ELASTIC MODULUS OF HUMAN SINGLE TRABECULAE ESTIMATED BY SYNCHROTRON CT EXPERIMENTS AND NUMERICAL MODELS

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Introduction

Accurate determination of the mechanical properties of trabecular bone is pivotal for bone fracture prediction and treatment. However, reported Young's modulus for the tissue level of human trabecular bone lies within a wide range of values (1-20 GPa) [1,2] and commonly stem from testing of a relatively large network volume of trabeculae or nanoindentation. Recent studies [3,4] have performed mechanical testing on single trabeculae to try to determine the trabecular Young's modulus more precisely. However, generally two main limitations remain: 1) displacement is hard to measure directly on the specimen due to the micrometer-to-millimeter length scale; 2) shape assumptions - the trabecular cross-section is far from homogeneous (Fig. 1c). The aim of this study was to overcome these limitations and provide a more precise method to estimate single trabecula elastic modulus, by using Synchrotron Radiation X-ray Computed Tomography (CT) to acquire high-resolution images while compressing single trabeculae in a relatively short period of time.

Methods

Four trabeculae, with a length of 2.2-2.8 mm, taken from human femoral bone (ethics committee approval EK-29/2007, Zürich) were subjected to uniaxial compression in a loading stage within the CT device (at Paul Scherrer Institute). After each loading step, sequential projections of the specimen were taken in about 200s with a resolution of 1.6 µm/voxel.

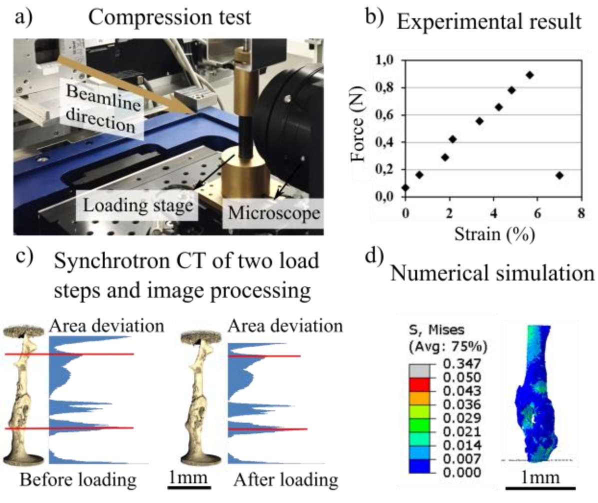

Figure 1: a) Single trabecula compression test set-up, b) experimental result, c) image processing and d) numerical simulation to estimate the Young's moduli.

Displacement of the specimen was estimated by tracking the shift of recognizable peaks in the cross-sectional area profile along the compression direction after deformation. Finite element analyses of the specimens between the selected peaks were performed with boundary conditions given by the estimated experimental displacements. The Young's modulus, E_t, of the trabecula was then estimated using relation $E_t \approx E_t^{fem} \cdot F^{exp} / F^{fem}$, where E_t^{fem} is the Young's moduli used in the FE simulation while F^{exp} and F^{fem} are the reaction forces in the experiments and the simulations, respectively. Homogeneous distribution of local elastic modulus in the specimens and that small deformations prevails were assumed.

Results

Sequential images were used to reconstruct the specimen geometry (Fig. 1). The estimated Young's modulus of the four human trabecular specimens was 6.9, 3.9, 4.3 and 4.2 GPa, respectively (i.e. 4.8 ± 1.9 GPa).

Discussion

The Young's moduli reported herein are within the range of other experiments on single trabeculae (0.76-16 GPa) [1,4]. In this study, however, the specimens were kept hydrated before the tests, which might result in a generally lower elastic modulus. The synchrotron CT provided a high-resolution description of the trabeculae and overcame some earlier experimental limitations in terms of specimen geometry and displacement estimations. The obtained results are encouraging and future studies will focus on acquiring data for a larger number of trabecula specimens to increase the statistical confidence.

References

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