ESTIMATION OF RAT VERTEBRAL STIFFNESS AND STRENGTH USING INVERSE MICRO-FE MODELLING

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Introduction

Micro-structural finite element (FE) analysis has become almost a standard technique for evaluation of mechanical properties of trabecular bone (TB). These micro-FE models can be successfully used not only for estimation of properties of TB samples, but they can be used to calculate the overall properties (stiffness, strength) of whole bones (including the superficial layer of cortical bone).

The reliability of the inverse estimation of the overall mechanical properties depends on the quality of the micro-FE models and on the estimation (or measurement) of material properties at the tissue level. The article deals with the modelling aspects of such inverse micro-FE calculations.

Materials and Methods

Five vertebral (L2) samples of Wistar rats were thawed to room temperature and tomographically scanned using a previously developed setup [Jakubek 2006]. The specimens were irradiated using a micro-focus X-ray tube with 5 μm emission spot. For the imaging a large-area flat panel X-ray detector with resolution 2368 × 2240 pixels was used. The acquisitions were performed using 360 projections with 1° increment. Maximum possible magnification was used, corresponding to source–object distance 170 mm and source–detector distance 500 mm. The images were reconstructed using a cone-beam back-projection algorithm which has been previously proven suitable for precise imaging of trabecular microarchitecture of whole-bone samples [Kytyr, 2011]. Resolution of the reconstructed three-dimensional images was approximately 30 μm^3.

Since the primary aim was determine compressive mechanical properties of whole rat vertebra, voxel-FE models of both cortical and trabecular bone was developed. The inverse problem was solved using a parallel direct solver on 72-CPU SGI Altix system with 512GB RAM.

To compute the overall stiffness and strength of the vertebral body in the infero-superior direction a unit displacement has been prescribed on the top surface of the vertebral body while the lower surface of the body was fixed. The tissue-level material properties were based on our previously published nanoindentation study [Jirousek, 2011].

To make the FE analyses computationally feasible, material properties at the tissue level were considered linear elastic. To estimate the strength of the vertebra using the linear model, we used the approach of [Pistoia, 2001] in which the yield load is reached when the strain value in certain volume of elements reaches the yield strain.

Results and Conclusions

Stiffness and strength of five L2 vertebral bodies of Wistar rats were calculated using inverse micro-FE models. Numerically predicted values were compared to experimentally measured ones.

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References

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