Revista Brasileira de Física Médica. 2011;5(2):127-32.

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

Influência do peso elementar dos tecidos humanos estimados pelo software ICCT no cálculo da dose absorvida

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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, it 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 with anatomical and functional information of the patient. The high accuracy is, at least in part, due to the Monte Carlo method allows human tissues to be characterized by elemental composition and mass density. Thus, a reliable estimation 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 Computed Tomography (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 intended to verify if the estimate values by software ICCT of the tissue parameter and elemental weights (ω_i) are plausible to estimate the absorbed dose with reasonable accuracy.

Keywords: nuclear medicine, tissue, dosimetry, radionuclide.

Resumo

O uso de radiofármacos na Medicina Nuclear vem se estabelecendo como terapia contra diversos tipos de câncer, apresentando boas taxas de sucesso. Os efeitos biológicos da terapia radionuclídica são medidos por intermédio de uma quantidade física, a dose absorvida, que é a dose absorvida pelo tecido divida pela massa desse tecido. Portanto, é de grande importância uma dosimetria precisa para avaliar os potenciais efeitos do tratamento e confirmar ou contradizer os prognósticos do tratamento. O método mais comumente utilizado para estimar a dose absorvida num órgão foi desenvolvido pelo Comitê Médico de Dose da Radiação Interna (MIRD), chamado de sistema MIRD. Entretanto, esse método não leva em consideração dados importantes do paciente para assim obter uma boa estimativa da dose para a terapia. Atualmente, há sistemas de dosimetria radionuclídica que avaliam a distribuição espacial da dose no interior do paciente. Tais sistemas são baseados em códigos de Monte Carlo para transporte de radiação juntamente com informações anatômicas e funcionais do paciente. A alta exatidão deve-se, ao menos em parte, ao código de Monte Carlo permitir que os tecidos humanos sejam melhormente caracterizados pela composição elementar e pela densidade em massa. Desse modo, uma precisa estimativa dos tecidos humanos (composição elementar e densidade em massa) deve ser obtida. De acordo com Schneider, Bortfield e Schlegel, os parâmetros do tecido (densidades em massa (ρ) e pesos elementares (ω_i)) podem ser obtidos usando as unidades de Hounsfield fornecidas nas imagens de tomografia computadorizada. Com base nisso, o Centro de Engenharia Nuclear do IPEN desenvolveu o software ICCT (Image Converter Computed Tomography – Conversor de imagem de tomografia computadorizada). Ele converte as imagens de tomografia computadorizada em parâmetros do tecido (densidades em massa (ρ) e pesos elementares (ω_i)). Este trabalho teve o propósito de verificar se os valores estimados dos pesos elementares (ω_i) mediante o software ICCT são plausíveis para estimar a dose absorvida com uma razoável exatidão.

Palavras-chave: medicina nuclear, tecidos, dosimetria, radionuclídeo.

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Introduction

Therapeutic use of radiopharmaceuticals in Nuclear Medicine has been well established and presented good success rates against many forms of cancer. The goal of this treatment is to deliver a lethal radiation dose to the tumor while avoiding or limiting the dose to critical organs[1]. Therefore, an accurate dosimetry to assess the potential effects of treatment and to confirm or contradict the treatment predictions is of great importancy[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. For the reason that the 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 dimensions (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 to the Monte Carlo method allows human tissues to be characterized by elemental composition and mass density[1]. Thus, a reliable estimation 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 to the radionuclide characteristics used in Nuclear Medicine. For this work, it was used the MCNP5/MCPLIB04 code to perform the transport of radiation and to estimate the absorbed dose.

Materials and methods

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 calculates 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, in which is assigned a constant density of 1.03 g.cm^{-3}.

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 feature is to provide several options for developing spatial and energetic distributions using complex geometric shapes.

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

Assess of influence of elemental weight (ω_i) in the absorbed dose calculation

In order to evaluate the influence of elemental weight in the absorbed dose, calculations have been performed through simulations in which the absorbed dose for two situations was estimated: (1) using the elemental weight (ω_i) of 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 corresponds to the same range in Hounsfield scale.

To evaluate elemental weight alone, the mass density (ρ) stipulated was 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, it was considered a cube with 2 mm 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 the whole cube, and were considered photon sources of 0.02 to 2.75 MeV and electron source of 0.1 to 4.0 MeV. The source energies

and type were chosen due to the radionuclide characteristics used in Nuclear Medicine.

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

$$D = \frac{E\text{x}1.60217646E - 13}{\rho \text{ x } V} \; [Gy] \quad (1)$$

In this expression, E is the deposited energy (MeV) measured by *F8 tally; the constant 1.602E-13 is used for convert MeV in Joule; ρ (g.cm^{-3}) is the tissue mass density in the cube; and V (cm^3) the cube volume.

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

$$Dose\ Difference(\%) = \left(\frac{D_0' - D_0}{D_0} \right) \text{x}100 \quad (2)$$

D_0 is the absorbed dose using tissues acquired by ICCT; and D_0' corresponds to the absorbed dose using tissue acquired by literature.

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.

Results of influence of elemental weight (ω_i) in the absorbed dose calculation for the soft tissue

The tissues defined for this case were the group 7 composition, obtained by ICCT software, and urine composition[9]. Table 1 shows the elemental weight of each element that makes up the two tissues.

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.

