2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-03-8**

DOSIMETRY ON OCULAR BRACHYTHERAPY WITH I-125 OPHTHALMOLOGIC ROPES AND COMS PLAQUES

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ABSTRACT

Radiotherapy is an alternative to ocular enucleation. However, the irradiation of ocular region can bring deleterious effects due to the high doses, mainly in the lens, retina and in the bone structures in growth phase. Brachytherapy instead of teletherapy looks for departuring absorbed doses in tumor minimizing doses in the lens and the adjacent tissues of the eyeball (orbital region), avoiding deleterious effects. Thus, a three-dimensional computational voxel model and an analytical model were coupled, including the heterogeneous properties of the globe and the adjacent tissues. The analytical model was applied to define the thin structures of the ocular globe. This computational model is used to simulate orbital irradiation with ROPES and COMS ophthalmologic plaques placed on the sclera surface filled to ten and eight iodine-125 seeds, respectively. Simulations are performed on the MCNP5 code. The computational simulation allows evaluating how the dose rates are spatially distributed in the orbital volume. The results are normalized to 100% at the maximum dose on the tumor base, and by the applied source activity. The external globe structures receive 0.5% of the maximum internal dose. The crystalline lens dosimetry depends on the position and thickness of the tumor and the plaque diameters. On the present case, 12.75% of maximum dose is found on the lens. The maximum dose is found onto the eyeball, in the vitreous. The present model represents an advance in simulating and predicting absorbed dose on ocular brachytherapy, incorporating anthropomorphic and antropometric features of the real eyeball.

1. INTRODUCTION

The ocular melanoma and the retinoblastoma are the most common ocular human tumors in adults and children respectively. A traditional treatment is the enucleation, which means the ocular globe removal. The radiotherapy is an alternative method to preserve the ocular globe. The teletherapy applies photons and protons beams and the brachyterapy have its on plaques with different radioactive sources. Brachytherapy is a suitable option and its side-effects are fewer when compared with external photon beams [1, 2].

Episcleral plaque therapy (EPT) is an alternative in the management of uveal tumors. A radioactive plaque is sutured on the sclera surface behind the tumor base. The plaque remains attached until a specified absorbed dose is delivered to the tumor [3]. Comparing EPT with external beam radiotherapy, EPT permits a higher dose delivery on tumor preserving the surrounding health structures. Beta radiation brachytherapy provide a large spatial concentration of absorbed dose due to the smallest beam penetration [4, 5, 6].

The objective of this paper is to develop a new model of the ocular region and to simulate ophthalmologic plaques containing ^{125}I seeds in order to generate the spatial distribution of the absorbed dose inside the ocular globe, vitreous body and lens, and in the external structures as bone, optical never and brain, due to the gamma and X rays. An accurate dosimetry is therefore fundamental for investigate the tumor control based on the applied dose and the judgment of risk of deleterious effects on the normal tissue.

1. MATERIALS AND METHODS

This paper addresses an ocular computational model in which two distinct commercial plaques were incorporated for irradiating ocular tumors. The plaques ROPES and COMS hold iodine-125 seeds, positioned in the medial area on the ocular bulb. MCNP5 was used to simulate the irradiation processes and to generate the characteristic of the dose spatial distributions.

2.1. Eye model description

The eye model was developed through the coupling of three distinct models: an analytical model and other two voxel model. The development of the voxel model representative of the external structures out of the eyeball and of the bone structure of the uvea was based on the images obtained from the *Visible Human Body* (VHB) [7]. A set of 43 transverse cross section images of the cranium was selected and only the area of interest was cut out. This selection allowed defining a volume of 41x50x38mm containing 82x100x42 voxels.

The analytic model was made to define the internal structures of the eyeball (sclera, choroid, retina, lens, vitreous and cornea). It was developed to improve the representation of its structures through smooth topology by geometric equations. The geometric parameters applied to the construction of the volumes were obtained through measurements of the anatomical structures of an adult human been found on literature, together with the directly measurements on the images of the ocular structures [8, 9]. The external surface of the sclera presents maximum values, on x, y and z axis, of 24.3, 23.6 and 24.3mm respectively.

