NANOSCALE STRUCTURAL CHANGES IN BONE CARTILAGE UNIT SUBJECTED TO COMPRESSIVE LOADS

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Introduction

The bone cartilage unit (BCU) plays a crucial biomechanical role in enabling pain-free articulation and smooth transmission of compressive and shear stresses across diarthrodial joints [1]. Structural degradation and alterations in bone-cartilage cellular communication at the bone-cartilage interface has been proposed as a key early-stage marker for osteoarthritis [2]. Historically, there is a lack of studies investigating tissue graded hierarchical transition from the articular cartilage into the trabecular bone as a continuous unit. Here we analyze the changes in the fibrillar nanomechanical parameters under compression throughout the length of uncalcified and calcified regions within the BCU, using high brilliance small-angle X-ray scattering (SAXS).

Materials and Methods

BCU cores of (~5 mm L x 2 mm D) were extracted from a metacarpal-phalangeal joint adult bovine steer (16-24 months), using diamond drill bit, under constant irrigation (Fig. 1A) [3]. SAXS scanning of the BCU were performed at beamline I22, Diamond Light Source, UK (beam-size ~20μm). A rectangular 2D area scan with the long side of the rectangle along the depth from the joint surface was performed on each sample before loading. A second SAXS scan was performed after samples were compressed to 30% strain and allowed to equilibrate, using a microcompression tester. Fibril-level ultrastructural parameters, fibrillar D-period (pre-strain), degree of variability associated with the D-period (wq), fibrillar orientation and degree of fibrillar orientation (ρ) were extracted from SAXS patterns (Fig. 1B).

Results and Discussion

The result shows the existence of a variation in fibrillar D-period (linked to fibril pre-strain), across the BCU, with higher values of D-period in calcified plate and a reduction of the D-period in the underlying trabecular bone to the values characteristic for Type I mineralized collagen in the pre-loaded state (Fig. 1C). Upon compression the changes in the D-period in each zone varies across the BCU, with significant reduction in deep zone and calcified plate ($p<0.05$). The result clearly shows that nanoscale ECM architectural parameters are inhomogeneous throughout the depths of BCU, and the deformation affects these nanoscale parameters differently. The findings may have biomechanical adaptative significance: higher in-built molecular level resilience/damage resistance to physiological compression, and disruption of the molecular-level pre-strains during remodelling of the bone-cartilage interface may be potential factors in osteoarthritis-based degeneration.

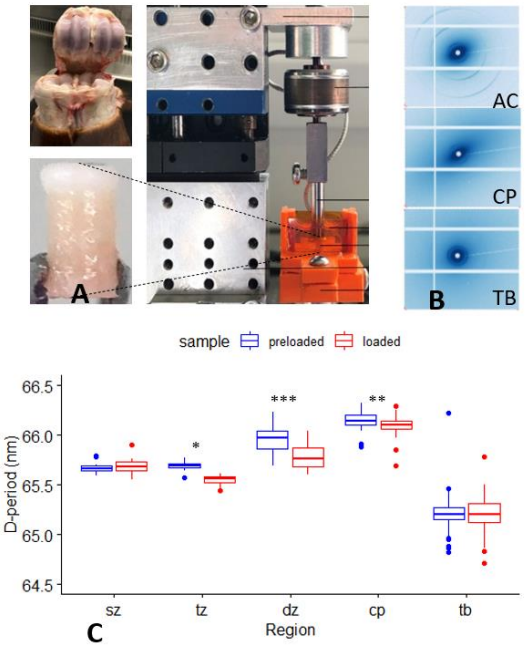

Figure 1: (A) BCU cores of 5mm length and 2mm dia. extracted from bovine metacarpophalangeal joints and placed in microcompression tester for SAXS scanning while kept hydrated (B) 2D SAXS patterns from articular cartilage, calcified plate and trabecular bone (C) Significant reduction in fibrillar pre-strain in deep zone of articular cartilage and underlying calcified plate upon loading.

References

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Acknowledgements

We thank Diamond Light Source for beamtime (SM25602-2). This work is supported by EPSRC (EP/V011383/1). We thank Andy Smith and Olga Shebanova (DLS) for excellent technical support during the synchrotron beamtime.