MicroCT parameters for multimaterial elements assessment

MicroCT parameters for multimaterial elements assessment

Olga M. O. de Araújo[1], Jaqueline Silva Bastos[2], Alessandra S. Machado [1], Thaís M. P. dos Santos[1], Cintia G. Ferreira[1], Ana Paula Rosifini Alves Claro [2] and Ricardo T. Lopes [1]

[1]Nuclear Engineering Program, UFRJ - Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil
[2]Paulista State University, UNESP, São Paulo, Brazil
E-mail: olgaufrjlin@gmail.com

Abstract. Microtomography is a non-destructive testing technique for quantitative and qualitative analysis. The investigation of multimaterial elements with great difference of density can result in artifacts that degrade image quality depending on combination of additional filter. The aim of this study is the selection of parameters most appropriate for analysis of bone tissue with metallic implant. The results show the simulation with MCNPX code for the distribution of energy without additional filter, with use of aluminum, copper and brass filters and their respective reconstructed images showing the importance of the choice of these parameters in image acquisition process on computed microtomography.

Keywords: Microtomography, additional filters, multimaterial elements.

1. Introduction

In non-destructive tests involving the use of X-rays, the choice of voltage, current and additional filters are determining factors in the image quality. The basic principle of image formation is the interaction of ionizing radiation with the sample. Image quality depends on several factors, such as contour sharpness, noise level and contrast between structures. Another factor that contributes to image quality is presence or absence of artifacts, taking into account their intensity and their influence in detection of relevant structures. The analysis of samples of materials with large difference of density, such as bone tissue with metallic material, can be a difficult task and provide an incorrect analysis if inappropriate parameters are selected.

The knowledge of the energy distribution of the photons produced by X-ray tube is an important information for different fields of research involving the use of ionizing radiation. In this work, to demonstrate the importance of the selection of these parameters, a spectra of X-ray tube with the code MCNPX were simulated and qualitative and quantitative parameters such as effective energy, half value layer and homogeneity coefficient were evaluated [1, 2]. The results show the acquisition of the images obtained by the microCT with the different combinations where it is possible to verify the final results on the reconstructed samples and the result when choosing a combination of additional filters that may generate unwanted artifacts in image such as metal scattering, a result hardly corrected by microCT reconstruction softwares.

2. Material and methods

2.1. MCNPX

To verify the distribution of the X-ray spectrum, was performed a simulation with MCNPX tool based on the Monte Carlo N-Particle Transport Code (MCNP), originally developed at the Los Alamos National Laboratory (LANL). The Monte Carlo method provides approximate solutions for a variety of physical and mathematical problems performing statistical samplings. Individual particles are simulated and the result of their histories are used to determine the average behavior of the particles carried [1]. Particle histories is determined by probability distributions of physical events such as interactions, scattering, capture, and so on.

In the proposed study, fundamental elements and processes in the operation of an X-ray tube were considered. The electron source was positioned in cathode towards anode where the electrons are accelerated to interact with a tungsten target. The selected voltage was 60kV compatible with this material analysis and the simulation was performed to estimate a spectrum without filters and for different types of additional filters. Some parameters are necessary to describe the beam of radiation and its power of penetration, to characterize the X-ray is necessary to determine quantitative and qualitative parameters which were estimated from energy distribution calculated with MCNPX code.

2.2. Average energy

Information about energy of the X-ray beam provides parameters on beam quality, such as semi-reducing layer and average energy [3, 4, 5]. The average energy of X-rays spectrum was obtained using the equation below:

$$E_{average} = \frac{\sum_{n=1}^{n}\left[\frac{d\Phi(E_n)}{dE}\right]E_n(\Delta E_n)}{\Phi} \quad (1)$$

Where $d\Phi(E_n)$ is the number of photons of energy spectrum distribution in energy interval ΔE, whose energy is E_n and Φ is the photon fluence [5, 6].

2.3. Half Value Layer (HVL) and Homogeneity Coefficient

HVL is defined as the thickness of a given absorber material required to reduce the intensity of the X-ray beam to 50% of the initial value under good geometry conditions [7]. This implies a configuration that minimizes the spreading that tends to increase its value. Is a parameter related to penetration power of X-ray beam. As more energetic the beam, greater the thickness required to reduce its intensity by half.

