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ANALYSIS OF CT AND PET/SPECT IMAGES FOR DOSIMETRY CALCULATION

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ABSTRACT

Computer images are routinely used in diagnostic centers and hospitals. In particular in the field of Nuclear Medicine they help in the diagnosis and planning therapy against cancer. In the case of the planning terapy the quantifying the distribution of dose in patients is very important, because it provides an estimate of the dose in the tumor and healthy tissues, allowing a greater understanding on the response and toxicity caused by this dose. The aim of this study is to analyze both kinds of images: CT and PET/SPECT and their potential utilization for dosimetry calculation. PET or SPECT images were analyzed using a Gamma Camera, brand Medis, model Nuclide-TH/22 through image acquisition of scanned phantoms containing a known activity inside their volume so that a relationship between the number of counts for each voxel in the image and the real activity will be constructed. The heterogeneous organism patient's is specified from the computed tomography (CT) through number of Hounsfield. However, there is not a simple correlation to convert Hounsfield numbers into material tissues, therefore, in this work we developed a software in Java to convert Hounsfield numbers in mass density. Moreover, the software provides a map of tissues and a text file containing the elementals weights to be used by the Monte Carlo transport code MCNP5 to perform dose calculations.

1. INTRODUCTION

Computer images are routinely used in diagnostic centers and hospitals. Progress in the acquisition of these images together to technological innovations has allowed new advances in both diagnosis and therapy.

In Nuclear Medicine, the acquisition of the image is made by equipment that detects the distribution of the activity issued by radiopharmaceuticals administered to patients. Through the biodistribution analysis of the radiopharmaceuticals, one has the functional information of the organism under study, however, the image do not provide the distribution of internal dose in these patients.

Quantifying the distribution of dose in patients is very important, because it provides an estimate of the dose in the tumor and healthy tissues, allowing better understanding on the response and toxicity caused by the administered dose.

Recent works in internal dosimetry use the resources of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), which convey basic information for building more realistic human body models through images formed by the volume elements called voxels. On the other hand functional imaging using single photon emission computed tomography (SPECT) and Positron Emission Tomography (PET), promote a three-dimensional representation of the distribution of activity inside the patient [2].

Once given the anatomical and functional information of the patient, in most cases the dosimetry can be done through Monte Carlo simulation of the radiation transport to obtain the energy deposition. One of the most used codes worldwide is MCNP5 which was developed at Los Alamos Laboratory (Los Alamos, NM) originally as a neutron and photon transport for reactor analysis in general. This program provides several options for developing spatial energetic distributions using complex geometric shapes [1].

In this context the present work intends to contribute for the development of a full methodology to be used in internal dosimetry for radionuclide therapy and diagnosis. The specific contribution presented here is the construction of software that builds an anatomical model from CT images of the patient, converting CT numbers in tissue densities. This information is needed for the Monte Carlo dose calculation. Also, the linearity between counts from SPECT images and their correspondent activities are checked.

2. MATERIALS AND METHODS

2.1. Gamma Camera

The gamma camera consists of a number of components (collimator, scintillation crystal, phtotomultiplier tube, pulse height analyzer) and each component has a specific function, but the interconnection of its functions have the purpose of converting the gamma rays in an image which can be viewed on a suitable device [3].

The collimators have the objective of projecting the image of a radioactive material onto surface of the crystal. The scintillation crystal has two main functions, the first being the function to absorb the gamma rays and the other function to convert the gamma-ray in photon of the light. The phtotomultiplier (PM) tubes have a function to convert the photons of light into electrical pulses and amplify these pulses and the position of the tube allows the detection of the place that each gamma photon is absorbed. The purpose of the Pulse Height Analyzer (PHA) is to select the pulse created by the radioactive source chosen and reject undesired pulses associated with others sources of radiation [3].

The reconstructed images represent the distribution and relative concentration of radioactive elements present in the organs imaged.

2.2. Radionuclide Tomographic Imaging

One of the advantages of tomographic imaging in relation to the conventional imaging with gamma camera is an increase in constrast sensitivity for detecting lesions. This is only possible because overlaying regions of radioactivity are removed as each slice of tissue is viewed directly [3].

