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MONTE CARLO SIMULATION FOR DOSE DETERMINATION IN THYROID CANCER PATIENTS

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ABSTRACT

This present study is focused on the dose determination due to I-131 administration in thyroid treatment in several parts and structures of the head and spine and also doses received by the thermo-luminescent dosimeters (TLD), placed in the patient´s neck as an attempt to find a correlation between doses received by the spine (bone marrow included) and the doses received by the TLD dosimeters. The average S-value in those dosimeters is 6.18E-07 mGy/MBq.s, which is about ten times lesser than the average S-value in the bone marrow region. Although any attempt to built a correlation between doses to bone marrow and to dosimeters is premature, the present calculation gives an indication of this value.

Keywords: bone marrow, MCNP-4C, dosimetry, thyroid, TLD.

I. INTRODUCTION

Thyroid cancer treatment using I-131 radionuclide has been traditionally used for many years in clinical centers around the world. In São Paulo, The *Centro de Medicina Nuclear (CMN-USP)*, have treated several patients with thyroid diseases through the administration of I-131, which radioactive activity varies from 3700 MBq to 7400 MBq.

Aiming to search for a safety optimization in this treatment it was recognized the necessity of a more accurate knowledge of dose levels received by the thyroid, spine and surrounding tissues in the neck and head regions, and also, doses received by patients accompanies with more accurate methods.

This present study is focused on the dose determination due to I-131 administration in thyroid treatment in several parts and structures of the head and spine and also doses received by the thermo-luminescent dosimeters (TLD), placed in the patient´s neck as an attempt to find a correlation between doses received by the spine (bone marrow included) and the doses received by the TLD dosimeters. This correlation, if exists, will help the medical physicists to quantitatively estimate the doses received in the spine region next to the thyroid gland by each patient, through the TLD dose measurements or other dosimetric measurement devices performed during the treatment period.

II. METHODS AND MATERIALS

A. The Phantom of Yale. The CT-image based Phantom of Yale was built from the CT scanning of an adult male human patient and consists of a 3-dimensional array of cubic voxels, 4 mm on each side [1,2]. It has been served as an important investigation tool in several works involving numerical dosimetry related to diagnosis and therapy studies. Previous works have been done with this phantom to obtain average doses and dose distribution in several internal organs present in the trunk region [3,4]. The head and neck region, where this present study is focused, consist of 63 slices each one composed by a 2-D array of 128 x 128 voxels. Several internal structures have been identified and their masses estimated based on the number of voxels present. Figure 1 shows a three-dimensional representation of the thyroid and surrounding organs as trachea and esophagus.

B. Computational Model Originally, the thyroid gland mass in the phantom of Yale is 7 grams [3], which is very small compared to normal cases. To correct this fact, the thyroid was re-modeled and the surrounding phantom structures have been modified to accommodate the new thyroid phantom.

The new thyroid gland has a mass of 18.64 g and is composed by 280 voxels (175 more voxels than the original one), located between slices number 58 and 68 (slices 58 to 62 in the original thyroid phantom). Most of the thyroid additional voxels belonged originally to the skeletal muscle surrounding the thyroid and few others voxels belonged to the blood pool. Organs like trachea, esophagus, spine and spinal chord were axially divided in two parts, i.e., one part which belongs to the neck region (upper part) which goes from slice 37 to 70 and the other part which is not in the neck region (lower part). In the same manner, the bone marrow inside the spine was divided in two parts (upper and lower). The top part was divided in four axial sub-regions to allow more detailed dose calculation. The first sub-region was inserted along slices 37 through 49, the second sub-region was inserted along slices 50 through 57, the third sub-region from slice 58 to 62 and the fourth sub-region was inserted along slices 63 to 70. Figure 2 shows slices 58 through 68 of the phantom where the thyroid is located surrounded by others structures.

