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RELATIONS BETWEEN FRACTAL DIMENSION AND VOLUME OF TRABECULAR BONE AND ITS BEHAVIOUR UNDER LOADING

T. Topoliński*, A. Cichański*, A. Mazurkiewicz*, K. Nowicki*, S. Jung**

Abstract: *Two parameters of bone microarchitecture: volume of bone layer and fractal dimension were used. 42 human bone samples were cut to cylindrical testing samples of 8.5 mm thickness and 10 mm diameter. We obtained 230 images (microCT) which, using binarisation technique, were transformed into pixels and voxels. We created geometrical mesh of layers of bone mass. This allowed the calculation of each layers volume and fractal dimension. Fractal dimension for each single layer has been calculated applying set of voxels using Sarkar's and Chaudhuri's box-counting algorithm. When comparing scatter for layers' volume and scatter for layers' fractal dimension we can see that scatter is clearly higher for volume. This might mean that relative scatter for fractal dimension is narrower, thus in diagnostic procedure fewer measurement data of fractal dimension than of volume are sufficient to conclude about bone structure.*

Keywords: ***MicroCT, bone structure, bone volume, fractal dimension.***

1. Introduction

The fact that life expectancy is constantly increasing imposes new challenges for medicine with the aim of providing not only longer life, but also good physical and mental health. One of the factors that contributes to the quality of life is physical fitness, which involves bone strength adequate for one's lifestyle. It is a natural phenomenon that bone density decreases with time, and this process starts at the age of 25-28, at first slowly and then at an accelerating rate (Seeman E., 2008).

These changes occur along with the decreasing activity of a person. The problem begins when the decrease of 'bone in bone' – usually osteoporosis related – definitely exceeds the norm, it can lead to fracture of the bone and fracture of femoral neck, distal radius or vertebral body are most common.

We ascertained that the process of destruction of the loaded bone is localized only at certain parts of the sample. Using microCT we obtained layers of 36 micrometers thickness. This allowed to determine the volume and fractal dimension for each sample. Analysis of variability of these bone structure indicators may show more effective one in the analysis of bone strength.

2. Materials and methods

2.1. Specimen

We tested trabecular bone samples. Samples were collected from 42 femoral heads (21 osteoporotic and 21 arthritic), the mean age of the patients with osteoporosis was 77 yrs (range 63 - 91) and the mean age of the patients with osteoarthritis was 70 yrs (range 50-79). These specimens were obtained during hip arthroplasty. First, slices were cut out from the base of the head 8.5 mm thickness, perpendicular to the axis of the neck of the bone. Next, from the central region of the slices, samples were cut out in the shape of a cylinder, about 10 mm diameter and 8.5 mm height. The method of obtaining samples is shown in Fig. 1.

* prof. Ing. Tomasz Topoliński, Ing. Artur Cichański Ph.D., Ing. Adam Mazurkiewicz Ph.D.and Ing. Krzysztof Nowicki Ph.D.: Faculty of Mechanical Engineering, University of Technology and Life Sciences, Kaliskiego 7 Street; 85-789, Bydgoszcz; PL, e-mails: tomasz.topolinski@utp.edu.pl, artur.cichanski@utp.edu.pl, adam.mazurkiewicz@utp.edu.pl, krzysztof.nowicki@utp.edu.pl

** Stanisław Jung: South Tyneside Hospital, South Shields, UK

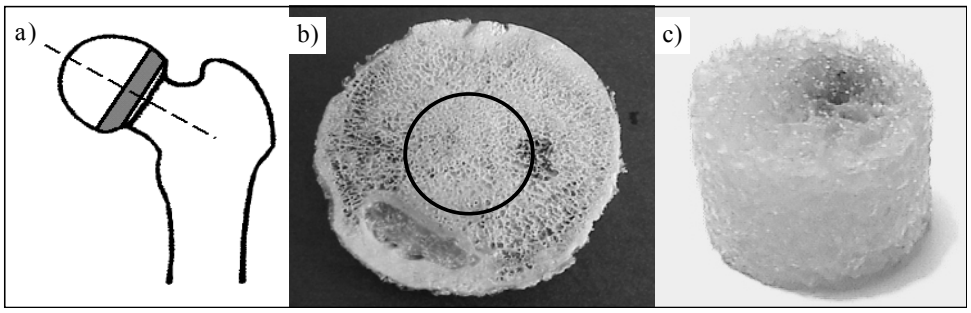

Fig. 1: Method of obtaining sample: a) cutting of slice; b) cutting of sample; c) final shape.