In terms of absolute values, the differences are considerable for photons reaching a maximum of 11.27% at 0.03 MeV. The analysis of 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 contribute with 2.59% in dose difference. The differences in the elemental weight of C=12.9% and O=-13.9% between the tissues contribute with 9.81% in dose difference, 8.90% of which 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, it has been observed a tendency to decrease as energy increases.

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

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

The tissues defined for this case were the group 12 composition, obtained by ICCT software, and D6, L3 including cartilage (male) composition[10]. Table 2 shows the elemental weight of each element that makes up the two tissues.

The chart presenting the differences in dose for photons and electrons calculated with MCNP5/MCPLIB04 is shown in Figure 2. They were obtained assuming that the

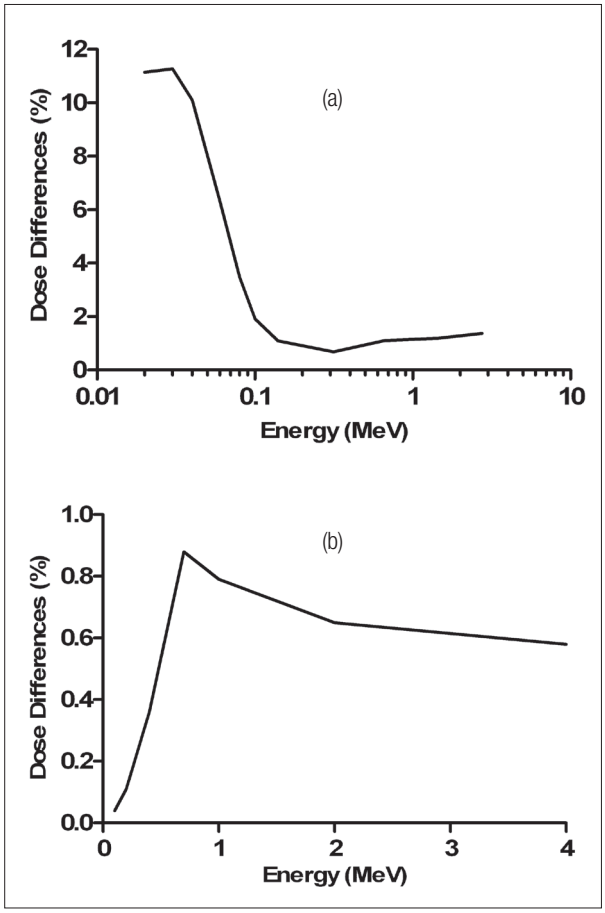

Figure 1. Differences in absorbed dose for the soft tissue range in two situation: (a) for photons and (b) electrons source. The dose was calculated with MCNP5/MCPLIB04 code.

results acquired from group 12 composition (ICCT) are the reference values.

As shown in the chart (a) of Figure 2, in the range from 0.02 up to 0.04 MeV, it was observed a small increase 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, it was observed a small decrease of 0.91% in dose differences. After this range, it was observed a small increase of 0.26% in dose differences up to 2.75 MeV reaching -0.43%. However, almost all the differences were smaller than -1.0%.

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

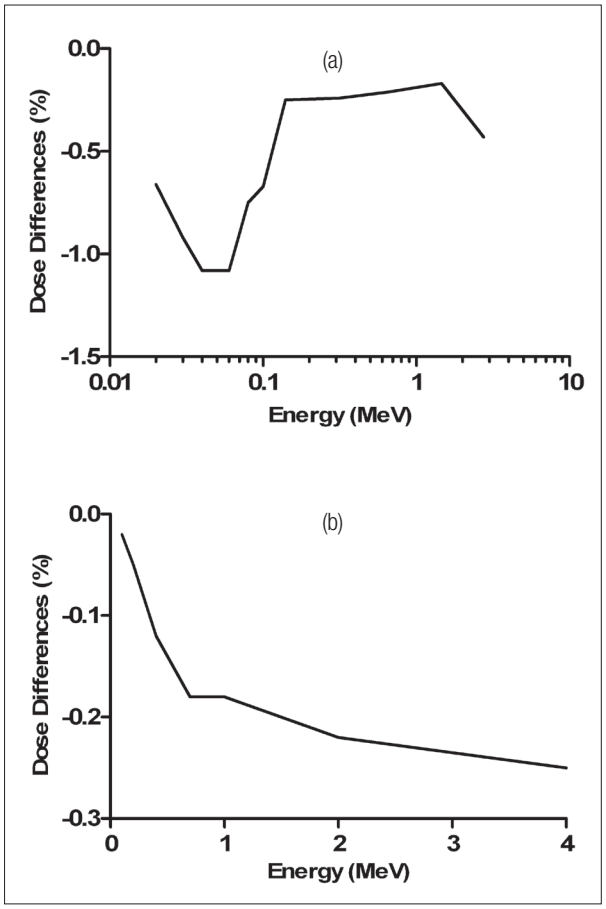

Figure 2. Differences in absorbed dose for the skeletal tissue range in two situations: (a) for photons and (b) electrons source. The dose was calculated with MCNP5/MCPLIB04 code.

The chart (b) of Figure 2 shows the dose differences for electron in which 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 including cartilage (male) composition[10].

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

Conclusions

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

Regarding to soft tissue, considerable differences in absorbed dose for photons reaching a maximum of 11.27% at 0.03 MeV were found. The analysis of 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 made very carefully in estimation 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 to the high precision of the elements H, P and Ca estimated 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, in 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.

Acknowledgment

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for partial economic support.

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