SENSITIVITY OF KNEE JOINT FINITE ELEMENT SIMULATIONS TO UNCERTAINTIES IN MUSCULOSKELETAL MODELING INPUTS

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Introduction

Various simulation pipelines combining musculoskeletal and finite element (MS-FE) analyses have been developed to investigate mechanical responses of knee joint cartilage under different physical activities. However, it is not fully understood how the uncertainty in the MS modeling and simulation assumptions (optimization function for muscle activation patterns, marker position, cartilage stiffness, maximum isometric force of muscles) affect the predicted tissue-level mechanical responses of the FE models. Thus, we investigated sensitivity of the mechanical responses of the knee joint FE model to the MS modelling and simulation assumptions during gait.

Methods

One female participant was selected from a previously collected dataset (CAROT study) [1]. A previously developed atlas-based MS-FE modeling framework was utilized to generate the MS and FE knee joint models of the subject [2]. First, a MS knee model [3] with cartilage elastic modulus of 20 MPa, weighted optimization and knee markers in the location as per during the data collection was constructed. Then, some of the critical assumptions made during the MS modelling and simulation were varied resulting in five sets of MS simulation results [4] (Figure 1A). Five walking trials of the study subject were averaged to provide motion input for each FE model.

The FE model with knee ligaments modeled as spring bundles, fibril-reinforced poroviscoelastic cartilage and fibril-reinforced poroelastic menisci was simulated using the outputs (knee flexion angle, tibiofemoral joint contact forces, and joint moments) obtained from each of the aforementioned MS simulation (Figure 1A). Cartilage stresses and strains, estimated by the FE model, were compared between the models.

Results

The different assumptions in MS modeling and simulation moderately influenced the simulated stresses and strains of cartilage in the FE model (Figure 1B). In femoral cartilage, altered muscle activation optimization function and misplaced knee markers (anteriorly or posteriorly), with respect to the reference, resulted in highest maximum principal stresses and fibril strains in the FE model along the entire stance. Moreover, in tibial cartilage these higher stresses and strains were observed after midstance. However, reduced stiffness of soft tissues and altered maximum isometric force of muscles had negligible impact on the simulated cartilage stresses and strains.

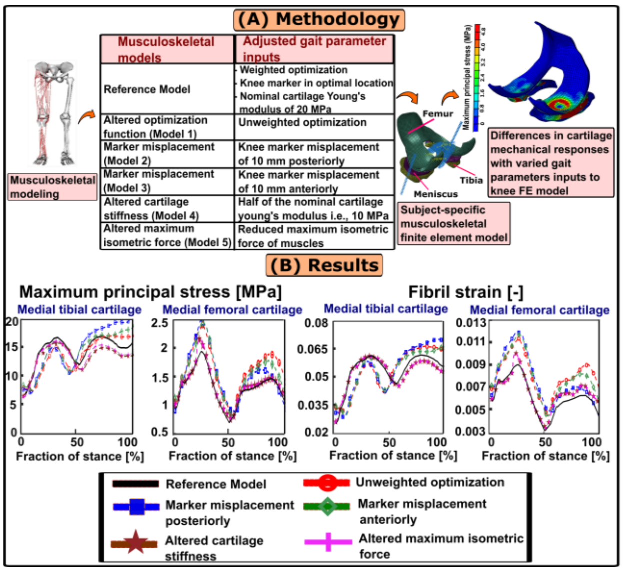

Figure 1: ***(A)*** *Workflow of the study.* ***(B)*** *Simulated maximum principal stress and fibril strain in medial tibial and femoral cartilage for the FE model simulated with different MS model inputs.*

Discussion

Marker placement and simulated neural solutions are important factors that affect the motion and muscle input parameters used in the FE model. However, the induced uncertainties in gait inputs to our FE model resulted in modest differences in tissue-level mechanical outcomes. These variations may become more significant when goal is to compare absolute mechanical responses.

References

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