

Practical problems in the preparation, acquisition and image processing of a cortical phantom

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Aims

The use of phantoms for micro-CT in biomedical research was already presented in literature for segmentation procedure, repeatability measures, densitometric calibration and in general for the improvement of micro-CT images [1-4]. Moreover, a high quality image was required to improve the accuracy of histomorphometric measurements. In particular these studies were performed for trabecular bone. The interest in the study of trabecular bone was due to the complex structure of this compound with thin trabeculae. In fact the quality of the image was dependent by the beam hardening and partial volume effects. The cortical bone was characterized by a thick structure with pores. A similar study could be performed for the cortical bone in order to find the limitations in the acquisition and reconstruction processes. Therefore, no phantoms commercially available were found. The aims of the present work were:

- a) the study of the limitation of the realization of a phantom which reproduce the structure of cortical specimens;
- b) the analysis of the effects on the image quality caused by the interaction between a polychromatic X-ray beam and the phantom in the acquisition process;
- c) the analysis of the effect of the application of a Gaussian filter on the signal to noise ratio in the reconstruction process.

Method

The phantom was cylinder-shaped and made in aluminium material in order to reproduce the attenuation coefficient ($\mu_{bone}(80kV)=0.23cm^{-1}$; $\mu_{Al}(80kV)=0.20cm^{-1}$) of the bone. The external diameter was 4mm. Blinded holes were produced on the body of the cylinder; they were located on the external perimeter at the same distance. Three series of six holes for each series with 40 μ m, 80 μ m and 120 μ m diameters were marked on the cylinder at 2mm-distance. The depth of the holes was chosen to be three times the diameter in order to have a good statistic for the accuracy measurements that were not taken into account in this study.

The dimensions of the holes of the phantom were chosen in order to reproduce the cortical porosity. In literature, the canals and pores of the cortical bones are measured to be 20-150 μ m in diameter [5].

The phantom was acquired with the following acquisition setting 80kV, 125 μ A, exposure time 5.9s for each frame. The rotation step was set to 0.90° on a total rotation of 180°. The magnification was set to 39x in order to obtain a pixel size of 8 μ m. The final acquisition image was obtained by averaging 2 frames and saved in 16bit format.

A second acquisition configuration was used (rotation step was set to 0.45° and the final acquisition images were averaged by 4 frames) and the results were compared. Reconstructed cross-section images were obtained by using the Nrecon software. The cross sections were reconstructed by applying the standard setting that are no smoothing filter, beam hardening correction 30% and the default value for the misalignment parameter. Another set of reconstructed images was obtained by using the previous setting but a Gaussian smoothing filter with different pixel radii (2, 4, 6, 8, and 10) was applied.

The presence of the pores in the reconstructed images was visually verified.

The analysis of the quality of the reconstructed images was performed by using CTAnalyzer software.

The grey level distribution was used to analyse and compare the two performed configurations and the application of a Gaussian filter of different pixel radii. A stack of 81 reconstructed images at the bottom of the phantom was chosen in order to exclude the holes and to calculate the average grey level value and standard deviation of the aluminium cylinder. The comparison of the grey level distributions advised about the differences between the acquisition configurations and the application of Gaussian filter in terms of improvement of the signal to noise ratio.

Results

An aluminum cortical phantom was acquired and reconstructed. The images were visually evaluated and the $40\mu\text{m}$ holes were not found in none of the studied procedure.

Figure 1A and Figure 1B show the reconstructed images of the phantom for the configuration 0.90° rotation step, 2 frames and 0.45° rotation step, 4 frames, respectively. Figure 1C shows the grey level distribution of the reconstructed images of the phantom for both acquisition configurations previous described.

The percentage frequency increased and the standard deviation decreased by using the second acquisition configuration (0.45° rotation step, 4 frames), compared to what was obtained in the first configuration (0.90° rotation step, 2 frames).

Figure 2 shows the comparison in terms of average grey level and standard deviation of the application of no smoothing filter and different pixel radii of the Gaussian filter during the reconstruction process. The standard deviation decreased to a minimum value for the Gaussian filter with a pixel radius of 6.

Figure 3 shows the difference in terms of percentage frequency among the Gaussian filters with different pixel radii. The increase in pixel radius produced an increase in the percentage frequency of the average grey level value.

