ERROR ESTIMATION ON THE ABSORBED DOSE DUE TO HETEROGENEITY OF HUMAN BODY TISSUE IN RELATION TO THE WATER PHANTOM

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Abstract. *During radiotherapy the patient is submitted to a radiation source in a controlled environment. Although the absorbed doses can reduce the proliferation of cancer cells, it can also damage normal cells. The incidence of the deleterious effects obeys a sigmoidal shape curve which means a very small increment of dose produces a large effect. So, a precise dose calculation and ministration are required to treat cancer without produce serious injuries. In spite of this very small margin of error the treatment doses are evaluating overlapping doses obtained and calibrated experimentally in a water phantom, mimicking the human body. However the heterogeneity of human structures can influence the value of doses due to the differences found in particle fluency related to the nuclear particle transport in human and in the water, also in the kerma dose evaluation, which convert fluency to kerma due to the heterogeneity found in the chemical composition from human tissue and water .This paper evaluates the error of the method using water based calculation, only considering the differences of tissues kerma coefficients. The errors were estimated by using kerma coefficients to calculate a dose absorbed in a various human tissue comparing it to the same in the water, when exposed to a radiation source of same spectrum. The results are presented as a ration of the tissue dose by water dose, submitted to the same spectrum. The dose of each tissue and of water was calculated using a discrete photon spectrum of two electron accelerators: 6MV and 15MV. To 6MV accelerator only the original spectrum was taken. To 15MV accelerator the original spectrum and one in-deep degraded spectrum were applied. As results the table of errors, and tomography overlapped isocurves of these errors in human body are shown.*

Keywords*: cancer, radiotherapy, kerma, absorbed dose, nuclear particle transport.*

1. INTRODUCTION

Cancer is an ordinary name given to a set of diseases which have in common an abnormal grow of cells. A common cancer treatment modality is radiotherapy. For example, the patient is submitted to an external radiation nuclear particle beam in a controlled environment. The radiotherapy is based in fact that cancerous cells are more sensible to ionising radiation than normal cells. So, the radiotherapist can determine the orientation of the radiation external beam, its energetic spectrum, and the irradiation field. If the time is defined enough to produce an internal absorbed dose suitable to kill cancerous cells without damage normal cells, this protocol can control the tumor and may cure the patient.

The main problem is the small interval between dose to control tumor and maximum allowing dose on normal tissue although the doses that can kill cancer cells are different of those that can damage normal cells. So, in radiotherapy, a precise dose calculation in treatment planning and a precise ministration of this treatment are required to treat cancer without produce serious injuries to patient.

In spite of this very small margin of error in treatment planning is allowed. Since there aren't fast algorithms to calculate doses, the absorbed doses are evaluated by overlapping of doses obtained experimentally in water phantom. However, the human body aren't made of water and it's very heterogeneous. And, this heterogeneity can influence doses in two main ways:

(i) the radiation can be spread by tissues and can be reflected in tissues interfaces, and

(ii) the interaction of the radiation with tissues are dependent of the chemical composition and density of each tissue.

The present paper addresses the first issue, calculating the error of the method using a water-based dose calculation comparing it one method that considered variations on the tissue chemical composition, but without taken in consideration the radiation spread or reflection (secondary radiation).

To calculate how chemical composition of the tissue influences in absorbed doses, it was used two human voxel models, one representative of the ear region and other representative of the thorax region. The comparison was made by

dividing the dose in each tissue by the dose in the water equivalent voxel. The doses on each voxel filled with tissue and filled with water were calculated using a discrete photon spectrum of two electron accelerators: 6MV and 15MV. For the 6MV accelerator, the primary spectrum presented on the literature was taken. For the 15MV accelerator, the primary spectrum and another representative of in-deep degraded water phatom were taken.

2. MATERIALS AND METHODS

2.1. Calculus of deviation of the absorbed dose on tissue in relation to water

The method used to calculate the absorbed dose in each voxel was multiplying the fraction of total beam in each energy present on the discrete beam by the tissue's fluence-kerma coefficient in those energy. The fluency was considered constant in all voxels (equation 1). When the sum of charged particles that enter in a volume is equal of the sum of charged particles that leave this volume the kerma is equal to dose. This condition is true in gamma radiation therapy far from the boundaries, so this is an efficient method to calculate dose.

$$D = \sum_{E=E_{mim}}^{E_{max}} F_E \,.\, k_E \qquad (1)$$

Equation 1 summaries the calculus of the tissue's absorbed dose subject to an expose field, in which D is absorbed dose; E is field's energy; F is the fraction of fluence to each energy; k is kerma coefficient to the same energy E.