In some cases is possible to obtain the same HVL value for different configurations of additional filters and voltage applied to an X-ray tube, although the energy spectra in each case are not similar. This difference can be characterized by the homogeneity coefficient (CH) and can be defined as the ratio of first to second HVL[8]:

$$CH = \frac{1^{\text{a}}\text{HVL}}{2^{\text{a}}HVL} \quad (2)$$

Where, $CH = 1$ for monoenergetic beams and $CH < 1$ for heterogeneous beams.

The lower the CH, smaller the homogeneity of the beam. As more low energy photons are attenuated, more 'hardened' or homogeneous the beam becomes and consequently an higher CH.

The microCT system used in this work is Skyscan model 1173 (*Bruker*, Belgium). The equipment has X-ray source operating between 40kV and 130kV voltages and detection system a Flat-Panel sensor, operating with a matrix of 2240x2240 (Hamamatsu Photonics, 2012a). Each pixel in image corresponds to average absorption, in reconstruction process, where slices are assembled to produce 3D reconstructed image pixel is mathematically transformed into voxel, capable of representing the depth of the radiological image. The main parameters in image acquisition in this study were: 15µm pixel size, 60kV voltage, current of 133µA, detector array 2240x2240, rotation step 0.5° (degrees).

3. Results

The spectra obtained from simulation without additional filter and filters of Aluminum, Copper and Brass with different thicknesses and tension of 60kV are shown in figure 1, and the qualitative and quantitative parameters in table 1.

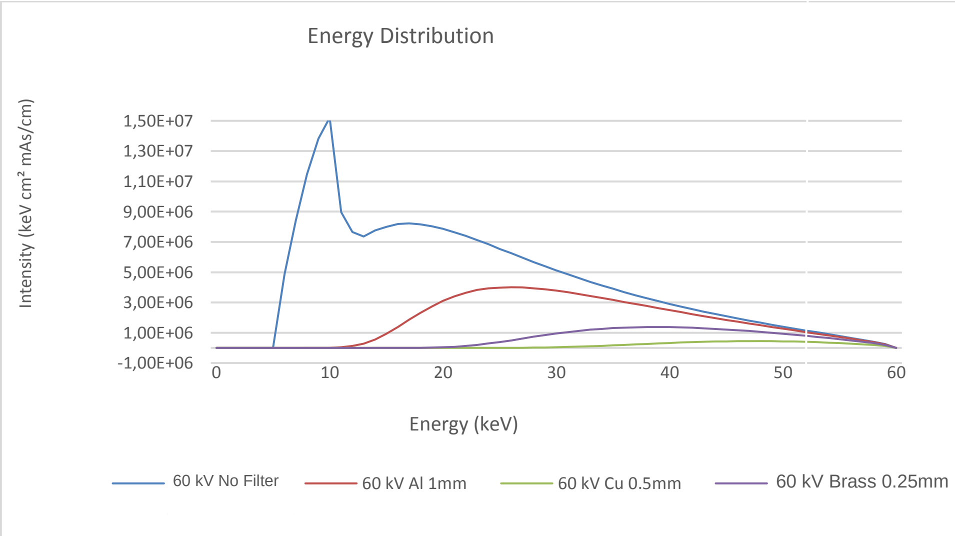

Figure 1. Spectrum of energy distribution for different additional filters and without the use of filters.

Table 1. Results of qualitative and quantitative parameters for different configurations.

60 kV Filter	No Filter	Al 1mm	Cu 0.5mm	Brass 0.25mm
Average Energy (keV)	22.536	32.322	46.236	40.436
HVL (cm)	0.008	0.118	0.020	0.0149
CH	0.471	0.624	0.858	0.795

Can be seen in graphs without additional filters a low energy photon peak which agrees with an X-ray beam without additional filtering of these low-energy beams [9, 10]. The 1 mm aluminium filter has a higher efficiency for lower voltages, filtering the low energy photons that do not contribute to formation of radiographic image, also not reducing considerably the intensity of beam, such as observed for copper and aluminium.

