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.

![Fig. 1. Method for evaluation of orthotropic properties of the bone tissue material “in situ.”](http://rcin.org.pl)

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.

![Fig. 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.](http://rcin.org.pl)
relationship \( \rho = f(HU) \) represented by equation (1) [5] was employed.

\[
\rho = 1.67 \cdot HU + 131 \quad [\text{kg/m}^3]
\]  

(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.

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

(2)

\[
E_1 = 0.58 \cdot \rho^{1.30}, \quad E_2 = 0.01 \cdot \rho^{1.86}, \quad E_3 = 0.004 \cdot \rho^{2.01}, \quad [\text{MPa}], \quad \rho [\text{kg/m}^3]
\]

(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 ].

\[
v_{ij} = v_{ji} \cdot \frac{E_{ij}}{E_i} \quad G_{ij} = \frac{E_i}{2(1+v_{ij})} \quad i, j = 1,2,3; \quad i \neq j
\]

(4)

The values of parameters: \( v_{12} = 0.307, \quad v_{23} = 0.622, \quad v_{31} = 0.119, \) for the cortical bone [4] and \( v_{12} = v_{23} = v_{31} = v = 0.2 \) [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.

<table>
<thead>
<tr>
<th>C, HU</th>
<th>( \rho ), g/cm(^3)</th>
<th>( E_1 ), MPa</th>
<th>( E_2 ), MPa</th>
<th>( E_3 ), MPa</th>
<th>( \nu_{21} )</th>
<th>( \nu_{32} )</th>
<th>( \nu_{31} )</th>
<th>( G_{12} ), MPa</th>
<th>( G_{23} ), MPa</th>
<th>( G_{31} ), MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>776</td>
<td>0.959</td>
<td>7284</td>
<td>4624</td>
<td>3503</td>
<td>0.195</td>
<td>0.471</td>
<td>0.247</td>
<td>2786</td>
<td>1425</td>
</tr>
<tr>
<td>B</td>
<td>1076</td>
<td>1.279</td>
<td>11765</td>
<td>7505</td>
<td>6704</td>
<td>0.196</td>
<td>0.556</td>
<td>0.209</td>
<td>4501</td>
<td>2313</td>
</tr>
<tr>
<td>C</td>
<td>920</td>
<td>1.113</td>
<td>9435</td>
<td>6007</td>
<td>5039</td>
<td>0.195</td>
<td>0.522</td>
<td>0.223</td>
<td>3609</td>
<td>1852</td>
</tr>
<tr>
<td>D</td>
<td>1170</td>
<td>1.386</td>
<td>13259</td>
<td>8465</td>
<td>7771</td>
<td>0.196</td>
<td>0.571</td>
<td>0.203</td>
<td>5072</td>
<td>2609</td>
</tr>
<tr>
<td>E</td>
<td>326</td>
<td>0.479</td>
<td>1769</td>
<td>966</td>
<td>976</td>
<td>0.109</td>
<td>0.202</td>
<td>0.366</td>
<td>737</td>
<td>402</td>
</tr>
</tbody>
</table>

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