There are two different types of e radionuclide tomographic imaging and they are differentiated by the radiation emission characteristic of radionuclides used. These two methods are discussed below [3].

2.2.1. Positron Emission Tomography (PET)

There are radioactive substances emitting positrons that are particles that have the same mass of the electron, but with opposite charge. When a positron emitted by a radioactive nucleus interacts with an electron, it results in the complete annihilation of both particles, the whole mass is convert in energy in the form of a pair of photons. Each photon has energy of 511 keV, traveling in opposite directions [3].

The feature of the interaction between electron and positron allows reconstruct the image using a circular array of detectors around the patient. So, in the mechanism of positron emission detection, the two photons resulting of annihilation process must be detected simultaneously. The equipment that makes the acquisition of images through the positron emitting nuclides is called Positron Emission Tomography (PET) [3].

The major advantage of PET imaging is the fact that the positron emitters (Oxygen, Nitrogen, Carbon, etc.) are elements that occur naturally in many biological molecules [3].

2.2.2. Single Photon Emission Computed Tomography (SPECT)

The radionuclides that are used in gamma camera emit in most cases one major photon for each radioactive transition. Tomographic images can be created utilizing these radionuclides and a gamma camera to acquire multiple 2-D images (projections), from multiple angles around the patient that will be used for the mathematical reconstruction of tomographic images. This technique is known as single-photon emission computed tomography (SPECT) [3].

2.3. Computed Tomography Image (CT)

The CT images are formed by a multi-step process. The formation of the image begins with the scanning phase. In this phase, an x-ray is beam projected through the edges of the body

section being imaged. On the opposite side of the beam is positioned an array of detectors to measured the radiation that penetrates the section. The detectors therefore see only a profile from one direction [3].

The data of the profile measure the penetration of x-ray along each ray extending from the x-ray tube to the individual detectors, so that to produce sufficient information and create a complete image, the x-ray beam is rotated around the body section to produce views from many angles [3].

The next process is known as image reconstrution that is a mathematical procedure that converts the scan data for the individual views into numerical images. The image is structured in an array of individual picture elements called pixels. The pixel contains a numerical value, or CT number that is related to the tissue density on the corresponding volume element called voxel [3].

In the last phase the digital image is converted into a video display so that it can be viewed directly. The relationship between the pixel CT number values and the gray scale, or brightness in the displayed image is determined by the window levels selection. The settings of the windows levels determines the range of CT numbers that are spread over the entire image gray scale [3].

The CT has the advantage of eliminate the superimposition of images of structures outside the area of interest. Furthermore, by inherent high-contrast resolution of CT, differences between tissues that differ in physical density by less than 1% can be distinguished [3].

Finally, data from a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task [3].

2.4. Using the IMAGEJ software

The IMAGEJ software [4] is a computational program of medical image analysis originally developed by the NIH (National Institute of Health) and is able to read, process and analyze images in DICOM format.

This software is written in JAVA language and is of public domain and can be downloaded via internet website [4]. In this work the IMAGEJ was used to aid in the analysis of CT imaging.

2.5. Procedures with Gamma Camera

The materials used for this procedure were a Gamma Camera, brand Medis, model Nuclide-TH/22, Bottle type 1 (type penicillin), individual protection equipment (gloves and apron), syringes and needles, dilute solution of sodium pertechnetate, ionization chamber, Capintec brand, model CRC-35R and generator ^{99}Mo-^{99m}Tc.

In order to acquire the images the following parameters were provided: number of counts of 300.000, the image orientation of 90 °, matrix size equal to 180 X 128 and finally the width of the window pulse height analyzer equal to 20%. The collimator used was the parallel-hole LEHR (Low Energy High Resolution).

First added to the bottle type 1 an initial activity of diluted solution of sodium pertechnetate and then was made three image acquisition. This procedure was repeated eight times.

Altogether there were made twenty-four image acquisitions and after a sequence of three images the activity in the phantom was increased. The analysis of the images was performed with the software of gamma camera.

2.6. Software ICCT - (Image Convertor for Computed Tomography)

The Monte Carlo method is able to recover with accuracy discordance in the radioactive doses caused by heterogeneity within the body of the patient. This occurs because the method of Monte Carlo allows that human tissues are characterized by elemental composition and mass density, and therefore allows the consideration of all atomic interactions.

