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Monte carlo simulation of dose perturbation in different breast tissues induced by radiographic contrast inside brachytherapy balloon applicators

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ABSTRACT

Background: MammoSite Radiation Therapy System with a high dose rate brachytherapy ^{192}Ir source is used to deliver partial breast irradiation after a lumpectomy for early stage breast cancer to treat the tissue immediately surrounding the lumpectomy cavity.
Materials and Methods: The spherical balloons with 4 cm to 6 cm radius have been considered filled with different mixtures of water and contrast solution in our simulation. We have used MCNP4C code to study the effect of the increased attenuation on absorbed dose value for the different glandular fraction of breast tissues.
Results and discussion: We have calculated Heterogeneity Correction Factor (HCF) for various balloon diameters from 4 to 6 cm, for 0%, 20%, 50%, 70% and 100% breast glandular fraction phantom with 0%, 25%, 50%, 75% and 100% contrast concentration inside the balloon.
Conclusion: The result can be used in treatment planning systems and also for computation of model dependent parameters. The calculated HCF for the Mammosite breast brachytherapy applicator are agree quite well with Clinical results which obtained by others.

Introduction

In the recent years, considerable advances have been made in the detection and treatment of breast cancers. Long studies of different groups have shown that early stages of the breast cancer can be cure by removing cancer cells and small edges of the surrounding tissue (lumpectomy) plus radiation therapy which is more effective method than the total breast removal (mastectomy). Therefore, surgeons think to apply lumpectomy followed by radiation therapy instead of breast mastectomy (1-4).

As it is well know, the ionized radiation damages all cells in its path including cancer and healthy cells. Therefore, many women and their doctors want to limit radiation treatment only to the area around the tumor (4-6). This kind of targeting therapy uses a high dose of radiation directed right at the area surrounding the lumpectomy cavity to destroy any cancer cells that may remain yet. And it helps to minimize side effects such as skin discoloration and scarring, burning, and damage to the surrounding organs. As well as, this kind of therapy can be completed in a shorter period of time compare with the conventional external beam radiation therapy which takes around 6 weeks.

MammoSite is a specialized catheter developed by Proxima Therapeutics to deliver partial breast irradiation. This device consists of a catheter with an inflatable balloon at the closed end. The catheter is placed in the lumpectomy cavity and the balloon is then inflated to conform to the volume of the cavity with diameter of 4 cm to 6 cm. A radioactive HDR (high-dose-rate) source like ^{192}Ir is then remotely placed at the center of the balloon to deliver appropriate dose to the surrounding lumpectomy cavity (5-8). The inflated balloon shapes and compresses the tissue adjacent to the cavity into a nearly spherical shell surrounding the balloon [(2)]. The presence of elements with a high atomic number such as iodine in the radiographic contrast solution increases the photoelectric attenuation compared to a balloon filled with water alone. Recently, Bensaleh at al. published a valuable review of MammoSite brachytherapy and they discussed about the advantages, disadvantages and clinical outcomes of this method (6).

Calculation of dose perturbation effect in different breast tissue for the MammoSite brachytherapy is the main aim of this study. We have used MCNP4C code (9) to study the effect of this increased attenuation in the different breast tissues phantoms when a MicroSelectron HDR ^{192}Ir source uses for irradiation.

Materials and Methods

Geometry and Tissue Composition simulated

Various breast compositions were studied, from 0% glandular-100% adipose to 100% glandular - 0% adipose, by mass. The elemental compositions and densities of breasts with different glandular properties and of skin are given in Table 1 [(10)].

The phantom was a sphere with 10 cm diameter and the balloon was assumed to be a sphere positioned at the center of the phantom. Three balloon diameters were simulated with 4 cm, 5 cm, and 6 cm radiuses, to model all potential clinical applications covered by the manufacturer's recommendations. The effects of the silicone balloon wall and nylon catheter were assumed to be negligible.

