STRUCTURE AND MECHANICS OF THE INTERVERTEBRAL DISC-ENDPLATE JUNCTION ANALYSED USING SYNCHROTRON CT AND DVC

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Introduction

The intervertebral disc (IVD)-endplate junction is mechanically vulnerable because material properties change abruptly, leading to stress concentrations. Failure of the endplates has been linked to spinal pathologies like disc degeneration, these conditions lead to back pain which is a major global health burden. Structural integration of the IVD and endplates involves the penetration of collagen fibres into the mineralised tissues of the endplates and underlying bone. High strains have been observed near the endplate junction in whole discs under axial compression, and failure of the IVD under axial compression usually occurs at the endplate. We have previously shown that it is possible to resolve the microstructure of both the hard and soft tissues of the disc endplate junction using synchrotron phase-contrast tomography, and that digital volume correlation (DVC) can be used to measure strains in the fibrous tissue of the annulus fibrosus [1]. We have also used DVC to measure nano-scale strains in bone and calcified cartilage [2]. This work combines these techniques to investigate load transfer across the soft-hard tissue boundary of the IVD.

Methods

Murine spine segments were imaged at beamline I13-2 at Diamond Light Source, UK with a voxel size of 1.6 µm. Samples were placed in a mechanical testing rig and imaged at multiple compressive load steps. DVC was used to measure displacement fields across the disc endplate boundary. Lagrangian strains were calculated from the displacement fields by polynomial fitting and differentiation. Tissue specific point clouds for DVC were created using Avizo 2021. Calcified tissue point clouds were generated from the nodes of a tetrahedral mesh of the microstructure. The uncalcified cartilage point cloud was created using manual segmentation, and fibre point clouds were generated using fibre tracing. DVC parameters were optimised for each tissue type individually, giving a displacement measurement accuracy of 17 nm in the calcified tissues and 327 nm in the fibrous tissue.

Results

Displacement fields and subsequent strains were measured for multiple regions of the disc-endplate boundary with sub-micron accuracy, see Figure 1. Optimal parameters for DVC depended on the tissue type analysed. Strain distribution varies regionally and with loading level, with calcified endplate strains initially significantly lower than strain in the soft tissues but becoming equivalent at higher loads, see Figure 2.

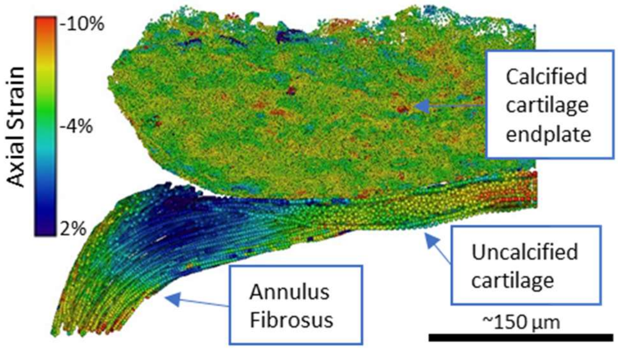

Figure 1: Axial strain across the IVD-endplate boundary. Each sphere represents a point in the DVC point cloud.

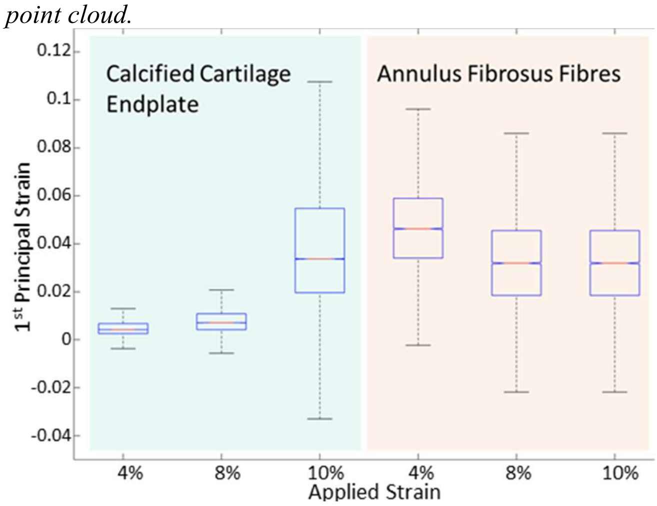

Figure 2: 1st principal strains in the calcified cartilage and annulus fibre bundles of the posterior caudal endplate at 4%, 8%, and 10% applied strain.

Discussion

These results improve our understanding of the 3D structure and mechanics of the IVD-endplate boundary. The methods used here provide an accurate way to investigate load transfer across soft-hard tissue boundaries at the microstructural scale and could be used to further our understanding of soft-hard tissue biomechanics in health, disease, and aging.

References

1. Disney et al, Acta Biomaterialia, 138:361-374, 2022
2. Madi et al, Nature Biomed Eng 4:343-354, 2020

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