CALCULATION OF DECREASE IN THE PROSTATE DOSE DUE TO POST-SURGICAL EDEMA AND HETEROGENEITY IN PROSTATE BRACHYTHERAPY

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Abstract. *This paper presents the simulation code MCNPX Monte Carlo of two factors that are possible causes of underdosing in the treatment of prostate brachytherapy. The first simulation will evaluate the effect of post-surgical swelling, the swelling was simulated in a spherical water phantom, and the varying the volume of 20 cm^3 to 30 cm^3, this growth volume represents of the prostate swelling undergoes after surgical procedures. The second simulation will show the differences between considering the Prostate being comprised two distinct materials, soft tissue and water, respectively, to evaluate inequalities in the dose to the heterogeneities were simulated by the differences in densities and chemical compositions of water and soft tissue for settings 80, 88 and 100 volumetric seeds, with the activity of 0.27 mCi. The results for the swelling showed that the dose of 4^{th} to 25^{th}, which are the days that the edema is more evident, may decrease by up to 30%, since the differences caused by heterogeneity reach 7% compared to the final dose at time $t = 0$ to $t = \infty$.*

***Keywords**: Monte Carlo, Brachytherapy, MAX Phantom, Edema, Heterogeneities.*

1. INTRODUCTION

Brachytherapy has been largely accepted in prostate cancer therapy, due to low energy photons emission proportionate high doses at the local of treatment. The organs next to the treated volume get low doses. However, there are some parameters which have not been completely evaluated, among them the reaction of edema during the first days after the surgery and the tissues' heterogeneities, the aims of the present work.

1.1 Prostate edema

Post-surgery edema is an issue, because prostate volume increases between 40 and 50%, especially after the first 28 days after the implant (KEYE *et al.*, 1992; MOERLAND *et al.*, 1997; WATERMAN *et al.*, 1998). It takes to the formulation of two situations: at first, the image gotten immediately after the implant, in order to check the results and calculations of dose distributions, may underestimate the total dose, because the edema can reduce the administrated dose at the prostate vicinity. On the other hand, if the image were gotten after the edema has been subdued, the dose may be overestimated, because the decrease of the dose ratio when the prostate were with the edema has been neglected.

The edema decreases, in an exponential way, between the 4^{th} and 25^{th} day, averagely 9.3 days. Using such average, the edema will be reduced 12.5% from its original value in 28 days (WATERMAN *et al.*, 1998). Some other authors (like KEHWAR *et al.*, 2009) report this value as something between the 3^{rd} and 34^{th} day. This work considers the edema effect between the 4^{th} and 25^{th} day.

1.2 Study of (heterogeneities) in prostate at Spheric Phantom and Max Voxel Phamtom

Nowadays, the Brachytherapy's planning treatment is done by software which has in theirs formulation data obtained experimentally and Monte Carlo calculations based on water phantom. This kind of phantom does not consider the heterogeneities of organs composition and the tissues next to the volumetric region to be treated. (MARTINS, 2010).

The proceeded study of heterogeneities considers the comparison of density and chemical composition as the spherical phantom as MAX voxel phantom, when two different environment were involved: water and soft tissue (JARRET, 1995). Table 1 shows the differences density and percentage of chemical composition of the elements which constitutes the two environments.

Table 1. Differences in chemical compositions and densities of soft tissues and water phantoms (ICRU, 1989).

Soft tissue (ρ = 1,05 g/cm^3)					
H	10,45%	C	12,45%	N	2,57%
O	73,52%	Na	0,17%	P	0,20%
S	0,18%	Cl	0,22%	K	0,21%
Ca	0,01%	Fe	0,01%	I	0,01%
Water (ρ = 1,00 g/cm^3)					
H	66,67%			O	33,33%

1.3 ^{125}I seeds characterization

^{125}I seeds used in brachytherapy consists of absorbed iodine, in iodide form, at a silver surface (ρ= 10,5 g/cm^3), which is placed at the middle of the seed and can be used as radiographical marker and the encapsulation of the source is proceeded with titanium (YU *et al.*, 1999; NATH *et. al.*, 1995). It's possible to see in the ^{125}I decay the x-ray emissions about 22.1 keV (0.15 photons per desintegration) and 25.5 keV (0.04 photons per desintegration), from photoelectric interactions between photons and silver cylinder.