2.2. Micro CT technique

MicroCT investigations of cylindrical samples were done on µCT 80 machine (SCANCO Medical AG, Bruettiselllen, Switzerland) with resolutions of 36 µm and with basic parameters: 70 kV, 114 µA, 500 projections/180°, 300 ms integration time. Thus we obtained around 230 scans for each sample. In this algorithm, single layers of a model were created by comparing images of two neighboring scans.

2.3. Volume calculation

On the basis of obtained images, bone volume was calculated for every layer and for sample: minimum volume V_{min}, maximum volume V_{max}, mean volume V_m, and standard deviation SD_v. Then we related SD_v to mean volume and we obtained relative standard deviation (RSD_v). Bone volume for layer was performed by calculating number of bone voxels of known dimensions. The resulting volume indicators for individual samples are shown in Fig. 2 (the numbering of the samples in Fig. 2 is used to determine the clinical case and has no connection with the calculated values of volumes).

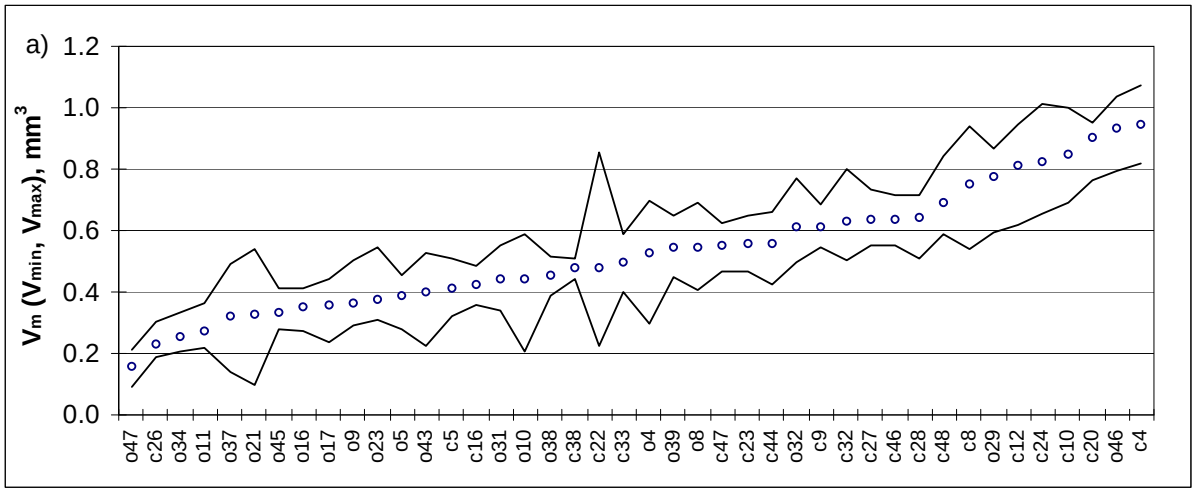

Fig. 2: Values of layer volume V.

2.4. Fractal dimension

To calculate fractal dimensions we applied box - counting method (Chen S.S., Keller J.M., Crownover R.M., 1993) using Sarkar's and Chaudhuri's algorithm (Sarkar N., Chaudhuri B.B., 1994). For each single layer, the fractal dimension Df was calculated and then the mean (Df_m), minimum (Df_{min}), maximum (Df_{max}) and standard deviation SD_{Df} values of those dimensions for each sample was determined. The relative standard deviation as standard deviation of fractal dimension to mean fractal dimension was calculated (RSD_{Df}). The resulting fractal dimension indicators for individual samples are shown in Figure 3 (the numbering of the samples in Figure 3 is used to determine the clinical case and has no connection with the calculated values of fractal dimensions).

