NUMERICAL FAILURE STUDY OF TRABECULAE IN OSTEOPOROTIC DEGRADATION OF LUMBAR VERTEBRAL BODY

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1. Introduction

Reduction of bone mineral density results in an increase in fracture risk which consequences are fraught with not only physical pain, but could also lead to disabilities, and is often fatal ([1]). The osteoporotic bone fractures account for 0.83% of all cases of non-infectious diseases in the world, and 1.75% in Europe. It was established that the relative probability of death after hip fracture in women is increased in 6 times, and after vertebral fracture in 9 times [2].

The problems of osteoporosis appearance, development, early diagnosis, treatment and rehabilitation have been studied by different authors ([3,4]). Bone is active viscoporoelastic material which fracture at different loads can be computed in details by finite element models (FEM), which has been done in a series of published articles and reports ([5–7]). The published results relate mostly to the passive elastic bone and static loads, while investigations of bone as trabecular-cortical structure of vertebra under dynamic loads is still important for understanding of remodelling properties of bone. Therefore, the aim of this investigation is numeric study of trabecular-cortical vertebra structure under axial dynamic load for obtaining stress distribution of trabeculae responsible in bone remodelling.

2. Methods and Materials

The bone tissue is modelled as elastoplastic continuum, so the Von Mises-Hencky criterion is chosen to predict the failure of the model. The selection of this criterion is based on mechanical properties of bone, which seems to behave as a ductile material [8]. The inhomogeneous lumbar vertebral body consists of two basic structural members outer cortical shell fulfilled by inner bone tissue. In this study, the DICOM data of human CT was used for development of initial anatomical geometry of vertebral body. The trabecular tissue was obtained by boolean cut operation of initial anatomical geometry model of vertebra by regular ellipsoid and cylinder systems in open source CAD software SALOME 7 with python script written for this purpose. The Von Mises stress criterion is applied on research of stresses, which occur on cortical shell and on trabecular tissue of the model. The Ramberg-Osgood equation mathematical model of the stress σ strain rate ε behaviour of bone was applied [9]

$$\varepsilon = \frac{\sigma}{E_0} + \left(\frac{\sigma}{K}\right)^n \tag{1}$$

where E_0 is the modulus of elasticity, K is the strain hardening coefficient and n is the strain-hardening exponent. Intervertebral disks were assumed as isotropic and perfectly elastic.

The bone is subjected by the physiological loads, which occur through daily activities. Generally, it presents as the axially acting pressure. Due to non-geometric linearity, the load depends on the displacement values while it's direction during compression changes with the deformed shape of the model. Finally, the model was meshed with tetrahedral grid due to its curvature and finite element method was applied for solving differential momentum equation of motion

$$\rho\frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla\cdot\sigma + \mathbf{f},\ \varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \tag{2}$$

for above proposed model.

3. Numeric Results

The numerical results of static, dynamic analysis and their comparison are presented. Also, the comparison between static and dynamic results is performed and presented graphically. Our results showed that the von-Mises stress was substantially higher at relatively low levels of apparent density, and critical due to thinner cortical shell, ant it suggests the high fracture risk even during daily activities. In addition, this model could be easily individualized according to the peculiar anatomical properties of patient. The developed model reflects cancellous bone and cortical shell, that allows to make the in-silico calculations using the finite element method software in order to make an urgent decision about the state of bone tissue in every individual patient.

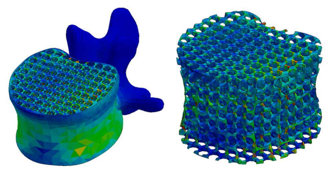

Figure 1. Von Mises stress of trabeculae and cortical shell in elastic region of stresses

4. References

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