densitometry test, bone tissue,
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THE INFLUENCE OF BONE TISSUE MICROSTRUCTURE' PARAMETERS ON BONE MINERAL DENSITY PARAMETER COMPUTED WITHIN THE COMPUTER SIMULATION PROCESS

The given article was created with reference to lack of correlation between results from densitometry test of bone tissue and its mechanical strength. The changes of bone mechanical strength cannot be solely connected with changes of bone mineral density with micro structural construction of bone tissue. The article describes the research using a computer simulation where changes of physical density and parameters of bone microstructure were modelled. The influences of those parameters for changing the bone mineral density have been computed. It has been calculated during simulation process similar to the way it has been provided from densitometry test. The computation process has been carried out on the basis of computer method of simulation of x-ray radiation propagating through the object and had been was created and tested in the previous research. The model of tested object was defined by spatial high resolution distribution of density. The simulation was executed on a sample of bone tissue. The input data to the model of sample were series of cross-sections obtained previously from micro CT of an animal sample. The changes of parameters were simulated in the model based on a method of 2D image processing. The procedure was used to reduce the trabecular surface for all cross-sections. The results of the algorithm were measured during algorithm process. Images were also analyzed by software to measure parameters of microstructure. It gave a chance to estimate the correlation between measured parameter and parameters of microstructure. The applied method of simulation of attenuation of x-ray radiation allowed to produce densitometry image and to compute parameter similar to bone mineral density. The analysis of obtained results shows how the bone mineral density computed from simulation depends on changes of parameters of microstructure.

1. INTRODUCTION

It has been widely known that results from densitometry test, which were realised based on Dual Energy X-ray Absorptiometry are not fully related to mechanical properties of a bone. The coefficient obtained from this medical test has been known as a bone mineral density unit which has a unit equal to [g/cm^2].

In the previous laboratory study it has been approved that the relation between bone mineral density and the parameters of mechanical stiffness would definitely differ [5],[6]. The mechanical micro-properties of bone tissue samples were measured and compared with the results of the densitometry test. The samples have been modified in order to change their biomechanical

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properties. The correlation between bone mineral density and mechanical parameters such as Young's modulus was very low. To find the reasons of this low correlation and explanation why it appears, there is a need to deliver qualitative and quantitative results of study. Precise analysis of the state in human bone tissue should contain much data from human specimens which should be statistically significant.

The main idea of the given article is to show how changes of parameters of bone microstructure influence the bone mineral density. This kind of study needs a precise steering of degree of changing microstructures' properties. Whilst creating changes is difficult but possible, the precise measurement of those changes is extremely hard to obtain. Computer simulation was used to solve this problem by maintaining the quality of research based on high resolution of computations. The calculation of attenuation of X-ray radiation during propagation through the bone was modelled nearly in the same way like in the densitometry test. The main expectation from computer calculations was to record how bone mineral density is sensitive under influence of changes of parameters of microstructure.

2. MATERIAL AND METHODS

Assumptions of the presented research were based on known possibilities of using the data from micro CT scanning of sample of a bone. There are several parameters which describe a microstructure of a tested sample. Table 1 presents a collection of those parameters. The figure 1 presents one image which shows a cross-section through the microstructure of the sample. The computation process has been performed on the basis of computer method of simulation of x-ray radiation propagated through the object. This method had been created and tested in previous research [19,20]. Our group has still been improving this idea to execute it within the validation process.

Table 1. Relation between the parameters of microstructure which are used in the presented research.