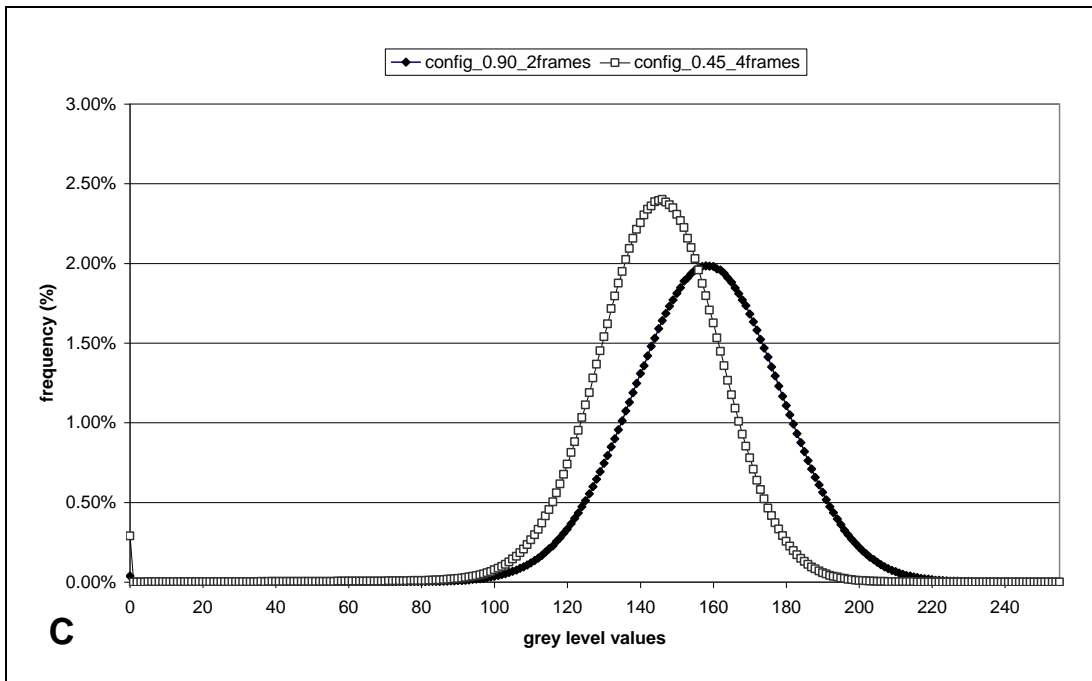
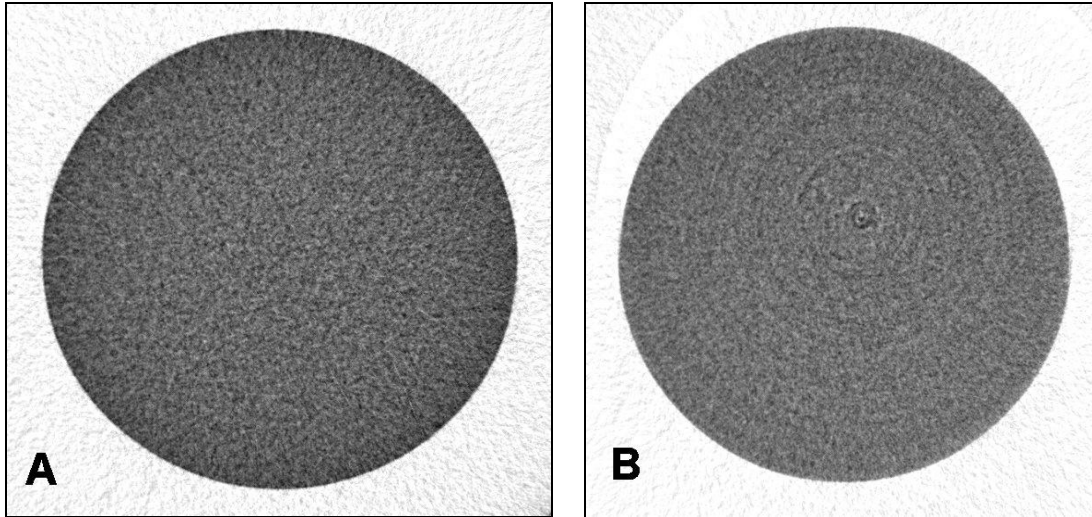


Figure 1: A) reconstructed image of the phantom acquired in configuration 0.90° rotation step, 2 frames averaging; B) reconstructed image of the phantom acquired in configuration 0.45° rotation step, 4 frames averaging; C) the difference between both configuration in terms of frequency of average grey level value and standard deviation.