The vitreous area was defined in a voxel model with the objective of allowing the measurement of the distribution of the dose inside the eyeball. So each cell (voxel) into the vitreous body has a dimension 0.5x0.5x0.5 mm. This model was applied to obtain the spatial doses distribution into the vitreous body in the simulation program. The complete model of the ocular area was obtained by the joining of the three models. The Figure 1 shows three cut images coupled model, generated by the MCNP graphic interface [10].

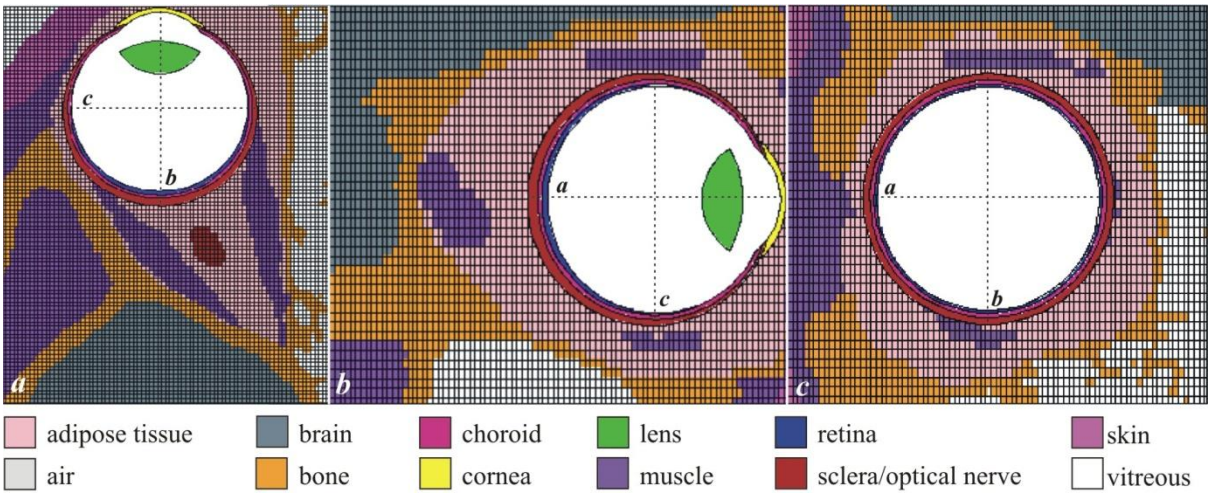

Figure 1. Ocular cross section pictures of the coupled model generated by the MCNP.5v graphic interface. (a) transversal section, (b) lateral section and (c) frontal section.

2.2. Ophthalmic applicator

Two distinct commercial plaques for ocular brachytherapy, containing iodine-125 seeds, with 12mm (COMS model) and 15mm (ROPES model) of diameter are used on the simulations. These specific plaques are applied for irradiating the ocular tumor and have a spherically concave shape with an inner 12mm radius curvature. This curvature allows a better joining with the sclera surface [11, 12, 13, 14, 15].

^{125}I is an X-ray and gamma-ray-emitting isotope with energy of 27-35 keV and half-life of 59.408 days. It is available in a cylinder seed shape measuring 4.5 x 0.8 mm. It is thus ideal for treating ocular bulb tumors [16, 17, 18]. Figure 2 presents the spatial distribution of eight iodine seeds in the COMS ocular plaque and ten iodine seeds in the ROPES ocular plaque. These specific plaques are applied for irradiating the ocular tumor and have a spherically concave shape with an inner 12 mm radius curvature. The COMS plaque has a back golden covering and the ROPES plaque has a back silver covering. These coverings are used to reduce the posterior beam propagation and to retain the seeds in the slots.

