Crack propagation in cortical bone modelled with the extended finite element method

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ABSTRACT

Healthy cortical bone tissue is both tough and strong but mechanical properties are deteriorated by age or diseases, which results in a higher risk for fracture. Bone tissue is reinforced by cylindrical osteons and crack deflection along the osteonal interfaces is an important toughening mechanism in healthy bone. This ability to deflect cracks is impaired in old bone tissue where cracks instead penetrate osteons, which results in straighter and shorter crack paths and lower fracture toughness compared to healthy bone [1]. The underlying changes that cause this behavior are not fully known and the aim of this project was to study how the fracture energy of the tissue affected the trajectory of a propagating crack.

A scanning acoustic microscopy (SAM) image of human cortical bone was used to create model geometries including bone matrix, osteons and cement line interfaces (Fig. 1A-C). Crack propagation was simulated with the extended finite element method (Abaqus v2017) using the modelling framework proposed in [2]. The quadratic nominal strain criterion was used to model damage in the interface and the maximum principal strain criterion was used in all other tissue components. All components were modelled as linear isotropic elastic materials. Tensile tests with high and low fracture energies (G=0.4 and G=0.05 kJ/m^2) were simulated while keeping all other parameters constant.

The results showed that the fracture energy in the tissue affected the crack trajectory. The model with low fracture energy predicted a straighter crack that penetrated the osteons (Fig. 1D), while the model with high fracture energy predicted a crack that was deflected to follow the interfaces around the osteons (Fig. 1E). The simulated crack patterns agree with what is reported from experiments [1]. However, alterations in fracture energy is not the only effect of aging and future work will, for example, also include the effect of increased porosity, to give a more comprehensive description of the effect of aging in bone.

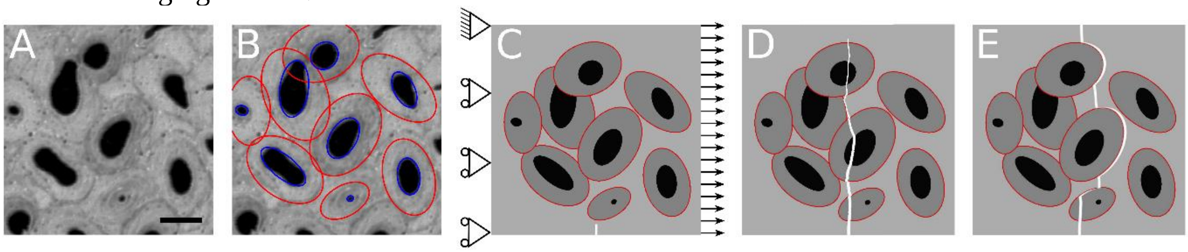

Figure 1: (A) SAM image of cortical bone. Scalebar is 200 μm. (B) Ellipses fitted to osteons and canals. (C) Boundary conditions for tensile test. An initial crack was inserted in the lower edge. Crack paths for models with (D) low and (E) high fracture energies.

REFERENCES

[1] K. Chan et al, “Relating crack-tip deformation to mineralization and fracture resistance in human femur cortical bone”, Bone, Vol. **45**, pp. 427-434, (2009)

[2] A. Gustafsson et al, “An interface damage model that captures crack propagation at the microscale in cortical bone using XFEM”, *JMBBM*., Vol. **90**, pp. 556–565, (2019).