APPLICABILITY OF INDICATORS OF TRABECULAR BONE STRUCTURE FOR EVALUATION OF ITS MECHANICAL PROPERTIES

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Abstract: The paper presents the results of examination of relations between indicators describing trabecular bone structure and its static and cyclic compressive strength. Samples of human trabecular bone were subject to microtomographic tests in order to specify indicators describing its structure. Part of the samples was subject to static compression tests, part to cyclic compressing loads with stepwise increasing amplitude. Evaluation of a degree of applicability level of estimation of bone compressive strength properties was conducted based upon values of structure indicators. Evaluation was performed based upon values of obtained determination coefficients R2 for linear regression. Obtained R2 values were within the range of 0.30-0.51 for relations between examined indicators and static compressive strength within the range of 0.47-0.69 for relations with the results of cyclic test with stepwise increasing amplitude.

Key words: Trabecular Bone, Testing Method, Bone Structure Indicators

1. INTRODUCTION

Structure of human bone is subject to constant changes depending on various factors e.g. human activity, type of work performed etc. After 20-30 year of age a process of decreasing of bone mass commences. It results in the change of bone structure describing indicators and decrease of compressive strength properties of bone tissue (Biewener, 1993; Taylor and Tanner, 1997; Warden et al., 2006). If, with age diseases impairing bone metabolism occur, such as e.g. osteoporosis, dynamics of such changes increases (Rapillard et al., 2006).

Typical bone load is the compressing load applied to e.g. long bones of lower limbs or spine. It is a cyclic load e.g. during walking, thus behaviour under such load is the fatigue behavior (Warden et al., 2006; Keaveny et al., 1993; Martin, 2003).

The target of the hereby paper is to specify applicability of indicators describing trabecular bone structure for the description of its compressive strength properties specified in static compression test and cyclic compression test under loads with stepwiseincreasing amplitude.

2. MATERIAL AND METHODS

For static tests 42 and for cyclic tests 62 samples of human trabecular bone were used, taken from human femur head. The samples were not divided into sub-groups acc. To e.g. age, sex, type of disease or any other factors. Preparations the samples were made of were obtained as a result of implantation of femoral joint.

Samples were in the shape of a cylinder of diameter of 10mm and height of 8.5mm. Sample taking manner is presented on Fig. 1. A slice of 8.5mm thickness was cut from the head base perpendicularly to neck axis, then a cylinder of 10mm diameter and 8.5mm height was cut from central part of the slice.

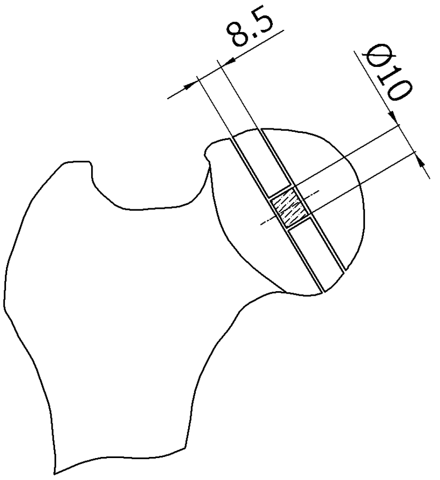

Fig. 1. Manner of taking samples for tests

All samples were tested at micro-tomograph μCT80 at separation of 36μm between subsequent scans for the following parameters: 70kV, 114μA, 500 projections/180°, and 300ms integration time. Upon scanning, as standard, values of 5 bone structure indicators were obtained: average constant trabecular number per sample volume – Trabecular Number Tb.N, average trabecular thickness in a sample – Trabecular Thickness Tb.Th, average trabecular separation in a sample - Trabecular Separation Tb.Sp, quotient of tissue volume vs. volume of the whole sample – Bone Volume Fraction BV/TV, and quotient of tissue surface field in a sample vs. its volume – Bone Surface Ratio BS/BV (Parfitt et al., 1987).

Static compression test was made on strength testing machine MiniBionix 858. The test defined compression strength of samples indicated as US (Ultimate Strength).

In the first part of a test five cycles of loading and relieving for deformation value from ε=0 to ε=0.8% were performed. Initial load, for which ε=0 was assumed, was specified as 50N. Intervals between cycles were five seconds. The cycles were made to stabilize contact surfaces of sample-machine. Test program is presented at Fig. 2.

At the next stage the test was performed until obtaining of compression strength value i.e. obtaining the first maximum at compression curve. From the specified curve compression strength value US was calculated, i.e. stress value at the first curve maximum point.

Static test was performed at room ambient temperature.