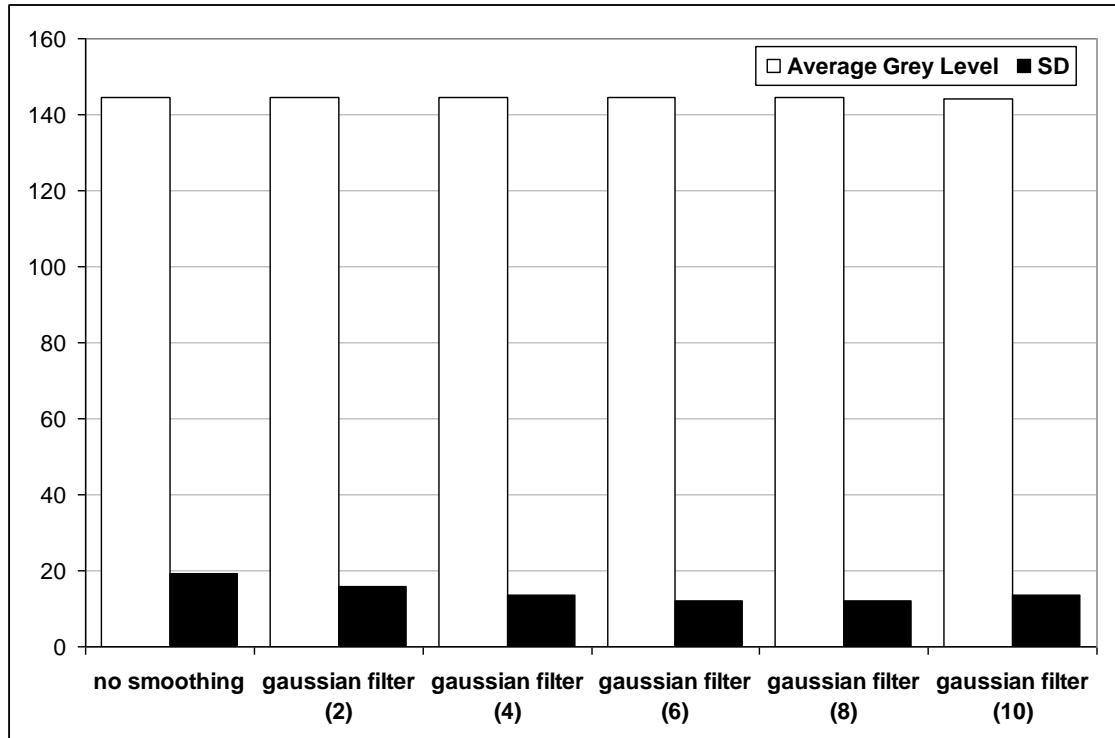


Figure 2: Comparison in terms of average grey level values and standard deviation among the different reconstruction settings.

