Dose evaluation in breast brachytherapy using different ^{125}I seeds: A Monte Carlo approach

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Abstract. A very common type of cancer among women is the breast cancer. The treatment choice depends, among several factors, on the clinical stage of the disease and the age. One way to treat breast cancer is the permanent breast seed implant, with Iodine-125 (^{125}I). Since they present some advantages: possibility to treat solid tumors, near the tumor site, induction of little trauma and strong lethality to cancer cells. In Brazil, a new ^{125}I seed was developed at the Instituto de Pesquisas Energéticas e Nucleares to be applied in brachytherapy. Given the large number of women diagnosed with breast cancer, in this work, the dose determination in organs and tissues was undertaken, considering this new seed and a commercial, Amersham 6711-Oncoseed®, employing the Monte Carlo method. Moreover, for a better understanding of the radiation doses delivered to different patients, the breast volumes were modified. For this purpose, the MCNPX Monte Carlo code was utilized coupled with female virtual anthropomorphic phantoms. The results pointed out the highest dose values for the breast and skin. Furthermore, the dose results for both types of seeds were very similar.

1. Introduction

According to the International Agency for Research on Cancer [1], breast cancer is the most common type among women worldwide, affecting approximately 1 in each 4 women, which represents almost 25% world incidence. In Brazil, the National Cancer Institute (INCA) estimate for malignant breast cancer is 59,700 new cases for the 2018/19 biennium, representing the second most common type of cancer among Brazilian women, behind only of non-melanoma skin cancer [2].

Brachytherapy consists of the implantation of radioactive seeds at the tumor site, which can be treated with sufficiently high doses affecting only the site to be treated. In this case, the energy deposited by the photons is low, but high enough to destroy the neoplastic cells, that also contributes to the reduction of unnecessary damage to healthy surrounding tissues [3].

Studies have shown that breast brachytherapy is effective if it is associated with other techniques, such as chemotherapy [4], conventional radiotherapy [5] and conservative surgery [6,7], producing even more efficient results and reducing the risk of serious side effects.

In the literature, studies demonstrated the efficacy and safety of the use of ^{125}I seeds for brachytherapy applications in several tumors as a form of treatment, as the work of Gutin et al. [8], Agbi et al [9], Wang et al. [10] and Vicini el al. [5]. The main advantages offered by the ^{125}I seeds are low trauma, high dosimetric precision, high lethality for solid tumors and fewer complications [4].

Therefore, the goal of this work was the determination of the absorbed dose, by the organs/tissues of a group of female phantoms, during a brachytherapy procedure with two types of ^{125}I seeds using the Monte Carlo MCNPX code, coupled to the female virtual anthropomorphic phantoms [11, 12]. These phantoms present different body mass index (BMI) and breast volumes to represent the patients. They were designed using different softwares, and they were based on anthropometric data from female adults provided by the ICRP 89 [13].

2. Materials and Methods

2.1. Monte Carlo method

The Monte Carlo method is a computational tool used to simulate the radiation transport through several types of materials, becoming very useful in internal dosimetry, since it is quite complicated to determine the radiation doses in such a complex structure, as the human body [14].

The Monte Carlo code used for the dose calculations was the MCNPX (v.2.7.0) [15]. This code simulates the interactions of particles such as photons and electrons. A total of 10^9 histories were simulated, in order to maintain low statistical uncertainties.

The absorbed doses of photons for all organs and tissues were calculated using the tally F6:p (in MeV/g/particle) of the MNCPX v.2.7.0 code.

2.2. Female virtual anthropomorphic phantoms

In this work three different female virtual anthropomorphic phantoms were used: FASH3 [11], F10_H10 and F90_H90 [12]. Figure 1 shows the FASH3 virtual anthropomorphic phantom with the ^{125}I seeds inserted in the breast, and Table 1 presents the mass, height and body mass index of each phantom.

In order to evaluate different situations, for each female virtual anthropomorphic phantom, three different breast volumes were considered; the volumes are listened in Table 2. All phantoms had a similar distribution of seeds in the breast.

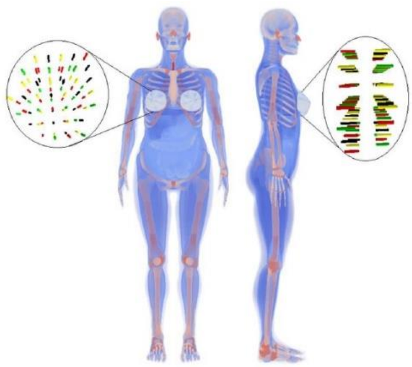

Figure 1. Front and side view of the ^{125}I seeds distribution in the FASH3 virtual anthropomorphic phantom. A similar distribution was used for the M10_H10 and M90_H90 phantoms.

