ESTIAMTION OF THE DENSITY OF THE TRABECULAR BONE TISSUE BASED ON HIGH RESOLUTION COMPUTED TOMOGRAPHY

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Summary: The methodology of determination of trabecular bone density using micro-CT approach is presented in the paper. The four type of densities are defined: trabeculae density, material density, apparent density and marrow density. The experimental results for cows in different stages of life (from one year old to nine years old) are presented. A conclusions about evolution of all four densities are drown.

1. INTRODUCTION

The bone density is a crucial parameter to determine the bone tissue strength. Two factors have the biggest influence on the Young moduli of trabecular bone: the density (almost 76%) and the trabeculae anisotropy (together with density nearly 98%) [1]. The determination of bone density is an important part of any study of mechanical properties of the bone. The correct values are also needed to model the behaviour of bone using FEM. Micro tomography gives the new and reliable tools to solve this problem.

2. EXPERIMENTAL METHOD

Trabecular bone tissue may be considered as a composition of trabeculae and marrow, which is mixture of water and fat. The trabeculae consist of mineral and organic part. Several studies collected in the work of Wagner [2] prove that organic part of the bone varies between 32% and 38% of the bone volume depending on the study and animal species. In this work the value of 33% was chosen, as the closest to the most of the reported results.
Four parameters describing density are defined:

- apparent density (ρ_A) – is a density of the whole trabecular tissue,
- trabecular density (ρ_T) – is a density of the trabeculae only
- material density (ρ_M) – is a density of the mineral part of the trabeculae, based on this value the mineral content may be calculated,
- marrow density (ρ_{MR}) – is a density of the mixture of water and fat filling pores inside the trabecular bone tissue.

To determine all four densities 76 cubic specimens (1cm^3) of trabecular bone were taken from upper head of bovine femur. The specimens were taken from six different slaughter animals in various ages between one-year-old to nine-year-old. The specimens have various porosity and depending on the age and part of the femur head have various mineral content. All specimens were measured using X-ray micro-CT on a Nanotom 180N (GE Sensing & Inspection Technologies, Phoenix X-ray GmbH). The machine is equipped with a nanofocus X-ray tube with a maximum 180 kV voltage. The tomograms were registered using a Hamamatsu 2300 × 2300 pixel 2D detector. The reconstruction of measured specimens was performed using datosX ver. 2.1.0 (GE) with the use of a Feldkamp algorithm for cone beam X-ray CT. The post reconstruction data treatment was performed using VGStudio Max 2.1 and free Fiji software with the BoneJ plugin [4]. All examined specimens were scanned at 100 kV of source voltage and 100 uA, with a 360-degree rotation of the specimen in 1800 steps. The exposure time was 500 ms, with a frame averaging of 3 and image skip of 1 applied, resulting in a scanning time of 60 minutes.

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The reconstructed images had a voxel size of 6.5 um^3.

Volume of trabeculae and volume of a marrow for each specimen were determined. After that each specimen was heated in the electric furnace at 300 Celsius degree for a period of 3 hours. After this process, all the organic part of the specimen as well as the water were evaporated from the trabecular bone. Each specimen bean weighted before and after heating.
The following symbols are used in the equations: V_{TS} – tissue (total) volume, V_{TR} – volume of trabeculae, V_{OR} – volume of organic part inside the trabeculae, V_M – marrow volume, m_B – mass before heating, m_A- mass after heating.
All volumes except of V_{OR} are measured by micro-CT scans. The organic part of the trabeculae is located in the regions much smaller than micro-CT resolution. According to the work [1] mentioned previously the V_{OR} was calculated as 33% of V_{TR}. For the same reason the density of the organic part can't be determined experimentally with our setup. We decided to assume ρ_{OR} =1.4 g/cm what is suggested in [3].
Finally, the four density values for each specimen were calculated using the formulas:

$$\rho_M = \frac{m_A}{V_{TR}-V_{OR}}, \rho_A = \frac{m_A}{V_{TS}}, \rho_T = \frac{m_A+\rho_{OR}\cdot V_{OR}}{V_{TR}}, \rho_{MR} = \frac{M_B-M_A-\rho_{OR}\cdot V_{OR}}{V_M}, V_{OR} = V_{TS} - V_{TR}, V_{OR} = 33\% \cdot V_{TR}$$

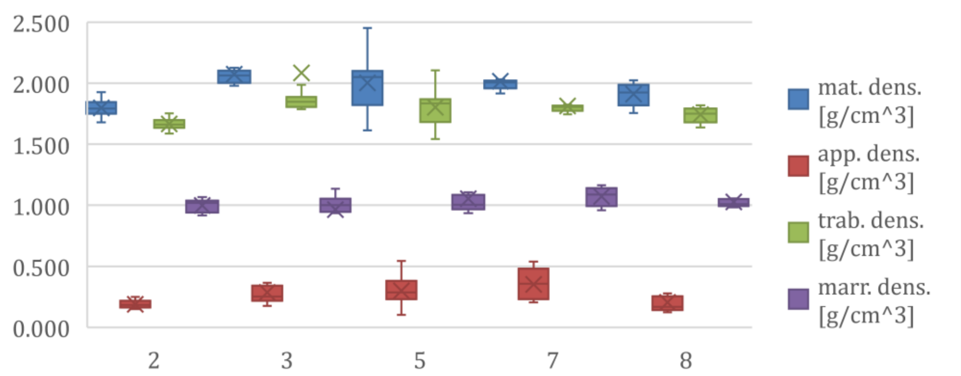

Figure 1: Evolution of material, apparent, trabecular and marrow densities during the life of the animal

3. RESULTS

Evolution of all four densities during the life of the animals were determined. Two assumptions were done during calculations: the density of the organic part and the relation between trabecular volume and its organic part volume were assumed. The statistical dispersion of a results is greater than uncertainty of assumed values.
From the figure 1 it can be seen, that material and trabecular densities change parallelly and have the highest values for medium age animals (between 3 and 5 years old). The apparent density grows up till 7 years and then suddenly drop even lower than for one year old cow. The marrow density seems to be constant during the animal life. Observed shift between maximum of material density and apparent density can be explained by thickening of trabeculae for older animals which gives greater apparent density even with lower material density. This behaviour may prolongate the period of the highest strength of animal bone. All these conclusions may be verified by analysis of trabecular tissue topology and morphology, what will be done in future.

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