The anatomical heterogeneities of the organs patient's are specified from the computed tomography (CT). However, there are not simple correlations to convert Hounsfield numbers for tissue materials, so that, a software was developed to convert the CT number in density using a method suggested by Schneider, Bortfield and Schlegel [5] which is based on a stoichiometric calibration between CT number with mass density and elemental weight. In this method CT number calculations were made for 71 human tissues types, whose characteristics were taken from the literature.

In this work, the o Hounsfield number range of -1000 to 1600 was grouped in 24 groups: a group for the air ranging from -1000 to -950 , a group for lung tissue ranging from -949 to -120, seven groups for soft tissues ranging from -119 to 120 and 15 groups for bone tissue ranging from 121 to 1600. Within each group, the elemental composition and weights are preserved, while the density increases as the of Hounsfield number increases [5].

The programming language chosen to develop the software was Java to be easier to implement it into the ImageJ software, because in the near future we intend to transform this software into an ImageJ software plugin [4].

The sequence of steps in the proposed methodology is as follows: The IMAGEJ software reads the CT images and converts them into text format files. Then, the ICCT software reads these files and generates three results that are: map of density, map of tissue and an output of elements weight. All these outputs are in text format which are formatted for the SCMS which will provide the input data for the MCNP5 that will perform the radiation transport simulation for dose calculation. Figure 1 shows a schematic of this methodology.

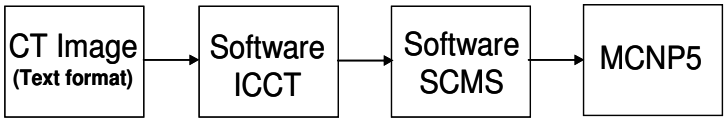


Figure 1: Methodology steps for the CT images data processing for MCNP radiation transport simulation.

3. RESULTS AND DISCUSSION

3.1 Results of Gamma Camera

Tomography imaging provides severals advantages over conventional imaging with a gamma camera. An increase in contrast sensitivity for detecting lesions is possible because overlying regions of radioactivity are removed as each slice of tissue is viewed directly [3].

The experiment was conducted so that the images were acquired in a sequence of three images per injected activity to increase the statistical of the data. As the activity in the bottle decays with the time for the same sequence of images, the activity in the last two images of the sequence were corrected on the first activity. After this process was then calculated the average of these three activities. This procedure was also performed for the counts.

Through these data we can plot the activity as a function of the number of counts. Figure 2 was made using the values of the average of activity and the values of average of counts per second. The error of counting is the composition of the two errors.

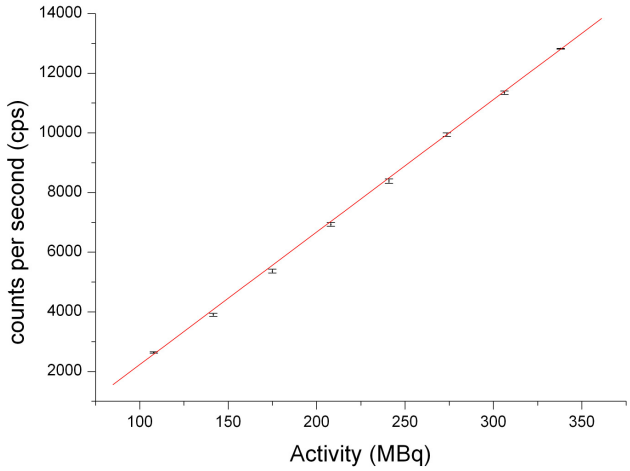


Figure 2: Correlation between activity (MBq) and counts per second (cps). The black line is a fit linear of points with r = 0.999.

According to the fit linear the activity and the number of counts are linearly related. This result is of great importance for the calculation of dosimetry, because is necessary only the relative value of the activity in each pixel and not the absolute value of the activity so that its is possible to normalize all counts by the highest count, which would result in a relative value of the activity in each pixel.

In the case of PET or SPECT images will be the need to process these images trying to minimize the effects of attenuation, scattering and noise, and then compare the count present in voxels with activity.

