INTRATRABECULAR DISTRIBUTION OF MECHANICAL PROPERTIES OF ISOLATED HUMAN TRABECULAE

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Indroduction

The purpose of this study was to investigate biomechanical behaviour of trabecular bone at the level of individual trabeculae. Intratrabecular variations of mechanical properties are influenced mainly by its microarchitecture and mineral density distribution [Smith, 2010]. Maps of micromechanical properties of the trabeculae refine description of mechanical behaviour of trabecular on a structural level obtained by three-point bending test [Jirousek, 2013].

Materials and Methods

Individual trabeculae were carefully extracted from human proximal femur (37-year old male donor). The samples were degreased from residuals of bone marrow using detergent solution in ultrasound bath and fixed in low shrinkage epoxy resin. Embedded specimens were grinded and polished to obtain very low surface roughness required for nanoindentation procedure.

Scanning electron microscope (SEM) equipped with backscattered electron (BSE) detector and energy-dispersive X-ray (EDX) spectroscope was used for morphological measurements and mineral density analysis. BSE imaging is a method based on detection of high-energy electrons backscattered surface region of a specimen struck by the primary electron beam of SEM. The backscattered electrons signal is proportional to the effective element weight. Hence one may distinguish between collagen fibres and hydroxiapatite lamellae and describe intratrabecular composition. Since EDX provides information about relative element content it can be used to estimate mineral density along the analysed surface.

The correlation between local stiffness and local element content is reported, therefore the modulus mapping (MM) technique was employed to quantify the data obtained by SEM. MM is a technique to obtain a map of the mechanical properties of a material surface through sinusoidally oscillating indenter probe [Asif, 2001]. From the resultant amplitude and phase lag of the indenter probe a map of elastic modulae was determined.

In spite of the advantages of MM (e.g. high spatial resolution, directly obtained material properties) it exhibits one significant limitation: small dimensions of the scanned region. To be able to determine stiffness fields based on BSE measurements, calibration of BSE material maps was performed using the maps of elasic properties obtained by MM.

Results and Conclusions

Combination of MM and BSE scanning is a promising method to obtain material properties and intratrabecular composition of isolated trabeculae. The obtained results show a decreasing stiffness gradient along the radial direction from the trabecula core to the surface. Knowledge of the material properties across the trabeculae enhances the understanding of biomechanical behaviour of trabecular bone. Based on obtained stiffness fields an advanced FE model of single trabecula with nonuniform material properties distribution may be developed.

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