The contrast inserts were filled with different mixtures of water and contrast into the balloon. The contrast concentration levels used were 10%, 25%, 50%, 75%, 100%. The 100% concentration refers to the pure contrast solution with density 1.34 g/cm^3 and contains 367 mg per cm^3 of organic bounded

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iodine (11). According to the reference 9, the radiographic contrast was modeled in MCNP by specifying the percentage weight of each component and the physical density of the contrast. Each ml of Gastrografin radiographic contrast has 660 mg diatrizoate meglumine ($H_{26}C_{18}O_9N_3I_3$) and 100 mg diatrizoate sodium ($H_8C_{11}O_4N_2Na_1I_3$). The percentage weight of each element of Gastrograf in contrast was determined from the total molecular weight of each element. For simplicity, water was modeled according to the percentage weights of its constituents, H_2O. The relative weight of each component was scaled according to the relative water and contrast volumes.

The source simulated in this study was the MicroSelectron HDR ^{192}Ir source (v2, model no. 105.002; Nucletron B.V., Veenendaal, Netherlands), which has been described in detail by Daskalov et al (12). The internal construction and dimensions of the HDR ^{192}Ir source is illustrated in Figure 1. The modeled source is a 100% solid iridium metal cylinder, 3.6 mm in length and 0.65 mm in diameter with beveled edges. A density of 22.42 g/cm^3 is used for the core, and the radioactivity is assumed to be uniform distribution within the metal source. The stainless steel used in all components is AISI 316L steel of 8.02 g/cm^3 density with the following elemental composition, by weight: 2% Mn, 1% Si, 17% Cr, 12% Ni, and 68% Fe (11).

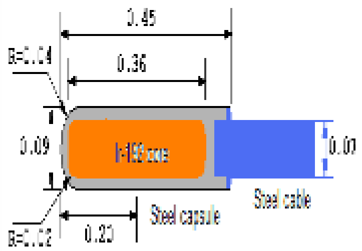

Figure 1: Schematic of the ^{192}Ir source

The photon energy spectrum of the simulated ^{192}Ir source was taken from the U.S. Department of Energy Radioactive Decay Tables. The photon energy spectrum includes 26 energies with 2.36 particles per disintegration. The energy spectrum ranges from 8.91 keV to 871.73 keV. Beta particles emitted from the source were not included because they will not contribute to dose outside the source due to their short ranges. The photon emission from the cylindrical source is assumed to be isotropic.

Monte Carlo Calculations

MCNP Monte-Carlo is a general purpose computer code which is particularly useful for phenomena which are random in nature such as interactions of nuclear particles with materials [(7)]. It does not solve the transport equation for the neutron, but rather simulates one neutron at a time and records its history. MCNP can be used for simulation of neutron, electron, photon, or a combined neutron/electron/photon transport problem. In the present work, the dose perturbations induced by the presence of radiographic contrast inside the Mammosite balloon were investigated using Monte Carlo simulations. Figure 2 shows a schematic of the Monte Carlo simulation geometry which is a 0.2 cm thick transverse slice through the centre of the balloon. The simulated source was inserted in the center of the balloon with diameters either 4, 5 or 6 cm and 4 guard rings were defined around it with 0.2 cm in radial thickness, 0.2 cm in width and spaced at 0.5 cm intervals. Dose depositions by photon were calculated using the *F8 tally (9).

The dose perturbation at each location is defined as the ratio of delivered dose with water-contrast mixture and pure water. For each combination of contrast concentration, C, balloon radii, d, and the location of dose evaluation, x, a heterogeneity correction factor, HCF(d,C,x), was calculated as follows:

$$HCF(d,C,x)=\frac{Dose(d,C,x)}{Dose(d,x)} \quad (1)$$

Where *Dose(d,C,x)* represents the dose with balloon radii d and contrast concentration level C at a distance x from the balloon surface. And *Dose(d,x)* represents the dose with balloon radii d, for water at the same location (8).

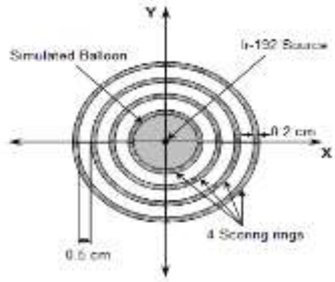

Figure 2: A schematic (not to scale) of the Monte Carlo simulation geometry

Results and Discussions

Table 2 shows the HCF as a function of contrast concentration levels for 0%, 20%, 50%, 70% and 100% breast glandular fractions at the balloon surface. The same values of HCF, but for 1 cm from balloon surface, are shown in Table 3. The statistical uncertainties in these calculations are less than 1%, and the time that is needed for any programs are about 100 minutes with a computer Pentium 4 Intel CPU 3.06GHz.