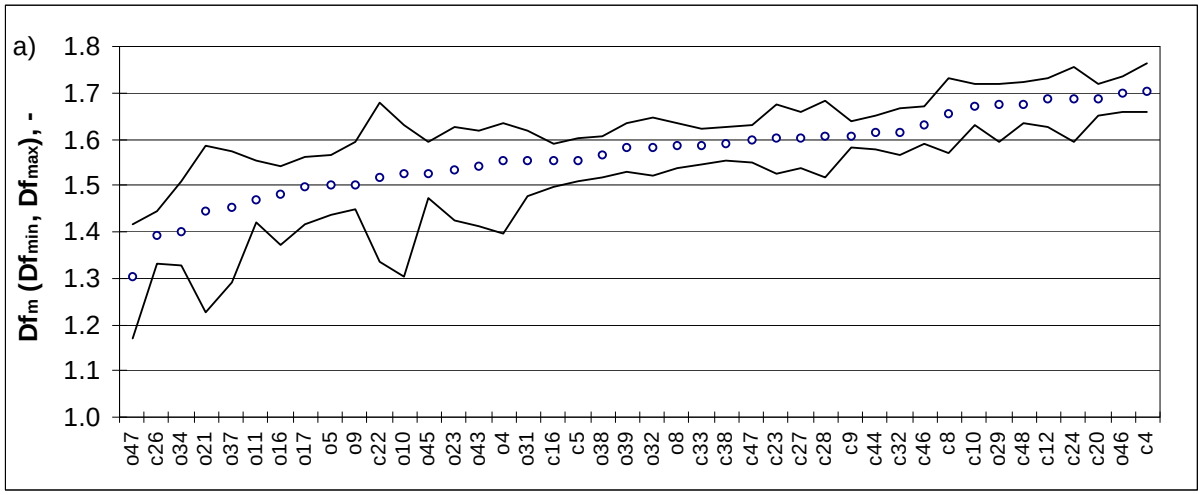

Fig. 3: Values of fractal dimension of layer Df.

3. Results

In both Figs. 2 and 3 the arthritic samples were marked as *c* while the osteoporotic – as *o,* although we did not assessed these samples according to etiology.

The range of variability of mean bone volume of the layers is between 0.18 and 0.94 mm^3, mean 0.54 mm^3 (Fig. 2). This variability is within the range from 42.6% and 174.8% of the mean value of the volume. Variability of the values of the volume of the layers is significant, 21 of 42 samples had relative standard deviation RSD_v below 10%, 15 of 42 samples –between 10 and 20% (closer to 10%), the remaining samples i.e. six are above 20% (in two cases above 30%).

The range of variability of mean fractal dimension (Fig. 3) is within 1.3 to 1.7 with mean value of 1.56. This variability is within the range between 83.1% and 108.7% of the mean value of the fractal dimension. The variability of the fractal dimension of the layers of the samples described by relative standard deviation RSD_{Df} is smaller than for relative standard deviation for volume. It is no more than 2% for 26 of 42 samples and between 4 to 6.5 % - for 4 samples. The remaining twelve samples are within 2 to 4 % of RSD_{Df}.

4. Discussion

Analyzing the process of volume variability (Fig. 2), it can be seen that the differences between the maximum and minimum values are similar in the whole range of mean volume variability. However the relative standard deviation slightly decreases with growth of mean volume of sample's layer. It proves that the uniformity of distribution of the bone tissue in the volume of the samples grows together with growth in mean volume.

Analyzing the process of variability in fractal dimension for the layers of the samples (Fig. 3), it can be seen that the difference between the minimum and maximum values is clearly bigger for samples of lower mean values of this dimension, i.e. for samples of less dense trabecular structures. These big differences between minimal and maximal values of Df may be in keeping with Bousson et al (2006) who found that for low BMD values local-microscopic variables contribute more to bone strength than macroscopic variables. Values of relative standard deviation of fractal dimension slightly decrease with increase of mean fractal dimension.

When comparing RSD for layers' volume and for layers' fractal dimension we can see that RSD is clearly higher for volume. This might mean that relative scatter for fractal dimension is narrower, thus in diagnostic procedure fewer measurement data of fractal dimension than of volume are sufficient to conclude about bone structure.

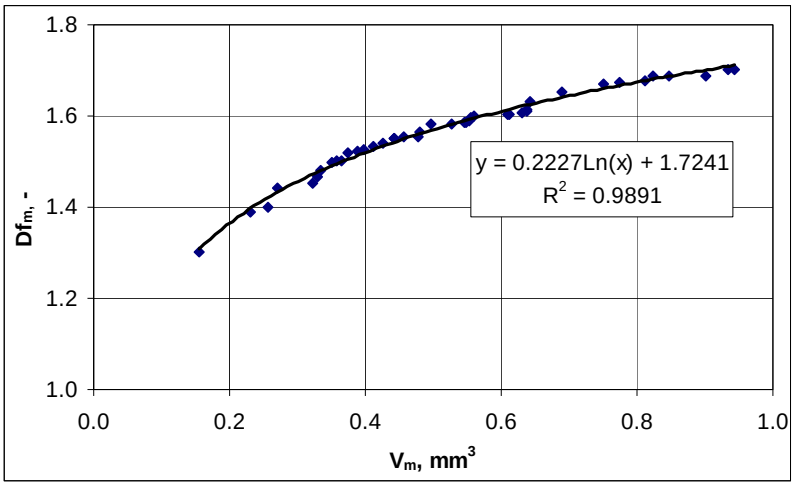

Fig. 4: Variability of mean fractal dimension in relation to mean volume.

There is a correlation between evaluated mean volume and mean fractal dimension (Fig. 4) (described by logarithmic function) and it is very strong as determination coefficient is nearly 1.

Acknowledgement

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