Name	Symbol	Unit
Bone Volume	BV(mm^3)	mm^3
Tissue Volume	TV(mm^3)	mm^3
Bone Surface	BS(mm^2)	mm^2
Relative Bone Value	BV/TV(%)	%
Trabecular Thickness	Tb,Th,(μm)	μm
Trabecular Separation	Tb,Sp,(μm)	μm
Trabecular Number	Tb,N,(/mm)	1/mm

2.1. MODEL OF BONE TISSUE

The model of a bone tissue was defined based on a spatial distribution of density, which was described by images from micro CT. Data allowed to define a resolution for each among three axes of the simulation space. A sample of bone had a cylindrical shape and it was obtained from calf's hip. The axis' direction of sample cylinder was corresponding to a bone axis. The diameter of the sample was equal to 8 mm and height was equal to 9mm. Dried sample was scanned in Department of Biomaterials in School of Dentistry at The University of Athens in Greece. The collection of cross-sections was used to define a model of a bone inside a software. The Table 2 shows cross-sections details.

Table 2. Details of cross-section through the microstructure of sample which was used to define a bone model.

Name	Value	Unit
Width	1024	pix
Height	1024	pix
Pixel size	9,442425	µm
Thickness of layer	9,442425	µm
Number of layers	978	

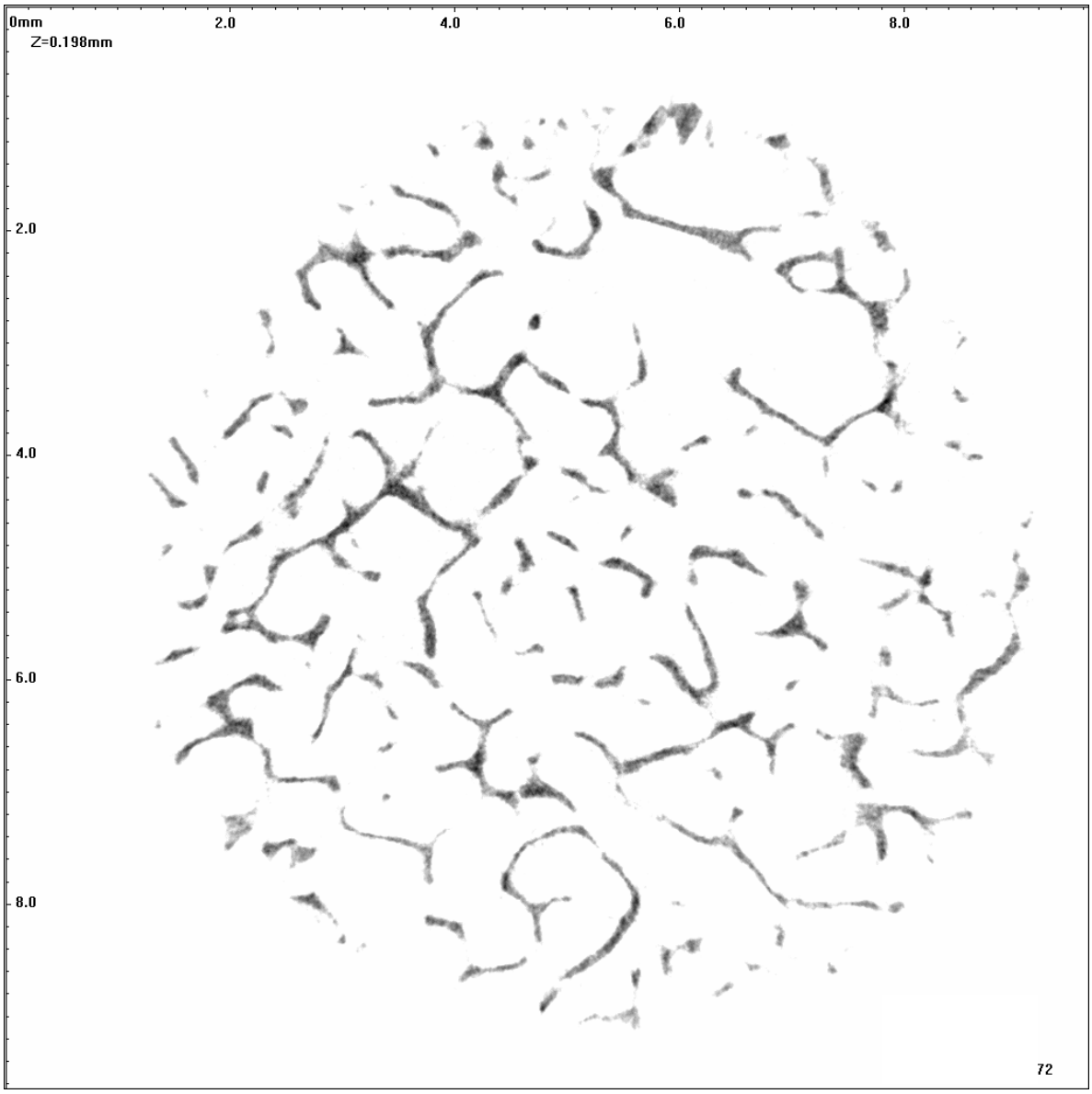

Fig. 1. Example of an transversal cross-section through the microstructure of the sample, which was used to define a bone model.

2.2. MODIFICATION OF BONE MODELS' MICROSTRUCTURE.

For the sake of changing the microstrutures' parameters the cross-sections were modified based on one improved method of image processing. An erosion of binary image was a basis for the procedure which was created to modify the microstructure. Additionally to implemented procedure, there was an option to change the percentage of range of a process, which was obtained due to the software option to regulate the number of iteration. It means that there was a possibility to keep control on a percentage of reduction of trabecular surface. Figure 2 shows two similar magnified areas of the cross-sectional images. One is original image of cross-section obtained form scanner, the second is after executing a procedure of reduction of trabecular surface.

