

Estimation of cortical bone strength using finite element analyses: the role of elastic properties, image resolution and bone

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Bone density, mechanical properties and geometry are the main contributors to bone strength. Until date, there is no alternative to experimental mechanical testing to account for all these parameters when determining bone failure loads. However, finite element models combined with computed tomography (CT) imaging seem to provide accurate estimations of bone strength and it is a common method used to characterize bone quality.

Both trabecular and cortical bone tissues are needed to assess bone quality. However, recent studies have proved that mechanical strength of bone is mainly determined by the cortical bone compartment. In this study, it is examined whether micro-CT images and finite element models can be used to estimate cortical bone strength under different loading conditions. Density dependent elastic properties, geometry, image resolution, bone porosity and aging are amongst the factors considered when predicting bone failure load. Appropriate boundary conditions and displacement controls are applied to simulate mechanical compression. Two different failure theories are tested and compared. It is hypothesized that bone strength is directly related to all these parameters, and that increased cortical bone porosity influences bone's resistance to fracture.

It was found that the different failure criteria can predict the same failure zones, but not the same failure loads. In addition, it was observed that density dependent elastic properties provided better approximations compared to constant elastic properties. High image resolution was used, and the results obtained showed that accuracy is not always mesh-size dependent. Important relations between bone strength, bone porosity and the aging process were found. Increased bone strength was found for the younger population with low porosity levels.

It was concluded that finite element models could help in estimating bone strength. Bone density, porosity and elastic properties were main contributors. Moreover, it was observed that selection of appropriate failure criteria was determinant when estimating bone failure load. In conclusion, accurate assessment of bone quality can be obtained when all these parameters are considered and appropriate methods are used.

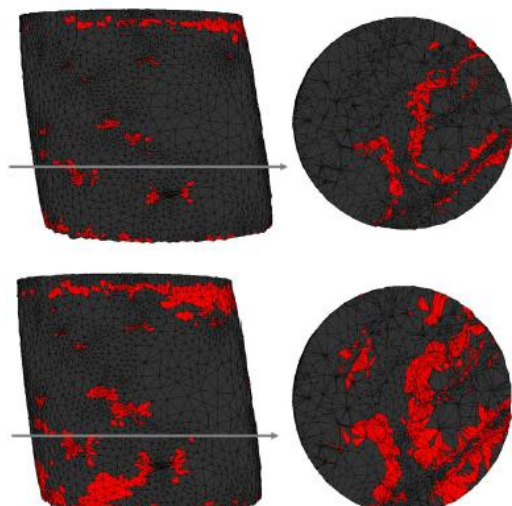


Figure: Failure zones (failed elements coloured red) in different cross-sections of a microCT sample model. Failure is predicted by Pistoria criterion of three consecutive increments from the onset of fracture