EVALUATION METHOD FOR ORTHOTROPIC PROPERTIES OF THE BONE TISSUE "IN SITU"

A.Dąbrowska-Tkaczyk
Institute of Mechanics and Design, Faculty of Production Engineering, Warsaw University of Technology, Warsaw, Poland

1. Introduction

A method for bone material properties evaluation of bone tissues „in situ" based on a CT images is presented. Calculations were made on the assumption that bone tissue was the orthotropic material. Calculation results obtained for chosen points of the femur section (trochanter minor) have been shown, as well.

2. Method

Computer tomography (CT) data on the patient, having the form of images of sections, were stored in the digital form DICOM (Digital Imaging and Communications in Medicine). They were then analyzed by means of the specialist software Mimics 9,0 to determine the distribution of radiological density C_T in terms the Hounsfield units [HU]. Those data make it possible to calculate other parameters of bone tissues, i.e. apparent density, Young modulus, shear modulus and Poisson's ratio, for evaluation the values of compliance matrix $[b_{ij}]$ elements. The consecutive steps of bone material property calculations are presented in Fig. 1.

CT IMAGES	Image Processing ⟹	**C_T, [HU]**	Experimental functions [4] ⟹	**ρ, [g/cm^3] E_i, MPa i = 1,2,3**	Relationships and experimental data [3] ⟹	$[b_{ij}]$ at points A, B, C, D,E

Figure 1. Method for evaluation of orthotropic properties of the bone tissue material "in situ."

3. Measurements and calculations

Using the Mimics technique „profile lines" one obtains the curves representing the changes in radiological density C_T, [HU] (Fig 2b), along the lines marked in the picture of section (Fig.2a). The C_T values read off at characteristic points A, B, C, D, E, are shown in Table.1.

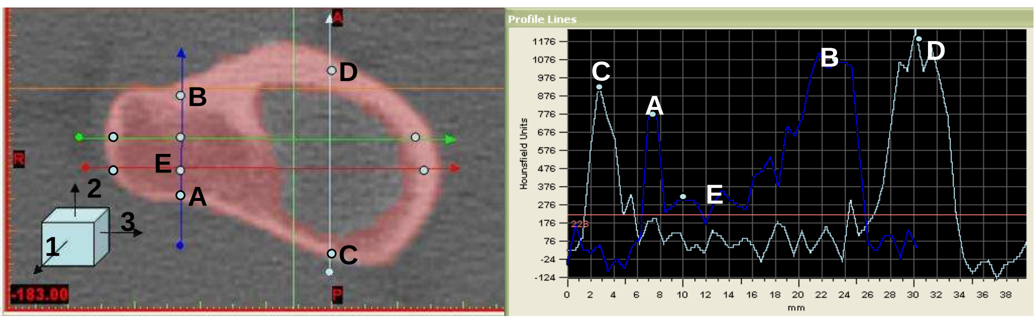

Figure 2. "Profile lines" technique for evaluation of radiological density at points A, B, C, D, E of the section through trochanter minor of the femur.

Basing on the C_T data, the values of apparent density were calculated. For the proximal femur the relationship ρ = f(HU) represented by equation (1) [5] was employed.

$$\rho = 1{,}67 \cdot HU + 131 \qquad [kg/m^3] \tag{1}$$

On the assumption that points A, B, C, D are situated within the area of cortical bone and after accepting suitable coordinate system the values of Young modulus: E_1, E_2, E_3 were calculated using equations (2), [5]. While since point E is situated within the spongy bone area equation (3) [5] should be applied.

$$E_1 = 0.014 \cdot \rho - 6.142, \quad E_2 = 0.009 \cdot \rho - 4.007, \quad E_3 = 0.010 \cdot \rho - 6.087, \; [\,GPa],\ \rho[g/cm^3] \tag{2}$$

$$E_1 = 0{,}58 \cdot \rho^{1{,}30}, \quad E_2 = 0{,}01 \cdot \rho^{1{,}86}, \quad E_3 = 0{,}004 \cdot \rho^{2{,}01}, \quad [MPa],\ \rho[kg/m^3] \tag{3}$$

Other parameters characterizing material properties of the bone tissue; i.e., Poisson's ratio and values of the shear modulus G_{ij} can be calculated using formula (4), [1,4].

$$\nu_{ji} = \nu_{ij} \cdot \frac{E_j}{E_i}, \quad G_{ij} = \frac{E_i}{2(1+\nu_{ij})} \qquad i, j = 1,2,3; \quad i \neq j \tag{4}$$

The values of parameters: ν_{12}= 0,307, ν_{23} = 0,622, ν_{31} = 0,119, for the cortical bone [4] and $\nu_{12}=\nu_{23}=\nu_{31}=\nu=0{,}2$ [2] for the spongy bone respectively, were taken from the literature for calculations the compliance matrix [b_{ij}] elements. The calculations results for points A, B, C, D, E are presented in Table1.

	C_T, HU	ρ, g/cm^3	E_1 MPa	E_2 MPa	E_3 MPa	ν_{21}	ν_{32}	ν_{13}	G_{12} MPa	G_{23} MPa	G_{31} MPa
A	776	0,959	7284	4624	3503	0,195	0,471	0,247	2786	1425	1565
B	1076	1,279	11765	7505	6704	0,196	0,556	0,209	4501	2313	2996
C	920	1,113	9435	6007	5039	0,195	0,522	0,223	3609	1852	2252
D	1170	1,386	13259	8465	7771	0,196	0,571	0,203	5072	2609	3472
E	326	0,479	1769	966	976	0,109	0,202	0,366	737	402	406

Table 1. Values of bone materials constants at points of the section through the trochanter minor

3. Conclusions

The introduced method makes it possible to calculate the parameters of orthotropic model of bone tissues in the organism ("in situ") on the basis of CT data. The results obtained for the plane sections can be transformed in to a 3D model [3] of the proximal femur .

6. References

[1] R. Bak, T Burczyński , 2001, *Wytrzymałość materiałów z elementami ujęcia komputerowego*,WNT, Warszawa

[2] Carter D., R, Beaupre G.,S. 2001, *Skeletal functions and form. Mechanobiology of skeletal development, Aging and Regeneration*. Cambridge University Press,

[3] Dąbrowska-Tkaczyk A., Borkowski P. (2007) *Badanie rozkładów gęstości pozornej oraz rozkładów modułu Younga w modelach kości stawu biodrowego odtworzonych na podstawie obrazów CT*. W: J. Kubik, W. Kurnik, W.K. Nowacki (Red.), Materiały I Kongresu Mechaniki Polskiej, 8 str.

[4] I.W. Knets, G.O. Pfafrod, J.Ż. Saylgozic, (1980) *Deformirowanije i razruszenije twierdych biologiczeskij tkaniej*. Zinatne, Riga

[5] Rho, J.Y., Hobatho, M.C., and Ashman, R.B. (1995) "*Relations of Mechanical Properties to Density and CT Numbers in Human Bone*" Medical Engineering and Physics, Vol. 17, No. 5 347-355