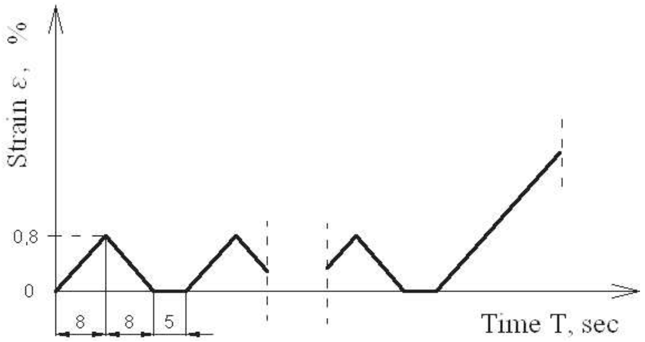

Fig. 2. Static compression test program

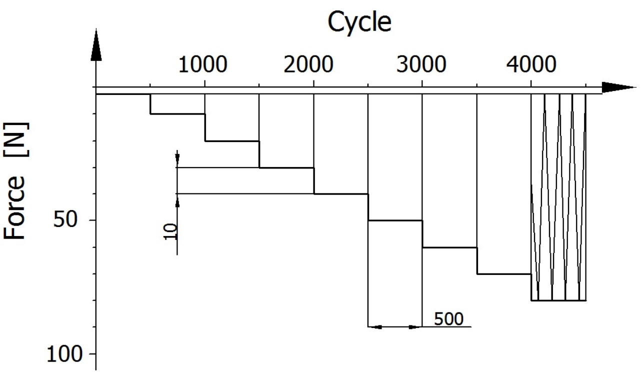

Fig. 3. Cyclic test with stepwise increasing amplitude program

Cyclic tests of bone samples were performed in the conditions of compression upon stepwise increasing load at strength testing machine INSTRON 8874. Frequency of changes of sinusoidal load was 1 Hz. Minimum load for all load levels was 5N. Maximum load started at 20N with 10N increments at subsequent stages. Volume of stages is 500 cycles realized in fixed amplitude conditions. The test program is presented at Fig. 3. During every tests 10 cycles recording of sample load and deformations was made with 100 Hz sampling. Measuring signal from strength testing machine processed with low-pass filter cutting off frequencies exceeding 10Hz in order to equalize current interferences and the noise of measuring devices (dynamometer).

In order to identify fatigue life median of values of deformations increments was specified; then, the first loop, was identified as the value of fatigue life N, for which deformation increment exceeded the value of the specified median by 10%.

Cyclic tests were performed in controlled environment – 0.9% solution of NaCl at temperature of 37±2°C.

3. TEST RESULTS

Tables 1-2 present ranges, average values and standard deviations, relative RSD values of structure indicators obtained from microtomographic tests for groups of samples subject to static compression and cyclic test. Tab. 3 presents analogical values achieved for US compressive strength and fatigue life N obtained in static compression test and in cyclic test with stepwise increasing load.

Tab. 1. Ranges, average values and standard deviations relative values of structure indicators obtained from microtomographic tests for samples subject to static compression

	BS/BV, 1/mm	BV/TV, -	Tb.N, 1/mm	Tb.Th, mm	Tb.Sp, mm
Min.	7.737	0.068	0.76	0.089	0.331
Max.	22.505	0.392	1.958	0.259	1.223
Average	13.903	0.222	1.436	0.151	0.572
RSD, %	22	36	19	24	32

Tab. 2. Ranges, average values and standard deviations relative values of structure indicators obtained from microtomographic tests for samples subject to cyclic test

	BS/BV, 1/mm	BV/TV, -	Tb.N, 1/mm	Tb.Th, mm	Tb.Sp, mm
Min.	5.206	0.066	0.511	0.105	0.424
Max.	18.995	0.459	1.543	0.384	1.829
Average	11.998	0.204	1.1329	0.176	0.749
RSD, %	23	37	20	26	34

Tab. 3. Ranges, average values and standard deviations relative values of US compressive strength and fatigue life N, obtained in static compression test and cyclic test with stepwise increasing load

	US, MPa	N, number of cycles
Min.	1.678	$9.75 \cdot 10^3$
Max.	36.143	$3.52 \cdot 10^4$
Average	12.675	$20.73 \cdot 10^3$
RSD	55%	55%

Tab. 4. Values of R2 determination coefficients for relations between bone structure indicators and its static compressive strength and cyclic strength

Indicator	Static compressive strength US, MPa	Fatigue life N, number of cycles
BS/BV, 1/mm	0.44	0.50
BV/TV, -	0.51	0.69
Tb.N, 1/mm	0.30	0.50
Tb.Sp, mm	0.36	0.47
Tb.Th, mm	0.48	0.50

Tab. 4 presents values of R^2 determination coefficients, obtained with application of linear regression for relations between bone structure indicators and its static compressive strength and fatigue life.

Figs. 4-5 present dependencies between BV/TV and Tb.Th and static compressive strength US

Figs. 6-7, on the other hand, present dependencies between BV/TV and Tb.Th and fatigue life obtained during the test with stepwise increasing amplitude.