In spectrum for copper filter a shift of the maximum curve point to right is observed, which corresponds to an average upper energy. The additional filters increase beam quality by increasing its penetration power and average energy, as can be seen in table 1. On the other hand it reduces beam intensity and spectral counts for copper and brass.

Quantitative and qualitative parameters for copper filter agree with the results obtained in Figure 1, presenting the highest increase in average energy. Brass and copper filters presented the highest result for the homogeneity coefficient compared to other combinations used in the simulation. The higher density of copper and brass related to aluminium can be considered a determining factor for this behaviour.

IOP Conf. Series: Journal of Physics: Conf. Series **975** (2018) 012053 doi:10.1088/1742-6596/975/1/012053

In figure 2 the comparison of images was possible visually verify the difference in effects of additional filtration: a) without additional filters presents a sample without definition at the edges, due to low energy photons that cause image noise; b) aluminium filter proved to be more efficient for artifacts that impair the quality of acquisitions, such as metal artifacts, because it absorbs the low energy photons without losing the intensity of the x-ray spectrum; c) and d) with the copper and brass filters is lost definition with a grainy image and a lot of metal spreads, due to loss of intensity that we can observe in figure 1 and the effect of scattering due do increase on average energy, estimated in table 1.

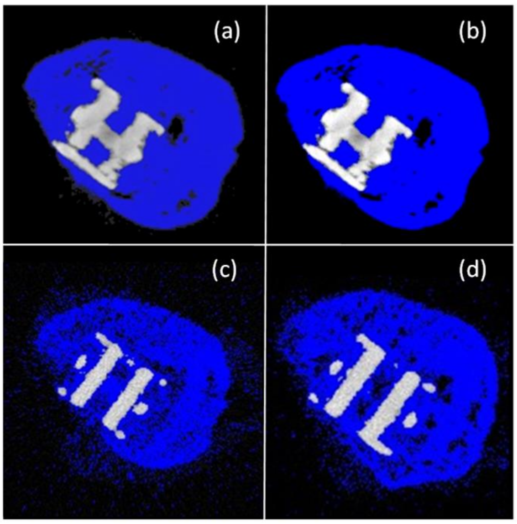

Figure 2. 2D segmented slices for configurations (a) without additional filter (b) aluminium filter (c) copper filter and (d) brass filter.

MicroCT is a non-destructive test technique that allows inspect materials with a definition of micrometers. In this example, studies involving analysis for evaluate bone growth by diversity of information that can be obtained. Images of figure 3 were obtained with Avizo Fire 9.01 software for projections with copper filter and shows the undesired effect of scattering caused by metal scattering in a sample containing bone and metal tissue.

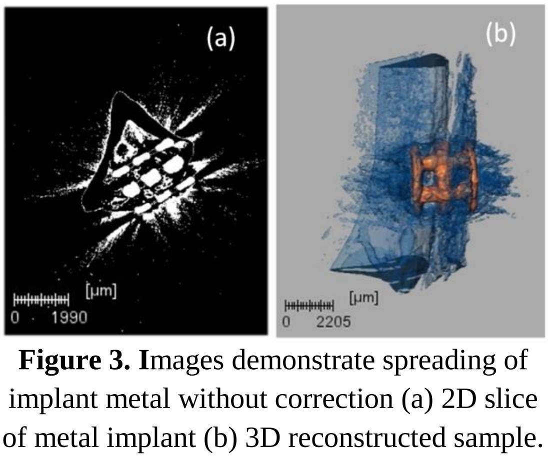

Figure 3. Images demonstrate spreading of implant metal without correction (a) 2D slice of metal implant (b) 3D reconstructed sample.

