

## BEAM HARDENING CORRECTION ALGORITHM IN MICROTOMOGRAPHY IMAGES

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### ABSTRACT

Quantification of mineral density of bone samples is directly related to the attenuation coefficient of bone. The X-rays used in microtomography images are polychromatic and have a moderately broad spectrum of energy, which makes the low-energy X-rays passing through a sample to be absorbed, causing a decrease in the attenuation coefficient and possibly artifacts. This decrease in the attenuation coefficient is due to a process called beam hardening. In this work the beam hardening of microtomography images of vertebrae of Wistar rats subjected to a study of hyperthyroidism was corrected by the method of linearization of the projections. It was discretized using a spectrum in energy, also called the spectrum of Herman. The results without correction for beam hardening showed significant differences in bone volume, which could lead to a possible diagnosis of osteoporosis. But the data with correction showed a decrease in bone volume, but this decrease was not significant in a confidence interval of 95%.

### 1. INTRODUCTION

The X-ray beams used for generation of tomographic images are polychromatic and have a moderately wide spectrum of energy. The non-uniform attenuation at different energies results in the decrease of X-rays in energy that varies with higher attenuation coefficients. In general, the X-rays that are more easily attenuated are called soft X-rays as those that are more penetrating are called hard X Rays. Thus, the beam hardening is the process of selective removal of soft X-ray from the X-ray beam. The amount of beam hardening depends on the initial X-ray spectrum as well as the composition of the material or tissue. This causes the effect called beam hardening artifacts in the tomographic images. If they are not corrected, the artifacts appear as cupping or a reduction in the attenuation coefficient to the center of an object in the reconstructed images.

The attenuation coefficients are directly related to density of the material inspected and when it is necessary to quantify an image, such as the quantification of bone mineral density of samples, it is essential to correct the effect of beam hardening. In this paper an algorithm is

used to beam hardening correction for the projection data (obtained experimentally) from bone samples of rats. The spectrum of Herman [1] was used in the simulation; only two materials were present in the samples, air and bone.

## **2. MATERIALS AND METHODS**

### **2.1. Bones Samples**

The samples used in the microtomography assay were bone samples of vertebrae of 3-month-old Wistar rats. The animals were obtained from a study protocol of hyperthyroidism, and the induction of hyperthyroidism in the animals was to administer the hormone thyroxine (T4) during a period of 10 days. In addition, for hyperthyroidism group it was also selected a control group that received only 0.9% NaCl solution with the same period of administration of T4 [2]. The rats were killed and the vertebrae samples were removed with the help of a scalpel. After vertebrae removal, they were placed in beetle larvae in order to remove all surplus material.

### **2.2. Experimental Set-up**

In order to obtain microtomographies, a Microfocus Fein Focus X-Ray – model FXS160-50 was used at the Nuclear Instrumentation Laboratory (LIN-UFRJ-Brazil) [3]. The experimental set up consists of a Microfocus X Ray tube with conic beam, which operates within an voltage interval of 0-160 kV and current 0-1mA. The detection system is composed of an image intensifier tube with 9” diameter coupled to a CCD video camera. The electronic signal, which comes from the intensifier, is captured by a CCD camera and then sent to a TV monitor that is on the console system where it is possible to visualize the radiographic image in real time.

This system has also a movable mechanical device which makes possible several degrees of freedom in relation to movement and positioning of the specimen, which makes possible the adjustment of the image magnification factor to be captured. The electronic signal from the CCD to the monitor is transformed into digital sign by an 8-bit analog-digital interface. This signal is processed in real time by a Pentium 233 MHz (64 Mb RAM) microcomputer and displayed in a super VGA monitor, being stored in bmp file format.

The vertebrae samples were centralized on the experimental set up table so that it could be used the entire visual field of the CCD camera. The region of interest (ROI) used in this study was the lumbar region where L3 and L4 of the control and hyperthyroidism group were tomographed. Table 1 shows the parameters of microtomographic images acquisition of the vertebrae samples.