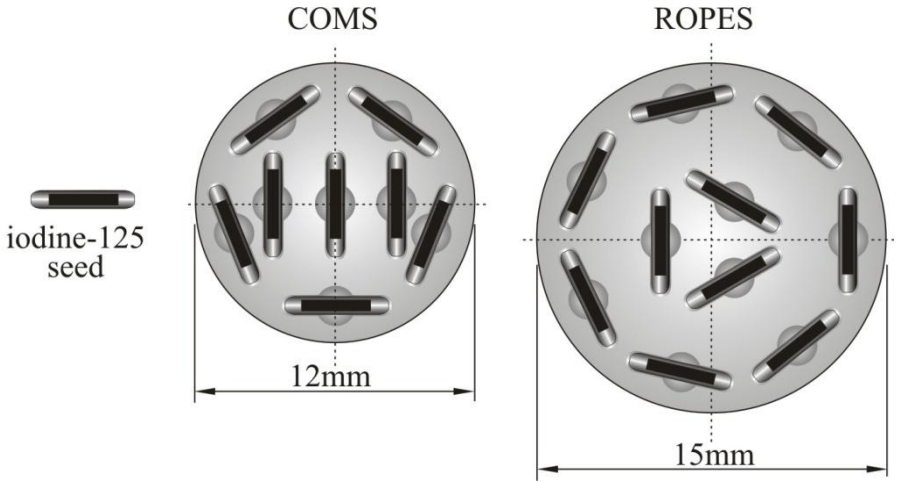

Figure 2. Spatial distribution of iodine seeds in the COMS and ROPES plaque.

2.3 MCNP Monte Carlo code and simulation

MCNP is a general-purpose Monte Carlo n–particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems. The code was originally developed for neutron Transport and has now been extended to include many particles, including photons and electrons [19, 20]. MCNP treats an arbitrary three-dimensional configuration of materials in geometric cells and it has been extensively used and validated for use in beta-particle brachytherapy.

Each plaque containing iodine seeds was placed into the coupled model of the ocular region and simulations on the MCNP5 code were carried on. The plaque was positioned on the outer sclera surface, in the medial area, behind the tumor base. Two simulations were accomplished for each plaque: one to calculate the dose distribution on the internal region of the ocular globe in order to evaluate the dose distribution in vitreous body and in the crystalline lens, and another to calculate the doses in the external region of the ocular globe, specially for evaluating the spatial dose distribution in the optic nerve, bones and brain.

3. RESULTS

The COMS and ROPES plaques were incorporated into the MCNP5 geometry eye model to perform the radiation transport simulation. The results obtained through MCNP5 code were plugged into the SISCODES [21] and transformed to a dose matrix matching the voxel matrix. The sections of these matrices are plotted together with a transparent routine, showing the spatial doses distribution. Figure 3 presents three transversal section images presenting the spatial dose distribution due to the photons emitted by the iodine-125 seeds in the COMS plaque.

