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RELATIONSHIP BETWEEN FATIGUE LIFE AND STRUCTURE OF HUMAN TRABECULAR BONE

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Abstract: *In the work results of investigation of fatigue behaviour of human trabecular bone are presented. In total, 61 samples were collected from human trabecular bone after hip arthroplasty. Samples were examined on microCT device. As the result, values of four structural indices (BV/TV, Tb.Th, Tb.N and BS/BV) describing the structure of trabecular bone were obtained. The fatigue tests of the samples were carried out with stepwise increasing amplitude. From the test obtained fatigue life N_s was found between $3{,}75 \cdot 10^3$ cycles and $5{,}02 \cdot 10^4$ cycles. Relations between fatigue life and structure indices were described by determination coefficient R^2. Values of the coefficient were found in range 0,49-0,69. On the base of the obtained results we ascertained existing relation between selected structure indices and fatigue life obtained from test with stepwise increasing amplitude.*

Keywords: ***Trabecular bone, Fatigue life, Structure indices of trabecular bone***

1. Introduction

A typical loading for bone, eg. during gait is the cyclic loading variable in time, and thus behaviors under such loading are fatigue behaviors (Taylor & Tanner, 1997; Martin, 2003). Thus, apart experiments with bone samples subjected to static compression, bending or torsion, research is carried out under cyclic variable loadings. These investigations include the cortical bone parts (Evens & Riolo, 1970) and the trabecular bone parts (Bewill et. al., 2009; Ding et. al., 2003).

The aim of the work is to determine relationship between fatigue life N_s under cyclic loadings with stepwise increasing amplitude and structural indices of human trabecular bone.

2. Material and Method

Investigated material were 61 samples of human trabecular bone. Samples were collected from osteoporotic and coxarthrotic femoral heads gained in result of hip arthroplasty. Diameter of the samples was 10 mm and height 8,5 mm. The age of the patients ranged from 46 to 88 years with an average of 73 years. The samples were obtained from 40 women and 21 men and were stored in 10% formalin solution at the room temperature. Position and direction of the sample in the femoral head is schematically shown in. Fig. 1

Samples were examined using a microCT device (μCT80) with resolution 36 microns (parameters: 70 kV, 114 μA, 500 projections/180°, 300 ms integration time). As a result, values of four structural indices of samples were obtained. Description the indices (Parfitt & Drezner, 1987) are included in Table 1.

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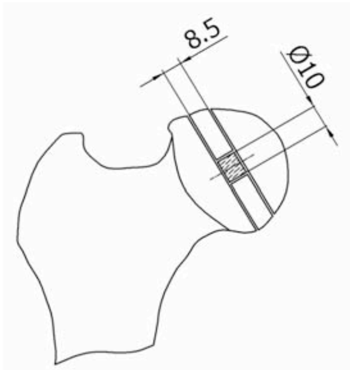

Fig. 1: Trabecular bone sampling method. The sample axis coincided with the axis of the head and neck of the femur.

Tab. 1: Description structure indices investigated on microCT system.

Indicator	Name	Description
BV/TV	Bone volume fraction	Volume of bone tissue inside sample BV /volume of sample TV
Tb.Th	Trabecular thickness	Mean thickness single trabeculae in sample
Tb.N	Trabecular number	Mean number continuous trabecular inside sample
BS/BV	Bone surface ratio	Surface of bone tissue inside sample BS/volume of bone tissue inside sample BV

The bone sample fatigue tests were carried out under compression with stepwise increasing loading using the testing machine INSTRON 8874. The frequency of sinusoidal loading was 1 Hz, the minimum loading for all the loading levels was 5-7 N. The maximum loading started from 20 N with a gain every 10 N at successive steps. Each level of load maintained 500 cycles realized under constant amplitude loadings. Program of the fatigue test is presented in Fig. 2.

