased by 10% after sectioning of the MFLs from a mean of 4.34 MPa in the intact knee to 4.78 MPa in the MFL-deficient knee ($p = 0.048$). With the tibia held in internal rotation (three DOF) mean pressure increased by 4% ($p = 0.015$). Mean pressure and peak pressure were not significantly different pre- and post-MFL sectioning between the four DOF test and the three DOF test ($p > 0.061$). There were no other statistically significant changes.

Discussion

Osteoarthrosis is at least partly mechanical in origin [14] with joint kinematics, contact pressures, and the lubrication characteristics of joints all contributing to the disease. The function of the menisci as load spreaders decreasing tibiofemoral contact pressures is well known [9, 15, 16]. This study has shown that the meniscofemoral ligaments play a role in reducing lateral tibiofemoral contact pressure in the human knee. This conclusion concurs with that of a similar study using pig knees [2]. This suggests that the MFLs play a significant role in the mechanics of the knee joint, combined with their known function as secondary restraints to posterior drawer [5]. Injury to these structures with the concomitant increase in contact pressure may be a contributory factor in the aetiology of osteoarthritis. Earlier work has shown that both MFLs are present in younger knees [3], whereas older knees are more likely to have one or no MFLs [7]. This suggests that there may be an age related relationship between the prevalence of osteoarthritis and the incidence of these structures.

This study has found that loss of the MFL function led to approximately 10% increase in peak contact pressure on the articular cartilage. Although that might seem small, it must be kept in mind that cartilage fails by a fatigue mechanism under cyclic loading [18]. Fatigue is a process requiring many load cycles, and there is a logarithmic relationship between stress and number of load cycles to cause failure. Thus, a small increase in stress can have a large effect on the fatigue life.

Although this study has shown an effect of the MFLs in reducing lateral compartment contact pressure, it has not assessed the methods by which that this occurs. The geometry of the insertions of the MFLs, combined with their material properties, may explain the means of load transmission. When the knee is loaded in compression, the menisci transmit the load from the femur to the tibia by means of compressive stresses. Because the menisci have wedge-shaped cross-sections, the compressive load also tends to squeeze them out of the joint space, away from the centre of the contact area. This radial expansion causes a proportional increase in the circumference, and this induces ‘hoop stresses’ around the circumference of the meniscus. Generation of the hoop stresses is dependent on the geometry of the menisci, their material properties, and their insertional properties. The tangential attachments of the MFLs on the posterior horn of the lateral meniscus may increase the level of hoop stresses that can be transmitted by the menisci, thus decreasing the contact pressures. It is also known [17] that the lateral meniscus moves posteriorly during knee flexion, so the MFLs may also help the posterior horn to act as a ‘sling’ supporting the femoral condyle as it approached the posterior edge of the tibial plateau.

There were no differences in contact pressure with and without locking of tibial rotation. This might be because the possible decrease in contact pressure due to loading of the MFLs (effectively tightening the meniscus, increasing the hoop stresses, thereby decreasing tibiofemoral pressure) was offset by the possible increase in contact pressure due to tightening of peripheral structures such as the collateral ligaments.

In conclusion, this study has found that loss of the MFLs led to a significant increase in tibiofemoral contact stresses when the knee was loaded in axial compression. This is further evidence that the MFLs are not merely vestigial structures.

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Table 1 Contact pressure in the lateral compartment, mean (+/- SD)

	Intact 4 dof	MFL absent 4 dof	Intact 3 dof	MFL absent 3 dof
Mean Pressure (MPa)	3.57 (0.25)	3.93 (0.43)	3.67 (0.60)	3.82 (0.61)
	$p = 0.065$		$p = 0.015$	
Increase in mean pressure	0.35 (0.41)		0.15 (0.10)	
Peak Pressure (MPa)	4.34 (0.36)	4.78 (0.57)	4.50 (1.29)	4.91 (1.43)
	$p = 0.048$		$p = 0.062$	
Increase in peak pressure	0.43 (0.44)		0.41 (0.47)	

Figure Legends

Figure 1 The 4 degree of freedom loading fixture with the knee joint fixed at full extension.

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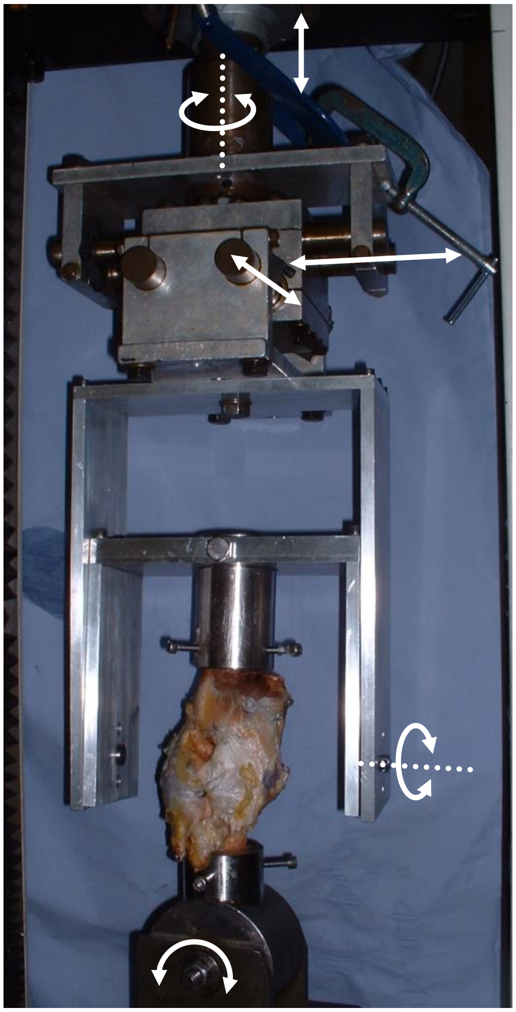

Crosshead Rig (compression)

Femoral rotation unconstrained (1DOF)

Anterior-posterior and mediolateral translations unconstrained (2 DOF)

Knee mounted with tibia mounted to baseplate

Varus-valgus rotation unconstrained (1 DOF)

Base Rig (fixed flexion angle)