**Table 1: Parameters of microtomographic images acquisition of the vertebrae on hypertiroidism study.**

<b>Experimental Parameters</b>	
Tension (kV)	41-46
Current (mA)	0.08-0.24
Boards Number	32
Projections Number	300
Magnification Factor	7.50-11.84
Resolution ( $\mu\text{m}$ )	10-20

### 2.3. Beam Hardening Corrections

The method of beam hardening correction used in this work was based on the linearization method [1, 4, 5], and the region of image reconstruction was considered just for two kinds of materials: bone and air.

A discrete X-Rays spectrum was used in energy for water (data provided by NIST [6]), where monoenergetic sum rays ( $m$ ) were calculated for 70 keV and polyenergetic sum rays ( $p$ ) were calculated assuming that 50% of photons are in 70 keV, 25% in 40 keV and 25% in 100 keV. The discrete spectrum is also called Herman spectrum [1], as can be seen in Table 2, where  $\tau_e$  is the probability of a photon to be detected and  $\mu$  is the attenuation coefficient.

**Table 2: Linear attenuation coefficient of water assumed in the calculation of monoenergetic and polienergetic projections data (Source NIST [6]).**

$\tau_E$	$\mu_{\text{water}, E} (\text{cm}^{-1})$	Energy (keV)
0.25	0.267	40
0.50	0.190	70
0.25	0.171	100

As a second step for linearization of the projection data, a relation ( $p, m$ ) of an X ray tube for a specific source-detector pair was plotted for the attenuation coefficient of water. The relation between ( $p, m$ ) was calculated by Equation 1.

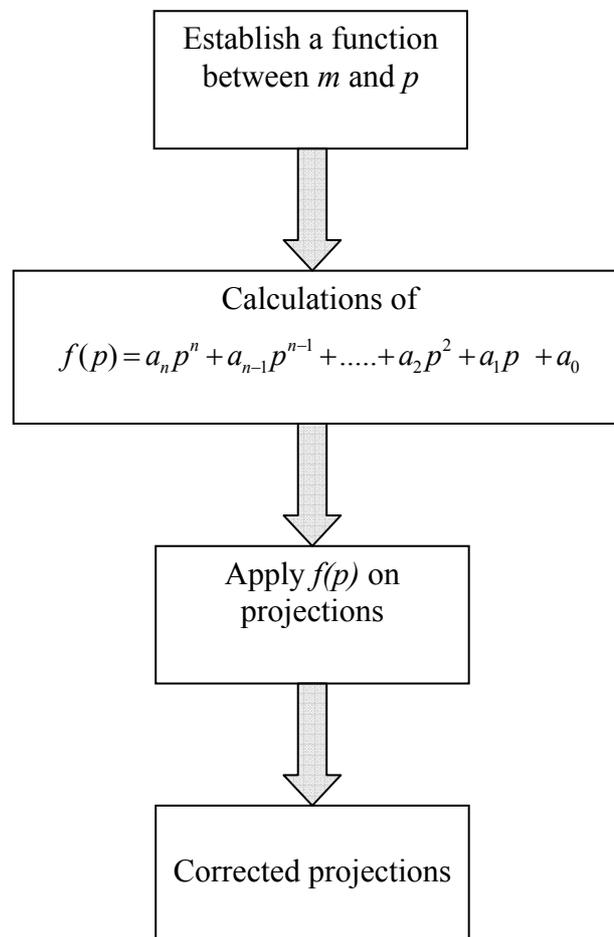
$$p = -\ln \left[ 0.5 \exp\left(-\frac{0.190}{0.190} m\right) + 0.25 \exp\left(-\frac{0.267}{0.190} m\right) + 0.25 \exp\left(-\frac{0.171}{0.190} m\right) \right] \quad (1)$$

A correlation function  $f(p)$ , given by adjustment curve between the approximate data of the relation between  $(p, m)$  given by Equation 1, was applied to the experimentally measured projection data. Function  $f(p)$  is given by Equation 2, where  $n$  is the polynomial order.

$$f(p) = a_n p^n + a_{n-1} p^{n-1} + \dots + a_2 p^2 + a_1 p + a_0 \quad (2)$$

The Projections linearization were done by polynomial of degree 3.

