Modelling Articular Contact of the Knee with the Finite Element Method

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INTRODUCTION
Mechanical factors are suspected to be partially responsible for malfunctions and degenerative symptoms such as osteoarthritis. The understanding of this mechanical behaviour can provide a greater insight into the function of articular structures of joints. The wide range of motion, complex geometry, loading and soft tissue material inhomogeneity render the finite element method (FEM) an appropriate computational tool for the modelling of this mechanical behaviour.

METHODS
Imaging and kinematic datasets were used to acquire the 3D geometry and to position the joint in six degrees of freedom; flexion-extension was constrained and a 0.5 kN compressive load was applied on the femur; the distal tibia was totally fixed (Fig.3). Two additional boundary conditions were employed to investigate their effect on mechanical variables.

RESULTS
• Calculated contact stress was elevated up to 100% with constrained adduction/abduction. Other contact variables such as displacements were significantly altered.
• Meniscal excision also resulted in significantly increased contact stresses.
• Meniscal insertional ligament stiffness and orientation considerably affect the mechanical behaviour.

MOTIVATION & AIMS
The important role of the menisci of the knee in reducing the stresses in the articular cartilage was not appreciated until recently (Fig.2). Previously damaged menisci were routinely excised. This is known to be implicated with osteoarthritis. Today’s treatment consists of repair (sutting techniques), meniscectomy (excision) or reconstruction (allografts, implants).

The purpose of this work is to gain greater insight into the mechanical behaviour of the healthy and symptomatic menisci within the knee joint with specific reference to the meniscal ligaments and constraints in motion.

FIGURE 1

(A) Six degrees of freedom (three translations and three rotations) can characterise the joint kinematics in space (B) Image-derived FE model of the tibio-femoral joint

FIGURE 2

Menisci are semi-lunar, fibro-cartilaginous tissues wedge-shaped in cross-section. They are composed of water and Type I collagen fibres, with a dominant circumferential orientation. Axial joint loads tend to squeeze them circumferentially. This is prevented by insertional ligaments that generate tensile circumferential (hoop) stresses.

FIGURE 3

3D Imaging Data (eg MRI)
Contour Segmentation
Surface Meshing
Solid (3D) Meshing
3D Kinematic Data
Geometry
Positioning
Boundary conditions
Load cases
Finite Element Analysis (FEA)
Contact scenarios
Material properties
Mechanical Behaviour

Figure 3: Method employed to create the 3D FE model

FIGURE 4

Mediolateral and axial translations under a 0.5 kN compressive load in the axial direction. Medial tibiofemoral contact is followed by adduction to involve lateral contact. This balances the contact stresses. In addition, the menisci are squeezed outwards as they generate hoop stresses.