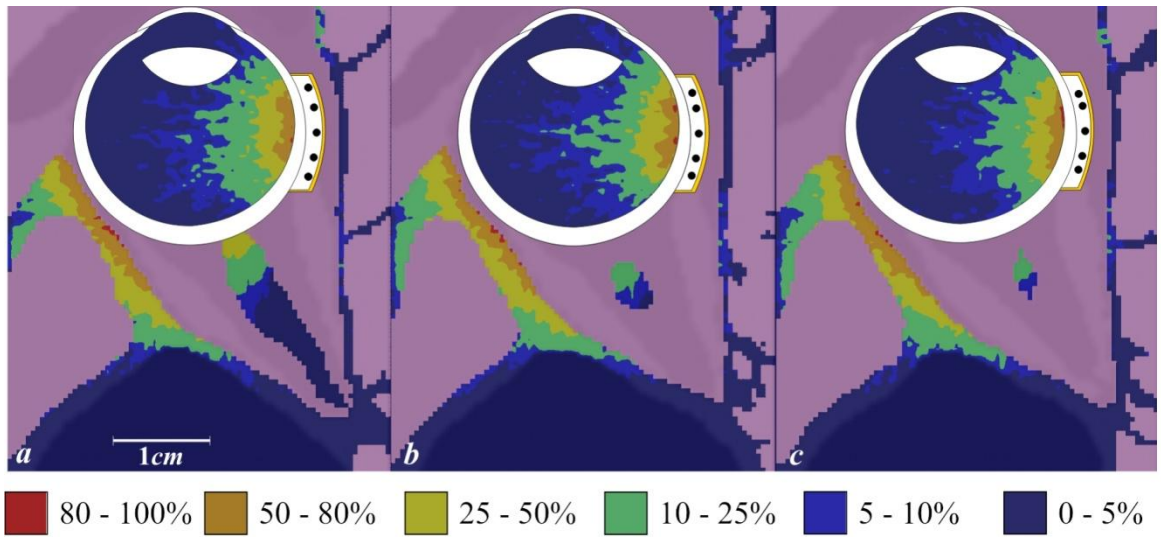

Figure 3. Dose distribution due COMS plaque holding eight iodine seeds. (a) z = 1mm, (b) z = 2.7mm and (c) z = 4.5mm.

In this figure, dose distribution data from the internal ocular globe were coupled with data of external ocular globe; however both set of data was simulated separately in MCNP5. The color legend indicates the percent strips of dose distribution so intern as extern to the ocular globe. The maximum value of dose rate for the intern region is $8.41.10^{-5}$ $Gy.h^{-1}.MBq^{-1}$. This value should be considered in the doses observations inside the ocular globe. The maximum value of dose rate for the extern region is $8.71.10^{-6}$ $Gy.h^{-1}.MBq^{-1}$ and this is the value to be considered in the observation of the dose distribution in the external region.

Figure 4 presents three section of the tissue voxel model in which the absorbed dose distribution is plotted altogether, as the results of the simulation for the photons emitted by the iodine-125 seeds in the ROPES plaque. In this figure, the two distinct simulations on the MCNP5 were coupled, providing data of internal ocular with data of the external ocular globe. The color legend presents the percent strips of dose distribution for internal and external to the ocular globe.

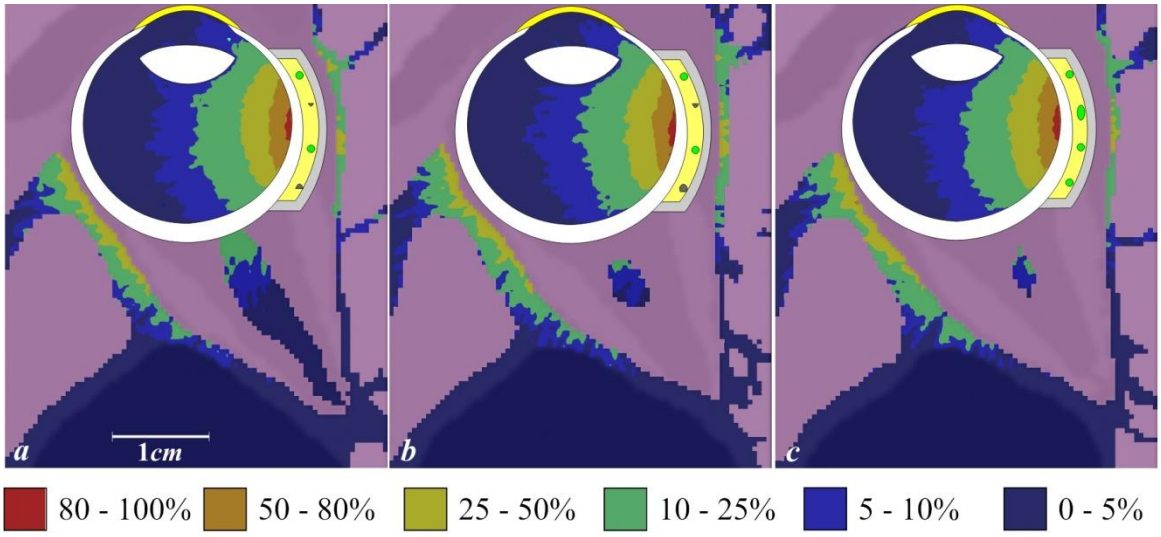

Figure 4. Dose distribution due ROPES plaque holding ten iodine seeds. (a) z = 1mm, (b) z = 2.7mm and (c) z = 4.5mm.

