MULTISCALE SIMULATION FRAMEWORK AS A RESEARCH TOOL FOR CLINICAL GAIT ALTERATION STRATEGIES

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Introduction

Computer simulations have become more accurate, and are increasingly used in industrial fields such as medical device design, where high level of detail is crucial. Employing computer simulations of different nature and their combinations gives an insight into the phenomena that have not been investigated with a required level of biofidelity before. For example, design of a test method for a trauma fixation plate requires a combination of finite element (FE) structural and musculoskeletal analyses [1].

Development of more efficient non-invasive knee osteoarthritis (KOA) treatment strategies has a potential of significantly reducing healthcare costs. However, clinical studies are often expensive, time-consuming, and not necessarily successful due to the dependency of the problem on multiple factors of different nature, e.g. subject-specific motion pattern, quality of soft tissues, etc. A multiscale simulation involving both, whole body and regional, scales can be used to gain an insight into the problem for designing new treatment strategies.

This study demonstrates an application of a multiscale simulation framework using musculoskeletal modeling and FE methods for assessing new KOA treatment techniques.

Methods

For the full-body scale, a subject-specific musculoskeletal model of a female, 61.2 kg, was developed in the AnyBody Modeling System (v.6.1) and the TLEM 2.0 dataset [2] using: a) soft tissue and bone geometries segmented from MR images; b) motion capture acquisitions of 5 gait variations (Qualisys, 39 markers); c) force plate data (Kistler). Recorded variations of gait represent a reference and different pressure reduction strategies on the cartilage in the medial compartment of the knee: a) normal; b) laterally wedged insole 5°; c) laterally wedged insole 10°; d) toes turned slightly inwards; and e) toes turned slightly outwards.

For the cartilage pressure scale, an FE (Abaqus, v.6.13-3) model, like the previously described in [3], was developed. This model was comprised of the soft tissues, cartilage and menisci, segmented from the subject-specific MR images, and modeled as fibril reinforced poroviscoelastic materials, and pre-strained springs to represent ligaments. To get more physiological boundary conditions, forces from the musculoskeletal analysis were applied onto Abaqus-based FE models.

Results and discussion

Despite showing the lowest reaction forces in the medial tibial compartment, “Toe in” method only marginally reduced peak stresses during the 2nd axial peak force of stance compared with normal gait, and average stresses were the highest. “Toe out” method increased peak and average stresses during the 1st peak. Both wedged insoles reduced both peak and average medial tibial stresses during stance phase. Insole 10° showed lowest peak and average stresses out of all techniques in the medial tibial cartilage surface.

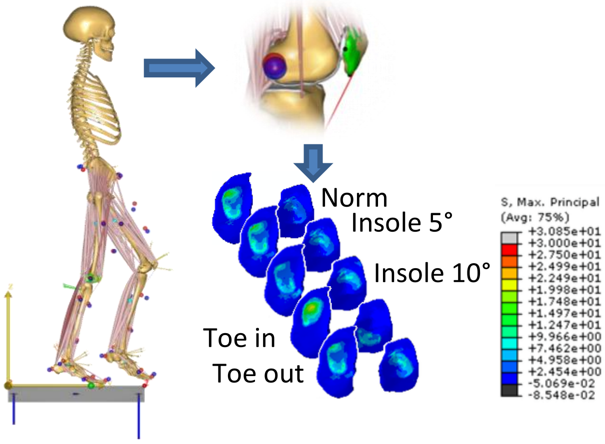

Figure 1: Scheme of the multiscale simulation: (left, top) personalized musculoskeletal model; (right, bottom) results of personalized FE models, showing maximum principal stress patterns at the medial cartilage for each configuration for the second axial peak force of gait.

Conclusions

A multiscale simulation framework composed of musculoskeletal and finite element analyses is a promising tool to assess non-invasive intervention strategies for medial cartilage stress reduction during gait. Laterally wedged insoles may reduce stresses in the medial compartment for KOA treatment. The findings need to be confirmed with more test subjects.

References

1. Coombs et al, Proc SIMULIA Community Conf, 2014.
2. Carbone et al, J Biomech, 48(5):734-741, 2015.
3. Halonen et al, J Biomech, 46(6):1184-1192, 2013.

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