

## MicroCT parameters for multimaterial elements assessment

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**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

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. In general, in non-destructive tests involving the use of X-rays, the choice of energy, current and additional filters are determining factors in image quality.

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. MATERIAL AND METHODS

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).

### 2.1. MCNPX

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 beam of radiation and its power of penetration, to characterize the X-ray is necessary to determine quantitative and qualitative parameters.

### 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 [2]. 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  $\Delta E$ , whose energy is  $E_n$  and  $\Phi$  is the photon fluence [3, 4].

### 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. 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[3]:

$$CH = \frac{1^{st}HVL}{2^{nd}HVL} \quad (2)$$

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

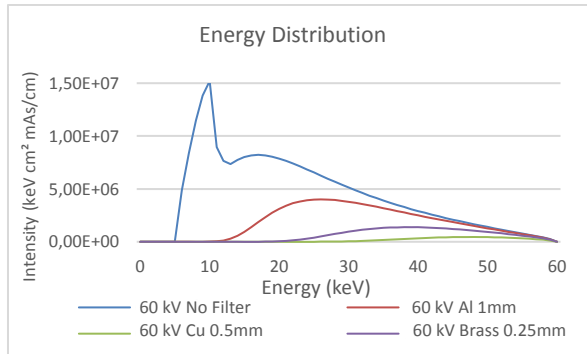
The lower the CH, smaller the homogeneity of the beam. As more filters are used, more low energy photons are attenuated, ie more 'hardened' or homogeneous the beam becomes and consequently an higher CH.

Besides the simulation, acquisitions and reconstructions of the microtomographic images were performed with the additional filter combinations to visually demonstrate the influence in choice of physical filters. The main parameters in image acquisition were: 15 $\mu$ m pixel size, 60kV voltage, current of 133 $\mu$ A, detector array 2240x2240, rotation step 0.5 $^\circ$  (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.



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

Can be seen in graphs without additional filters a low energy photon peak. The 1 mm aluminum 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, as observed for copper and aluminum. In spectrum for copper filter a shift of the maximum curve point to right is observed, which corresponds to an average upper energy.

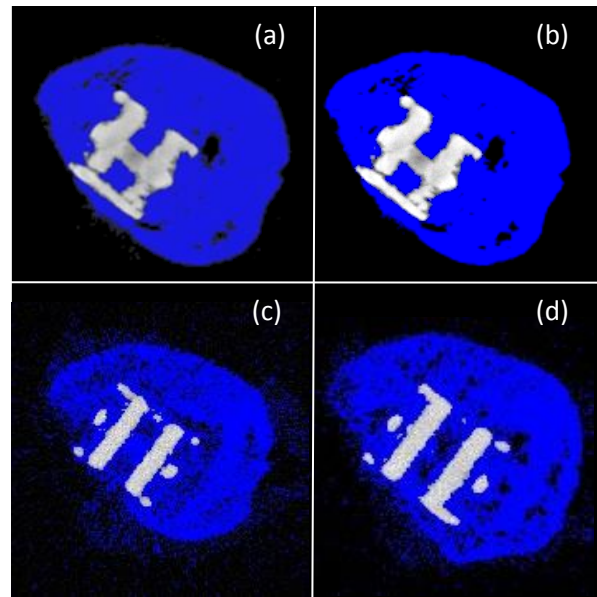
The additional filters increase beam quality by increasing its penetration power and average energy, as can be seen in table 1. On the other hand it reduces beam intensity and spectral counts for copper and brass.

**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)	22.5365	32.32224	46.23634	40.43649
HVL (cm)	0.0087	0.1180	0.0203	0.01498
CH	0.4711	0.6247	0.8584	0.7953

Quantitative and qualitative parameters for copper filter agree with the results obtained in Figure 1, presenting the highest increase in

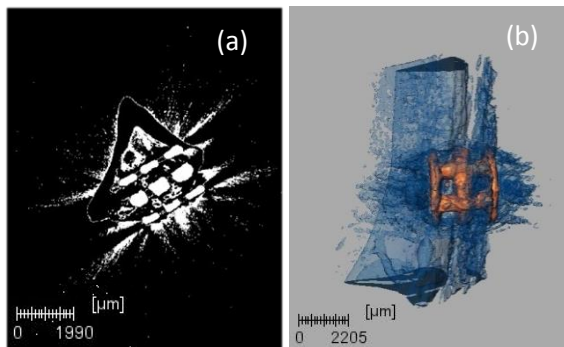
average energy. Brass and copper filters presented the highest result for the homogeneity coefficient compared to other combinations used in the simulation. The higher density of copper and brass related to aluminum can be considered a determining factor for this behavior.



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

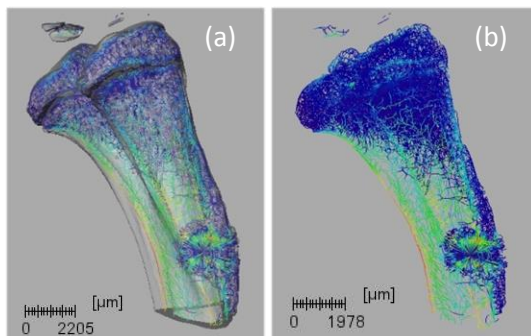
In figure 2 the comparison of images was possible visually verify the difference in effects of additional filtration: a) without additional filters presents a sample without definition at the edges, due to low energy photons that cause image noise; b) aluminum filter proved to be more efficient for artifacts 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. 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 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.

Microtomography is a non-destructive test technique that allows inspect materials with a definition of micrometers. In this case, studies involving analysis for evaluate bone growth by diversity of information that can be obtained.



**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. CONCLUSIONS

Results obtained by the microtomography 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 aluminum filter for multimaterial sample of this study presents the best reconstruction results for analysis.

#### Acknowledgments

To CNPq and FAPERJ, for their financial support and scholarships granted for this study.

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