The value X assigned to each voxel is an adimensional value that corresponds to the dose in the tissue divided by the dose obtained in water at same conditions. Equation 2 presents the procedure to generate the X value. This value represents the fraction of dose that will be absorbed if chemical composition of the tissue was the same of the water. The error due to the heterogeneity found in the chemical composition from human tissue and water, present in method of isodoses overlapping, can be obtained subtracting the value calculated to each tissue by the unit (Equation 3).

$$X = D_T / D_w \qquad (2)$$

Equation 2 presents the calculus of the value assigned to each tissue, in which D_T is the tissue dose; D_w is the water dose at the same conditions.

$$E = (D_T - D_w) / D_w;$$

or

$$E = D_T / D_w - 1;$$

or

$$E = X - 1 \qquad (3)$$

Equation 3 evaluates the Error of calculus, since the value . E is the relative error; D_T is the tissue dose; D_w is the water dose at the same conditions; and X is the relative dose obtained from equation 1.

2.2. Calculus of the kerma coefficients for water and tissue material

The kerma-dose conversion coefficients (also called kerma coefficients) are used for converting the particles fluency for absorbed dose in a volume. These coefficients are well known to great part of chemical elements and great part of the gamma rays energies below 20MeV. The kerma coefficient to a chemical compound, in a specific energy, can be obtained by taken the mean of the kerma coefficients of each chemical element of the compound weight on mass (equation 4). Using this equation, the kerma coefficient to each tissue of human body can be evaluated. The standard to dose calculus on radiotherapy is the method in with isodoses curves taken in water phantom are overlapped, so a good parameter to show how this standard is overestimating or underestimating doses is to find the fraction of the tissues kerma coefficient by the water kerma coefficient. Figure 1 shows the quotients of tissue kerma coefficient divided by water kerma coefficient to various tissues on many energies (Trindade, 2006). This figure shows that water doses are, in most cases, super estimated. But for some tissues on energies between 10keV and 100keV the doses are greatly sub estimated.

$$K_{compound} = \sum_{E=E_{beg}}^{E_{end}} M_E \,.\, k_E \tag{4}$$

Equation 4 shows how to calculus of the compound's kerma coefficient ($k_{compound}$) to an arbitrary energy, in which E is the energy; M_E is the mass fraction of the chemical element of compound; k_E is kerma coefficient of the chemical element.