A comparison of the HCF for the brachytherapy balloon applicator reported by Kirk et al. (8) and this work have been present in Figure 3. Whereas the tissue with 70% glandular weight fraction has density near to water density, we compared this glandular weight fraction with water phantom. The results of Kirk et al. for HCF are expressed for water phantom but are not contained the breast tissue phantom. The dose perturbation is larger for larger balloon diameter and higher contrast concentration. As we see in Table 2 and 3, the HCF decreased by increasing in radiographic contrast concentration. Also, the HCF decreased by increasing in glandular weight fractions. Furthermore, by increasing glandular weight fraction the HCF falls much faster. Thus, the amount of radiographic contrast used in the Mammosite breast brachytherapy applicator should be minimized.

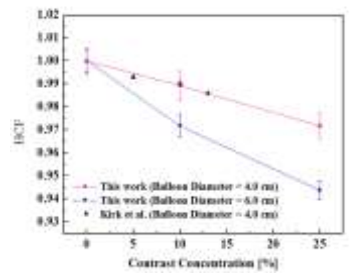

Figure 3: Comparison of the results HCF in this study (for glandular weight fraction = 70%, at the surface of applicator) with the result of Kirk et al. (8)

Conclusion

Dose deposition in high gradient region, near the source, can only be calculated accurately by Monte Carlo method. The result can be used in treatment planning systems and also for computation of model dependent parameters. The calculated

HCF for the Mammosite breast brachytherapy applicator agree quite well with clinical results of Kirk et al (8) and are useful in treatment in therapeutic plan. The present work demonstrates a useful approach using MCNP code in dose calculation that can be applied in many other fields.

References

1.Vicini FA, Kini VR, Chen PY, et al. (1999). Irradiation of the tumor bed alone after lumpectomy in selected patients with early-stage breast cancer treated with breast conserving therapy. *J Surg Oncol*, 70: 33–40.

2.Edmundson GK, Vicini FA, Chen PY, Mitchell C, Martinez AA (2002). Dosimetric characteristics of the MammoSite RTS, a new breast brachytherapy applicator. Int J Radiat Oncol Biol Phys, 52: 1132-1139.

3.Zannis VJ, Walker LC, Barclay-White B, Quiet CA (2003). Postoperative ultrasound-guided percutaneous placement of a new breast brachytherapy balloon catheter. Am J Surg, 186: 383-385.

4.Keisch M, Vicini F, Kuske RR, Hebert M, White J, Quiet C, Arthur D, Scroggins T, Streeter O (2003). Initial clinical experience with the MammoSite breast brachytherapy applicator in women with early-stage breast cancer treated with breast-conserving therapy. Int J Radiat Oncol Biol Phys, 55(2): 289-293.

5.Swartz MJ, Petereit DG (2010). The role of Radiation Therapy in the Management of Breast Cancer in South Dakota. South Dakota Medicine, special issue: 38-40.

6.Bensaleh S, Bezak E, Borg M (2009). Review of MammoSite brachytherapy: advantages, disadvantages and clinical outcomes. Acta Oncol.; 48(4):487-94.

7.King TA, Bolton JS, Kuske RR (2000). Long-term results of wide-field brachytherapy as the sole method of radiation therapy after segmental mastectomy for T(is, 1, 2) breast cancer. Am J Surg Pathol, 180: 299-304.

8.Kirk MC, Hsi WC, Chu JC, Niu H, Hu Z, Bernard D, et al (2004). Dose perturbation induced by radiographic contrast inside brachytherapy balloon applicators. Med Phys, 31: 1219-24.

9.Briesmeister JF, editor (2000). MCNP^{TM}- A general Monte Carlo N-particle transport code, Version 4C, Los Alamos National laboratory Report LA–13709–M.

