THE EFFECTS OF TOTAL MENISCECTOMY ON KNEE JOINT CONTACT STRESSES: A FINITE ELEMENT STUDY

Diagarajen Carpanen, Robert Walker, Howard Hillstrom, Carl Imhauser and Rajshree Mootanah
1Anglia Ruskin University, Chelmsford, Essex, UK
2Hospital for Special Surgery, New York, USA; email: diagarajen.carpanen@anglia.ac.uk

SUMMARY
The overarching aim of this study is to carry out a computational investigation to understand how partial meniscectomies influence knee joint contact stresses.

As a first step to answer this research question, we carried out a comparison study, by finite element methods, on the contact stresses in the tibiofemoral joint of an intact knee and one with a total meniscectomy. Peak compressive stress increases after total meniscectomy. Results of this study show that the meniscectomised knee is subjected to high stress levels which may cause cartilage matrix damage resulting in osteoarthritis (OA).

INTRODUCTION
The meniscus and cartilage play an important role in the absorption and distribution of load in the knee joint. The difficulty of integrating juxtaposed meniscal surfaces, following a meniscal tear, remains challenging [1]. Partial meniscectomy is a common surgical practice for treating torn menisci, whereby part of the torn meniscus is excised. This has a dramatic adverse effect on load distribution in the knee joint and the development of knee OA [2]. Hence, it is important to know the safe proportions and locations of a partial meniscectomy and the corresponding joint contact stresses. However, the link between the proportion and location of the partial meniscectomy and the contact stresses in the knee joint is not known. The overarching aim of this study is to determine how the contact stress is affected by proportion and location of the resected meniscus using the finite element (FE) method. The work reported here will focus on the stress distributions in (i) a simulated healthy intact knee and (ii) a simulated knee with total meniscectomy.

METHODS
Computer tomography (CT) scans using a GE Medical Systems CT-scanner, at 120 kV and 100.00 mAs (Citigroup Biomedical Imaging Center) and magnetic resonance images (MRI) using 3T scanning systems (GE Healthcare, Waukesha, WI) of the same cadaveric knee (Hospital for Special Surgery, New York) were acquired.

A three dimensional model (Figure 1) of a cadaveric knee, including the femur, tibia, patella, the tibial and femoral cartilages, the menisci and the ligaments, was created from these high resolution (512 x 512 pixel) radiological images, using Mimics v14 (Materialise, Belgium). MIMICS is a specialised imaging density segmentation software for processing medical images and creating 3D models which can then be directly linked to FE analysis packages. The 3D models were created using a number of operations within MIMICS. Thresholding is used to create a first definition of the segmentation object. A high threshold value made it possible to select the osseous tissue of the scanned patient. The use of the thresholding tool alone did not allow separation of femur from the tibia or vice versa. The region growing tool was used to obtain a mask for only the femur or the tibia separately. The 3D model of the soft tissue created from MRI data was then registered to the 3D models of the bones generated from the CT scan data. Both point registration and global registration techniques were used, employing the least root mean square method, where the distance between the movable and fixed parts is calculated. Ten-noded tetrahedral elements were used to mesh both the osseous tissues and soft tissues as they provide much better accuracy than four-noded tetrahedral elements.

Figure 1: 3D model of knee joint (posterior view)

The material properties of the tissues were taken from literature data [3]. The 3D models were exported to a finite element package ANSYS v12.1 (ANSYS, Pennsylvania, USA) where loading and boundary conditions, defined as
follows, were applied. Each meniscal horn was attached to the tibial plateau to simulate the horn-meniscus attachment. Frictional contact was assumed between cartilages, between menisci and cartilages, between tibia and fibula and between the ligaments (Figure 2).

Figure 2: Contact Elements 1. Tibial cartilage – meniscus; 2. Femoral cartilage – meniscus; 3. Femoral cartilage – tibial cartilage; 4. Tibia - fibula

An axial compressive load of 800 N, simulating body weight, was applied at the proximal surface of the femur while the distal surfaces of the tibia and fibula were fixed in all six degrees of freedom. In the analyses, flexion-extension was fixed for the femur to simulate full extension. Only static analyses were carried out.

RESULTS AND DISCUSSION
The peak compressive stress in the tibial cartilage of the simulated intact knee was 2.6 MPa. Following total meniscectomy the peak stress increased to 4.9 MPa.

These preliminary results are consistent with those published by Peña who mentioned that the peak compressive stress in the tibial cartilage rose from 2.55 MPa to 4.55 MPa after total meniscectomy [4].

CONCLUSIONS
Results of this study demonstrate the importance of the meniscus in reducing knee joint contact stress. This is a first step towards understanding the safe location and proportion of partial meniscectomy.

ACKNOWLEDGEMENTS
This research is gratefully funded by The Higher Education Funding Council for England.
We acknowledge Professor Kevin Cheah for his clinical input.

REFERENCES