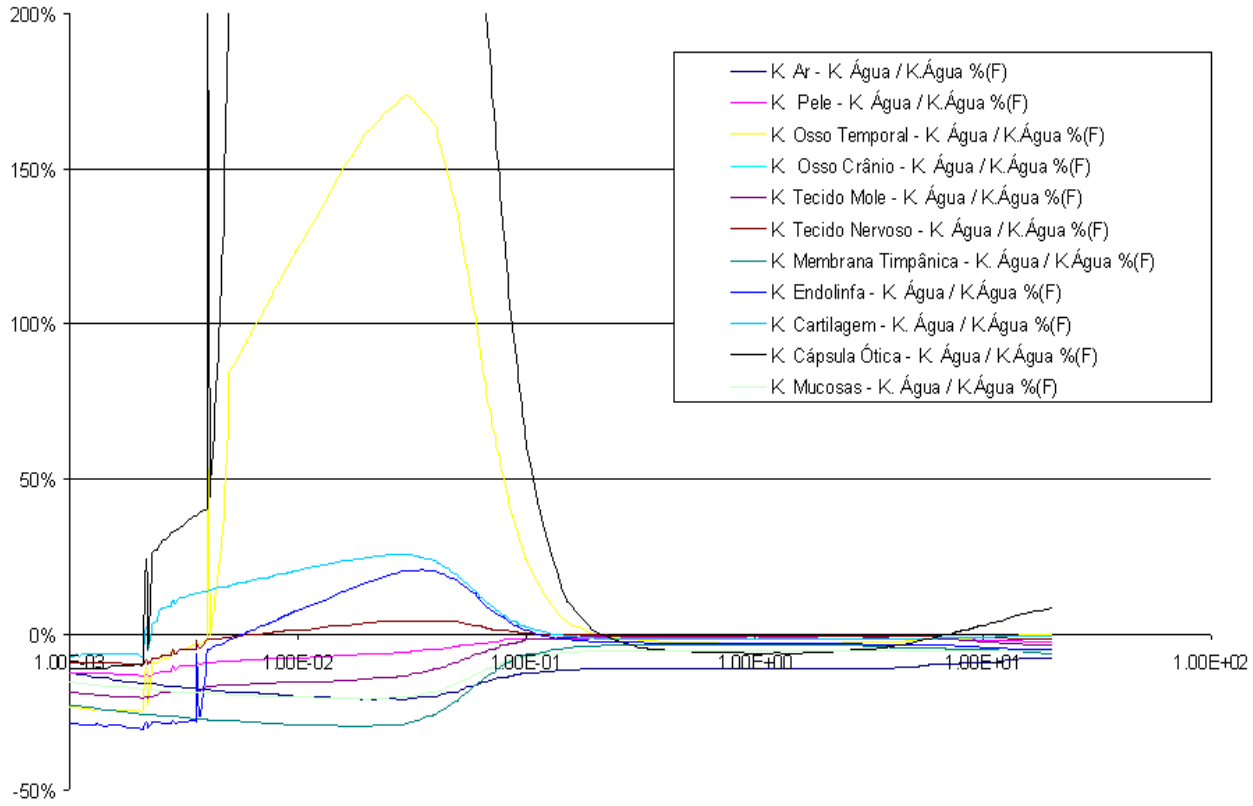


Figure 1. Tissue kerma coefficients divided by water kerma coefficients vs. energy.