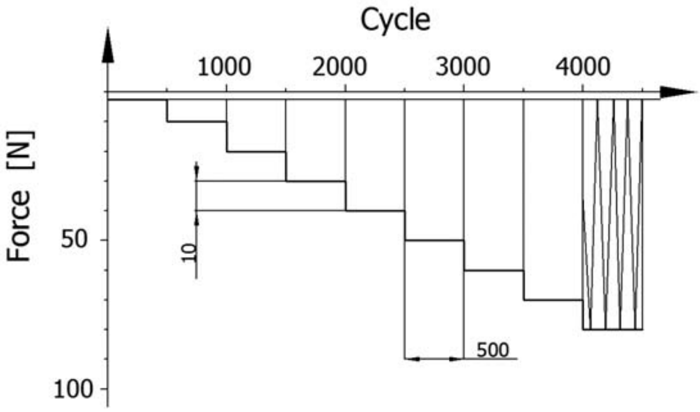

Fig. 2: Program of the fatigue test.

Fatigue life N_s was determined by estimation of the median of the values of deformation increment and then considering the value of the first loop for which the deformation gain exceeded the value of the median by 10% (to be the fatigue life).

The temperature plays an important role in fatigue tests because it influences the obtained fatigue life. Therefore the tests were conducted in 0,7% NaCl water solution in constant temperature 37±2 ^{0}C, which corresponds to the normal human body temperature.

3. Results

Structural indices of trabecular bone obtained from microCT investigation are presented in Tab. 2. For investigated indices relation between the fatigue life N_s described value determination coefficient R^2 was minimum 0,49 (it corresponds value of correlation coefficient R=0,7).

Fatigue tests with stepwise increasing loading demonstrated the fatigue life of the trabecular bone samples between $3{,}75 \cdot 10^3$ cycles and $5{,}02 \cdot 10^4$ cycles (time of test between 1,04 h and 13,95 h).

Tab. 2: Values of selected indices structure of trabecular bone obtained from microCT investigation.

Indicator	Value				
	Min	**Max**	**Mean**	**SD**	**RSD**
BV/TV,-	0,0759	0,4595	0,2049	0,0759	37 %
Tb.Th, mm	0,1053	0,2677	0,1714	0,0354	21 %
Tb.N, 1/mm	0,511	1,544	1,133	0,222	20%
BS/BV, 1/mm	5,206	18,995	11,998	2,747	23%

Min - minimum value, Max - maximum value, Mean - mean value, SD - standard deviation, RSD - relative standard deviation

Relationship between fatigue life and BV/TV and Tb.Th is presented in Fig. 3 and 4. Relationship between fatigue life and Tb.N. and BS/BV is presented in Fig. 5 and 6.

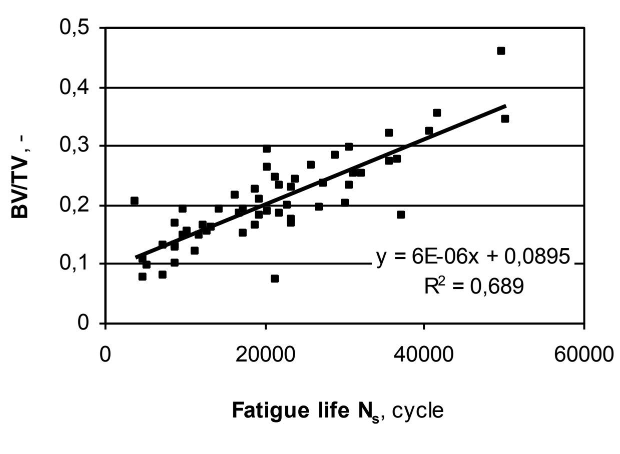

Fig. 3: Relationship between bone volume fraction BV/TV and fatigue life N_s.

