EFFECT OF GEOMETRY FEATURES ON KNEE JOINT MECHANICS: SUBJECT-SPECIFIC VS GENERIC MODELS BASED ON 39 PATIENTS

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Introduction

Finite element modelling is a useful alternative method for investigating stress distributions in knee joints since analytical solutions are not possible. Subject-specific knee joint modelling is well-established over decades. However, the geometry of knee tissues varies greatly among individuals, and these morphological differences may have substantial consequences for injury and disease risk [1]. To better improve patient outcomes, we must question whether a single-subject knee model is sufficient, e.g., for driving implant design decisions. Statistical shape modelling (SSM) is a well-established computational approach that uses compact descriptive values to capture the morphological diversity dispersed across a group of matching surfaces. SSM has not been applied to investigate the poromechanical behaviour [2] of the knees of a cohort. Our ongoing research uses a unified material and geometric modelling approach to isolate the effects of patient demographics, including sex and ethnic differences in tissue properties and knee anatomy, in a large population through modelling to discover generic and subject-specific biomechanical behaviours. The objective of the present study is to test the capacity of a SSM workflow to produce generic knee models for finite element contact analysis.

Methods

Two generic knee models have been created so far using a previously developed SSM workflow [3]: averave-39 was generated from the right knees of 39 healthy subjects (45-69 years, white male), and average-8 from 8 knees randomly selected from the 39 subjects. Modal variations from average-39 will be examined. As an essential step for all subject-specific models, tissue geometries of each knee were reconstructed and meshed from MRIs obtained from the OAI [4], using an automated hexahedral meshing approach [5]. The SSM approach used the Coherent Point Drift algorithm to establish node correspondence between individuals' point clouds for the bones, cartilages, and menisci. Following alignment of the point clouds, principal component analysis was applied to the registered knee joint data to extract the principal modes of geometric variation. Cartilages and menisci were modelled as fibril-reinforced fluid-saturated materials using a previously developed nonlinear constitutive model that is implemented in ABAQUS using the user-defined material option (UMAT) [2]. To model creep response associated with fluid pressure in cartilaginous tissues, we simulated a full extension joint load for each generic cohort and selected subject specific models. Joint loading consisted of a 600-N force ramped in 1s and remained constant for 6000s.

Results

Example results are shown in Figure 1. Statistical analysis on variations in joint contact mechanics will be performed once we have obtained all results in the coming months.

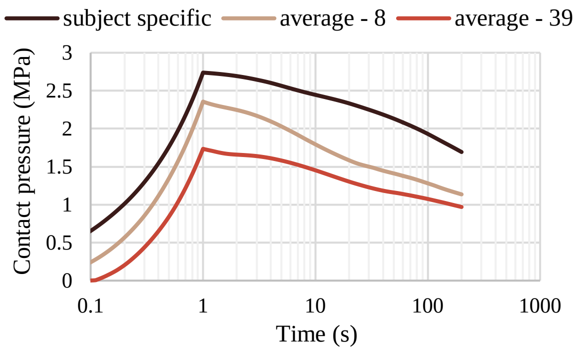

Figure 1: Maximum contact pressure in the medial tibial cartilages with creep loading obtained from one subject-specific and two generic knee models.

Discussion

The generic model built from randomly chosen 8 knees yielded quite different results from the model based on 39 knees, indicating a big number of joints is required for SSM modelling. Results have shown significant variance between subject and cohort averaged models. It is critical to capture inter-subject variability in subject-specific models as the results may be different from cohort averaged. Ongoing work includes reconstruction of multiple shape models and a complete comparison between the reconstructed shape models and subject-specific models.

References

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