How An Anatomically-shaped Isotropic Meniscus Implant Influences Knee Joint Mechanics Compared To Native And Meniscectomy Conditions

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Disclosures: 

Introduction: Replacing damaged menisci with synthetic meniscal implants has been introduced as a promising treatment relative to traditional meniscectomy approaches. Currently, however, outcomes of such implantations vary in their success. Therefore, developed implants still require improvement. For optimal functionality in the joint, a synthetic implant should mimic the native meniscus as close as possible. The native meniscus has a wedge-shaped geometry (Fig.1a) adapted to conform to the irregular shape of the femur and tibia. The importance of the geometrical characteristics of the menisci has been indicated in the literature [1]. However, little attention has been considered, so far, to develop meniscal implants with anatomical shapes. Being part of the Dutch national consortium (TRAMMPOLIN), we have recently addressed the development of an anatomically shaped, isotropic non-resorbable total meniscus implant [2]. Experimentally it is challenging to systematically study how such implant influences joint mechanics post-implantation when compared to the native or meniscectomy conditions. Computer simulation techniques are valuable tools in estimating the mechanical conditions in the joint post-implantation. The aim of the present study is, therefore, to use 3D finite element simulations of knee joint to investigate the alterations in the joint mechanics where the native anisotropic medial meniscus is either removed (i.e. meniscectomy) or replaced by an anatomically-shaped isotropic implant.

Methods: Adopting MRI-extracted 3D geometry of a left knee substructures from the Open Knee [3], a 3D finite element model of the knee (Fig. 1b) was developed in Abaqus v6.11 (Pawtucket, RI, USA). The soft tissues were discretized into hexahedral elements with a full geometrically nonlinear formulation. Femur and tibia were modeled as rigid bodies. Native meniscus and ligaments were modeled as transversely isotropic nearly-incompressible neo-Hookean materials [3]. Cartilage was modeled as a linear elastic material with Young’s modulus of 15 MPa and Poisson’s ratio of 0.475 [1]. The meniscus implant was modeled as an isotropic neo-Hookean material (C1=1.84 MPa and D1=0.01 MPa). A femoral load of 1560 N (two times body weight) was applied to simulate gait load of a single leg in full extension. The tibia was fixed and the femur was unconstrained in all translational and rotational degrees of freedom except in the flexion.

Results: Native meniscus distributed contact pressure of 5.7 MPa and shear stress of 0.14 MPa on tibial and femoral cartilage (Fig 2.left). Removal of the meniscus resulted in high concentration of contact pressure (up to 8.5 MPa) and shear stress (up to 0.21 MPa) at the central region of the tibial and femoral cartilage (Fig 2.Middle). Including the meniscus implant, compared to the meniscectomy, decreased the peak contact pressure by 32% and also reduced the area in which peak shear stresses were induced (Fig 2.right). Compared to the native case, with the implant, the central region of the cartilage experienced 19% higher contact pressure and a slight concentration of shear stresses was observed. Yet, the implant did not change the peak contact pressure and shear stress.

Discussion: Herein predictions of the mechanical stresses in a knee joint with native meniscus are consistent with experimental findings [4]. This study confirms that, in comparison with meniscectomy, an anatomically-shaped isotropic medial meniscus implant does reduce elevated mechanical stresses on knee joint cartilage. Importantly, it is also indicated that compared to native conditions, with such implant, peak mechanical stresses induced on cartilage remain in the physiological levels. Although the implant may regionally increase contact mechanical variables up to 19%. It should be further explored to which extent such variations in the joint contact mechanics may induce cartilage damage post-implantation. Such evaluations may reveal whether or not the development of anisotropic implants with circumferential reinforcement is essential. The present study shows the potential of the computer simulations in predicting the mechanical conditions of the knee joints post-implantation. This may help to optimize the design of the meniscal implants prior to the implantations and thereby improve the long-term functionality of such implants in clinical practice.

Significance: This study shows the mechanical functionality of an anatomically-shaped isotropic medial meniscus implant in keeping peak mechanical stresses induced on knee cartilage in a physiological range. It is also shown that with such implant, peak mechanical stresses may significantly reduce compared to the meniscectomy conditions.

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Figure 1. A wedge-shaped medial meniscus on top of medial tibial cartilage (a) and 3D finite element model (b) of a knee joint including femur, tibia, anterior and posterior cruciate ligaments (ACL and PCL, respectively), medial and lateral collateral ligaments (MCL and LCL, respectively), articular cartilage, and meniscus.
Figure 2. Comparison between contact pressure (a) and surface shear stress (b) of the femoral (top) and tibial (bottom) cartilage in a joint with a native medial meniscus (left), meniscectomy (middle) or with the isotropic meniscus implant.

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