REIS (2009) validated Amersham ^{125}I seed model 6711, using MCNPX (X-5 Monte Carlo Team, 2005). Amersham seed is the most used in prostate permanent implants. The parameters values importants to the seed are anisotropic function F(r,θ) and radios dose function g(r).

The seeds have 4.5 mm lenght and 0.8 mm diameter, encapsulated in 0.05 mm titanium (model 6711) as ilustrated in Figura 2.2 (DUGGAN, 2004). The seeds can be provided either individually or fitted up in Vicryl (absorbable material by organism), containing 10 seeds each. The typical activity of eacy seed is between 0.27 mCi (10.0 MBq) a 0.38 mCi (14.1 MBq).

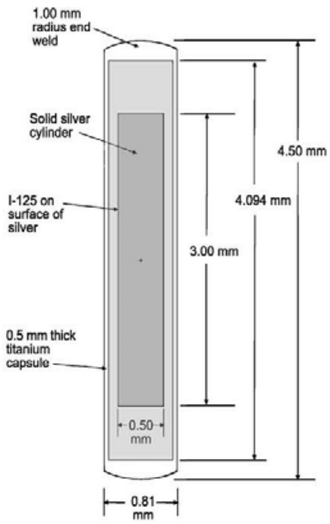

Figure 1. ^{125}I seed's geometry (DUGGAN, 2004).

2. METHODOLOGY

In the present section the all the procedures were described, in order to evaluate the edema effect at the prostrate and calculate the heterogeniedade of both phantoms materials

2.1 Methodology for prostate edema evaluation in the permanent implant

The study of the edema prostate impact after the surgery was preceded by Monte Carlo simulations. For such purpose, the prostate was assumed as a water sphere, with the volume increasing 50%, from 20 cm^3 to $30cm^3$, with volumetrical variation steps about 1 cm^3.

This simulation was performed using an ^{125}I seed placed at the middle of coordinate system, and four mini-spheres detectors were place in the vicinity at 0º, 90º, 180º, 270º, and a radius of 0.05 cm. Figure 3.1 shows the sphere that represents a 20 cm^3 prostate and 1.68 cm radius. The tally command from *F8 MCNPX was used in order to register the absorbed dose in each mini-sphere. The simulated number of histories was 1.5×10^9, resulting in relative errors lower than 4% in all of them.

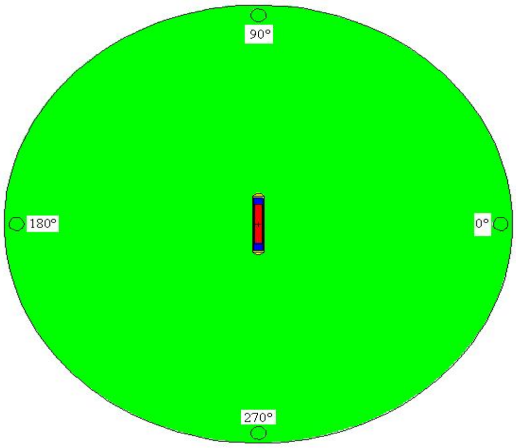

Figure 2. Simulated prostate's geometry (SCHWARZ, 2007).

2.2 Methodology for evaluation of heterogeneities effects with spherical phantom and the MAX voxels phantom prostates

The first set of simulations were performed on MCPNX code for 80, 88 and 100 ^{125}I seeds inside the spherical phantom and the MAX voxels prostate volumes. The density was set up as $\rho = 1{,}00$ g/cm^3.The simulations were performed in both phantoms and two different materials were considered. For the first set, water was water and for the second set that material was replaced by equivalent tissue. Six simulations for each set up were proceeded for each phantom. The aim of these results is the checking the percentual discrepancy only by chemical composition of both environments and phantoms.