The present analysis is for the simulations of the continuum beta emitting spectrum provide by the radioactive device. The maximum value of dose rate for the internal region was $1.42.10^{-4}$ $Gy.h^{-1}.MBq^{-1}$. This value should be considered as reference (100%) to investigate the dose rates inside the ocular globe. The maximum value for the dose rate on the extern region was $2.21.10^{-5}$ $Gy.h^{-1}.MBq^{-1}$ and this is the value to be considered as reference (100%) to evaluate the scale of colors representative of the spatial dose distribution.

Figure 5 presents a graph of the normalized dose in function of the depth on the vitreous body for the irradiation with the plaques COMS and ROPES, along with the axis that leaves to the center of the device in direction to the bulb center. The graph was obtained starting from the simulations in MCNP5 and it takes in consideration the total absorbed dose in each point starting from 1.5 mm depth, which is the thickness of the sclera, choroid and retina in this area.

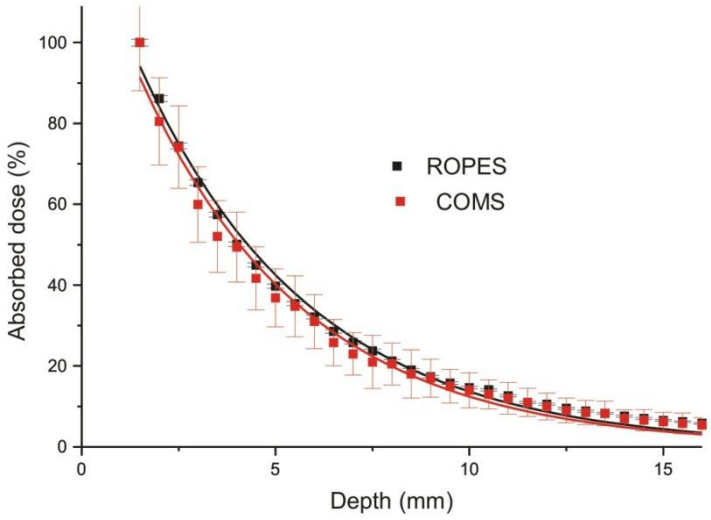

Figure 5. Normalized dose versus depth inside the vitreous body.

This figure presents the dose decreasing with depth, showing the typical exponential feature of the energy deposition for photon beams. The dose inside of the vitreous body corresponding to 50% of the maximum dose that happens a 4.31mm depth (ROPES) and 3.99 mm (COMS) and, for 10%, it happens a 11.15 mm depth (ROPES) and 10.76 mm (COMS).

The present research addresses two commercial ocular plaques with iodine-125 seeds incorporated. It had provided the spatial dose distribution in function of the activity in MBq carried by each plaque and the time of exposition. The choice of the plaque diameter is made in agreement with the size of the tumor base and the therapeutic dose is defined in the tumor apex. Table 1 summarized the results of the simulation, predicting the tumor apex 3mm and 5mm depth and suggested therapeutic dose of 80Gy in the tumor apex [22].

Table 1. Summary of the dose values at various positions to 80Gy therapeutic dose in the tumor apex.

At a position on	Dose (Gy) Apex 3mm		Dose (Gy) Apex 5mm	
	COMS	ROPES	COMS	ROPES
Vitreous	122.32	117.44	201.82	190.70
Outside globe	12.66	10.00	20.90	16.24
Lens	38.6	67.48	63.83	109.58

4. CONCLUSIONS

The development of the coupled voxel models: internal ocular voxel model with higher resolution and the external one together with the analytical model of the structures of the eyes demonstrate an advance in the dosimetric protocols for radiation therapy on the uveal region. The present model will be explored in new investigations simulating other types of radioactive devices.

The plaque of larger diameter (ROPES) holds more iodine seeds and it presents a larger dose rate than the plaque of smaller diameter (COMS). The larger penetration of the beam of the ROPES plaque results in a smaller dose in the sclera surface for a same therapeutic dose in the apex. The largest proximity of the plaque's surface (ROPES) with the crystalline lens results in a larger dose on it. The dose values increase with the increasing of the depth of the tumor apex.

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