10.Boone JM (1999). Glandular Breast Dose for Monoenergetic and High-Energy X-ray Beams: Monte Carlo Assessment. *Radiology,* 213: 23-37.

11.Kassas B, Mourtada F, Horton JL, Lane RG, Buchholz TA, Strom EA (2006). Dose modification factors for ^{192}Ir high-dose-rate irradiation using Monte Carlo simulations. *J Appl Clin Med Phys*, 7(3): 28-34.

12.Daskalov GM, Loffler E, Williamson JF (1998). Monte Carlo-aided dosimetry of a new high dose-rate brachytherapy source. *Med. Phys.*, 25(11): 2200-2208.

Table 1: The weight fractions of elements and total tissue density as a function of glandular weight fraction (10)

Glandular Weight Fraction (%)	Tissue Density	Hydrogen	Carbon	Nitrogen	Oxygen	Phosphorus
0	0.9301	0.112	0.619	0.017	0.251	0.001
10	0.9399	0.111	0.576	0.019	0.294	0.001
20	0.9501	0.110	0.532	0.020	0.336	0.002
30	0.9605	0.109	0.488	0.022	0.379	0.002
40	0.9711	0.108	0.445	0.023	0.421	0.003
50	0.9819	0.107	0.401	0.025	0.464	0.003
60	0.9930	0.106	0.358	0.026	0.507	0.003
70	1.0044	0.105	0.315	0.028	0.549	0.004
80	1.0160	0.104	0.271	0.029	0.592	0.004
90	1.0278	0.103	0.227	0.030	0.634	0.005
100	1.0400	0.102	0.184	0.032	0.677	0.005
Skin	1.0900	0.098	0.178	0.050	0.667	0.007

Table 2: The HCF values at balloon surface for various balloon diameter (4, 5 and 6 cm), contrast concentration (0, 25, 50, 75 and 100%) and breast glandular fraction (0, 20, 50, 70 and 100%).

Balloon diameter (cm)	Contrast (%)	Heterogeneity correction factor for different breast glandular fraction				
		0%	20%	50%	70%	100%
4	0	1	1	1	1	1
4	25	0.97227	0.97216	0.97207	0.97199	0.97191
4	50	0.94617	0.94548	0.94508	0.94485	0.94424
4	75	0.92055	0.91966	0.91937	0.91895	0.91836
4	100	0.89610	0.89540	0.89489	0.89462	0.89353
5	0	1	1	1	1	1
5	25	0.95662	0.95612	0.95172	0.95208	0.95151
5	50	0.92625	0.92597	0.92180	0.92164	0.92133
5	75	0.89533	0.89489	0.89083	0.89055	0.88959
5	100	0.86242	0.86202	0.85779	0.85731	0.85614
6	0	1	1	1	1	1
6	25	0.94609	0.94496	0.94394	0.94377	0.94289
6	50	0.90371	0.90237	0.90145	0.90054	0.89969
6	75	0.87083	0.86924	0.86778	0.86685	0.86600
6	100	0.83516	0.83361	0.83164	0.83071	0.82941

Table 3: The HCF values at 1 cm from balloon

Balloon diameter (cm)	Contrast (%)	Heterogeneity correction factor for different breast glandular fraction				
		0%	20%	50%	70%	100%
4	0	1	1	1	1	1
4	25	0.97480	0.97218	0.97035	0.96986	0.96921
4	50	0.94969	0.94699	0.94486	0.94465	0.94371
4	75	0.92455	0.92234	0.92024	0.91919	0.91738
4	100	0.89843	0.89588	0.89393	0.89253	0.89089
5	0	1	1	1	1	1
5	25	0.96395	0.96148	0.95452	0.95560	0.95578
5	50	0.92969	0.92750	0.92035	0.92095	0.92029
5	75	0.90052	0.89814	0.89160	0.89175	0.89093
5	100	0.86982	0.86823	0.86191	0.86199	0.86113
6	0	1	1	1	1	1
6	25	0.95405	0.95077	0.94868	0.94769	0.94696
6	50	0.91460	0.91183	0.91073	0.90925	0.90729
6	75	0.87878	0.87602	0.87483	0.87363	0.87097
6	100	0.83997	0.83695	0.83663	0.83601	0.83398