CREEP AND STRESS RELAXATION OF THE KNEE JOINT IN LARGE COMPRESSION

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Introduction

Fluid pressurization in articular cartilages and menisci plays an essential role in the mechanical functions of human knee joint. Fluid flow is also important for the nutrient supply in these cartilaginous tissues. For simplicity, however, the fluid pressure and flow have not been generally considered in whole knee joint modelling. We have recently modelled the fluid-pressure-induced creep and relaxation of the knee joint with small deformation. The objective of the present study was to incorporate a large deformation theory to investigate the creep and stress relaxation of the knee joint reconstructed from MRI. We considered collagen fibre reinforcement and fluid pressurization in the cartilaginous tissues.

Methods

The geometry of the knee was reconstructed from the MRI data of a 27-year-old male using Mimics. Cartilages and menisci were modelled as fibril-reinforced solid-fluid mixture. Ligaments were modelled as fibril-reinforced solid. Nearly incompressible, Neo-Hookean hyperelasticity was considered for the non-fibrillar solid matrix of all tissues. Quasi-linear viscoelasticity was considered for the collagen network. A user defined subroutine, UMAT in ABAQUS, was developed for the case of large deformation. The UMAT was extensively verified numerically and the relevant material model was validated with creep and relaxation data from cartilage explants.

Two loading protocols were used in the finite element simulations of the knee joint: a creep force of 700N, and a relaxation of 0.6mm, both are compressive. The force or compression was applied at a constant rate in 1s in the proximal-distal direction and then held unchanged to equilibrium.

Results

Fluid pressures, velocities, contact pressures, stresses and strains were obtained as functions of time. Maximum contact pressure occurred in the medial condyle of femoral cartilage in both creep and stress relaxation (Fig. a). As creep developed, the contact pressure between femoral and tibial cartilages decreased while the contact pressure between the menisci and cartilages increased (Fig. b). In contrast, during stress relaxation, all contact pressures decreased monotonically (not shown). The maximum fluid pressure was observed in the medial compartment in both cases (not shown). As creep/relaxation developed, the fluid pressure decreased and diffused over cartilages.

Discussion

The predicted femoral axial displacement under 700N force was 0.65mm, which was in a fair agreement with measurements (0.45-0.65mm under 500N and 0.7-0.8mm under 1000N). Consistent with experiments, the medial compartment supported greater load as compared to the lateral compartment. Under 700N, the average contact area was about 1140 mm^2, which was in good agreement with experiments (960±170mm under 500N and 1150±250 under 1000N). The load support mechanism was different in creep and stress relaxation: during creep, the contact pressure in femoral cartilage decreased and the contact pressure in menisci increased. During relaxation, however, the contact pressure decreased monotonically in both cartilages and menisci. Our previous poromechanical model of the knee was limited to small deformation. Large knee compression was successfully tested in the present study, which is a step forward towards the modelling of knee joint contact mechanics in physiological conditions.

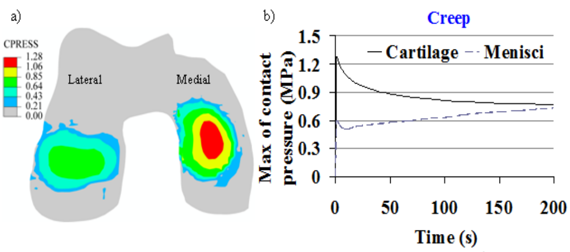

Figure 1: a) *Contact pressure shown on the femoral cartilage;* Fig. b) *Maximum contact pressure found in cartilages and menisci.*