POST-TRAUMATIC FIBRIL REORIENTATION IN CARTILAGE: ADAPTIVE IN SILICO MODEL VALIDATED AGAINST IN VITRO OA MODEL

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Introduction

Articular cartilage is a fibril-reinforced soft tissue, presenting a depth-dependent collagen fibril structure. Based on fibril orientation, cartilage can be divided into three zones in depth: superficial zone (parallel to the surface), middle zone (random orientation) and deep zone (perpendicular to the surface) [1]. Injurious mechanical loading and consequent cartilage defects in post-traumatic osteoarthritis (OA) are known to impair the mechanical environment of the tissue microstructure and consequently change the fibril orientation [2].

Recently, we introduced a finite element (FE)-based cartilage adaptive reorientation degeneration (CARED) model that includes a fibril reorientation algorithm (initially introduced for arterial wall tissue) to predict changes in cartilage fibril orientation upon altered mechanical environments [3]. In this study, we aim to validate the fibril reorientation predicted by CARED model with depth-dependent fibril reorientation upon longitudinal loading in a post-traumatic *in vitro* OA model.

Methods

Sixteen healthy human hip cartilage explants (8 mm diameter) were harvested from 80 yo female (fractured hip). Half-thickness focal defects were created on 8 samples using a scalpel. Both the intact and defect samples were loaded for 7 days using a dynamic loading bioreactor (10% unconfined compression at 1 Hz, 1 hr on - 1 hr off - 1 hr on). On days 1, 3, 5 and 7 of loading, one sample per group was fixed and sectioned. Depth-dependent fibril orientation was measured using polarized light microscopy (PLM) [4].

3D FE models of both defect and intact samples were created in Abaqus, based on the geometry and depth-dependent fibril orientation information of the samples before loading obtained from PLM measurements. A fibril-reinforced poro-elastic material [5] was used, with model parameters characterized using experimental loading data and inverse FE analysis. One cycle of unconfined compression (10%, 1 Hz) was applied to the FE model. The fibril reorientation algorithm of CARED model [3] was used to run the FE simulations iteratively and estimate the fibril reorientation upon loading based on the principal strain directions.

Results

The depth-dependent collagen fibril orientation before loading in an intact sample (as control reference) is compared with intact and defect samples after 7 days of dynamic bioreactor loading in figure 1. For each sample, the PLM measurements across the sample depth, agreed qualitatively with the fibril orientation predicted by the adaptive FE model.

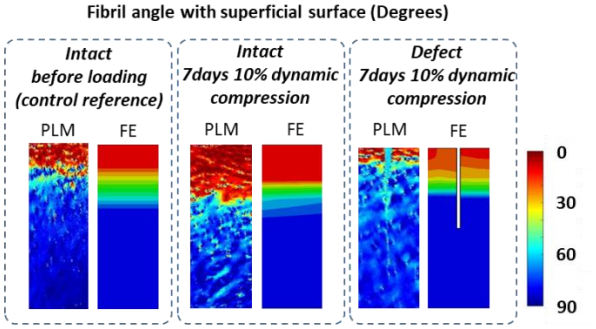

Figure 1: Depth-dependent fibril angle with superficial surface obtained from PLM measurements and adaptive FE simulations.

Discussion

The PLM results suggest that longitudinal loading of an intact explant increased the thickness of the superficial zone (red zone in figure 1) compared to the reference sample. In contrast, subjecting the defect sample to identical loading conditions, decreased the thickness of the superficial zone, by reorienting the fibrils perpendicular to the articular surface. This agrees with previous *in vitro* and *in silico* observations of decreased superficial zone thickness in post-traumatic OA [3, 4, 6]. Interestingly, the predicted depth-dependent fibril orientations after loading using the adaptive FE model for both intact and defect samples are in agreement with the PLM measurements. Therefore, FE-based principal strain directions are confirmed to be valid parameters to predict the collagen fibril reorientation in the adaptive FE models of intact and damaged cartilage upon mechanical loading.

References

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Acknowledgements

This work was supported by Marie Sklodowska Curie Individual Fellowship (CREATION project: MSCA-IF-2019-893771) and KU Leuven Happy Joints project (C14/18/077).