3.2 Results of ICCT

Figure 3 shows the initial screen of the software ICCT, where the user provides the name of the directory that contains the images of CT scan. As seen in section 2.6, the images contained in the directory should be in text format.

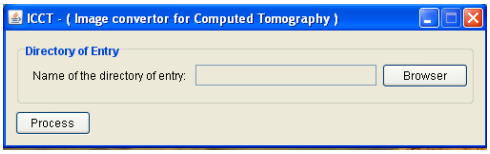


Figure 3: Initial screen of the ICCT.

The user will search the directory that contains images using the button "Browser". Besides showing the map of the density the ICCT also provide a map of tissue that is formed by an array of numbers varying from 1 to 24 which represent the groups described in the method of Schneider [5].

The correlation between CT number (H) and tissue density (ρ) were built following the equations below:

For -1000 <H <-98:

$$\rho = 1.031 + 1.031 \times 10^{-3} * H \quad (1)$$

For -98 < H < 14:

$$\rho = 1.018 + 0.893 \times 10^{-3} * H \quad (2)$$

For 14 < H < 23:

$$\rho = 1.03 \tag{3}$$

For 23 < H < 100:

$$\rho = 1.003 + 1.169 \times 10^{-3} * H \tag{4}$$

For H > 100:

$$\rho = 1.017 + 0.592 \times 10^{-3} * H \tag{5}$$

Figure 4 shows the relation between the CT numbers (H) with density tissue (ρ) through the equations above.

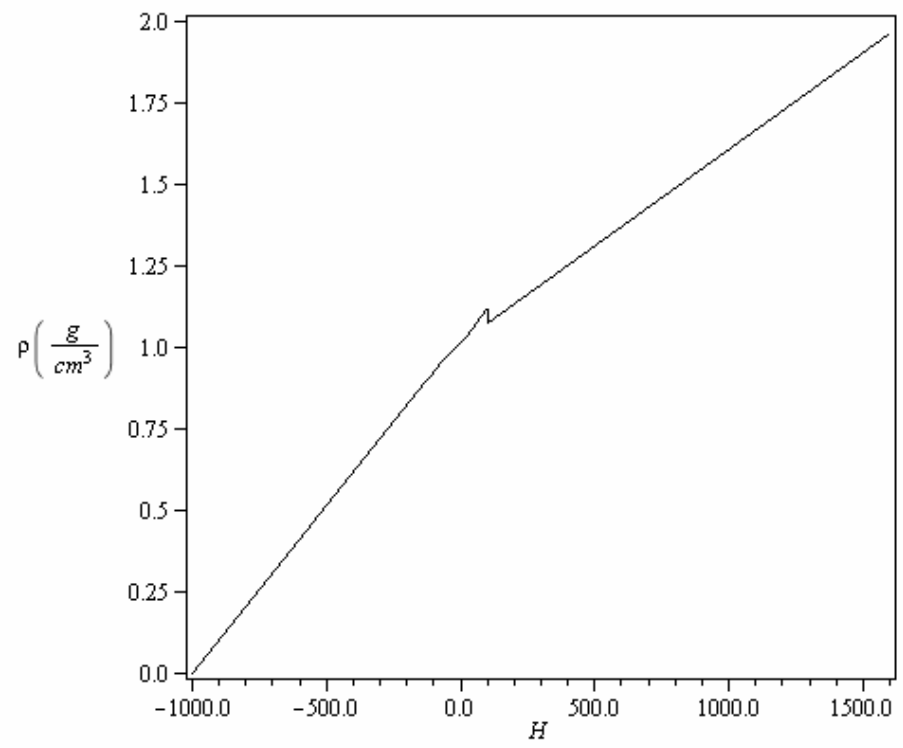


Figure 4: Conversion of CT number to mass density.