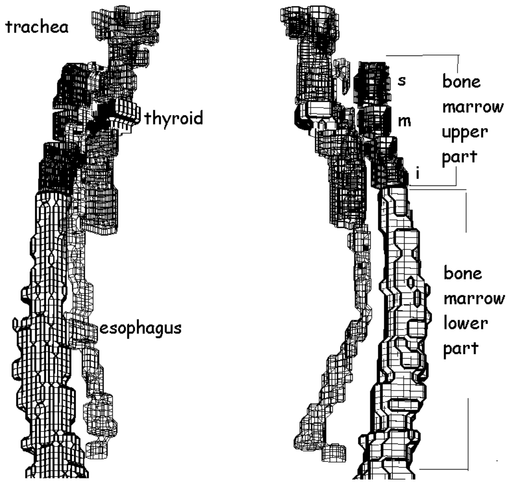

Figure 1 3-D representation of thyroid, trachea and esophagus

Further modifications have been implemented to place four sets of TLD dosimeters on the skin surface of the neck region of the phantom. These dosimeters were placed in the slices 37 to 70, distributed in the same manner of bone marrow sub-regions. This modification gave origin to a new phantom called here as the Modified Phantom of Yale (MPY). Table I shows the masses of the main organs and its parts and respective number of voxels in each of those organs or sub-organs. The soft tissue, bone tissue and TLD dosimeters densities are respectively: 1.04, 1.40 and 2.64 g/cm^3.

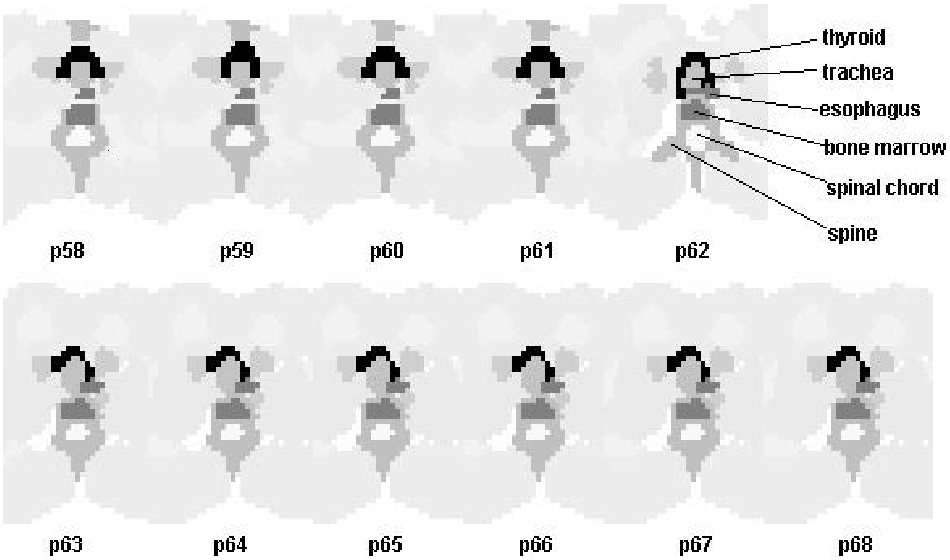

Figure 2. Cross-sectional view of each slice containing the thyroid and surrounding structures.

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The purpose to insert dosimeters is to find insights of a correlation (if exists) of doses received by the bone marrow and the doses that would be received by these dosimeters if they are placed on the neck region of the patient in treatment.

TABLE I. Masses of organs and sub-organs with their respective identification number and number of voxels

Organ name	Organ Identification	Number of Voxels	mass (g)	Volume (cm^3)
Brain	2	18299	1217.981	1171.136
Skull	4	8114	727.014	519.296
Thyroid	28	280	18.637	17.92
bone marrow(spine p37 to p49)(*)	49	189	16.934	12.096
bone marrow(spine p50 to p57)	50	159	14.246	10.176
bone marrow(spine p58 to p62)	51	107	9.587	6.848
bone marrow(spine p63 to p70)	52	170	15.232	10.88
Trachea (p37 to p70)	53	700	46.592	44.8
Esophagus(p37 to p70)	54	144	9.585	9.216
Spine(p-37 to p70)	55	3108	278.477	198.912
Spinal cord (p37 to p70)	56	656	58.778	41.984
TLDs (p37 to p49)	65	52	3.461	3.328
TLDs(**) (p50 to p57))	66	32	2.13	2.048
TLDs (p58 to p62)	67	20	1.331	1.28
TLDs(p63 to p70)	68	32	2.13	2.048
Dens of axis	70	15	0.998	0.96
Jaw bone	71	1183	105.997	75.712
Spinal canal	75	102	6.789	6.528
Hard palate	76	455	30.285	29.12
Cerebellum	77	2468	164.27	157.952
Tongue	78	588	39.137	37.632
Medulla oblongota	85	19	1.265	1.216
Pons	91	349	23.229	22.336
Sinuses/mouth cavity	104	1287	85.663	82.368
Optic nerve	106	93	6.19	5.952
Cerebral falx	113	205	13.645	13.12
Eye	119	242	16.108	15.488
Lens	121	23	1.531	1.472
Teeth	125	260	23.296	16.64

(*) p37 means slice number 37
(**) TLDs means Thermo-Luminescent Dosimeters.