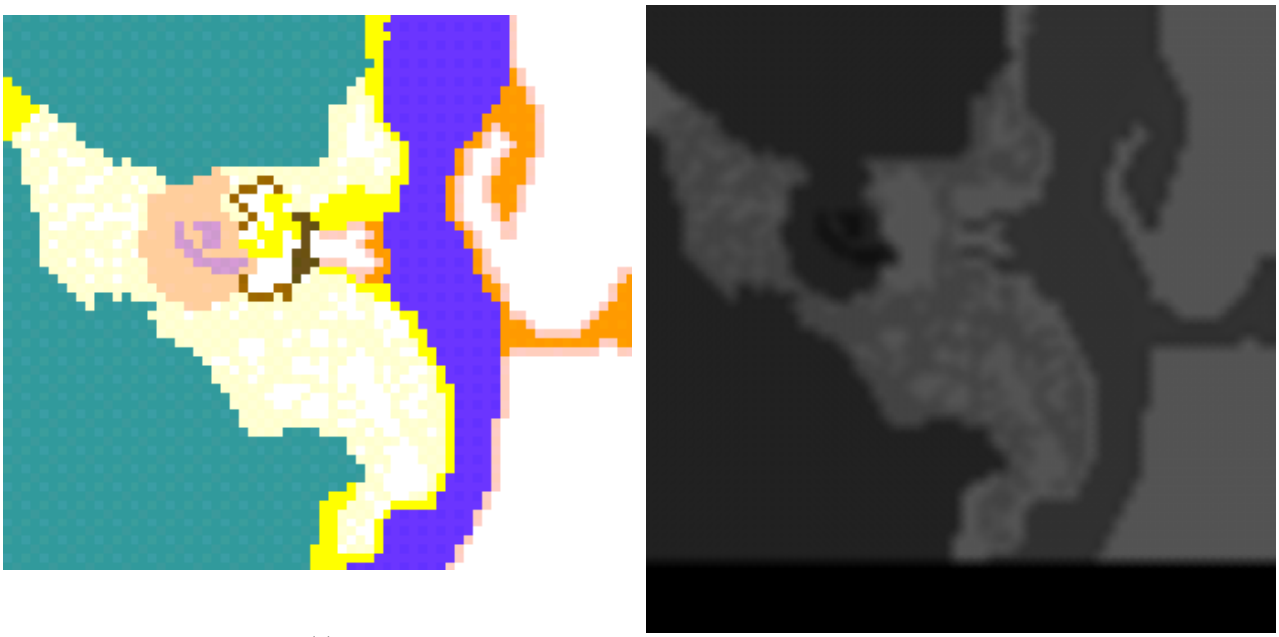
2.3. Accelerator beam spectra

Three distinct source spectrums were used on the calculations: photons spectrum of the primary field generated by a 6MV electron accelerator; photons spectrum of the primary field generated by a 15MV electron accelerator; photons spectrum of the primary field from the 15MV electron accelerator in-deep degraded by 4mm of tungsten (Huang, 2004). Indeed, an in-deep water spectrum should be used but this spectrum can't be found in literature and are special cases for each region on the body. Therefore, the primary spectra generated by the linear accelerator will be used on our calculation that will be applied to all voxels without considering the spatial degradation of the spectra on the human being.

2.4. Voxel models

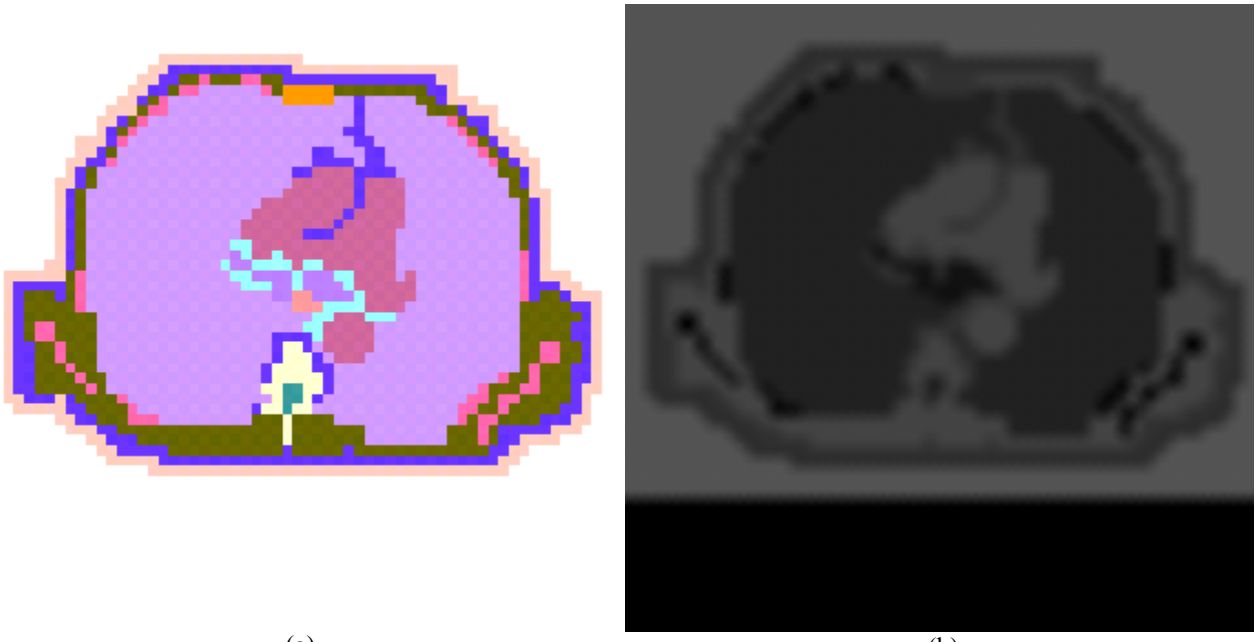
Voxel is a volume element, just like a pixel but in three-dimensional space. So a voxel model is a three-dimensional matrix which each matrix element represents one voxel. On voxel models for radiotherapy each voxel must store information that can reproduce how radiation interacts with that tissue. On the models used in this paper, this information includes the chemical composition of the tissue and its mass density as well as the experimental microscopic cross sections of the atoms that compose the tissue.

Two models were applied: The first one represents the ear region of body with all internal structures (Trindade, 2006), as shown in "Fig. 2". The second model (Maia, 2004) represents the thorax with organs and internal structures "Fig. 3".



