NON-INVASIVE MRI-BASED CHARACTERIZATION OF CARTILAGE DEGRADATION USING VIRTUAL FIELDS METHOD

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Introduction

Articular cartilage degeneration is *the* hallmark of osteoarthritis (OA), the most common joint disease. Early stages of tissue degeneration are characterized by changes in the proteoglycan concentration and the collagen network. These changes alter the mechanical behavior, as the interaction between the constituents determine the mechanical properties of cartilage [1].
Although mechanical characteristics of cartilage were extensively studied *in vitro* [2], *in vivo* assessment lack behind, given the invasive nature of the experimental techniques. This study is a proof of concept that proposes a non-invasive MRI-based approach that uses the virtual fields material parameter identification method (VFM) to quantitively distinguish material parameters in a healthy and enzymatically degraded *in vitro* OA cartilage model, as the first step towards *in vivo* characterization.

Methods

2D displacement fields, determined from two bovine osteochondral plugs, one control and one enzymatically degraded (combination of collagenase inducing collagen degradation and chondroitinase inducing proteoglycan degradation) were collected [3]. Pixel-wise displacement data (shown in **Figure 1**) were extracted based on a unique MRI DENSE sequence performed during compressive loading at steady-state tissue response [4].

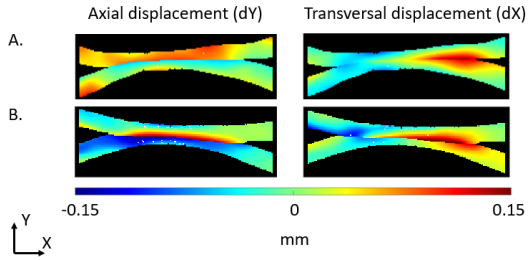

Figure 1: Pixel-wise displacement maps in axial and transversal direction during cartilage-on-cartilage contact of A. control osteochondral plugs and B. enzymatically degraded osteochondral plugs

An inhouse code was developed based on an iterative approach of the VFM, presented in **Figure 2** assuming a compressive Neo-Hookean constitutive model.
Because the exact forces acting at the cartilage-on-cartilage interface are unknown, only Poisson's ratio can be evaluated, as this material parameter is suggested in literature to be independent of boundary conditions [5].
The implementation of the VFM was validated using a finite element model with pre-determined material parameters.

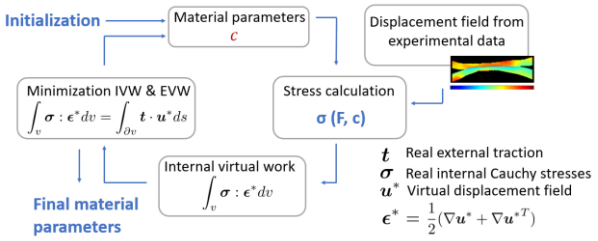

Figure 2: The VFM workflow: At initialization, an initial guess of the desired material parameters (c) is used to calculate the Cauchy stresses, which are a function of the experimentally determined deformation gradient tensors (F). This allows estimating the internal virtual work (IVW). The objective function defined as the difference between internal and external virtual works (EVW), is then minimized by iteratively altering the material parameters.

Results and discussion

The simulated Poisson's ratios are **0.445** and **0.320** for the control and enzymatically degraded osteochondral plugs respectively. The results show a significant decrease in Poisson's ratio of the degraded plug, which corresponds to an increase in tissue compressibility. This increase in compressibility can be a direct result of changes in tissue permeability, a characteristic of degraded tissue [6].
In conclusion, the developed non-invasive MRI-based approach allows us to not only distinguish between control and enzymatically degraded osteochondral plugs, but also gives quantitative insight into the changes in mechanical properties. Ultimately the proposed mechanical characterization approach could serve as a potential *in vivo* biomarker for early OA.

References

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Acknowledgements

This work was supported by the FWO fundament fellowship (11M9422N).