C. Monte Carlo Simulation Numerical dosimetry nowadays has gained great impulse with increasing utilization of versatile Monte Carlo program packages to treat many problems in the area of cancer therapy and radio-diagnosis. One of these program packages, increasingly used by medical physicists is the MCNP code [5] which was developed at Los Alamos National Laboratory to solve problems demanding transport of electrons, photons and neutrons [6].

This present study utilizes the MCNP version 4C code for the simulation of radiation transport for the dose calculation in a phantom which represents the head and neck region of an adult male based on the CT image data of the Modified phantom of Yale described in the previous section.

The input data for the MCNP radiation transport simulation was built with the auxiliary of the SCMS software [4], which reads and interprets the CT-based image data containing the modified phantom of Yale. The SCMS software processes all the information and provides an input data appropriate to be used by the MCNP code.

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III. RESULTS

S-Values have been estimated with the present methodology assuming homogenous I-131 distribution in the thyroid volume. Since that each organ volume is composed by a set of single cubic voxel volumes, the homogeneity of the source has been established considering the same radiation emission probability in all voxels which contains the source. Table II shows the average S values in mGy/MBq-s for some of the organs listed in Table I.

TABLE II. S-values of some organs in the head region.

Organ name	S values mGy/MBq-s
Brain	2.40e-07
Thyroid	1.60e-03
bone marrow(spine p37-p49)	2.48e-06
bone marrow(spine p50-p57)	6.88e-06
bone marrow(spine p58-p62)	1.10e-05
bone marrow(spine p63-p70)	7.50e-06
Cerebellum	3.59e-07
Medulla oblongota	5.96e-07
Pons	4.05e-07
Sinuses/mouth cavity	5.11e-07
Optic nerve	3.93e-07
Cerebral falx	1.53e-07
Eye	3.44e-07
Lens	3.11e-07
Tlds (p37-p49)	6.28e-07
Tlds (p50-p57))	7.51e-07
Tlds (p58-p62)	6.13e-07
Tlds(p63-p70)	4.81e-07
Trachea(p37-p70)	2.89e-05
Esophagus(p37-p70)	2.27e-05
Spine(p37-p70)	3.21e-06
Spinal cord(p37-p70)	3.02e-06

S-values to the thyroid obtained in the present work is 1.60E-03 mGy/MBq.s, differing in 3 % from the value obtained by Snyder [7] in his mathematical adult male phantom which is 1.65E-03 mGy/MBq.s. The total S-value to the bone marrow in the upper spine region which is the sum of S-values to the four bone marrow regions (slices 37 to 70) is 2.79E-05 mGy/MBq.s.

The upper spine region runs from Z=14.8 to Z=27.6 cm covering 13.2 cm long. The largest S-value is found in the bone marrow region that runs from Z=23.2 to Z=24.4 cm facing the thyroid organ. The correspondent S-value for this region is 1.10E-05 mGy/MBq.s which is ten times greater than the average dose estimate in the upper spine obtained by Stabin [8].

These values demonstrates that although the self-S-values (S-values to the source organ) in the thyroid obtained in both phantoms, MPY and Snyder phantom, agreed well, the S-values are quite different in target organs other than the source organ as already demonstrated by Yoriyaz [3] in calculations performed in organs of the trunk region of the phantom.

S-values in four sets of TLD´s dosimeters have also been calculated to estimate doses in a hypothetical situation where these dosimeters are placed on the neck surface region of patients receiving I-131 administration. The S-values varies from 4.81E-07 mGy/MBq.s to 7.51E-07 mGy/MBq.s, so that the average value is 6.18E-07 mGy/MBq.s, which is about ten times lesser than the average S-value in the bone marrow region.

Although any attempt to built a correlation between doses to bone marrow and to dosimeters is premature, the present calculation gives an indication of this value.

IV. DISCUSSION

The dose obtained in the thyroid agreed well with the results obtained by Snyder in its mathematical phantom, however, doses in organs other than the source organ are quite different mainly due to differences in geometry between the phantoms.

The average S-value in the TLD dosimeters is 6.18E-07 mGy/MBq.s, which is about tem times lesser than the average S-value in the bone marrow region. This preliminary result gives an indication of the dose relation between bone marrow and the dosimeters and can be confirmed with more accurate calculations and with measurements performed in patients during the treatment period.

The achievement of a correlation between measured doses in TLD´s and doses calculated in the bone marrow region could be of great help in the optimization of thyroid deseases treatment using I-131 administration.

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