Influence of elemental weight of human tissues estimated by ICCT software in absorbed dose calculation

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Abstract— **Therapeutic use of radiopharmaceuticals in Nuclear Medicine has been well established and presented good success rates against many forms of cancer. The biologic effects of radionuclide therapy are measured via a physical quantity, the absorbed dose, which is defined as per unit mass of tissue. Therefore, is of great important an accurate dosimetry to assess the potential effects of treatment and to confirm or contradict the treatment predictions. The most common method used to estimate the absorbed dose at organ level was developed by Medical Internal Radiation Dose (MIRD) Committee, called MIRD system. However, this method does not have adequate patient data to obtain a dose estimate accurate in therapy. In recent years, internal radionuclide radiation dosimetry system evaluated spatial dose distribution. This system is based in Monte Carlo radiation transport codes together with anatomical and functional information of the patient. The high accuracy is, at least in part, due the Monte Carlo method to allow human tissues to be characterized by elemental composition and mass density. Thus, a reliable estimating of human tissues (elemental composition and mass density) must be obtained. According to Schneider, Bortfield and Schlegel the tissue parameters (mass densities (ρ) and elemental weights (ω_i)) can be obtained using Hounsfield units provided from CT images. Based on this, the Nuclear Engineer Center of IPEN developed the ICCT software (Image Converter Computed Tomography). It converts CT images in tissue parameters (mass densities (ρ) and elemental weights (ω_i)). This work was intended to verify if the estimate values by software ICCT of the tissue parameter, elemental weights (ω_i), are plausible to estimate the absorbed dose with reasonable accuracy.**

Keywords— **Nuclear Medicine, tissue parameters, internal radionuclide radiation dosimetry system.**

I. INTRODUCTION

Therapeutic use of radiopharmaceuticals in Nuclear Medicine has been well established and presented good success rates against many forms of cancer. The goal this treatment is to deliver a lethal radiation dose to the tumor while avoiding or limiting the dose to critical organs [1]. Therefore, is of great important an accurate dosimetry to assess the potential effects of treatment and to confirm or contradict the treatment predictions [2].

To determine the average absorbed dose at organ level, the formalism developed by the Medical Internal Radiation Dose (MIRD) Committee is widely considered as the reference method [3]. To support the calculation of nonuniform absorbed doses and to account for nonuniform activity distributions at the level of imaging instrumentation voxels, the MIRD Committee has also published S value tabulations for different voxel sizes and source-target voxel distances. Because use of previously tabulated S values requires a fixed anatomic model, this approach is not easily amenable to geometries that differ substantially from the fixed anatomic models [4].

In recent years, internal radionuclide radiation dosimetry system evaluated spatial dose distribution. This system is based in Monte Carlo radiation transport codes together with anatomical and functional information of the patient [5][6]. Anatomical information can be obtained from medical images, e.g. with MRI or CT, expressed in 3 dimensional (3D) in voxel format. Similarly, SPECT and PET imaging systems can provide 3D representation of activity distributions within patients (functional information). It is called patient-specific dosimetry system. This system provides most accurate dose calculations on the patient compared with the MIRD method [4].

The high accuracy is, at least in part, due the Monte Carlo method to allow human tissues to be characterized by elemental composition and mass density [1]. Thus, a reliable estimating of human tissues (elemental composition and mass density) must be obtained. It can be obtained using Hounsfield units provided from CT images [7].

Based on this, the Nuclear Engineer Center of IPEN developed the ICCT software (Image Converter Computed Tomography) [8]. It converts CT images in tissue parameters (mass densities (ρ) and elemental weights (ω_i)). The method implemented in ICCT was described by Schneider, Bortfield and Schlegel [7].

The aim of this work was to compare the variation in absorbed dose caused only by differences in tissue parameters ω_i (elemental weight) estimated through two forms: ICCT software and data acquired from the literature. For simulation the source energies and type were chosen due the radionuclide characteristics used in Nuclear Medicine. For this work was used the MCNP5/MCPLIB04 code to perform the transport of radiation and to estimate the absorbed dose.