Table 1. Body mass, height and body mass index for the three virtual anthropomorphic phantoms utilized in this work [11, 12].

Feature	FASH3	F10_H10	F90_H90
Mass (kg)	60	48.6	94
Height (cm)	163.3	155.5	172.2
BMI ($kg.m^{-2}$)	22.7	20.1	31.7

Table 2. Breast volumes for the three virtual anthropomorphic phantoms utilized in this work [11, 12].

Breast Volume (cm^3)	FASH3	F10_H10	F90_H90
V1	347.02	204.79	536.70
V2	400.47	258.23	590.15
V3	436.77	311.67	643.59

2.3. ^{125}I seeds

Two types of seeds were considered: a commercial seed ^{125}I (Amersham 6711-Oncoseed®) [16] and another one developed at the IPEN [16], as shown in Figures 2 and 3, respectively. In all simulations, 75 seeds were employed in each phantom breast.

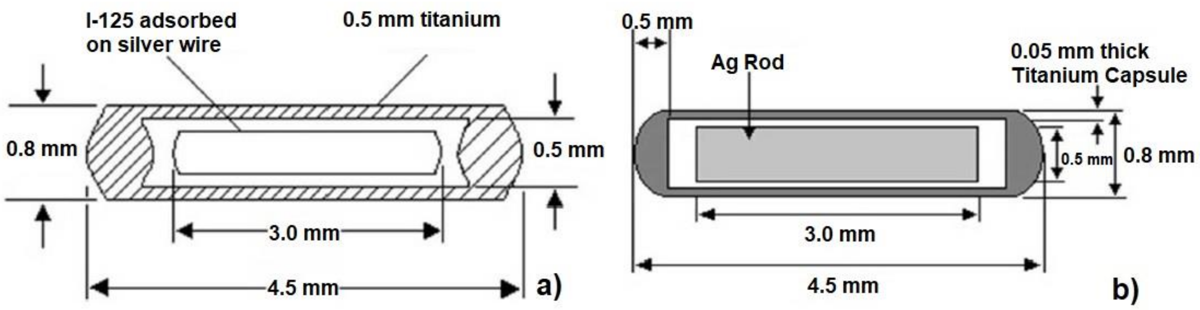

Figure 2. a)IPEN ^{125}I seed (Figure reproduced from [16]); and b) Commercial ^{125}I seed (Amersham 6711-Oncoseed®) (Figure reproduced from [16]).

2.4. Dose determination in organs and tissues

The absorbed doses in the organs and tissues of the phantoms were calculated using Equation 1.

$$D(Gy) = 1.602 \times 10^{-10} \times N \times A \times K \times F6 \quad (1)$$

were

- 1.602×10^{-10} – Conversion factor of MeV/g/particle to Gy;
- N - Total number of ^{125}I sources used in each computational scenario (75 seeds);
- A - Total activity (Bq) of the source used (8.99×10^{13} Bq/source);
- K - Total number of photons by disintegration emitted by the source (K = 1.476 to ^{125}I);
- F6 - Energy per mass (MeV/g/particle) estimated in the cell volume using the MCNPX code.

3. Results and Discussion

Brachytherapy treatments using two radioactive ^{125}I seeds and different breast volumes, as shown in Table 2, were simulated in this work. After the simulations, the absorbed doses were obtained for organs and tissues. The results obtained are listed in Tables 3, 4 and 5, for the F10_H10, FASH3 and F90_H90 phantoms, respectively.

Table 3. Absorbed doses in organs and tissues, varying the breast volume and using two different ^{125}I seeds, for the F10_H10 phantom.

