Estimating Knee Joint Cartilage Mechanics Using Finite Element Models Assisted by Neural Network Based Kinetic Data

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Summary

We developed our previous method to investigate knee cartilage stresses and strains using a finite element (FE) model assisted by artificial intelligence (AI)-based kinetic data. The data was obtained from artificial neural networks (ANNs) with specific information of the study participants. For comparison, a FE model driven by 3D motion capture (Mocap) and musculoskeletal modeling (MSM) was generated. Results showed maximum principal stresses in the medial tibial cartilage were similar between the modeling approaches.

Introduction

Low-fidelity, AI-assisted approaches are increasingly used to estimate human musculoskeletal kinematics and kinetics traditionally measured by high-fidelity, Mocap-assisted approaches [1]. Less attention has been given to tissue mechanics (i.e., stress and strain) estimated with low-fidelity methods, which are crucial developments for out-of-lab estimation of tissue degeneration or failure. Herein, we estimated knee joint cartilage mechanics during gait using FE models driven by 3D Mocap- and AI-assisted data.

Methods

Healthy participants (4 females, 5 males; age 30±7 years; body mass index 27±7 kg/m²) were studied. Marker trajectories and ground reaction forces were recorded during walking gait in a Mocap laboratory, and magnetic resonance imaging was used to generate knee geometries. For the high-fidelity approach, Mocap data were used in OpenSim and CEINMS to estimate knee joint contact forces, moments, and flexion angle (Fig. 1A) and used as inputs in the complete knee joint FE models that included cartilage, menisci, and ligaments (Fig. 1B) [4]. For the low-fidelity approach, ANNs were used to estimate knee joint contact forces from the subjects' information (Fig. 1A) [2,3] and, with a generic flexion angle, used as inputs in the simplified and fast FE models that consisted of cartilages, with the effects of menisci and ligaments considered in the boundary conditions (Fig. 1B). FE meshes for the models were generated using auto-segmentation [4]. Maximum principal stresses during the stance phase were analyzed (see Fig. 1C for one person).

Results and Discussion

In the medial tibial cartilage, average stress values were not significantly different between the modeling approaches (P>0.05, Fig. 1D). The only significant differences in the peak stresses were observed in the lateral tibial cartilage at ~80% of stance (P<0.05). Further model refinements are needed to improve the predictive accuracy in the lateral tibial cartilage.

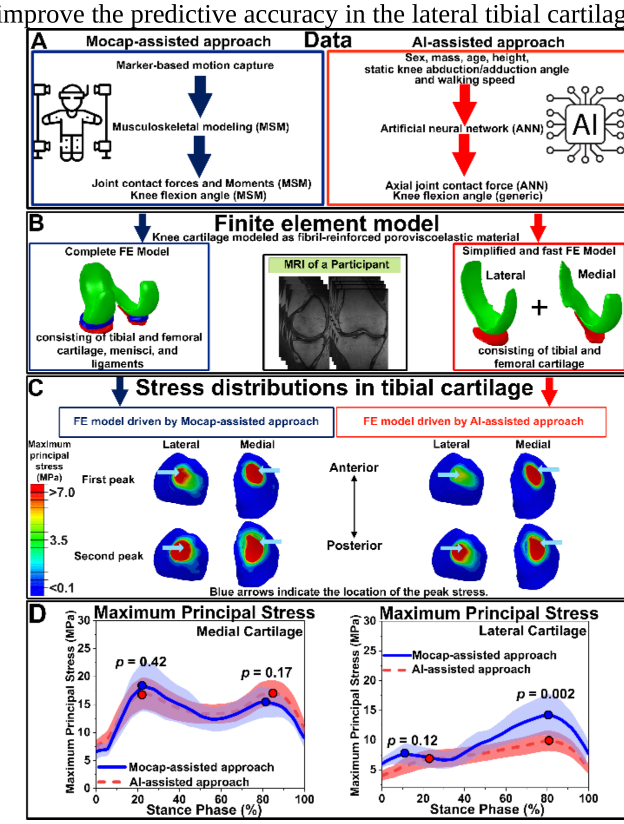

Figure 1: Workflow and results of the finite element models driven by Mocap- and AI-assisted approaches.

Conclusions

We present a method to estimate knee joint cartilage mechanics during gait without marker-based Mocap. This approach will enable out-of-lab tissue failure estimation, degeneration prediction, as well as rehabilitation planning and self-management of musculoskeletal diseases.

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