The calculations of  $f(p)$  and the corrections projections of the experimental data were obtained using the MATLAB<sup>®</sup> software. A scheme with the steps done by the software is presented in figure 1.



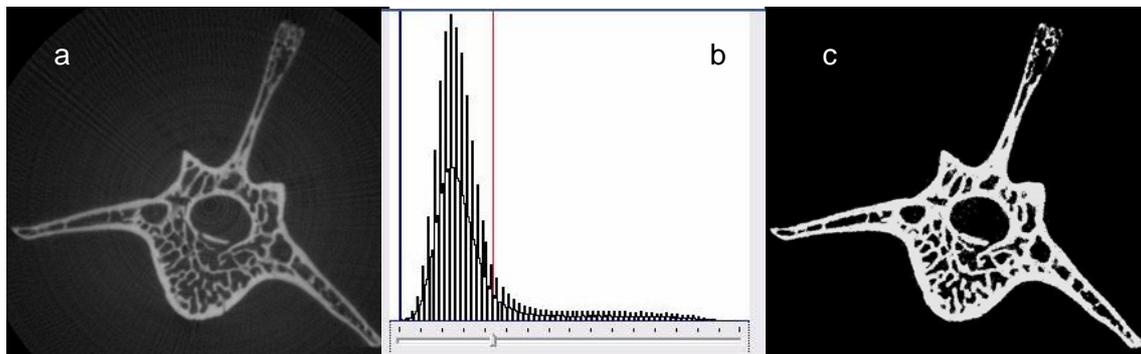
**Figure 1. Algorithm used in MATLAB<sup>®</sup> to correction the projections.**

## 2.4 Histomorphometric Quantification

The quantification of bone morphology by microtomography is done based on the histomorphometry technique. This technique was developed in the 1960s after Sacker and Nordim [7] and later Bordier et al. [8] have introduced methods for obtainment of bone tissues by means of special trephines biopsies and under local anesthesia. The histomorphometric indexes described in this work are in accordance with the standard nomenclature given by American Society of Bone and Mineral Research [9].

- Trabecular Volume – BV/TV (%): It is the volume occupied by trabecular bone.
- Bone Surface – BS/BV (%): It is the ratio between bone surface and bone volume.
- Trabecular Thickness – Tb.Th (mm): It is the thickness of trabeculae bones.
- Trabecular Number – Tb.N ( $\text{mm}^{-1}$ ): It is the number of trabeculae bones per millimeter of tissue.
- Trabecular Separation – Tb.Sp (mm): It is the distance between medium points of bones trabeculae.

The quantification of bone morphology by  $\mu\text{TC}$  was based on choosing a region of interest (ROI). In order to differentiate bone from the rest of the tissue it is necessary to perform image binarization by choosing an optimum threshold value. All pixels, whose values are higher or equal to the threshold value, will be converted into a value called saturated and in an analog mode all pixels that have values below the threshold value will be converted into zero. The result is a black and white image, where the white part corresponds to the bone and the black part to the non-bone. Figure 2 shows an example of image binarization process.



**Figure 2: Binarization process where (a) an image of 8 bits is shown, (b) histogram and TH choice, and (c) the result of binarized image.**

### 3. RESULTS

Tables 3 and 4 show the results of the processes of histomorphometric quantification of the control and hypertiriodism groups with and without correction of beam hardening, respectively. It is shown the mean values of each lumbar region analyzed (L3 and L4) with their standard deviations for each histomorphometric parameter.