II. MATERIALS AND METHODS

A. Software ICCT (Image Converter Computed Tomography)

ICCT software uses the method developed by Schneider, Bortfield and Schlegel [7], which is based on a stoichiometric calibration of Hounsfield units (H) with mass density and elemental weights.

Using experimentally determined parameters the ICCT calculate Hounsfield units for 71 human tissues, whose compositions were taken from literature [9][10]. Mass density and elemental weights of any Hounsfield unit are obtained through linear interpolation.

The ICCT binned into 24 groups the Hounsfield scale for human tissues: one group for air with range of -1000 to -950, one group for lung tissue with range of -949 to -120, seven groups for soft tissues with range of -119 to +120 and 15 groups for skeletal tissues with range of +120 to +1600.

Within each group, the elemental composition and weights are constant. The mass density continuously increases with the Hounsfield units, except in the small range of 14 – 23 is assigned where a constant density of 1.03 g.cm^{-3}.

B. The MCNP5 code

The MCNP code was developed at Los Alamos Laboratory (Los Alamos, NM) and is used worldwide to solve neutron, photon and electron couple transport problems. A main features is provides several options for developing spatial and energetic distributions through of complex geometric shapes.

Therefore, the MCNP code offers several possibilities for the user to model their problem [11].

C. Assess of influence of elemental weight (ω_i) in the absorbed dose calculate

In order to evaluate the influence of elemental weight in the absorbed dose calculates has been performed through simulations where the absorbed dose for two situations was estimated: (1) Using the elemental weight (ω_i) of alone one of the 24 groups stipulated by ICCT which corresponds to a given range in Hounsfield scale; (2) Using the elemental weight (ω_i) of human tissues obtained by literature [9][10] which correspond to the same range in Hounsfield scale.

To evaluate elemental weight alone, the mass density (ρ) was stipulated the same either by group of ICCT or data of literature. The mass density of group stipulated by ICCT was adopted as reference value.

To simulate geometry was considered a cube with 2mm dimension which will contain both tissues and radiation sources. This cube was immersed in a 2 cm diameter water sphere.

Isotropic source was distributed in whole cube and were considered photon sources of 0.02 to 2.75 MeV, and electron source of 0.1 to 4 MeV. The source energies and type were chosen due the radionuclide characteristics used in Nuclear Medicine.

In order to absorbed dose measure within cube was used the *F8 tally which obtain deposit energy (MeV) inside of the cube. The absorbed dose (Gy) was calculated by expression:

$$D = \frac{E \times 1.60217646E - 13}{\rho \times V}[Gy] \qquad (1)$$

where E is the deposit energy (MeV) measured by *F8 tally, the constant 1.60217646E-13 is used for convert MeV in Joule, ρ (g.cm^{-3}) is tissue mass density present in the cube and V (cm^3) the cube volume.

The comparison between absorbed doses of two situations was calculated as percentage relative difference:

$$DoseDifference(\%) = \left(\frac{D_0^{'} - D_0}{D_0}\right) \times 100 \qquad (2)$$

where D_0 is the absorbed dose using tissues acquired by ICCT and $D_0^{'}$ correspond the absorbed dose using tissue acquired by literature.

III. RESULTS AND DISCUSSION

In order to appraise the influence of elemental weight, in the absorbed dose the experiment mentioned in section II-C were performed.

A. Results of influence of elemental weight (ω_i) in the absorbed dose calculate for the soft tissue

The tissues defined for this case were the group 7 composition, obtained by ICCT software, and urine composition [9]. Table I shows the elemental weight of each element that makes up the two tissues.

Table 1 Elemental weight of tissue composition obtained by ICCT and literature for the soft tissue range

Tissues	**Elemental weight (%)**								
	H	**C**	**N**	**O**	**Na**	**P**	**S**	**Cl**	**K**
Group 7 ICCT	10.3	13.4	3.0	72.3	0.2	0.2	0.2	0.2	0.2
Urine	11.0	0.5	1.0	86.2	0.4	0.1	-	0.6	0.2

Figure 1 shows the differences in dose for photons and electrons calculated with MCNP5/MCPLIB04. They were obtained assuming that the results acquired from group 7 composition (ICCT) are the reference values.

