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Viscoelastic Behavior of Human Bone Tissue under Nanoindentation Tests

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Abstract : Cancellous bone is a porous composite of a hierarchical structure and anisotropic properties. The biological tissue is considered to be a viscoelastic material, but many studies based on a nanoindentation method have focused on their elasticity and microhardness. However, the response of many organic materials depends not only on the load magnitude, but also on its duration and time course. Depth Sensing Indentation (DSI) technique has been used for examination of creep in polymers, metals and composites. In the indentation tests on biological samples, the mechanical properties are most frequently determined for animal tissues (of an ox, a monkey, a pig, a rat, a mouse, a bovine). However, there are rare reports of studies of the bone viscoelastic properties on microstructural level. Various rheological models were used to describe the viscoelastic behaviours of bone, identified in the indentation process (e. g Burgers model, linear model, two-dashpot Kelvin model, Maxwell-Voigt model). The goal of the study was to determine the influence of creep effect on the mechanical properties of human cancellous bone in indentation tests. The aim of this research was also the assessment of the material properties of bone structures, having in mind the energy aspects of the curve (penetrator loading-depth) obtained in the loading/unloading cycle. There was considered how the different holding times affected the results within trabecular bone.As a result, indentation creep (CIT), hardness (HM, HIT, HV) and elasticity are obtained. Human trabecular bone samples (n=21; mean age 63±15yrs) from the femoral heads replaced during hip alloplasty were removed and drained from alcohol of 1h before the experiment. The indentation process was conducted using CSM Microhardness Tester equipped with Vickers indenter. Each sample was indented 35 times (7 times for 5 different hold times: t1=0.1s, t2=1s, t3=10s, t4=100s and t5=1000s). The indenter was advanced at a rate of 10mN/s to 500mN. There was used Oliver-Pharr method in calculation process. The increase of hold time is associated with the decrease of hardness parameters (HIT(t1)=418±34 MPa, HIT(t2)=390±50 MPa, HIT(t3)= 313±54 MPa, HIT(t4)=305±54 MPa, HIT(t5)=276±90 MPa) and elasticity (EIT(t1)=7.7±1.2 GPa, EIT(t2)=8.0±1.5 GPa, EIT(t3)=7.0±0.9 GPa, EIT(t4)=7.2±0.9 GPa, EIT(t5)=6.2±1.8 GPa) as well as with the increase of the elastic (Welastic(t1)=4.11•10-7±4.2•10-8Nm, Welastic(t2)= 4.12•10-7±6.4•10-8 Nm, Welastic(t3)=4.71•10-7±6.0•10-9 Nm, Welastic(t4)= 4.33•10-7±5.5•10-9Nm, Welastic(t5)=5.11•10-7±7.4•10-8Nm) and inelastic (Winelastic(t1)=1.05•10-6±1.2•10-7 Nm, Winelastic(t2) =1.07•10-6±7.6•10-8 Nm, Winelastic(t3)=1.26•10-6±1.9•10-7Nm, Winelastic(t4)=1.56•10-6± 1.9•10-7 Nm, Winelastic(t5)=1.67•10-6±2.6•10-7)) reaction of materials. The indentation creep increased logarithmically (R2=0.901) with increasing hold time: CIT(t1) = 0.08±0.01%, CIT(t2) = 0.7±0.1%, CIT(t3) = 3.7±0.3%, CIT(t4) = 12.2±1.5%, CIT(t5) = 13.5±3.8%. The pronounced impact of creep effect on the mechanical properties of human cancellous bone was observed in experimental studies. While the description elastic-inelastic, and thus the Oliver-Pharr method for data analysis, may apply in few limited cases, most biological tissues do not exhibit elastic-inelastic indentation responses. Viscoelastic properties of tissues may play a significant role in remodelling. The aspect is still under an analysis and numerical simulations. Acknowledgements: The presented results are part of the research project founded by National Science Centre (NCN), Poland, no.2014/15/B/ST7/03244.

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