**Table 3: Result of the process of histomorphometric quantification of the control and hypertiriodism groups without correction of beam hardening**

Parameters	Control Group (n=3)		Hypertiriodism Group (n=3)	
	L3	L4	L3	L4
BV/TV (%)	40.68 ± 3	49.58 ± 2	26.90 ± 4 <sup>a</sup>	36.36 ± 2 <sup>a</sup>
BS/BV (mm <sup>-1</sup> )	34.55 ± 2.97	28.32 ± 4.35	40.96 ± 3.64	35.21 ± 3.93
Tb.Th (mm)	0.059 ± 0.005	0.074 ± 0.013	0.050 ± 0.005	0.058 ± 0.007
Tb.N (mm <sup>-1</sup> )	7.0 ± 0.7	6.9 ± 0.8	5.5 ± 0.4 <sup>a</sup>	6.3 ± 0.4
Tb.Sp (mm)	0.092 ± 0.018	0.079 ± 0.008	0.150 ± 0.026	0.114 ± 0.009

*\*All values are mean ± standard deviation.<sup>a</sup> Statistically significant with  $\alpha = 0.05$ .*

**Table 4: Result of the process of histomorphometric quantification of the control and hypertiriodism groups with correction of beam hardening**

Parameters	Control Group (n=3)		Hypertiriodism Group (n=3)	
	L3	L4	L3	L4
BV/TV (%)	36.28±5.9	49.20±6.9	29.97±5.0	37.33±4.0
BS/BV (mm <sup>-1</sup> )	36.9±4.9	28.6±6.5	38.4±5.8	34.4±5.2
Tb.Th (mm)	0.056±0.007	0.074±0.016	0.054±0.009	0.061±0.010
Tb.N (mm <sup>-1</sup> )	6.6±0.5	6.9±0.7	5.6±0.3	6.4±0.8
Tb.Sp (mm)	0.105±0.016	0.080	0.140±0.019	0.114±0.022

*\*All values are mean ± standard deviation.*

According to the results showed in Table 3 (beam hardening without correction) the group submitted to hypertiriodism protocol presented a lower percentage value of bone volume BV/TV in two lumbar regions analyzed - L3 and L4, when compared with the control group.

In relation to other histomorphometric parameters, the trabeculae number parameter Tb.N ( $\text{mm}^{-1}$ ) in lumbar region – L3 – from hyperthyroidism group, was the only one that presented significant decrease (confidence interval of 95%) when compared to control group.

According to the results showed in Table 4 (beam hardening with correction), when comparing the results obtained between control and hyperthyroidism groups, it is possible to verify that the lumbar region – L3 – from hyper group presented a lower value of bone volume BV/TV and trabeculae number Tb.N ( $\text{mm}^{-1}$ ). And according to the statistical test – “t-Student” – these variations were not significant within a confidence interval of 95%. On the other hand, region L4 from hyperthyroidism group presented lower values of bone volume BV/TV and thickness of trabeculae Tb.Th, but these reductions were not significant according to the statistical test applied.

Hyperthyroidism is an illness caused by the increase of production of T4 (Thyroxine) by thyroid gland. Calcitonin, another hormone secreted by thyroid, takes part in the control of blood calcium concentration, this way inhibiting the removal of calcium from bones and its release to blood plasma stimulating its absorption by bones. As T4 increases on blood current the levels of calcitonin decrease leading to an imbalance on bone metabolism, that is, the bone resorption exceed bone tissue formation leading to a negative imbalance. The consequence of this negative imbalance is the decrease of bone mineral density (BMD) that can provoke a secondary osteoporosis.

### **3. CONCLUSIONS**

In this work results obtained by X Ray Microtomography on histomorphometric of bones from Wistar rats submitted to a study of hyperthyroidism were presented. Data were quantified with and without beam hardening correction and according to statistical tests applied, it was possible to realize the importance of beam hardening correction. The results without correction presented significant differences on bone volume, what could lead to a diagnostic of a possible osteoporosis due to the increase of T4. On the other hand, data with correction showed that there were a decrease on bone volume, but this difference was not significant within a confidence interval of 95%.

### **ACKNOWLEDGMENTS**

This work was partially supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and FAPERJ.

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