Organs	IPEN ^{125}I seed						Commercial ^{125}I seed					
	V1		V2		V3		V1		V2		V3	
	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)
Bone Marrow	1.89E-03	0.06	1.85E-03	0.06	2.63E-03	0.05	1.89E-03	0.06	1.85E-03	0.06	2.63E-03	0.05
Colon	6.11E-03	0.31	6.12E-03	0.31	8.94E-03	0.25	6.09E-03	0.31	6.10E-03	0.31	8.93E-03	0.25
Lung	1.38E-01	0.04	1.39E-01	0.04	1.47E-01	0.04	1.38E-01	0.04	1.39E-01	0.04	1.47E-01	0.04
Stomach	8.79E-02	0.13	8.85E-02	0.12	1.11E-02	0.11	8.78E-02	0.13	8.84E-02	0.12	1.11E-02	0.11
Breast	2.26E+01	0.01	1.96E+01	0.01	9.35E-02	0.03	2.26E+01	0.01	1.96E+01	0.01	9.35E-02	0.03
Oesophagus	2.23E-02	0.41	2.25E-02	0.41	2.52E-02	0.39	2.23E-02	0.41	2.24E-02	0.41	2.52E-02	0.39
Liver	7.73E-02	0.07	7.36E-02	0.07	9.30E-02	0.07	7.32E-02	0.07	7.34E-02	0.07	9.28E-02	0.07
Thyroid	1.33E-02	0.90	1.20E-02	0.95	1.96E-02	0.74	1.32E-02	0.89	1.19E-02	0.95	1.95E-02	0.74
Brain	4.84E-04	0.98	4.34E-04	1.04	7.31E-04	1.79	4.86E-04	0.98	4.35E-04	1.04	7.31E-04	1.79
Salivary glands	2.66E-02	0.18	2.35E-02	0.19	4.12E-02	0.14	2.66E-02	0.18	2.35E-02	0.19	4.11E-02	0.14
Skin	2.33E-01	0.01	2.37E-01	0.01	3.32E-01	0.01	2.33E-01	0.01	2.37E-01	0.01	3.31E-01	0.01
Eyes	1.50E-02	0.89	1.34E-02	0.94	2.05E-02	0.76	1.50E-02	0.89	1.34E-02	0.94	2.05E-02	0.76
Eye Lens	3.01E-02	2.05	2.66E-02	2.19	4.22E-02	1.73	3.02E-02	2.04	2.67E-02	2.18	4.19E-02	1.73

Table 4. Absorbed doses in organs and tissues, varying the breast volume and using two different ^{125}I seeds, for the FASH3 phantom.

Organs	IPEN ^{125}I seed						Commercial ^{125}I seed					
	V1		V2		V3		V1		V2		V3	
	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)
Bone Marrow	1.31E-03	0.06	1.32E-03	0.06	1.32E-03	0.06	1.31E-03	0.06	1.32E-03	0.06	1.32E-03	0.06
Colon	8.92E-03	0.26	8.96E-03	0.26	9.03E-03	0.26	8.89E-03	0.27	8.93E-03	0.26	9.00E-03	0.26
Lung	1.06E-01	0.05	1.07E-01	0.05	1.07E-01	0.05	1.06E-01	0.05	1.07E-01	0.05	1.07E-01	0.05
Stomach	9.22E-02	0.12	9.22E-02	0.12	9.25E-02	0.12	9.19E-02	0.12	9.19E-02	0.12	9.23E-02	0.12
Breast	1.57E+01	0.01	1.46E+01	0.01	1.38E-02	0.01	1.56E+01	0.01	1.45E+01	0.01	1.38E-02	0.01
Oesophagus	1.57E-02	0.47	1.58E-02	0.47	1.58E-02	0.47	1.57E-02	0.47	1.58E-02	0.47	1.58E-02	0.47
Liver	8.57E-02	0.06	8.55E-02	0.06	8.56E-02	0.06	8.55E-02	0.06	8.54E-02	0.06	8.55E-02	0.06
Thyroid	4.55E-03	1.52	4.81E-03	1.48	4.97E-03	1.45	4.57E-03	1.52	4.82E-03	1.48	4.98E-03	1.45
Brain	1.72E-04	1.61	1.74E-04	1.60	1.76E-04	1.60	1.69E-04	1.61	1.71E-04	1.60	1.73E-04	1.60
Salivary glands	9.95E-03	0.29	1.01E-02	0.29	1.02E-02	0.29	9.95E-03	0.29	1.01E-02	0.29	1.02E-02	0.29
Skin	1.79E-01	0.01	1.82E-01	0.01	1.83E-01	0.01	1.79E-01	0.01	1.81E-01	0.01	1.83E-01	0.01
Eyes	6.02E-03	1.35	5.98E-03	1.35	5.94E-03	1.36	6.02E-03	1.35	5.95E-03	1.35	5.91E-03	1.36
Eye Lens	9.47E-03	3.77	9.38E-03	3.78	9.24E-03	3.80	9.46E-03	3.75	9.33E-03	3.78	9.17E-03	3.79

Table 5. Absorbed doses in organs and tissues, varying the breast volume and using two different ^{125}I seeds, for the F90_H90 phantom.

