

MICROMECHANICAL MODEL OF BOVINE HAVERSIAN BONE PREDICTS STRAIN AMPLIFICATION THROUGH SOFT INTERFACES

Sabah Nobakhti¹, Orestis L. Katsamenis¹, Orestis G. Andriotis¹, Georges Limbert^{1,2}, Philipp J. Thurner¹

¹Bioengineering Science Research Group, Faculty of Engineering and the Environment, University of Southampton, UK; ²National Centre for Advanced Tribology at Southampton (nCATS), Faculty of Engineering and the Environment, University of Southampton, UK

Introduction

The evaluation of fracture risk in osteoporotic patients is still mostly based on Bone Mineral Density (BMD) measurements. During the past decades the research community has identified that not only bone mass, *i.e.* BMD, but also bone quality should be evaluated in order to achieve a reliable diagnosis of bone fracture risk for individuals. Bone quality includes among many other parameters the matrix material properties, which are dependent on the ultra- and microstructural arrangement of components that make up bone tissue. Our past research has shown that networks which form by noncollagenous proteins (NCPs) are able to repeatedly dissipate and store energy upon compression [Zappone, 2008]. NCPs can accumulate in interfaces *i.e.* inter-lamellar areas and cement lines and densely populated fracture surfaces [Nanci, 2006; Derkx, 2005]. Accordingly, we hypothesize that osteopontin and other NCPs strengthen interfaces, toughen the bone and impede crack propagation.

Methods

In this study, we explored the osteonal level of bone and investigated the elastic behaviour of inter-lamellar areas and cement line structures. Based on the hypothesis that interfaces are more compliant than the bone matrix [Bigley, 2006], a finite element micromechanics model was built. Atomic force microscope (AFM) and cantilever-based nanoindentation tests were used to verify computational observations.

Results

1. Interfaces are compliant structures; Our computational findings showed that average isotropic elastic modulus of interface structures was 88.5 MPa, which is in close agreement with data from cement line reported by Bigley et al. [2006]. This finding is also supported by nanoindentation experiments.

2. Interfaces are areas of accumulated strain and deflection; As shown in Figure 1,

interfaces were subjected to higher strains compared to the surrounding lamellar bone.

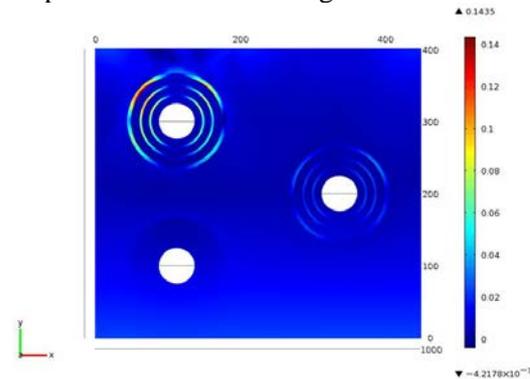


Figure 1- 1st principle strain ($\mu\epsilon$) at the sample cross section. Empty spaces are Haversian canals.

Discussion

While μ -Raman imaging showed that inter-lamellar areas are enriched in NCPs, AFM imaging did show that collagen orientation changes in the interlamellar areas, to transverse from longitudinal fibrils in lamellae. Strains at interfaces elevate upon loading in bone and these microstructural features guide crack propagation, provide toughening mechanisms via crack deflection, energy-dissipation in the NCP moiety and ligament bridging. Accumulation of strain at soft interfaces could also be an important mechanism for amplification of physiological strains to levels required for maintenance of bone mass as our results predict a tenfold increase in strain compared to lamellae.

References

Bigley *et al*, J Biomech, 39: 1629–1640, 2006; Derkx *et al*, Bone, 22: 367-373, 1998; Nanci, J Struct Biol, 126: 256-269, 1999; Zappone *et al*, Biophys J, 95: 2939-2950, 2008.