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Using MCNP5 Code for Simulation of Betatherapy Procedures for the Pterygium Prevention

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Abstract— **Pterygium is the triangular growth of the fibrovascular tissue of the bulbar conjunctiva. Its initial treatment is surgical with a recurrence rate around 20-40% of operated cases. In order to prevent their recurrence, betatherapy with ^{90}Sr+^{90}Y applicators is the one that has shown better results, decreasing the recurrence rate to 20% or less. These applicators have high dose rate so special attention should be payed when planning these applications, always remembering that the lens (the critical region of the eye) must be preserved. Based on the above, we performed a simulation of a betatherapy application considering a ^{90}Sr+^{90}Y applicator in the treatment of pterygium prevention using the MCNP5 code. The human eye has been modeled with all its main structures and characteristics and a plate of ^{90}Sr+^{90}Y was attached to the eye in the place where the pterygium was removed. The purpose of this simulation was to calculate the amount of dose that each region of the eye receive during an application of betatherapy. The results are plausible: the regions closer to the plate received greater doses than the farther ones. Another important point observed is that the lens was preserved during the procedure receiving about 0.015% of the maximum dose that the sclera receives. With the results of this simulation has an effective and practical guide that may be inserted into the routine of medical physicists in order to facilitate and streamline their work.**

Keywords— **Pterygium; Betatherapy; ^{90}Sr+^{90}Y applicators; MCNP5.**

I. Introduction

Pterygium is a benign disease originated from a fibrovascular formation of the conjunctiva bulb. This lesion has a triangular shape and it may occur in temporal or nasal limbus, with 97% of the cases in the nasal limbus, as shown in Figure 1, and 3% in temporal limbo [1].

The lesion may invade the cornea causing visual disturbance, eye irritation and redness. Pterygium is typically developed in adults between 20 and 50 years old and its incidence is more pronounced in tropical and subtropical areas and also due to excessive exposure to ultraviolet rays [2].

There are several different treatments. The most common ones are conventional surgery or scraping bare sclera technique, adjuvant therapies such as beta irradiation postoperatively, postoperative thiotepa, mitomycin intraoperative, and postoperative mitomycin.

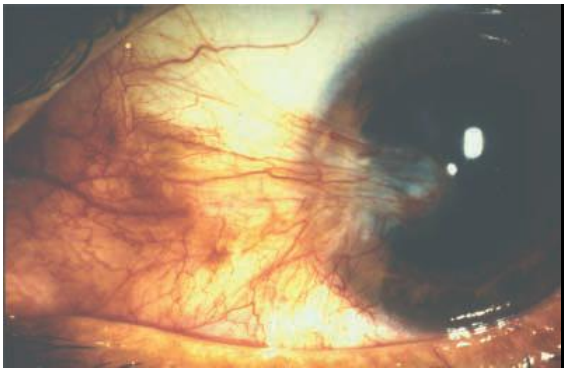

Fig. 1 Nasal pterygium in a patient man of 41 years old [3]

Usually, the initial treatment is the surgical excision of the lesion. However, the surgery or the bare sclera technique has reported a recurrence rate around 20-40% of the operated cases. Among the various techniques used after surgery to prevent recurrence of pterygium, radiotherapy with beta rays has showed better results in reducing this rate to 20% or less [4,5,6].

In 1950 the ^{90}Sr plate betatherapy was introduced in the treatment of pterygium to prevent the formation of a new scar, inhibiting the vascular endothelial cells of shoots and, consequently, the fibroblast migration [7].

The betatherapy is a form of radiation therapy that uses beta (β) type radiation sources for prevention and treatment of skin diseases, such as keloids and some very superficial skin lesions, and eye diseases, such as pterygium.

In Brazil and in the United States the most used betatherapy applicators have as a source of radiation the 90-strontium (^{90}Sr) which has a 28.5 years half-life and emits β particles of 0.546 MeV maximum energy [4,8,9].

