INTRODUCTION

Different numerical models have been proposed to investigate the effect of meniscectomy on the knee joint biomechanics [1-4]. The general output of these studies indicates the decrease in joint contact area after meniscectomy. This change in mechanical contact causes high stresses in articular cartilage leading to osteoarthritis or other cartilage pathologies. Existing results were obtained from elastic models that assume no fluid flow in any tissues. Our recent studies showed altered joint contact by the fluid pressurization in cartilages. Thus it may be interesting to reexamine this issue for possible new information when the fluid pressure is modeled. The objective of this study was to determine the changes in fluid pressurization in articular cartilage after meniscectomy. A fibre-reinforced 3D finite element model of the knee joint was used for this purpose. As one of our initial attempts, nonlinear anisotropic tissue properties and fluid-flow dependent load response were considered for menisci and cartilages.

METHODS

The solid model of the right knee was previously constructed from MRI of a healthy male [5]. A 3D finite element model was developed including femur, tibia, fibula, cartilages, menisci and the four major ligaments. Because of their high stiffness, bones were considered as rigid. A fibre-reinforced model was applied to cartilages and menisci, which were assumed as fully saturated porous media. For the articular cartilage, collagen fibre orientation was assumed based on split-line pattern. For the menisci, collagen fibres were oriented in radial and circumferential directions. 3D elements were also used to model ligaments with fibres aligned in longitudinal direction. For collagen fibres, the Young’s modulus was taken to vary linearly with tensile strain but to be zero for compression. The 3D anisotropic and nonlinear properties of the collagen networks were introduced in the commercial program ABAQUS using a user-defined material subroutine [6]. Six contacts were modeled with 3 on the medial side and 3 on the lateral side: femoral cartilage and menisci, femoral and tibial cartilages, and menisci and tibial cartilages. The surface to surface contact modeling was used for this multiple contact problem.

Tissue material properties were taken from literature. A single leg stance ramp loading of 300 N was considered, which was applied in 1s and remained constant thereafter. The load was applied to the femur in proximal-distal direction. Femur was free to translate in anterior-posterior and medial-lateral directions but fully constrained in rotations. Tibia was constrained in all directions and fibula was assumed to be fixed to it. For the purpose of comparison, two cases were considered: in the first case, the intact joint was analyzed while in the second case both lateral and medial menisci were removed.

RESULTS

Pore fluid pressure and maximum principal stress at element centroids for intact and meniscectomy knees were obtained (Figs. 1 to 3, 100 seconds after loading). In both intact and meniscectomy joints, the maximum pressure occurred in the medial condyle (Figs. 1 and 2). The maximum pressure was increased by 13% after menisci were removed. Furthermore, the pressure was increased by 126% in the central region of the meniscal condyle, because of the shift of maximum pore pressure from the medial groove to the central region of the medial condyle (Figs. 2 vs Fig. 1). The increase in fluid pressure for the central region of the lateral condyle was about 72%, while the high pressure in the lateral condyle moved towards the central region from the lateral side (Fig. 2 vs Fig. 1). This indicated a great pressure increase in the central regions of tibial cartilage after meniscectomy, because the contact pressure on the opposite surface should be identical.

Considering the maximum principal stress in the solid matrix of the cartilage, an increase of 23% was seen for the peak value (Fig. 3, only meniscectomy result is shown). Consistent with the fluid pressure changes, the maximum stress zone moved towards the center of medial condyle after menisci were removed. A maximum increase of 175% was seen for the stress in the central region of the medial condyle.

DISCUSSION

In agreement with published studies, the present study shows significant changes in contact areas and stresses after meniscus removal. In addition, we found remarkable changes in the fluid pressure, consistent with the function of fluid pressure in cartilage load bearing mechanism. In particular, the central regions of the condyles, which are uncovered by the meniscus, encountered great pressure increase after the menisci were removed. The increase in the fluid pressure produced extra tension in the collagen network, which might trigger cartilage degeneration or tissue damage. Therefore, cartilage degeneration or lesion could be initiated from the central regions of the condyles after meniscectomy, although this assumption needs to be tested in future studies.

REFERENCES

Canadian Institutes of Health Research; NSERC.