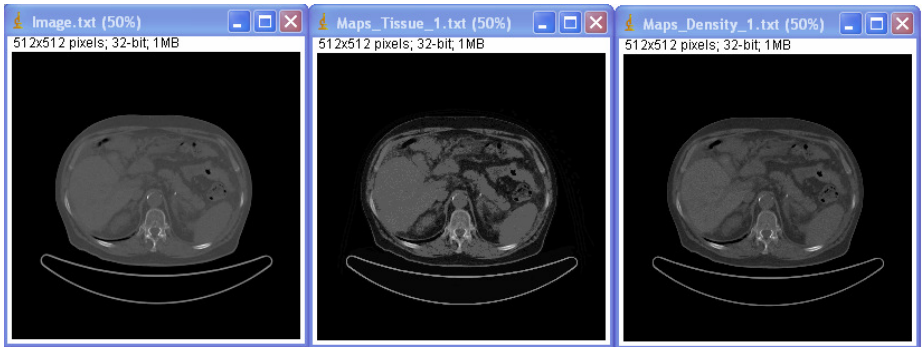
To generate the tissue map the ICCT reads a file containing the CT number in each pixel of the CT image and assigns to a specific tissue density following the information given in Table 1 (extract from Schneider [5]). This table provides the tissue composition for 24 CT

number groups. Each of this group covers a range of CT numbers and also corresponds to a specific density tissue. The CT number read from the CT image is checked to verify in which range it belongs and assigns the correspondent tissue density to this pixel.

Table 1: Conversion of CT number to elemental weights. The scale of Hounsfield units is divided into 24 bins.

	w_i(points pencentual)											
CT number	**H**	**C**	**N**	**O**	**Na**	**Mg**	**P**	**S**	**Cl**	**Ar**	**K**	**Ca**
-1000 – -950	-	-	75.5	23.2	-	-	-	-	-	1.3	-	-
-950 – -120	10.3	10.5	3.1	74.9	0.2	-	0.2	0.3	0.3	-	0.2	-
-120 – -83	11.6	68.1	0.2	19.8	0.1	-	-	0.1	0.1	-	-	-
-82 – -53	11.3	56.7	0.9	30.8	0.1	-	-	0.1	0.1	-	-	-
-52 – -23	11.0	45.8	1.5	41.1	0.1	-	0.1	0.2	0.2	-	-	-
-22 – 7	10.8	35.6	2.2	50.9	-	-	0.1	0.2	0.2	-	-	-
8 – 18	10.6	28.4	2.6	57.8	-	-	0.1	0.2	0.2	-	0.1	-
19 – 80	10.3	13.4	3.0	72.3	0.2	-	0.2	0.2	0.2	-	0.2	-
80 – 120	9.4	20.7	6.2	62.2	0.6	-	-	0.6	0.3	-	-	-
120 – 200	9.5	45.5	2.5	35.5	0.1	-	2.1	0.1	0.1	-	0.1	4.5
200 – 300	8.9	42.3	2.7	36.3	0.1	-	3.0	0.1	0.1	-	0.1	6.4
300 – 400	8.2	39.1	2.9	37.2	0.1	-	3.9	0.1	0.1	-	0.1	8.3
400 – 500	7.6	36.1	3.0	38.0	0.1	0.1	4.7	0.2	0.1	-	-	10.1
500 – 600	7.1	33.5	3.2	38.7	0.1	0.1	5.4	0.2	-	-	-	11.7
600 – 700	6.6	31.0	3.3	39.4	0.1	0.1	6.1	0.2	-	-	-	13.2
700 – 800	6.1	28.7	3.5	40.0	0.1	0.1	6.7	0.2	-	-	-	14.6
800 – 900	5.6	26.5	3.6	40.5	0.1	0.2	7.3	0.3	-	-	-	15.9
900 – 1000	5.2	24.6	3.7	41.1	0.1	0.2	7.8	0.3	-	-	-	17.0
1000 – 1100	4.9	22.7	3.8	41.6	0.1	0.2	8.3	0.3	-	-	-	18.1
1100 – 1200	4.5	21.0	3.9	42.0	0.1	0.2	8.8	0.3	-	-	-	19.2
1200 – 1300	4.2	19.4	4.0	42.5	0.1	0.2	9.2	0.3	-	-	-	20.1
1300 – 1400	3.9	17.9	4.1	42.9	0.1	0.2	9.6	0.3	-	-	-	21.0
1400 – 1500	3.6	16.5	4.2	43.2	0.1	0.2	10.0	0.3	-	-	-	21.9
1500 – 1600	3.4	15.5	4.2	43.5	0.1	0.2	10.3	0.3	-	-	-	22.5

Opening the text file, generated by the ICCT, through ImageJ, its possible to compare the outputs of the ICCT whit the CT images. The figure 5 compares the CT image with the images of the maps of the density and tissue.