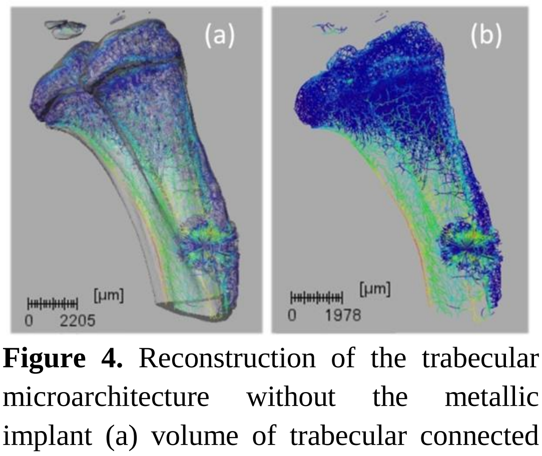

Figure 4. Reconstruction of the trabecular microarchitecture without the metallic implant (a) volume of trabecular connected (b) trabecular thickness. The degree of connection of the trabecular thickness present different colors, separated as warmer to colder colors.

4. Conclusion

Results obtained by microCT provide analysis of microarchitecture of the trabecular bone, which are used to evaluate the bone integrity. However, the choice of morphometric indexes to be studied depends mainly of the research objectives. The parameters of acquisition and reconstruction are of extreme importance in image quality as can be observed in comparative figures between different filters and this loss of image quality directly influences posterior analysis. Energy distribution simulation provides beam quality information with and without the use of additional filters. These data contributed to interpret the reconstructed images where it was possible to observe that use of aluminium filter for multimaterial sample of this study presents the best reconstruction results for analysis.

5. References

[1] Astuto, A., Salgado, A. P., Leite, S. P., Patrão, K. C. S., Fonseca, E. S., Pereira, W. W., & Lopes, R. T. (2014). "Thermal neutron calibration channel at LNMRI/IRD", Radiation Protection Dosimetry, 161(1-4), 185-189.

[2] Podgorsak, E., 2005. “Radiation Oncology Physics: A Handbook for Teachers and Students”, International Atomic Energy Agency, pp. 373-398, Vienna.

[3] Giarola, R. S., Coelho, T. S., Fernande S, M. A. R., ribeiro, V. A. B., Yoriyaz, H., 2013. “Quantification of the anode effect by Monte Carlo method (MCNP-5) simulation of a X-ray generator in diagnostic radiology”, Revista Brasileira de Física Médica, v. 7, n. 3, pp. 157-161.

[4] Carlsson, G.A., Carlsson, C.A., 1984. “Effective energy in diagnostic radiology – a critical review”, Physics in medicine and biology, v. 29, n. 8, pp. 953-958.

[5] Kharrati, H., Zarrad, B., 2003. “Computation of beam quality parameters for Mo/Mo, Mo/Rh, Rh/Rh, and W/Al target/filter combinations in mammography”, Medical physics, v. 30, n. 10, p. 2638-2642.

[6] Attix, F.H, 1986. “Introductionto Radiological Dosimetry”, John Wiley& Sons, 2ª Ed, 607 p.

[7] Kerur, B. R., Manjula, V. T., Lagare, M. T., AnilKumar, S., 2009. “Mass attenuation coefficient of saccharides for X-rays in the energy range from 8 keV to 32 keV”, Radiation Measurements, v.44, n.1, pp. 63-67.

[8] Lacerda, M. A. D. S., Silva, T. A. D., Oliveira, A. H. D., 2007. “Influência da metodologia de avaliação da camada semi-redutora em radiologia diagnóstica” Radiol. bras, v. 40, n. 5, p. 331-336.

[9] Podgorsak, E. B., “Review of radiation oncology physics: a handbook for teachers and students”, International Atomic Energy Agency, Educational reports series, Vienna 2003.

[10] Deslattes, R.D., Kessler Jr, E.G., Indelicato, P., Billy, L., Lindroth, E., Anton, J., Cours EY, J. S., Schwab, D. J., Chang, J., Sukuma R, R., Olsen, K., Dragoset R. A., 2005. “X-ray transition energies”, Nist Standard reference database. http://www.nist.gov/pml/data/xraytrans/index.cfm (acessado em 03.02.2017).

Acknowledgments

To UFRJ Nuclear Instrumentation Laboratory, CNPq and FAPERJ for their financial support and scholarships granted for this study.