In the second set of simulations, the density values were changed in the spherical phantom and MAX phantom, to $\rho = 1{,}05$ g/cm^3, were simulated for the ^{125}I seeds used previously: 80, 88 e 100. The results obtained will show percentual discrepancies by density changes in the environments, for water and soft tissues. The last set or results will show the total discrepancies due to the chemical compositions and the environment densities. Tally *F8 was used in order to get such results and 5×10^6 histories were simulated and na less-than 1% error was achieved.

3. RESULTS

In the following subsections, the results of the factors that cause underdoses at prostrate (the effect of after surgery edema and the tissue's heterogeneities) will be shown.

3.1 Influence of edema in the prostate's total dose

The resulting edema from the ^{125}I seed's insertion during brachytherapy's surgery may be meaningful, affecting the dose. The results were normalized in function of the found highest absorbed dose, for a set-up where the simulated prostate volume was 20 cm^3.

On Figure 3, the reduction of absorbed dose is shown in the prostate vicinity, for detectors placed in 0º and 180º angles, in order of 24.1%. The reduction of absorbed dose can be in order of 30.2% for detectors placed in 90º and 27º, as shown on Figure 4. Such value was already expected, because, as shown in the geometry of ^{125}I seed at simulated prostrate, the source shows more (blindagem) thickness of in y axis than in y axis.

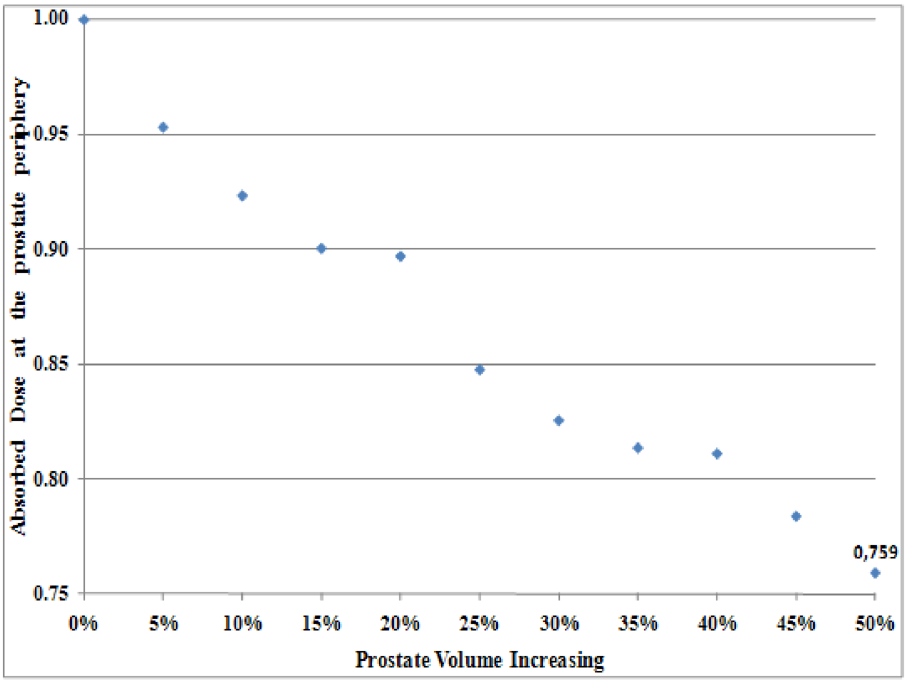

Figure 3. Decreasing of average absorbed dose in detectors placed in 0º e 180º angles.