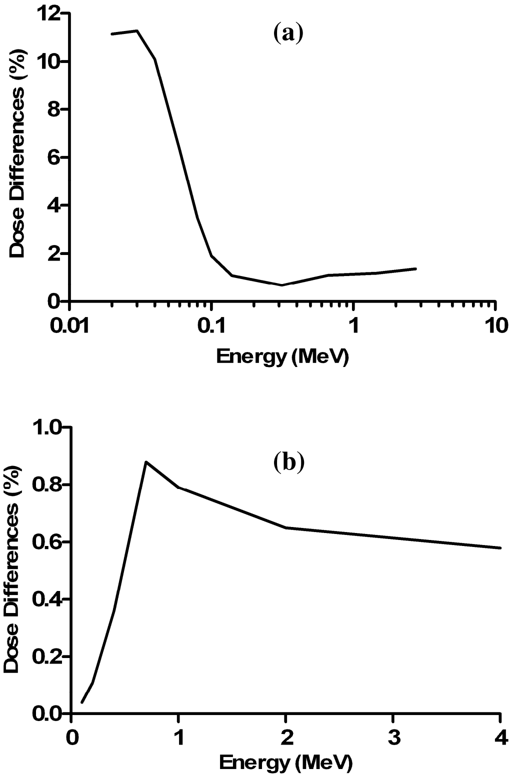

Fig. 1 Differences in absorbed dose for the soft tissue range in two situation: (a) for photons and (b) electrons source. The dose was calculated with MCNP5/MCPLIB04 code.

In terms of absolute values, the differences are considerable for photons reaching a maximum of 11.27 % at 0.03 MeV. The analysis this energy has shown that the deviations in the elemental weight of H = -0.7 %, N = 2.0 %, Na = -0.2 %, P = 0.1 %, S = 0.2 %, Cl = -0.4 % and K = 0 % between the tissues, contributes with 2.59 % in dose difference. The differences in the elemental weight of C = 12.9 % and O = -13.9 % between the tissues, contributes with 9.81 % in dose difference, which 8.90% is due to C and 0.91% to O. The dose difference high due to C is justified because the urine composition contains only 0.5% of C while the group 7 contains 13.4%. However, from 0.1 up to 2.75 MeV the dose differences were insignificant with a maximum value of 1.37 % at 2.75 MeV.

The differences for electrons were insignificant with a maximum value of order of 0.88 % at 0.7 MeV, above this energy has been observed a tendency to decrease as energy increases.

B. Results of influence of elemental weight (ω_i) in the absorbed dose calculate for the range skeletal tissue

The tissues defined for this case were the group 12 composition, obtained by ICCT software, and D6, L3 include cartilage (male) composition [10]. Table II shows the elemental weight of each element that makes up the two tissues.

Table 2 Elemental weight of tissue composition obtained by ICCT and literature for the skeletal tissue range

Tissues	Elemental weight (%)										
	H	**C**	**N**	**O**	**Na**	**Mg**	**P**	**S**	**Cl**	**K**	**Ca**
Group 12 ICCT	7.5	35.8	3.1	38.1	0.1	0.1	4.8	0.2	0.1	0.1	10.3
D6,L3 incl. Cartilage (male)	7.3	26.5	3.6	47.3	0.1	0.1	4.8	0.3	0.1	0.1	9.8

The chart presentation the differences in dose for photons and electrons calculated with MCNP5/ MCPLIB04 is shown in Figure 2. They were obtained assuming that the results acquired from group 12 composition (ICCT) are the reference values.

