Optimization of X-ray microtomography reconstruction quality and acquisition time in the study of the biocompatible scaffolds

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Biodegradable polymers are increasingly used in the modern world. There is a greater number of their varieties and types. In this regard, there is a need to study such polymers both in their original form and over time under the influence of the environment, while producing minimal impact on them from the research methods.
X-ray microtomography is a technique that uses X-rays to create cross-sections of a physical object that can be used to recreate a virtual model (3D model) without destroying the original object.
Experimental device

X-ray microtomograph (a) and its diagram (b): 1 – X-ray tube; 2-crystal-monochromator; 3-vacuum volume; 4 – forevacuum pump; 5-coordinate table with goniometric device for sample rotation; 6-X-ray detector XIMEA xiRAY11; 7-biosecurity
The aim of this work was to optimize the measurement time of biodegradable polymers while maintaining the contrast and accuracy of determining their spatial structure.
Porous matrix from PDL-05 (a) and its structure obtained by SEM (b)
### Radiation selection

<table>
<thead>
<tr>
<th>Type of radiation</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monochromatic</td>
<td>• the possibility of obtaining a quantitative absorption coefficient of the sample.</td>
<td>• low radiation intensity relative to polychromatic radiation with the same radiation source parameters.</td>
</tr>
<tr>
<td>Polychromatic</td>
<td>• high radiation intensity relative to monochromatic radiation with the same radiation source parameters.</td>
<td>• the ability to only evaluate the quality of the images obtained • the appearance of the &quot;cup-shaped artifact&quot;.</td>
</tr>
</tbody>
</table>
Selection of X-ray spectrum parameters

The radiation spectrum of an X-ray tube with a molybdenum anode at a current of 40 mA and a voltage of 45 kV before passing through an aluminum filter with a thickness of 500 microns and after it.
X-ray flux optimization

1600 pulses
2000 pulses
3000 pulses

central sections of tomograms
Tomogram processing algorithm

- Removing noise
- Selection of the sample region
- Pores and sample matrix segmentation
- Calculation of porosity (the ratio of the pore volume to the total volume of the polymer)
Noise reduction

Without median filtering processing

After processing by median filtering
Automatic detection of sample boundaries

Selection of sample borders automatically using the Hough method (left) and manually (right)
Sample selection (using Otsu binarization)

\[ f_{\text{bin}} = \begin{cases} 0, & f(x, y) \leq t \\ 1, & f(x, y) \geq t \end{cases} \]
Porosity calculation

\[ P = \frac{N_p}{N_p + N_o} \]

- \( N_p \) – the number of pixels of the "background" class
- \( N_o \) – the number of pixels of the "object" class
- \( P \) – polymer porosity
Estimation of reconstruction noise level
## Determining the optimal filter thickness

<table>
<thead>
<tr>
<th>Exposure, ms</th>
<th>Filter thickness, microns</th>
<th>Porosity, %</th>
<th>Standard deviation $\times 10^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3600</td>
<td>1380</td>
<td>82.52</td>
<td>300</td>
</tr>
<tr>
<td>3000</td>
<td>1200</td>
<td>88.67</td>
<td>250</td>
</tr>
<tr>
<td>2300</td>
<td>1000</td>
<td>88.14</td>
<td>200</td>
</tr>
<tr>
<td>1800</td>
<td>700</td>
<td>88.15</td>
<td>230</td>
</tr>
<tr>
<td>1500</td>
<td>500</td>
<td>88.70</td>
<td>17</td>
</tr>
<tr>
<td><strong>Monochromatic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>absent</td>
<td>88.71</td>
<td>30</td>
</tr>
</tbody>
</table>
In the course of this work, a methodology for conducting studies of bioresorbable polymers was developed. After a series of experiments at different exposure times and using aluminum filters of different thicknesses, it was determined that for the study of polylactide biodegradable polymers, it is best to use polychromatic radiation using an aluminum filter with a thickness of 500 microns to minimize the impact of X-rays on them and preserve the contrast and accuracy of determining the spatial structure. The calculated values of porosity during such probing differed from the measurements in the reference, monochromatic radiation with an exposure of 4 seconds, by 0.01%, and the standard deviation used as an estimate of image noise was almost twice less than the reference, by 0.013. This leads to the conclusion that this method allows for more accurate measurements of polylactide polymers with less impact on them. The results obtained can be used for further studies of the spatial structure and its changes over time of bioresorbed polymers.
Acknowledgements

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