(a) (b)

Figure 2. Coronal slice of voxel model of ear region showing internal structures of ear, brain, skull, etc. (a) Reconstructed image which a color is associated to each tissue; (b) Reconstructed image which a gray level is associated to each tissue and these gray levels were isotropicaly interpolated.



(a) (b)

Figure 3. Coronal slice of voxel model of thorax region showing the heart, the lungs, the backbone, etc. (a) Reconstructed image by color-tissue association. (b) Reconstructed image by gray-tissue association, isotropic interpolated.

3. RESULTS

In order to develop the calculus of the relative dose for each tissue, as well as to create a compatible file for the SISCODES (Trindade, 2004) output module, a python program was developed namely HEC (homogeneous Error calculation). This program reads tissue kermas from database and, through the equation 1, calculates the absorbed dose in the tissue due to exposition to the selected radiation field. After the tissue doses has been evaluated, the program

HEC applied the equation 2 to divide the dose on each tissue by the dose obtained in water, obtaining the "relative value " X. So, the program could read the voxel model from a file and saves it in a format compatible with the interface namely Gera_Saída of the SISCODES code. In this file each voxel have the relative dose value impress in color scale. .

The SISCODES module was applied to produce the kerma coefficient values. This program, through equation 4, calculates the kerma coefficient for each tissue-energy data pair, and stores these coefficients in a database.

The program, in order to calculus of relative value X, was executed for two phantoms and for each spectrum beam. Table 1 was created using the output values X. The output files were load on the interface Gera_Saída from SISCODES code merged with phantom files. The results of this execution are depicted on the images showed on Fig. 4 and Fig. 5.

To both models, after the application of the selected radiation spectra, it was observed that the absorbed water doses were super estimated in relation to the tissue dose. However, for the deep degraded spectrum, the absorbed dose in water sub estimate the dose on bone tissues.

Table 1. Relative values X of the tissues registered on SISCODES, for radiation field spectrums of 6MV, 15MV and 15MV degraded in-deep.

Tissue	6MV	15MV	Degraded 15MV
Water	1.000	1.000	1.000
Tumour 1	0.768	0.750	0.764
Air	0.890	0.898	0.892
Tumour 2	0.893	0.875	0.889
Tumour 3	0.893	0.875	0.889
Articular capsule	0.902	0.932	0.912
Bone: Posterior arc of the vertebra	0.915	0.991	0.937
Bone: vertebra body	0.915	0.991	0.937
Bone: rib	0.915	0.991	0.937
Bone: vertebral foramen	0.915	0.991	0.937
Bone: Iliac bone	0.915	0.991	0.937
Bone: Ischium	0.915	0.991	0.937
Bone: Pubic bone	0.915	0.991	0.937
Otoliths	0.915	0.991	0.937
Breast calcifications	0.915	0.988	0.936
Bone: cortical vertebrae	0.937	0.978	0.949
Bone: cortical vertebrae (child 15 year-old)	0.940	0.979	0.952
Bone: Jaw	0.946	0.979	0.956
Mucosa of the tympanic cavity	0.948	0.947	0.948
Mucosa of the tuba auditive	0.948	0.947	0.948
Ear bones (ossicles)	0.949	0.980	0.958
Bone: cranium	0.949	0.980	0.958
Bone: cochlea	0.949	0.980	0.958
Carbohydrate	0.954	0.951	0.953
Protein	0.956	0.950	0.955
Bone: humerus	0.956	0.979	0.964
Tympanic membrane	0.963	0.958	0.962
Bone: Femur (child 15 year-old)	0.964	0.979	0.969
Bone: Femur (adult 30 year-old)	0.964	0.981	0.970
Bone: Sacrum (male)	0.966	0.980	0.971
Endolinfa	0.970	0.966	0.970
Bone: petrous portion of the temporal bone	0.974	0.980	0.977
Bone: Vertebrae (spongy bone)	0.975	0.981	0.978
Eye crystalline	0.985	0.982	0.984
Cartilage	0.985	0.988	0.986
Articular cartilage	0.985	0.988	0.986
Trachea	0.985	0.988	0.986
Peritoneum	0.987	0.986	0.987
Skin	0.988	0.985	0.987
Conjunctive tissue	0.988	0.985	0.987
Brain	0.989	0.987	0.988
Mediastine	0.989	0.988	0.989

Table 1. Continuation....

