Indirect determination of trabecular bone effective tissue properties using micro-finite element simulations

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Introduction

Osteoporotic fractures mainly occur at sites with relatively large amounts of trabecular bone. The devastating effects of such fractures can be prevented with accurate predictions of trabecular bone strength. Micro-finite element (μFE) models have been successfully used to study and predict trabecular bone elastic and yield properties. Strength predictions, on the other hand, require the post-yield behavior of trabecular bone tissue. Due to experimental difficulties this data is not available. The purposes of this study were to (1) indirectly determine the tissue properties using μFE models by iteratively fitting of simulation to experimental results for a trabecular bone specimen and (2) test to what extent the post-yield behavior of other similar specimens can be predicted when using these parameters in μFE analyses.

Materials and methods

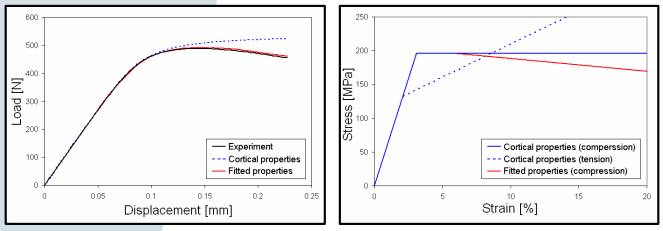
Seven cylindrical trabecular bone specimens were obtained from bovine tibiae. The samples were compressed in a micro-compression device [1] to create high-resolution CT scans of their original and deformed state. At the same time, the load-displacement curve was measured. The scans of the original structures were converted to μFE models. Following Cezayirlioglu [2], the element were divided into two groups depending on their loading mode (tension or compression) as a result of a linear analysis.

A single specimen with median volume fraction (sample 0) was chosen for the fit procedure. First, the properties of the trabecular tissue were based on cortical bone. The yield and post-yield properties were subsequently adjusted in order to get the same apparent load-displacement curve. The resulting properties were used to simulate the compression of the remaining bone samples. The load-displacement curves and local deformations in the scans were used to validate the μFE analyses.

Results

The results showed that the apparent behavior of the selected trabecular bone specimen could be accurately simulated with the μFE model when the tissue properties were adjusted (Fig. 1). The resulting properties were similar to those of cortical bone, but 'compression softening' had to be introduced to obtain the typical descent in the load-displacement curve seen during compression tests. The fitted tissue behavior for sample 0 was used to simulate the compression experiments of the remain six samples. The results are shown in Fig. 2.

Validation on a local level revealed extreme deformations and localized high strains in the μFE meshes (Fig. 3). Cracks were also observed at those locations.



a) Specimen level b) Tissue level

Fig. 1: *μFE-model results before and after the fit procedure compared with the apparent behavior of sample 0 (a), and the accompanying stress-strain relations for the tissue (b).*

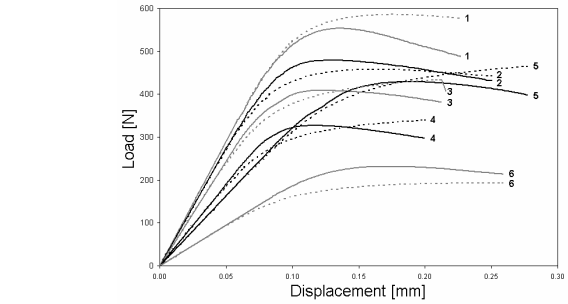


Fig. 2: *Apparent load-displacement curves of samples 1 – 6. The experimental data is represented with solid lines. The dotted lines are obtained with μFE models that incorporate the tissue properties from the fit procedure.*

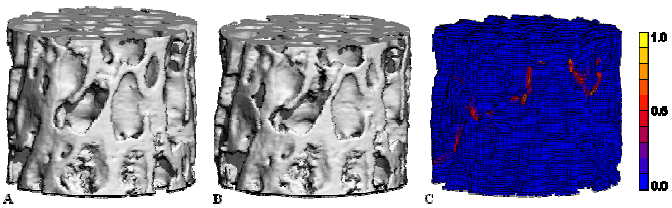


Fig. 3: *Rendered CT scans of sample 0 in its initial (A) and deformed (B) state. The deformed μFE mesh (C) is shown for comparison. Local deformations in the CT scans compared well with deformations and high equivalent strain values in the μFE models.*

Conclusions

The fit procedure resulted in an accurate reproduction of the measured load-displacement curve of the selected specimen. However, the force-displacement curves of the other specimens predicted from μFE analyses based on the fitted tissue parameters compared less favourable to the experimental data. Natural variations exist in bone tissue properties [3]. It is not clear whether the differences in Fig. 2 are caused by this variations or by other factors, such as experimental artifacts or the formation of cracks, which are not accounted for in the μFE analyses.

References:

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