VIRTUAL SAMPLES OF TRABECULAR BONE

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INTRODUCTION:

Micro level finite element (μFE) models of trabecular bone have a variety of possible applications that include understanding fracture mechanism in normal and osteoporotic bone and examining the mechanical response of bone to implants. Previous investigators used images or CT attenuations of real bone samples to develop μFE models. This involves: generating images of a bone sample using, for example, μ-CT; converting CT attenuations to elastic moduli; and mapping elastic moduli to 3D finite elements. The computational models created using these methods can only represent the samples used in their construction and any possible variations due to factors such as anatomical site, sex, age or degree of osteoporosity cannot be included without additional sample collection and processing. To authenticate any hypothesis it is essential to consider a wide range of samples with different characteristics. It is a colossal task to generate 3D μFE models from real samples for this range. This study discusses development of virtual samples i.e. samples that look like and mechanically behave like real trabecular bone, but are generated computationally.

METHODS:

Virtual samples are generated using a pseudo-random procedure that aims to maintain the random nature of trabecular structure while satisfying key topological indices of trabecular bone [1]. The algorithm starts with a 3D domain filled with hexahedral element spaces. Although the 3D volume can be of any shape or size, in the present study it is assumed to be cubical. An increase in sample size clearly results in a larger FE mesh. The empty 3D domain is then filled with elements that constitute the trabecular microstructure i.e. these elements are assigned tissue mechanical properties. The pseudo-random sample generation algorithm ensures that the virtual sample has: a prescribed porosity or bone volume to total volume ratio (BV/TV); a well connected porous structure; and specified mean and deviation in trabecular spacing.

At the tissue or element level the material properties are assumed to be isotropic. This implies that apparent level anisotropy is due to micro-architecture alone. Although the generation algorithm is general, this study attempts to develop samples that have higher elastic modulus in a principal direction and identical properties in the other two orthogonal directions. Typical FE models of the generated samples using the above process are shown in Fig. 1.

RESULTS:

It was first important to evaluate the smallest sample size required for the determination of the apparent elastic moduli E. A number of models with edge length of 10, 20, 30 and 50 elements were tested numerically in the major principal direction (vertical direction 2). The results showed that models with 30 element width, which is approximately 5 times mean pore size, give fairly consistent results.

A number of models were generated with a width of 30 elements and with the BV/TV ratio varying from 4% to 24%. Elastic moduli were determined numerically for each sample in the three orthogonal directions. The results are shown in Fig. 2.

DISCUSSION:

The above results need to demonstrate that the samples generated to satisfy topological indices behave, mechanically, in a realistic manner. The minimum sample size of approximately 5 times pore size is in line with the results found previously for real trabecular bone samples [2]. The results shown in Fig. 2 are also consistent with previous studies on real bone samples [3] in which it has been shown that the variation of elastic moduli with bone volume fraction follows a power law. Figure 3 shows that with an increase in elastic modulus in one principal direction the elastic moduli in the other two directions decrease and that this variation is linear. For a given bone volume fraction this would appear to be an obvious finding. However, it was found that this is only true for models with “similar” trabecular connectivity. Previous studies [4] have reported that a disruption of the trabecular network with age is mainly caused by collapse of the horizontal supporting struts. The algorithms developed in this study were found to be able to demonstrate this effect.

REFERENCES:


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