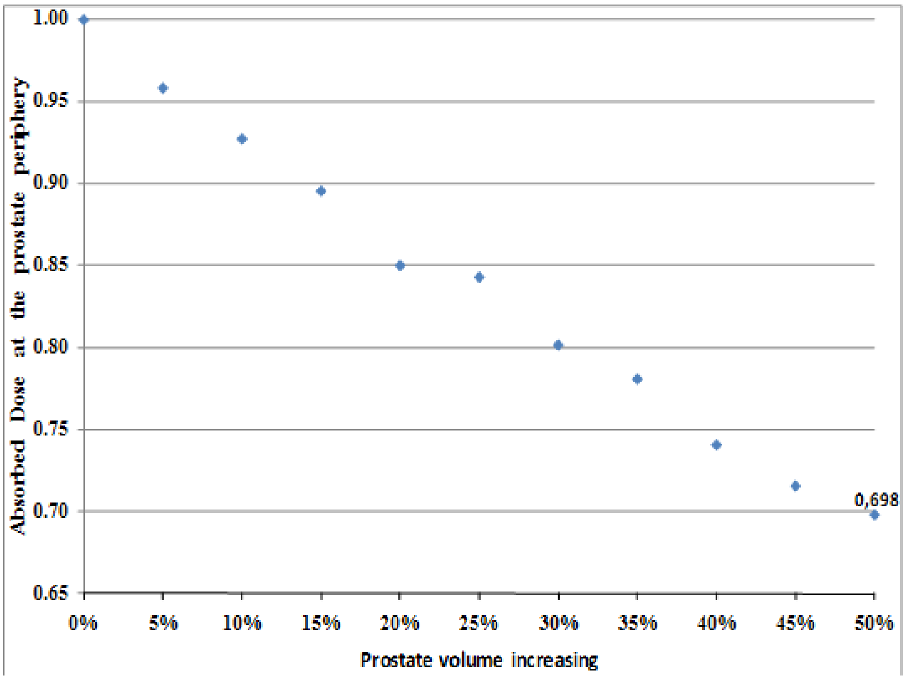

Figure 4. Decreasing of average absorbed dose in detectors placed in 90º e 270º angles.

A good estimation of the after surgery prostate edema's impact shown on Equation (1). Using this equation, the administered dose between the 4th and 25th day was calculated, when the edema is more visible. The administered dose during that time was 30,09 Gy, and the maximum percentual reductions were between 24.1% e 30.2%, resulting in a maximum reduction of dose at prostrate vicinity about 7.25 Gy for detectors in 0º and 180º angles and 9.09 Gy for detectors 90º and 270º angles.

The dots in Figures 4.5 and 4.6 can be adjusted by a tendency line, which regression coefficients are, respectively, 0.97 and 0.99. As such values are closed to 1.00, it's possible consider the dots of plot as a straight line. Using the functions that originated those straight lines, the reduction of doses at prostate vicinity (y axis), replacing in such functions the mean value of 25%, related to x axis. So, the obtained average reduction of doses at the prostate vicinity are between 13.5% and 16.6%, resulting, hence, in the values of 4.06 Gy and 4.90 Gy (Table 4.3).

Table 2. Average and maximum reductions of dose at prostate vicinity.

Maximum Reduction 90º e 270º **(31%)**	**9,09 Gy**
Maximum Reduction 0º e 180º **(25%)**	**7,25 Gy**
Average Reduction 90º e 270º **(16,3%)**	**4,90 Gy**
Average Reduction 0º e 180º **(13,5%)**	**4,06 Gy**

3.2 Analysis of percentual discrepancies spherical phantom

The results of the simulations that were performed by MCNPX code in the spherical phantom were organized in Table 2, which shows the percentual discrepancies due to chemical composition and density, as well the total difference between these two parameters. The mean discrepancy by chemical composition and density had, respectively, the values 3.21 Gy and 6.56 Gy, and the mean total difference for these two parameters was 9.77 Gy. The results, in special the total discrepancy of 9.77 Gy, showed that the heterogeneities in dose calculus for prostrate brachytherapy treatment cannot be neglected.

Table 3: Density and total percentual discrepancy for the spherical phantom that represents the prostate.