Organs	IPEN ^{125}I seed						Commercial ^{125}I seed					
	V1		V2		V3		V1		V2		V3	
	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)	D(Gy)	Unc.(%)
Bone Marrow	7.74E-04	0.08	7.78E-04	0.08	7.80E-04	0.08	7.74E-04	0.08	7.78E-04	0.08	7.80E-04	0.08
Colon	2.54E-03	0.44	2.57E-03	0.44	2.57E-03	0.44	2.54E-03	0.44	2.56E-03	0.44	2.57E-03	0.44
Lung	5.82E-02	0.06	5.83E-02	0.06	5.84E-02	0.06	5.80E-02	0.06	5.83E-02	0.06	5.85E-02	0.06
Stomach	4.77E-02	0.16	4.80E-02	0.16	4.81E-02	0.15	4.76E-02	0.16	4.79E-02	0.16	4.80E-02	0.16
Breast	1.35E+01	0.01	1.28E+01	0.01	1.20E-02	0.01	1.35E+01	0.01	1.28E+01	0.01	1.20E-02	0.01
Oesophagus	8.67E-03	0.60	8.71E-03	0.60	8.73E-02	0.60	8.66E-03	0.60	8.69E-03	0.60	8.72E-02	0.60
Liver	3.94E-02	0.09	3.95E-02	0.09	3.96E-02	0.09	3.93E-02	0.09	3.95E-02	0.09	3.96E-02	0.09
Thyroid	1.69E-03	2.55	1.72E-03	2.52	1.72E-03	2.52	1.67E-03	2.54	1.70E-03	2.51	1.70E-03	2.50
Brain	7.67E-05	2.24	7.69E-05	2.24	7.57E-03	2.27	7.80E-05	2.24	7.82E-05	2.24	7.70E-03	2.27
Salivary glands	3.07E-03	0.51	3.18E-03	0.51	3.17E-03	0.51	3.05E-03	0.52	3.16E-03	0.51	3.15E-03	0.51
Skin	1.10E-01	0.01	1.14E-01	0.01	1.15E-01	0.01	1.10E-01	0.01	1.13E-01	0.01	1.14E-01	0.01
Eyes	3.74E-03	1.75	3.60E-03	1.78	3.40E-03	1.82	3.83E-03	1.73	3.69E-03	1.76	3.50E-03	1.79
Eye Lens	5.74E-03	4.66	5.46E-03	4.75	5.23E-03	4.88	6.06E-03	4.55	5.83E-03	4.63	5.56E-03	4.75

The results listed in Tables 3, 4 and 5 show that the dose in the breast varied according to the breast volume. For example, for the F10_H10 phantom, that has the small volumes (V1, V2 and V3), the dose in the breast is higher in relation to FASH3 and F90_H90 phantoms. This is justified because the number of seeds is the same in all 3 phantoms. Comparing the results between the ^{125}I seed types, it is possible to verify that the absorbed doses for several organs are very similar, and it is possible to observe that the breast received the highest dose, followed by the skin.

In the literature, Lettmaier et al. [17] compared the radiation doses between partial breast irradiation using multicatheter brachytherapy, and whole breast teletherapy, and the results demonstrated that the organ with the highest dose was the skin, followed by the lung, as the results in the present work also pointed out. This paper also showed that brachytherapy and radiotherapy treatments have the same effects in relation to tumor control and death, but in relation to the radiation doses, brachytherapy treatment was more advantageous by depositing less dose in the studied organs [17].

A comparison with other studies on absorbed doses in breast brachytherapy treatment with ^{125}I seeds, utilizing Monte Carlo simulation, was not possible, because there are no published studies (to the best of our knowledge) utilizing this methodology for this treatment type.

An important fact noticed in this paper is that the breast volume sizes influenced the scattered radiation, implying in significant variation in the absorbed dose values. For the larger breast, the dose to other organs, due to scattered radiation was lower than the values for the smaller breast. For example, the lung of the F10_H10 phantom irradiated with the IPEN ^{125}I seeds obtained a dose 137% higher than the F90_H90 phantom. However, in relation to the FASH3 reference phantom, this difference was only 30%. Within the statistical uncertainties, the same difference was observed for the commercial ^{125}I seeds.

As can be seen in Tables 3, 4 and 5, the uncertainties were, in all situations, less than 5%, proving to be reliable estimates of the absorbed dose.

4. Conclusion

The results pointed out the highest dose values for the breast and skin, while the lowest dose values were for the brain and bone marrow. The main reason for these organs and tissues to present the highest values is due to their proximity to the seeds. Moreover, the dose results for the two types of ^{125}I seeds were very similar, showing an excellent performance of the IPEN seed. Therefore, the data obtained in this work are useful for evaluating the specific organ doses during breast brachytherapy treatments, using ^{125}I seeds, presenting a great contribution to radiological protection. The precise knowledge of radiation doses in breast cancer brachytherapy is extremely important for the successful healing of the patient, and the preservation of the radiation effects of the other healthy organs and tissues, located near the treated volume. However, this is not an easy task, because it depends on complex factors such as breast geometry and the presence of critical organs such as the lung and heart.

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