The applicators are typically made of metal plates in which the ^{90}Sr is deposited on one of the surfaces. These plates can be flat or concave. The face of the plate is placed in contact with the skin or the sclera in order to inhibit the proliferation of fibroblasts.

The use and handling of these applicators in radiotherapy services are limited by the data that is supplied by international manufacturers since the exhausting routine of physicists in radiotherapy services

do not favor the implementation of dosimetry procedures for confirmation of the physical parameters of these sources, which, somehow, could compromise the quality and flexibility of treatment.

Considering the computational resources available nowadays the Monte Carlo method has been widely applied in problems involving radiation sources modeling. Thus, this paper presents the simulation of a betatherapy application for prevention of pterygium recurrence using the MCNP5 code. The purpose of this simulation is to determine the regions of the eye that receive the highest and lowest doses preserving the lens, the critical region of the eye.

II. Methodology

A. Monte Carlo código MCNP5

The Monte Carlo method simulates a mathematical problem stochastically. Its application extends to any problem that may be described in terms of a probability density function using a random number generator to sample all possible events of the problem. The estimated responses of these random samplings are stored properly in order to produce the desired result.

The essence of the Monte Carlo method applied to radiation transport is in estimating determined quantities. This estimate is made by the analysis of the behavior of a large number of individual events, i.e. the Monte Carlo method deals with an event at a time so that complex processes are simulated based on the sum of simple procedures. The set of events that occurs with a given particle, from the moment it is emitted by the source until the moment it is absorbed or escapes from the system is called the particle trajectory [10].

The average behavior of these particles is described by macroscopic quantities, such as flow or particle density, since the specific quantities, like energy deposition or dose, are derived from those ones. The value of these macroscopic quantities is determined by the deterministic solution of the Boltzman equation which governs the radiation transport phenomenon [11,12]. There are several codes that use the Monte Carlo method for particle transport, including the NWA, Penelope, EGS, etc.

The MCNP5 code is a software that uses the Monte Carlo method for particle transport, where particle means neutrons, photons and electrons [13]. To perform a simulation of particle transport is necessary to create an input file (input) which allows the user to specify all the information from geometry modeling to sources, materials, and tallies specifications. The tally is the option of the quantity to be obtained as a result, that is, the kind of response one would like to obtain from the MCNP5 code calculation. This information is obtained through one or more card tallies.

B. Equations of the mathematical model of the human eye anatomy

We used a detailed mathematical model of the human eye taking into account their size and major structural regions, including the sclera, choroid, retina, vitreous body (VB), lens, cornea, anterior chamber (AC), optic nerve (ON) and the wall of the optic nerve [14]. The modeling of a $^{90}Sr+^{90}Y$ plate was connected to the modeled eye for dose calculations in the eye regions. The equations used to describe the eye structures are:

►Sclera, choroid and retina: are defined as three concentric spherical shells with 1.0 mm thick each approximately, according to the expression:

$$(R_i - 0.1)^2 \le (x)^2 + (y+1.6)^2 + (z)^2 \quad (1)$$

with i= 1, 2, 3; R_1=1.22 cm (sclera), R_2=1.13 cm (choroid) e R_3=1.03 cm (retina).

►Cornea: is an elliptical shell bounded by two concentric ellipses and the outer spherical surface of the sclera:

$$1.56(x)^2 + 1.62(y+1.6)^2 + 1.66(z-0.73)^2 \ge 1 \quad (2)$$

$$1.29(x)^2 + 1.39(y+1.6)^2 + 1.52(z-0.73)^2 \le 1 \quad (3)$$

$$(x)^2 + (y+1.6)^2 + (z)^2 \ge 1.22^2 \quad (4)$$

► Optic Nerve and Wall of Optic Nerve: are represented by a cylinder and a concentric cylindrical shell, respectively, extending to the outer surface of the sclera in the plane y = 3. The cylinders are rotated 30 degrees from the coordinate of the system.