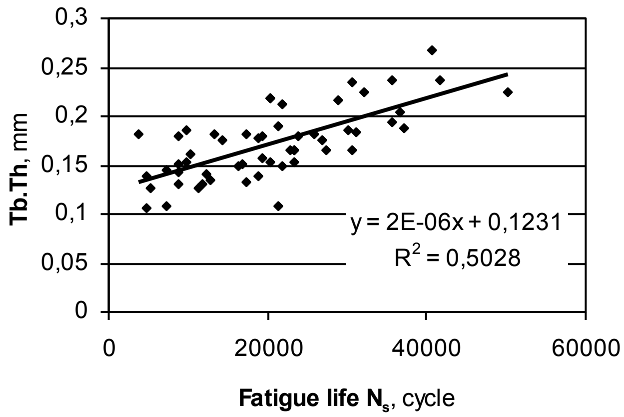

Fig. 4: Relationship between trabecular thickness Tb.Th and fatigue life N_s.

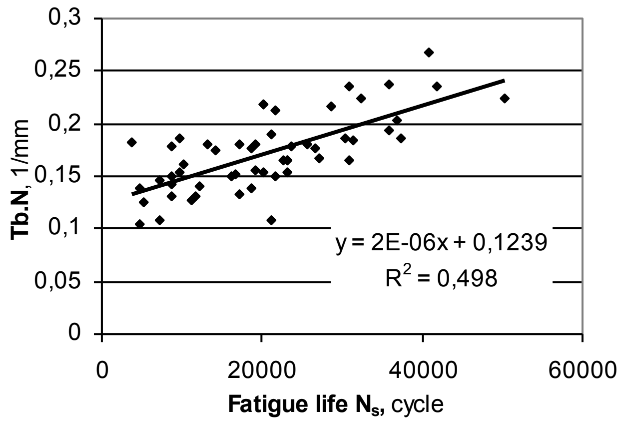

Fig. 5: Relationship between trabecular number Tb.N and fatigue life N_s.

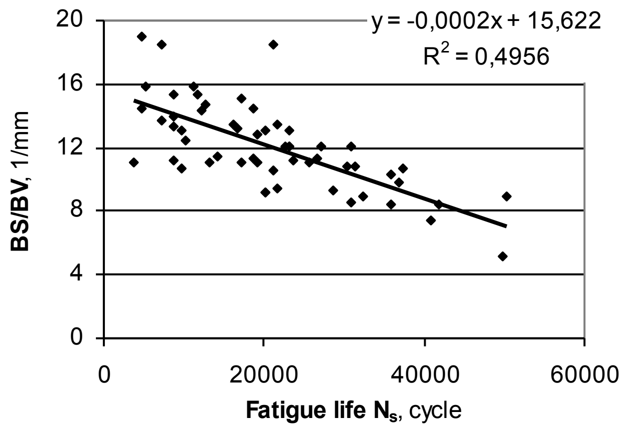

Fig. 6: Relationship between bone surface ratio BS/BV and fatigue life N_s.

4. Conclusions

Indices BV/TV and Tb.Th are often use for description of the trabecular bone. For the investigated samples value of indices varying in wide range (0,08-0,46 and 0,11-0,27 for BV/TV and Tb.Th respectively) and significant values SD or RSD.

From the comparison of obtained relation between fatigue life and structure indices with results other investigators was impossible, because majority fatigue tests trabecular bone was carried out with constant load amplitude. Therefore it is possible comparison ours results with the similar relations obtained during this kind of test.

Haddock et. al. (2004) presented results fatigue test trabecular bone carried out constant load amplitude. The scatter of BV/TV values for 35 samples (9 donors RSD=38,5%) was comparable with the scatter obtained in our experiment (61 donors and RSD=37%). Obtained fatigue curve was described by the value of coefficient of determination R^2=0,54.

Rapillard et. al. (2006) obtained for 29 samples from 4 donors scatter higher than in our experiment (RSD=42,5%), however they introduced the stress modification, included in fatigue equation volume fraction and the fabric eigenvalue. It resulted in a higher correlation between the stress and the fatigue life R^2=0,95 (fatigue test was also carried out under constant load amplitude).

Concluded, the relationship between the fatigue life results and structure indices, does exist. The highest value coefficient of determination R^2=0,69 obtained for bone volume fraction. In opinion of authors these relations cover not only the bone properties (structure characteristics, damage and the effects of remodeling) but also the specificity of the fatigue damage process for stepwise loading with the dynamics, also associated with the bone properties.

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