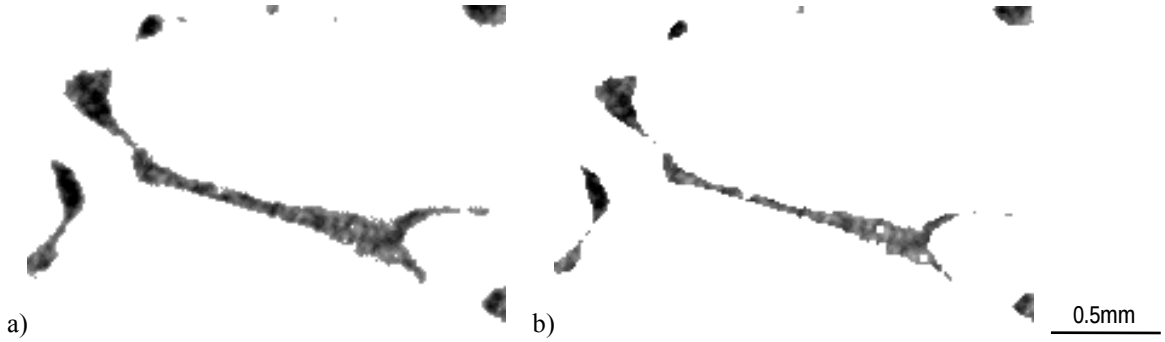

Fig. 2. The images of the similar areas of the cross-sections: a) original image b) image after processing

The range of working a procedure of trabecular surface reduction can be adjusted by increasing of iteration process. The software can measure a parameter of trabecular surface reduction which should be given as a coefficient for a single cross-section or/and for whole sample. The measurement was realised in the time of processing a sample during simulation. It was done to enable the check how this parameter corresponds with known parameters of microstructure, which were measured by typical software. The research contains simulation of x-ray radiation propagation through the model of original sample without any modification as well as through the models with several degrees of reduction. A calculation of propagation of x-ray radiation has been provided for each model. The intensity of radiation was recorded in the "detector" as a matrix of radiation intensity. The matrix was used to assess densitometry parameter similar like bone mineral density in the densitometry test.

3. RESULTS

For every model which was used in the research the results contain received from simulation percentage value of a densitometry parameter, which was computed similar like BMD and percentage value of coefficient of reduction of trabecular surface. From software to calculation of microstructure parameters several parameters were also brought to following comparison. The figure 3 presents a relation between curves of measurement coefficient and parameters of microstructure. The percentage values are listed in the table 3. The figure 4 stands as relations between measurement coefficient and separate parameters of microstructure.