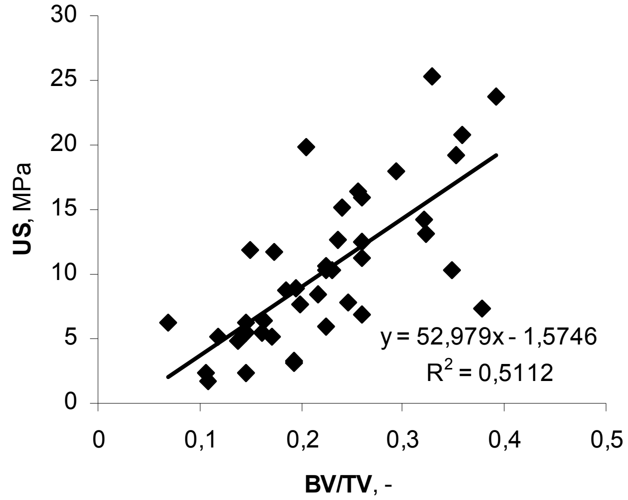

Fig. 4. Relation between BV/TV and static compressive strength US

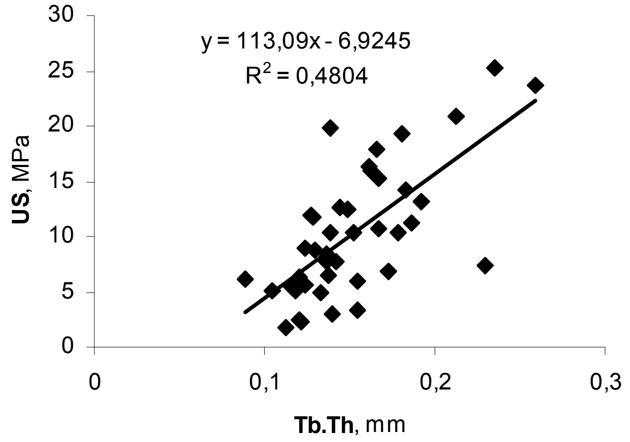

Fig. 5. Relation between Tb.Th value and static compressive strength US

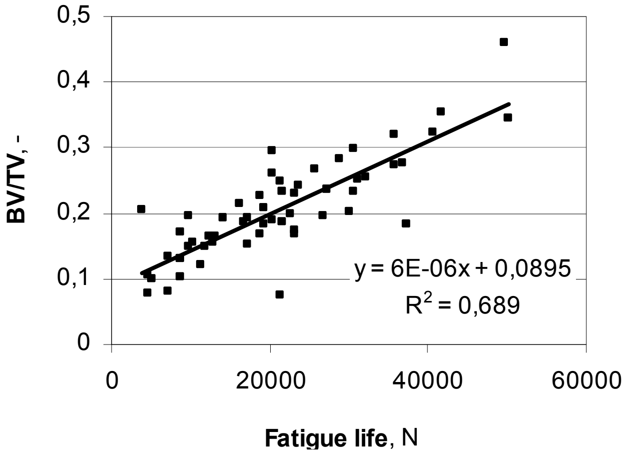

Fig. 6. Relation between BV/TV value and fatigue life obtained during the test with stepwise increasing amplitude

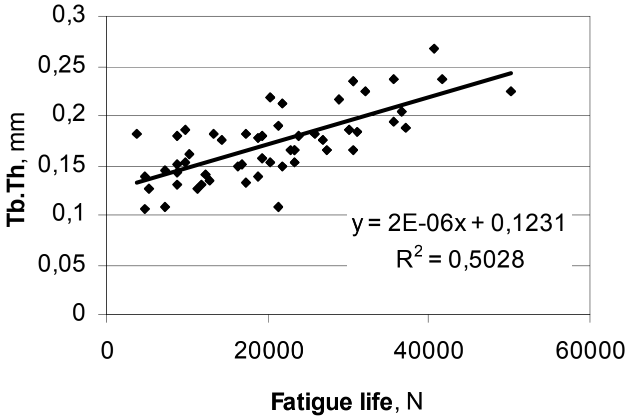

Fig. 7. Relation between Tb.Th value and fatigue life obtained during the test with stepwise increasing amplitude

4. DISCUSION

Performed tests refer to samples from over 100 donors thus on relatively big population. Usually (Rapillard at al., 2006; Haddock et al., 2004; Zioupos et al., 2008) tests refer to no more than 10 donors and the samples are multiplied by taking of more than a single sample from each donor. Thus, we are dealing with significant variability of sample structures resulting from individual properties and pathological properties (osteoporosis, coxarthrosis**).** If the structure was described with variability of relative BV / TV volume coefficient, it would be 36-37%, which is close to maximum values of variability quoted in literature (Haddock et al., 2004). Both performed tests are statistically homogenous – examined relative structure indicators differ maximally by 2%.

The measure of strength of connection of two independent factors in functional description of regression is R^2 determination coefficient. Referring the results obtained from structure tests for first group to static compressive strength determination coefficient R^2 for tested indicators was specified up to the value of 0.5 – the highest value for BV/TV. For the second group the same value, but for fatigue life, is 0.69 which can be considered high for this variability. Also, for all other structure indicators with respect to fatigue life, determination coefficient value is significantly higher. It indicates that examinations of bone fracture risk testing method with stepwise increasing amplitude allows for obtaining better correlation with bone structure, in particular with BV/TV indicator.

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