$$(x)^2 + (z)^2 \le 0.35^2 \quad (5)$$

$$(x)^2 + (z)^2 \le 0.4^2 \quad (6)$$

$$(x)^2 + (y+1.6)^2 + (z)^2 \ge 1.22^2 \quad (7)$$

$$y \le 3 \quad (8)$$

►Lens: correspond to the area enclosed by the two spherical surfaces of the sclera and the elliptic surface given by:

$$2.98(x)^2 + 2.98(y+1.6)^2 + 9.15(z-0.73)^2 \le 1 \quad (9)$$

$$(x)^2 + (y+1.6)^2 + (z)^2 \ge 1.22^2 \quad (10)$$

►Anterior Chamber: is the geometric region between the surface of the cornea inner wall and the outer surface of the sclera:

$$1.56(x)^2 + 1.62(y+1.6)^2 + 1.66(z-0.73)^2 \le 1 \quad (11)$$

$$(x)^2 + (y+1.6)^2 + (z)^2 \ge 1.22^2 \quad (12)$$

►Vitreous Body: is a spherical region limited by the outer surface of the retina.

$$(x)^2 + (y+1.6)^2 + (Z)^2 \leq 0.935^2 \quad (13)$$

The coordinates of the above equations refer to the center of a sphere offset 1.6 cm in y. The volumes of the eye parts were calculated by the MCNP5 code F4 tally as shown in Table 1. The F4 tally estimates the flow of particles in the cell ("Track length" the mean path traveled by the particle in a given cell), and is also used as an option to calculate volumes.

Table 1 Characteristics of the regions of the human eye

Regions of the human eye	Mass (g)	density (g/cm^3)	volume (cm^3)
Lens	0.21	1.0	0.228
Vitreous Body	3.06	1.0	3.893
Retina	1.01	1.0	0.928
Choroid	1.25	1.0	1.214
Sclera	1.36	1.0	1.312
Cornea	0.19	1.0	0.190
Anterior Chamber	0.37	1.0	0.343
Optic Nerve	0.27	1.0	0.225
Wall of the Optic Nerve	0.09	1.0	0.083

A concave circular plate of ^{90}Sr+^{90}Y with 12 mm diameter was modeled as two parallel spheres separated by a distance of 0.05 mm and cut by a plane, as illustrated in Figure 2 The source is located in the y axis in contact with the sclera in the region where the pterygium was removed.

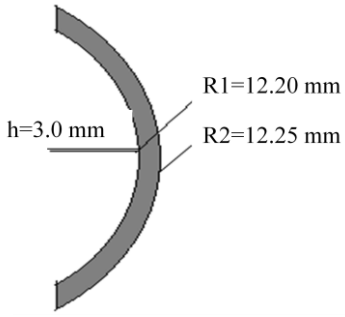

Fig. 2 Modeling of the ^{90}Sr+^{90}Y plate used in simulation

Figure 3 presents the modeling of the eye and the ^{90}Sr+^{90}Y plate in the simulation of a pterygium betatherapy treatment. The eye and the applicator were placed inside a water sphere. The *F8 tally was used to calculate the energy deposition in each region of the eye.

The F8 tally builds a histogram of transferred energy. This corresponds to the energy particles balance in the volume. This energy difference is accumulated in a given energy distribution which is multiplied by the energy when the * is added to the F8 tally. In other words, the *F8 tally performs an integration of the histogram calculated by the F8 tally estimating the energy deposited per particle (MeV / particle).