Tissue	6MV	15MV	Degraded 15MV
Urethra	0.989	0.988	0.989
Blood (adult)	0.990	0.989	0.990
Iliac vein	0.990	0.989	0.990
Liver	0.990	0.989	0.990
Health Liver	0.990	0.989	0.990
Cupola ampular	0.990	0.989	0.990
Cupola utricular	0.990	0.989	0.990
Thin intestine	0.990	0.989	0.990
Thick intestine and colon	0.990	0.989	0.990
Thick intestine and mesocolon	0.990	0.989	0.990
Labyrinth mucosa	0.990	0.989	0.990
Skeletal muscle	0.990	0.989	0.990
Human muscle	0.990	0.989	0.990
Recto	0.990	0.989	0.990
Urethra	0.990	0.989	0.990
Plexus choroids	0.990	0.990	0.990
Blood 1	0.990	0.990	0.990
Stern bone	0.991	0.982	0.989
Kidney	0.991	0.990	0.991
Thyroid	0.991	0.990	0.991
Spleen	0.991	0.991	0.991
Lung health	0.991	0.991	0.991
Heart	0.992	0.990	0.992
End of the veins	0.992	0.990	0.992
Salivary Gland	0.992	0.985	0.991
Breast: tissue fibre glandular	0.992	0.985	0.991
Seminal vesicle	0.992	0.985	0.991
Placenta	0.992	0.992	0.992
Soft tissue	0.992	0.986	0.991
Bladder empty	0.993	0.993	0.993
Ovary	0.993	0.993	0.993
Pancreas	0.993	0.991	0.993
Esophagus	0.994	0.992	0.994
Rabbit: gastrointestinal tissue	0.994	0.992	0.994
Gastrointestinal tract	0.994	0.992	0.994
Rabbit: Gastrointestinal tract	0.994	0.992	0.994
Brain	0.994	0.993	0.994
Brain (adult)	0.994	0.993	0.994
Nervos raiz	0.994	0.993	0.994
Neurovascular plexus	0.994	0.993	0.994
Nervous tissue	0.994	0.993	0.994
Medulla spinal	0.995	0.994	0.995
Testicle	0.996	0.995	0.996
Lymph	0.996	0.996	0.996
Perilymph	0.996	0.996	0.996
Bladder full of urine	0.996	0.997	0.996
Adipose tissue (adult)	0.997	0.983	0.994
Adipose tissue (child 1 to 18 year)	0.997	0.987	0.995
Liquor	0.997	0.983	0.994
Urine	1.008	1.009	1.008
Penis bulb	1.063	1.062	1.063

