Real-time Prediction of Subject-specific Joint Mechanics in the Osteoarthritic Knee

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Summary

Finite element (FE) models can provide insight into joint mechanics in the osteoarthritic knee, but developing and running subject-specific simulations can be time-consuming. We have developed a method for real-time prediction of knee joint mechanics from knee anatomy. We tested this approach on over 200 knees and found predictions of most joint metrics to be within 20% of the FE values.

Introduction

Knee osteoarthritis (OA) is an extremely prevalent and degenerative musculoskeletal condition with no cure. It is also a highly subject-specific disease in an inherently variable patient population. There is an urgent need to better identify individuals at high risk of OA and develop customized treatment plans to prevent or slow disease progression.

Computational models, particularly FE simulations, can provide valuable insights into joint mechanics and disease progression of OA [1]. However, developing subject-specific FE analyses has typically been limited to small cohorts due to the extensive time and effort required to develop models and perform simulations [2]. Our objective is to develop a statistical method to rapidly predict subject-specific joint mechanics from shape parameters derived from magnetic resonance (MR) scans.

Methods

Imaging data was obtained from the Osteoarthritis Initiative (OAI) database [3], a longitudinal study of the progression of knee OA. We previously developed a robust image-to-simulation pipeline for bone, cartilage, and meniscus [4] and an algorithm to automate identification of soft-tissue attachment sites [5]. Here we applied these methods to 209 knees from the OAI baseline dataset, which included subjects with Kellgren-Lawrence (KL) grades from 1 to 4.

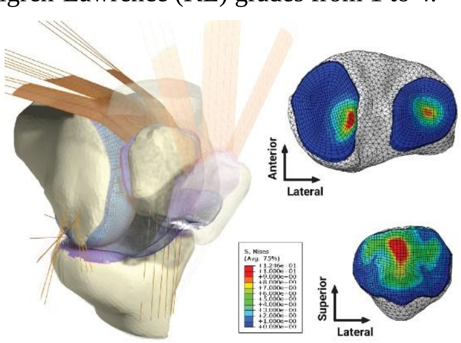

Figure 1: Subject-specific FE model showing tibial and patellar cartilage stresses.

We performed FE simulations of a deep-knee-bend (DKB) for each knee (Abaqus/Explicit, SIMULIA). These subject-specific models included bone, cartilage, menisci, ligaments and quadriceps muscle (Figure 1). We extracted tibiofemoral (TF) and patellofemoral (PF) contact mechanics, joint loads and kinematics, and cartilage stresses and strains.

We used principal component analysis to extract shape parameters for each knee. We developed an inferential machine learning model which integrated these shape parameters with joint mechanics outputs from the FE simulations. We used Ridge, Lasso, ElasticNet, Support Vector Regression and Random Forest regressors with an 80-20 train-test split and a 7-fold cross validation to predict joint mechanics outputs directly from shape parameter inputs.

Results and Discussion

Simulation outputs demonstrated reliable predictions across TF contact mechanics (19.1%), joint loads (17.6%), kinematics (23.1%) and PF joint loads (20.7%) and kinematics (19.8%) (Figure 2). We are currently applying this pipeline to longitudinal data from the OAI database to quantify our ability to predict OA progression from baseline MR scans.

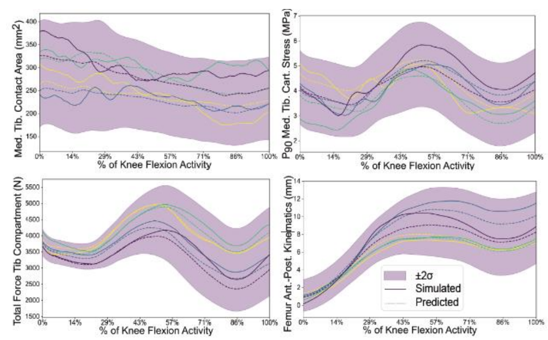

Figure 2: Comparisons between FE simulation with classic machine learning predictions.

Conclusions

This automated pipeline enables researchers and clinicians to analyze biomechanics outputs rapidly and at scale to build population-based datasets of joint mechanics in the OA knee.

Acknowledgments

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