Density and Chemical Composition	Value	Total Percentual Discrepancy	Density Percentual Discrepancy	Chemical Composition Percentual Discrepancy
Spherical Water Phantom 80 seeds	143,19 Gy	6,4%	4,3%	2,1%
Spherical Soft Tissue 80 seeds	152,35 Gy			
Spherical Water Phantom 88 seeds	155,48 Gy	6,4%	4,1%	2,3%
Spherical Soft Tissue 88 seeds	165,42 Gy			
Spherical Water Phantom 100 seeds	174,16 Gy	5,9%	4,1%	1,8%
Spherical Soft Tissue 100 seeds	184,37 Gy			

3.3 Analysis of percentual discrepancies at MAX Voxels prostate

For voxel phantom MAX, all the results concerning to the simulations were organized at Table 3. The mean difference by chemical composition was 2.73 Gy and by density the mean value was 5.56 and the total difference was 8.29 Gy. So, as what occurred during the spherical phantom analysis, the simulations in MAX phantom confirmed that is risky to neglect the heterogeneities when a prostate brachytherapy treatment is considered.

Table 4. Density and total percentual discrepancy for MAX's prostate.

Density and Chemical Composition	Value	Total Percentual Discrepancy	Density Percentual Discrepancy	Chemical Composition Percentual Discrepancy
Spherical Water Phantom 80 seeds	119,87 Gy	6,6%	4,5%	2,1%
Spherical Soft Tissue 80 seeds	127,72 Gy			
Spherical Water Phantom 88 seeds	132,32 Gy	6,2%	4,1%	2,1%
Spherical Soft Tissue 88 seeds	140,51 Gy			
Spherical Water Phantom 100 seeds	149,61 Gy	5,9%	3,9%	2,0%
Spherical Soft Tissue 100 seeds	158,42 Gy			

3.4 Analysis of total dose between MAX and water phantom

The results showed that the differences of the simulated values between MAX and water phantom , for 80, 88 and 100 seeds are, respectively, 21.58 Gy, 20.41 Gy and 20.85 Gy, with a mean difference about 20.95 Gy. Using such value as reference, the mean difference in function of dose and percentage was determined for MAX (a) and water phantom (b). As showed by density and chemical composition, this difference is about 40% for MAX and 47% for water phantom. Another influent factor, but not evaluated here, was the geometry of both phantoms.

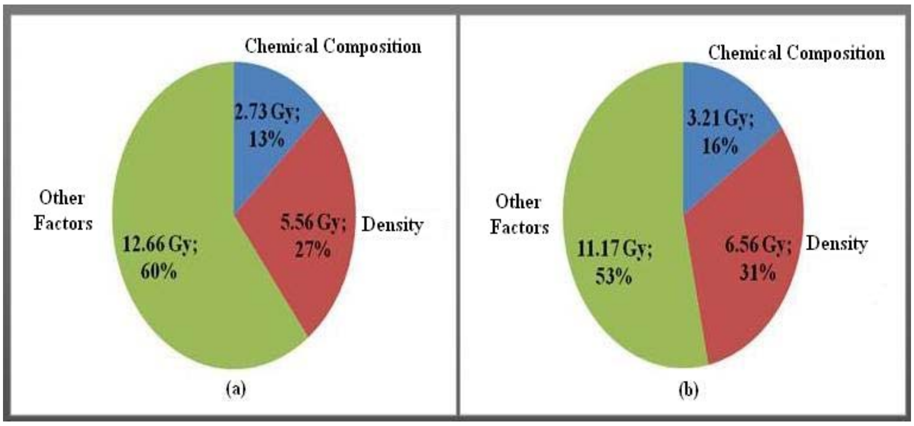

Figure 5. Average percentual discrepancies for MAX Voxels (a) and the water (b) phantoms.

4. CONCLUSION

The studies performed by MCNPX showed that important factors concerning to brachytherapy, such as edema after surgery and the heterogeneities of tissue, cannot be neglected. The maximum reduction of dose for the edema and the heterogeneities' average total differences were, respectively, 9.07 Gy and 20.95 Gy. If the sum of these factors that cause underdoses, 30.72 Gy were compared to the total dose prescribed to the patient, 144 Gy, the percentage 21.3% was found. It's kwon that dose's overestimation can provide unnecessary dose in organs next to the prostate; on the other hand, the underestimation of a 144 Gy dose may not provide the essential dose in order to remove the tumor. Because of the influence of effect edema and the heterogeneities, discarding the edema's effect and the heterogeneities is not recommendable for brachytherapy.

5. AKNOWLEGEMENTS

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