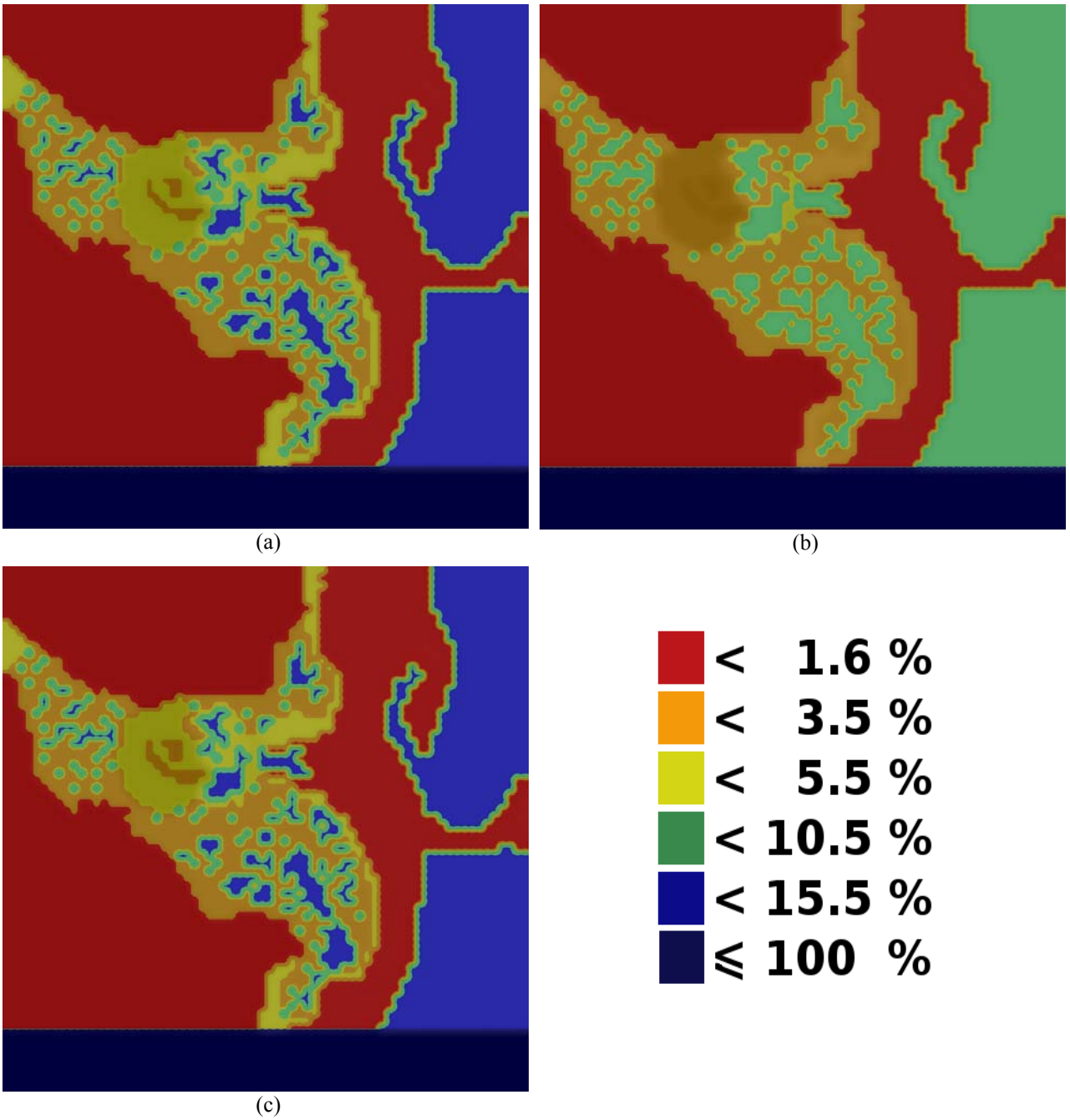


Figure 4. Same slice of figure 2 but showing the error, due to kerma coefficients, of relative dose. (a) To spectrum of 6MV electron accelerator; (b) To spectrum of 15MV electron accelerator; (c) To in-deep degraded spectrum of 15MV electron accelerator.