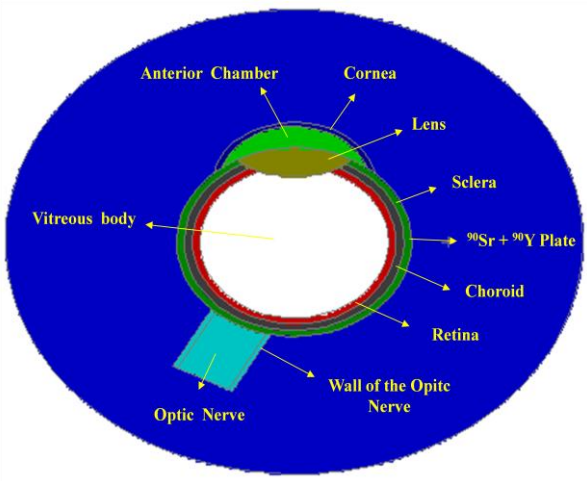

Fig. 3 Modeling of the human eye at MCNP5

III. Results and Discussion

From this simulation of the clinical case using the model of a human eye with all its major structural features and also the ^{90}Sr+^{90}Y plate attached to it, in the place where the pterygium was previously removed, it was possible to calculate the dose received at each one of the eye structure: sclera, choroid, retina, optic nerve (ON), wall of the optic nerve, vitreous body (VB), cornea, anterior chamber (AC), and lens.

The dose is defined by the energy deposition in a given mass (MeV/g). Table 2 shows the values of the energy deposition at each part of the eye as well as their uncertainties. The simulation was conducted with 100 million stories.

Table 2 Dose distribution in the human eye

Nº	Regions of the human eye	Mass (g)	Energy deposited (MeV/part.)	Gy/Bq.s	Incerteza (%)
1	Lens	0.21	3.49E-06	**2.66E-15**	4.44
2	VB	3.06	2.07E-02	**1.08E-12**	0.11
3	Retina	1.01	2.53E-02	**4.01E-12**	0.08
4	Choroid	1.25	5.14E-02	**6.59E-12**	0.06
5	Sclera	1.36	1.53E-01	**1.80E-11**	0.03
6	Cornea	0.19	3.39E-07	**2.86E-16**	8.99
7	AC	0.37	6.57E-07	**2.84E-16**	6.13
8	ON	0.27	4.32E-07	**2.56E-16**	9.54
9	Wall ON	0.09	1.43E-07	**2.55E-16**	10.24

Table 3 shows the eye regions which receive the highest and lowest dose and sets the dose rate in each region. In order to calculate the dose rate a $^{90}Sr+^{90}Y$ plate activity of 156.51 MBq was used. This table was created aiming to compile a guide for radiotherapy services to facilitate the exhausting daily routine of medical physicists. Considering a betatherapy application of 10 s treatment time, it can be predicted, through this results, the dose received in each part of the eye.

This table shows that the regions closer to the $^{90}Sr+^{90}Y$ plate (as the sclera, choroid, and retina) receive higher doses than other regions of the eye. Special attention should be payed to the lens which is considered the critical region of the eye. The results indicate that the lens receives about 0.015% of the maximum dose that receives the sclera.

The dose rate in the sclera region is 0.00282 Gy/s while the manual's applicator provides a dose rate of the applicator on the surface of 0.0257 Gy/s. This discrepancy is due to differences in volume dimensions of the regions where the dose rates were estimated.

Table 3 Dose rate calculated in the eye regions

	Eye regions	Dose rate (Gy/s)	Dose (Gy)
Greater dose	**Sclera**	**2.82E-03**	**2.82E-02**
	Choroid	1.03E-03	1.03E-02
	Retina	6.28E-04	6.28E-03
	VB	1.70E-04	1.70E-03
	Lens	**4.17E-07**	**4.17E-06**
	Cornea	4.47E-08	4.47E-07
	AC	4.45E-08	4.45E-07
	ON	4.01E-08	4.01E-07
Smaller dose	Wall ON	9.98E-08	9.98E-07

IV. CONCLUSION

The simulation of the clinical case, by idealizing a betatherapy application for the prevention of pterygium recurrence resulted in a practical and effective guide that may be inserted into the routine of medical physicists in order to facilitate and streamline their work.

One can quickly identify the various regions of the eye human differentiating and quantifying their dose-rate variations. The Previous knowledge of the dose of radiation released in the tissue may provide greater patient comfort during treatment, aiding in therapeutic conduct and enabling the repositioning of the applicator in order to maintain the dose levels within the limits indicated in the betatherapy protocols.

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