(a) **(b)** **(c)**

Figure 5: Comparison of CT image and density and tissue data maps: a) CT images, b) tissue map and c) density map.

This image was acquired by PET/CT service at the Hospital do Coração (Hcor, São Paulo). The maps of density and tissue acquired are used as input data for the SCMS that is an auxiliary program that was developed to serve as an interface between image data and the MCNP5 code, forming an integrated system for the calculation of dosimetry [1].

The ICCT also provides a text file containing the elemental weights of these materials in a specific format to MCNP5 code. Figure 6 shows the output.

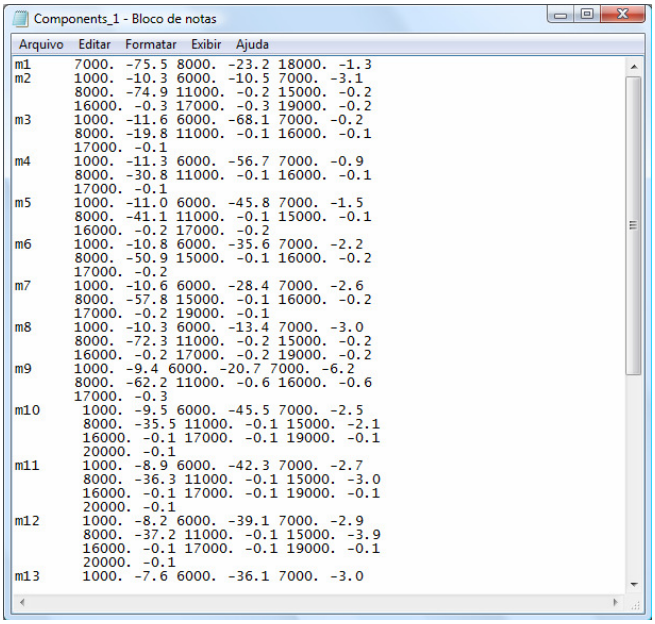


Figure 6: The output of the ICCT providing data for MCNP.

All these results are saved in the directory of the entry specified by the user in a folder called "Results_of_the_Maps".

4. CONCLUSIONS

This paper presents an analysis of images acquired in Gamma-Camera which represents SPECT and PET images and computed tomography images to obtain data for the calculation of dosimetry through MCNP5 code.

Regarding image data obtained by gamma-camera can be concluded that there is a linear relationship between the values of the activity with the number of counts, which is of great importance because it allows finding a value on the activity in each pixel. With these data it is possible to construct the radioactive source in the code MCNP5 through the image using the software SCMS.

The software was developed to obtain information from images of CT and through these making the maps of density and tissue. These data serve as input for the program SCMS which will provide the input data for the MCNP5 that will do the calculation of dosimetry. The software will also write a text file that contains the elementals weights that provide the input to MCNP5.

So the software is capable of generating input data for the SCMS and MCNP5 code by means of an image of CT.

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REFERENCES

1. H. Yoriyaz et. al., "Monte Carlo MCNP-4B-based absorbed dose distribution estimates for patientspecific dosimetry". J. Nucl. Med., v. 42, p. 662-669, 2001
2. X-5 Monte Carlo Team. "MCNP - A general Monte Cano N-Particle transport code, version 5" Los Alamos National Laboratory Report. LA-CP-03-0245, 2003.
3. J. S. Perry, Physical principles of medical imaging, Medical Physics Publisher, USA (1995)
4. "IMAJEJ - Image processing and analysis in Java", http://rsb.info.nih.gov/ij/ (2009)

5. S. Wilfried, B Thomas, S. Wolfgang. "Correlation between CT numbers and tissue parameters needed for Monte Carlo simulations of clinical dose distributions". Phys Med Biol ; Vol. 45, 459–478. (2000)