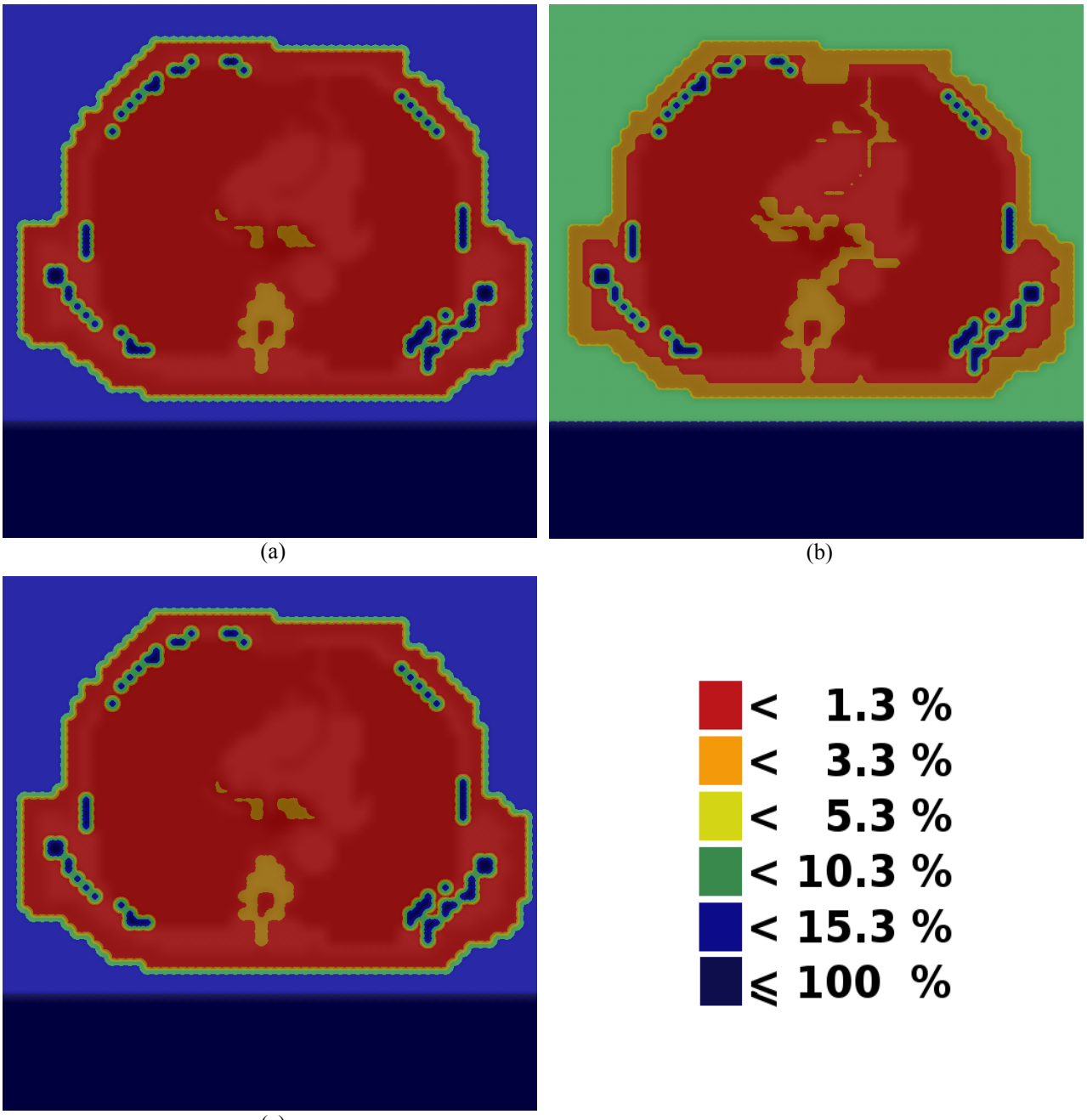


Figure 5. Same slice of figure 3 but showing the error, due to kerma coefficients, of relative dose. (a) To spectrum of 6MV electron accelerator; (b) To spectrum of 15MV electron accelerator; (c) To in-deep degraded spectrum of 15MV electron accelerator.

4. CONCLUSIONS

The use of water phantom, mimicking a human being, on radiodosimetry produces not-so-small variations on the absorbed doses. Those results found values superior to the 5% preconizing in radiation therapy protocols, such as ICRU-50. The absorbed dose depends on the radiation field spectra that is suffer a degraded on the human tissue, which is a geometric and material problem. So, deeper a structure is, greater is the spectrum degradation, and smaller is the average energy. For radiation fields studied on the present paper, all tissues doses are smaller than water dose. Bones and tumors are structures with great relative deviations (the relative dose is always smaller than water dose up to 12%). However for radiation fields with smaller energies spectrum the water dose becomes sub estimated, and correction should be introduced to adequate treatment dose prediction. Further studies should be done for finding a suitable correction protocol.

5. BIBLIOGRAPHY

Trindade, D. F. M., 2006 - "Efeitos Deletérios Induzidos por Exposição Indireta do Aparelho Auditivo em Radioterapia de Cabeça e Pescoço - Correlacionamento Dosimétrico", PCTN/UFMG.

Maia, M., 2004, "Fantoma Antropomórfico Antropométrico de Tórax para fins de Radioproteção e Dosimetria", Dissertação de Mestrado, PCTN/UFMG.

Trindade, B. M., 2004, "Desenvolvimento de Sistema Computacional para Dosimetria em Radioterapia por Nêutrons e Fótons baseado em Método Estocástico – Siscodes", Dissertação de Mestrado, PCTN/UFMG.

Huang, W.L., 2004 - "Calculation of photonneutrons produced in the targets of electron linear accelerators for radiography and radiotherapy applications", Science Direct.

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