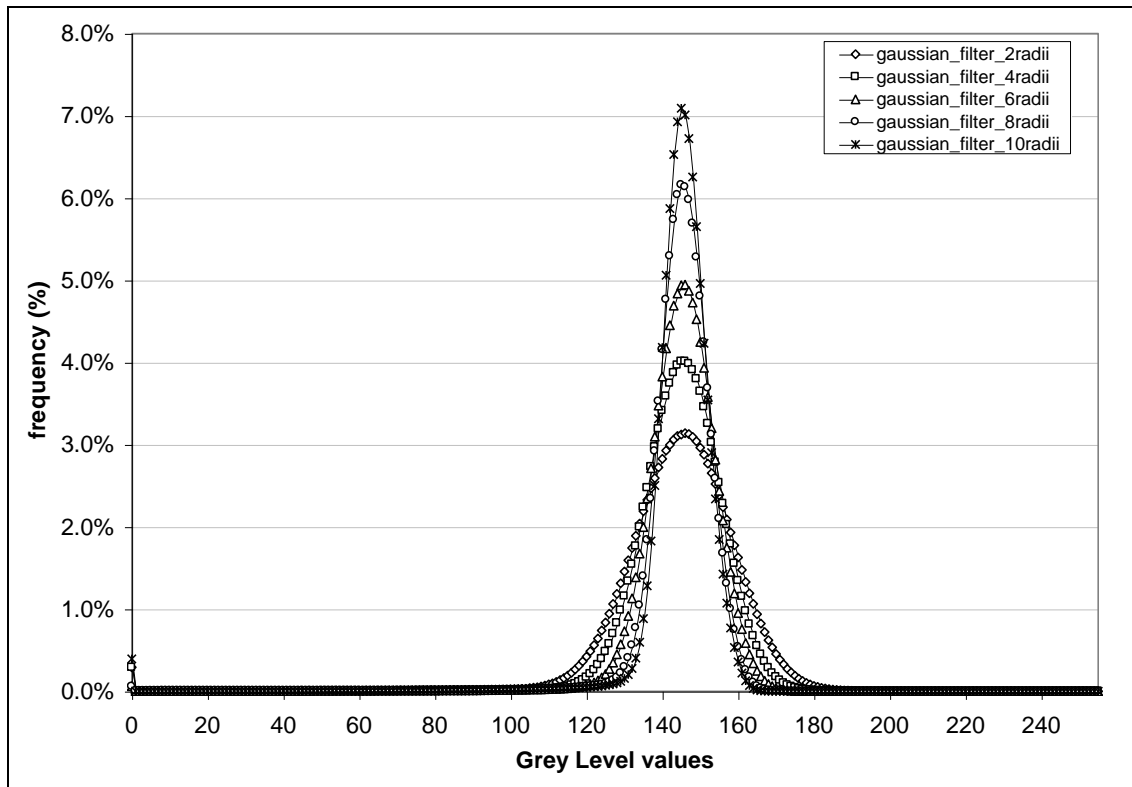


Figure 3: Comparison among the Gaussian filter of different radii applied during the reconstruction process.

Conclusion

The first aim of the present study was to analyze the limitations of the realization of a phantom that reproduce the typical 3D structure of the cortical bone. The limitation was caused by the difficulty to obtain cylinder-shaped holes because of the used technology. The technology used to realize the 40 μ m holes was the laser beam and it was the unique one. The holes were made blinded because passing holes were not physically possible. Moreover, aluminum material was chosen to represent the cortical bone because of its attenuation coefficient, but it showed practical problems during the manufacturing process. Aluminum material had the characteristic to melt instead of vaporize. This property caused practical problems to control the cylindrical shape of the holes. Measures to check the tolerance about the cylinder-shape of the holes will be performed.

The second aim of this study was to analyze the effect of the interaction between the polychromatic X-ray beam and the material.

The phantom was a filled object and a big attenuation effect was observed. During the visual inspection no problems appeared in the identification of the holes of 120 μ m and 80 μ m in diameter. But the holes of 40 μ m were not identified even if the pixel size of the acquisition images was 8 μ m.

In the Figure 1C the effect of the decrease of the noise in the background by using the acquisition configuration with a 0.45° rotation step and final image averaged on 4 frames was showed. The standard deviation decreased and the frequency of the average grey level value increased. The increase of the percentage frequency of the average grey level value was linked to the homogenization of the image.

The third aim of the present work was to analyze the effect of the application of a Gaussian filter during the reconstruction process. In the Figure 2 the application of a Gaussian filter produced the decrease of standard deviation. The noise of the image was at the minimum value if a Gaussian filter with pixel radius 6 was used.

Figure 3 shows the difference among the Gaussian filter. The percentage frequency distribution became tight when the radius increased. The increase of the percentage frequency was an index of the degree of homogenization of the image. But if the homogenization of the image increased too much, the standard deviation (noise) increased and some details of the object could be lost (Figure 2).

In conclusion, the limitation to realize a phantom that reproduced the structure of cortical specimens was presented. The analysis of the effect of X-ray interaction showed that object thinner than 40 μ m were not visualized although the phantom was acquired with 8 μ m resolution. The analyses of the use of a Gaussian filter in comparison with no smoothing showed better results when a pixel radius 6 Gaussian filter was used. The homogeneity and the loss of some details of the image could be correlated to the increase of the percentage frequency and the standard deviation respectively, when a Gaussian filter (pixel radius>6) was used.

References:

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