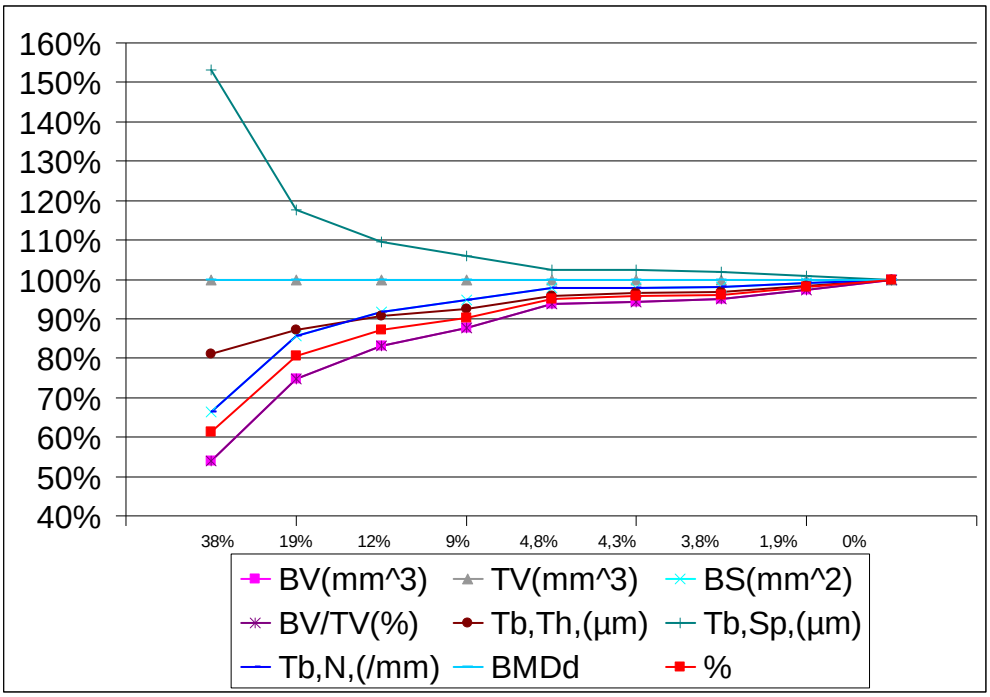

Fig. 3. Relation between curves of measurement coefficient and parameters of microstructure. The percentage of reduced trabecular surface is drawn on the horizontal axis. The parameters of microstructure was shown in percents on the vertical axis.

Table 3. List of percentage values of measurement coefficient and parameters of microstructure. The values are presented in current unit and additionally in per cents.

	measurement coefficient (%)								
	39%	19%	13%	10%	5%	4%	4%	2%	0%
BV(mm^3)	54%	75%	83%	88%	94%	94%	95%	97%	100%
	0,126	0,174	0,194	0,205	0,219	0,220	0,221	0,227	0,233
TV(mm^3)	100%	100%	100%	100%	100%	100%	100%	100%	100%
	8,828	8,828	8,828	8,828	8,828	8,828	8,828	8,828	8,828
BS(mm^2)	66%	86%	92%	95%	98%	98%	98%	99%	100%
	7,443	9,622	10,303	10,634	10,993	10,985	11,024	11,135	11,227
BV/TV(%)	54%	75%	83%	88%	94%	94%	95%	97%	100%
	1,422	1,974	2,199	2,317	2,477	2,493	2,509	2,574	2,641
Tb,Th,(µm)	81%	87%	91%	93%	96%	96%	97%	98%	100%
	28,048	30,142	31,370	32,031	33,125	33,363	33,463	33,989	34,591
Tb,Sp,(µm)	153%	118%	110%	106%	102%	102%	102%	101%	100%
	1954,874	1500,935	1398,098	1352,674	1306,280	1306,907	1302,158	1288,220	1276,727
Tb,N,(/mm)	66%	86%	92%	95%	98%	98%	98%	99%	100%
	0,506	0,654	0,700	0,723	0,747	0,747	0,749	0,757	0,763
"BMD"	99,91%	99,96%	99,97%	99,98%	99,99%	99,99%	99,99%	100,00%	100,00%
	0,7354	0,7357	0,7358	0,7358	0,7359	0,7359	0,7359	0,7360	0,7360

