EFFECT OF PARTIAL LATERAL MENISCECTOMY ON THE FLUID PRESSURIZATION OF ARTICULAR CARTILAGE - A 3D FINITE ELEMENT STUDY OF THE KNEE JOINT

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SUMMARY
The objective of this study was to investigate the effect of partial longitudinal lateral meniscectomy on the mechanics of the knee joint. A 3D fibril-reinforced finite element (FE) model of the knee joint was used for this purpose. The model includes bones, cartilages, menisci as well as four major ligaments. The cartilages and menisci were modeled as fully saturated porous media reinforced by collagen fibres. Three different cases of partial removal of the lateral meniscus were considered. In each case, the changes in fluid pressurization of articular cartilage were compared with the results from the intact joint. It was found that fluid pressure increases significantly after partial lateral meniscectomy. Moreover, the rate of decay in fluid pressure was remarkably lower than the intact joint. Furthermore, the fluid pressure level of the femoral cartilage was proportional to the amount of meniscus that was removed.

INTRODUCTION
Due to its role in load bearing, injuries are very common in menisci. Repair, allograft replacement and meniscectomy are possible treatments for the injuries [1,2]. If the tear is far from the vascular zone of the meniscus, chance of healing is very low and so partial meniscectomy is a preferable technique. However, both clinical and numerical studies indicate changes in the knee joint mechanics after partial meniscectomy [3,4]. In general, meniscectomy results in decrease in contact area, increase in stresses and change in joint alignment and kinematics [5].

In recent years, many computational studies have investigated the effects of partial meniscectomy on the knee joint. Significant changes in joint contact mechanics, such as stress distributions, were predicted for a partial meniscectomy joint [6]. The maximal stress in articular cartilage in meniscectomy joint was reported about double of that in an intact joint [4]. In terms of post-effects of meniscectomy, cartilage degeneration was reported to be possibly initiated from either surface or subchondral zones [7].

In published 3D computational studies, hydrated tissues of the knee joint (cartilages and menisci) are assumed as single phase materials [4,6]. Using this assumption, convergence difficulties associated with fluid pressure modeling have been avoided and yet comprehensive results have been obtained. The fluid pressure has been only modeled in simplified 2D and axisymmetric studies [7]. As a step towards developing recent FE studies, a real 3D FE model of the knee joint considering fluid pressurization for cartilages and menisci is used in the present work.

METHODS
The knee geometry was constructed using magnetic resonance imaging of a healthy male’s right leg. The finite element model (Fig. 1) contains femur, tibia, fibula, femoral and tibial cartilages, medial and lateral menisci as well as four major ligaments: anterior cruciate, posterior cruciate, lateral collateral and medial collateral. To simulate fluid pressure in cartilages and menisci, these tissues were assumed as fully saturated porous media. To consider the role of collagen fibres, a fibril-reinforced model was used for the solid matrix of cartilages and menisci. In case of articular cartilage, collagen fibres orientation was assumed based on split-line pattern. For the menisci, the main direction of collagen fibres was oriented in circumferential direction.

Ligaments were modeled as linearly elastic matrix with fibres aligned in longitudinal direction. Material properties of different tissues were obtained from the literature. In case of collagen fibres, the Young’s modulus was taken to vary linearly with tensile strain but to be zero for compression [8]. The 3D anisotropic and nonlinear properties of the collagen networks were introduced into the commercial program ABAQUS using a user-defined material subroutine.

A compressive force of 300N (approximately half of body weight) and an internal torque of 500 N.mm were applied to the femur. Both loads were applied in one second and remained constant thereafter. Femur was constrained in varus-valgus and flexion-extension rotations but free in all other degree of freedoms. 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. To simulate the partial lateral meniscectomy, three different cases were considered: anterior longitudinal (AL), central longitudinal (CL) and extended longitudinal (EL) (Fig. 2).

RESULTS AND DISCUSSION
In case of the intact joint, the peak fluid pressure of femoral cartilage at 10s occurred at the lateral condyle (Fig. 3a). As creep developed, the peak pressure decreased monotonically and the high-pressure region stabilized at the anterior part of lateral condyle (not shown). The decrease in peak pressure...
was about 27%, 45%, 67%, 76% and 77% of the maxima at \( t = 100s, 1000s, 4000s, 8000s \) and 10000s, respectively (Fig. 4).

In all meniscectomy cases, the high-pressure region was observed in central area of the lateral condyle which is in direct contact with tibial cartilage (Fig. 3). In case of AL meniscectomy, the high-pressure region extended towards anterior-lateral direction as creep developed (up to 10000s, not shown). For CL and EL meniscectomy, the high-pressure region extended towards anterior-posterior direction.

Compare to the intact joint, the pressure level in femoral cartilage increased after meniscectomy (Fig. 4). For instance, at \( t = 10s \), the increase in peak pressure was about 20%, 24% and 26% for AL, CL and EL cases, respectively. The rate of decay in pressure was lower in meniscectomy cases compared to the intact joint (Fig. 4). In case of EL, the pressure level was considerably high even after 10000s. This high pressure level is consistent with the increase in removed area of the meniscus.

**CONCLUSIONS**

Effects of partial lateral meniscectomy on fluid pressurization of femoral cartilage was investigated using a 3D fibril-reinforced FE model of the knee joint. Three cases of partial longitudinal meniscectomy were considered. It was found that partial lateral meniscectomy alters the contact mechanics of the joint. As a result, the fluid pressure in femoral cartilage increased significantly after partial meniscectomy. The highest increase in fluid pressure was observed in EL case, which is consistent with the increase in removed area of the meniscus. Moreover, the rate of decay in fluid pressure was remarkably lower than the intact joint. In case of extended meniscectomy, high-pressure levels were observed even after several thousand seconds of creep.

**REFERENCES**