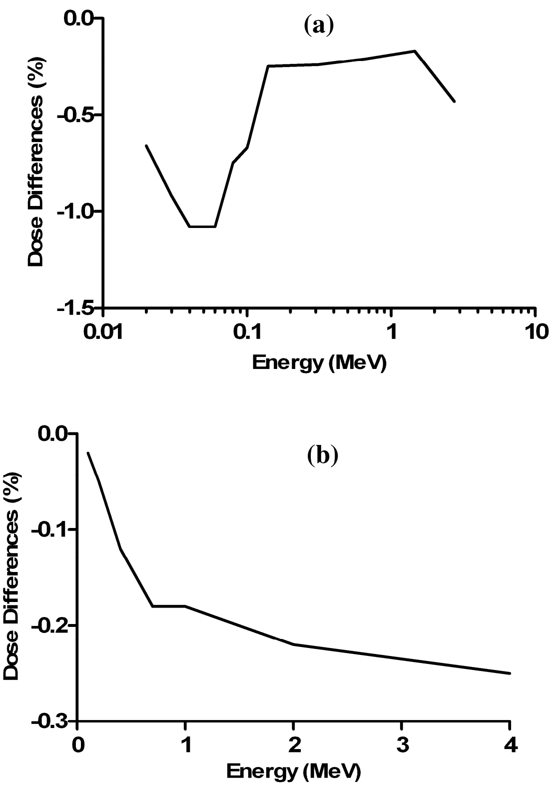

Fig. 2 Differences in absorbed dose for the skeletal tissue range in two situations: (a) for photons and (b) electrons source. The dose was calculated with MCNP5/MCPLIB04 code.

As shown in the chart (a) of Figure 2, the range from 0.02 up to 0.04 MeV was observed a increase small of 0.42 % in dose differences with a maximum value of -1.08 % at 0.04 MeV. In the range from 0.04 up to 1.46 MeV was observed a decrease small of 0.91% in dose differences and after this range was observed an increase small of 0.26% in dose differences up to 2.75 MeV reaching -0.43 %. However, all almost the differences were smaller than -1.0%.

The chart (b) of Figure 2 shows the dose differences for electron where a trend to increase the dose differences as energy increases was observed. The differences are considerably smaller reaching a maximum value of -0.25 % at 4.0 MeV.

The negatives signals mean that the calculated doses with the group 12 (ICCT) composition were greater than the calculated with the D6, L3 include cartilage (male) composition [10].

The small dose differences found were due the high precision of H, P and Ca that are very important to dose calculation in skeletal tissue [12].

IV. Conclusions

Accuracy in estimate of human tissues composition is essential for the patient-specific dosimetry system. With this concern was developed the ICCT software which convert CT images in tissue parameters (mass densities (ρ) and elemental weights (ω_i)). In this work it was proposed to compare the absorbed dose caused by differences in tissue parameters ω_i estimated by ICCT and data acquired from the literature.

Regarding to soft tissue were found considerable differences in absorbed dose for photons reaching a maximum of 11.27 % at 0.03 MeV. The analysis this energy has shown that the differences in the elemental weight of C = 12.9 % and O = -13.9 % were mainly responsible for this high difference. Nevertheless, the other energies analysis obtained insignificant values of dose differences with a maximum value of 1.37 % at 2.75 MeV. For electrons the differences in absorbed dose were insignificant with a maximum value of order of 0.88 % at 0.7 MeV. It becomes clear that considering photons source with low energies must be very careful in estimate of the soft tissue.

Concerning to skeletal tissue with photon sources of 0.02 to 2.75 MeV and electron source of 0.1 to 4 MeV, most differences in absorbed dose were smaller than -1.0 %. In this case, the small dose differences found were due the high precision of the elements H, P and Ca estimate by ICCT. These elements are very important to dose calculation in skeletal tissue.

In conclusion the ICCT software reaches a reasonable approximation for determine the elemental weights (ω_i) of tissues obtaining low variances in the absorbed dose, except in relation to soft tissues which was found a high variation of C and O, leading to significant differences in the absorbed dose for energy smaller than 0.1 MeV.

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