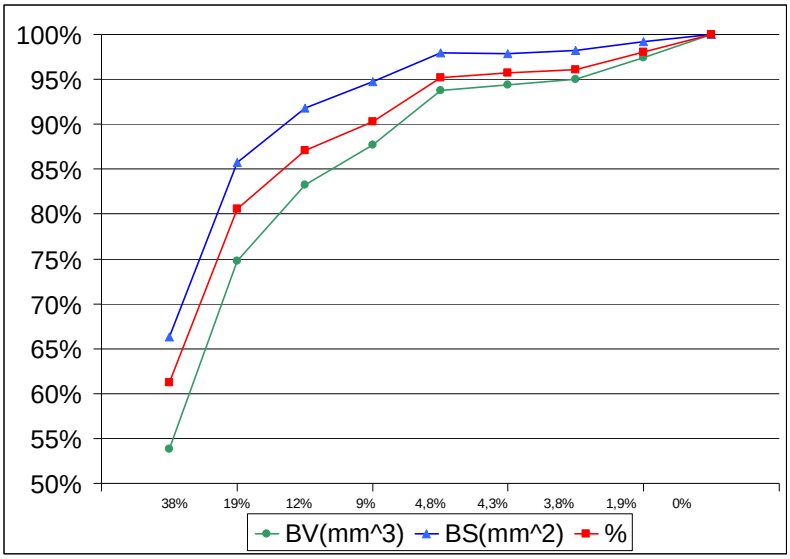

Fig. 4. Relation between curves of measurement coefficient and selected parameters of microstructure like Bone Volume and Bone Surface. The percentage of reduced trabecular surface has been drawn on the horizontal axis. The parameters of microstructure has been shown in percents on the vertical axis.

4. CONCLUSIONS

The results from simulation provide information to estimate how changes of parameters of microstructure influence on the BMD value.

The table 3 contains collection of results from simulation and from software to assess a parameter of microstructure. The situation is also shown on the figures 3 and 4. The BMD value which was computed from simulation is changed only within range not more then 1%. It looks like BMD could be almost not sensitive on the changes of microstructure. There would be very interesting to compare upper results with result computed for the model with different physical density of a bone. This kind of study**,** in authors' opinion, will be possible after validation of the model.

It is widely known that parameters of bone microstructure are more precise to qualify bone as a strong or weak construction. Bone mineral density is only an average parameter, which has been improved through years experiments with Dual Energy X-ray Absorptiometry method. Especially the test of a femur by this method is recommended by World Health Organization as the best method of densitometry diagnosis of osteoporosis.

Because of problems with accuracy of the BMD parameter which are mentioned in the Introduction section, authors tried to find how BMD is dependant on change of microstructure. The model of bone was modified by a procedure of reduction of trabecular surface. It is a procedure which works on the 2D images.

Measurement coefficient which was estimated during reduction of trabecular surface is useful to regulate a percentage of modification of a bone model. Figure 5 shows that it is similar like Bone Surface. There is the question how this kind of reduction is similar to osteoporosis process? Obviously there is not a very high correspondence existing**.** The real reduction of bone surface during osteoporosis disclose in whole volume of a bone. It is reaction in 3D space.

In this article we did not attempt to concentrate on simulation of osteoporosis process itself. What we tried was to deliver quantitative information about connections (or their lack) between BMD and parameters of microstructure. The main gain from this work is that even the changes of

macrostructure are equal to 38%, there is approximately only 1% changes in the bone mineral density computed during simulation.

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