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The Effect of Breast Phantom Material on the Dose Distribution in AccuBoost Brachytherapy

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ABSTRACT

Introduction: Long-term teletherapy program is not suitable for old and working patients and those living in areas where little access to primary health care is available. Accelerated partial breast irradiation (APBI) using high dose rate (HDR) brachytherapy is an appropriate alternative for these patients due to its limited number of fractions. The AccuBoost is a system for delivering APBI. The brachytherapy dose is delivered from parallel-opposed beams from ^{192}Ir sources in circle applicators. This study was conducted to investigate the effects of breast phantom material on the dose distribution in AccuBoost brachytherapy using Monte Carlo N-Particle method.

Material and Methods: In this study, different inhomogeneous breast phantoms composed of various materials were simulated. Dosimetric evaluations including a comparison of dose distribution between different breast phantom materials and water phantom was performed.

Results: There was no significant difference between the breast and water phantoms in terms of mean dose values in different positions of each phantom. The most significant differences between the doses of different compositions and water were found to be about 6% near the skin.

Conclusion: No significant differences were observed between the breast phantoms composed of diverse materials and water phantoms considering the dose distributions. Therefore, it is not necessary to replace the current treatment planning systems using Task Group No. 43 formalism with combined model-based and patient-specific dosimetry methods.

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Introduction

Breast conserving therapy (BCT) is widely accepted as an effective treatment modality for early stage breast cancers. BCT with external beam radiotherapy lasts approximately 6-7 weeks. Such long-term treatments are not suitable for old and working patients and those living in areas where little access to primary health care is available [1, 2]. Accelerated partial breast irradiation (APBI) with high dose rate (HDR) brachytherapy is an appropriate alternative for these patients due to its limited number of fractions [3].

AccuBoost (Advanced Radiation Therapy, Billerica, MA) is a peripheral applicator that provides a HDR breast brachytherapy treatment. This device consists of two applicators, which are placed directly in contact with the breast skin. The breast is compressed between these applicators in order to immobilize it. Each applicator has 18 sources and a conical shield made from alloy of tungsten, which helps to collimate the radiation. HDR collimating applicators are located along an axis towards each other on both sides of the breast [4, 5].

The American Association of Physics in Medicine Task Group No. 43 (TG-43) published an algorithm for dose calculation in treatment planning systems (TPSs), which perform their calculations in homogeneous water phantom. In real treatment conditions, the radiation passes through several tissues with different attenuation and absorption properties. Various phantom materials cause different dose distributions due to different absorption and attenuation of the primary photon beam, and changing the secondary electron fluence perturbation.

According to the literature, the errors in dose calculations are as a result of ignoring the phantom materials and their attenuation, scattering, and absorption coefficients [6-13]. Sina et al. indicated that for-low energy sources there were errors in calculations by TPSs, which were not negligible in the bone and around the sources. They suggested correction factors to modify the calculations [6].

The material-specific conversion factors were found by Sina et al. to correct the dose distributions in different tissue-equivalent phantoms in high and low

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dose rates brachytherapy. It was shown that the results were dependent on the phantom size and materials [14]. Other Monte Carlo simulations were performed to obtain dose distribution in different phantom materials [15-18].

In another study performed by Ghorbani et al., several geometries were considered to evaluate the effects of materials with specified tissue composition characteristics (density, elemental compositions, etc.) on dose distributions from various sources [19]. Therefore, it is essential to perform these calculations in TPSs based on TG-43. Several studies were conducted with the aim of obtaining the dose distribution around HDR ^{192}Ir brachytherapy sources used in MammoSite, Strut-Adjusted Volume Implant, AccuBoost, and interstitial multicatheter brachytherapy systems [4, 20-23].

AccuBoost brachytherapy device is a novel HDR modality that is completely non-invasive and provides adequate dose coverage [24]. It is essential to consider the effect of the breast tissue, which is usually made up of glandular and adipose tissue, for accurate dosimetric evaluations. The ratio of these compositions depends on the age and demographic characteristics of women [25, 26]. According to the Task Group No. 186 (TG-186), a real breast tissue should be considered based on 3-dimensional images. It is recommended to use glandular and adipose regions in simulations, and if they were not available, a mean uniform tissue based on the true mass percentages of both compositions should be used (Table 1). In addition, TG-186 suggests using the adipose-to-glandular ratio of 80% to 20%, as the mean ratio in general population, in simulations without any information about the breast tissue [27, 28]

Although the effect of phantom material on dose distribution was considered in the literature, no comprehensive study was carried out into the breast and HDR brachytherapy. The objective of this study was to investigate the effects of breast phantom material on dose distribution caused by AccuBoost brachytherapy using Monte Carlo N-Particle (MCNP) transport code.

Materials and Methods

Simulation of different breast tissues

A MCNP simulation, which is a model-based dose calculation algorithm was performed using MCNP transport code, version 5 (MCNP5) (Los Alamos National Laboratory, Los Alamos, NM). Simulations were performed to evaluate more exact differences between the effects of breast tissues on dosimetric calculations for breast brachytherapy treatment by AccuBoost system.

A 2-dimensional geometry of simulation is shown in Figure 1. Each applicator consists of 18 HDR ^{192}Ir sources located in a 2 mm air channel on a 4.5 mm thick polycarbonate disk with 2.8 cm radius (Figure 1.b), walls with 6 mm thickness, a cone made of tungsten alloy (90% W, 6% Ni, and 4% Fe by weight), and a shield of polycarbonate with 3.67 mm thickness placed on the breast skin [4].

A cubical water tank was considered as the chest containing an ellipsoid air-filled part as the lung. A 6×12×12 cm^3 cube of water was used to represent the breast compressed along X-axis (Figure 1.c). The prescribed dose of 34 Gy was assumed to be delivered to the breast center.

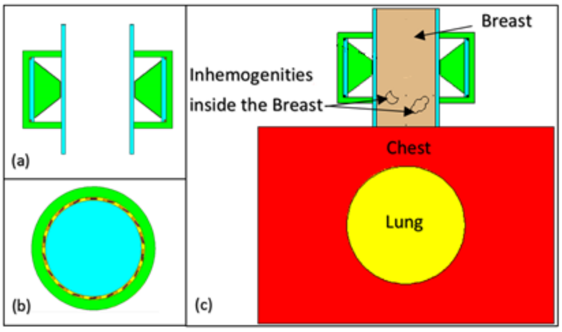

Figure 1. a) AccuBoost system, b) Source dwell positions in each applicator, c) Phantom geometry

Table 1. The elemental compositions of different materials used in phantom simulations

Materials	Elemental composition (% by mass)									Mean densities (g/cm3)
	H	C	N	O	Na	S	Cl	P	Ca	
Mean adipose tissue [25]	11.4	59.8	0.7	27.8	0.1	0.1	0.1	0	0	0.95
mean glandular tissue [25]	10.6	33.2	3	52.7	0.1	0.2	0.1	0.1	0	1.02
ICRU-44 breast tissue [29]	9.4	61.9	3.6	24.5	0	0	0	0	0.6	1.1
Normal breast tissue [25]	11.24	54.48	1.16	32.78	0.1	0.12	0.1	0.02	0	0.964

To measure the dose distribution, the breast and body phantoms were divided to small cubical cells, and the dose was scored in these cells using F6 tally. Then, 300,000,000 photon histories were performed with the averaged statistical error of 1% in all Monte Carlo simulations. To ensure the accuracy of evaluations, the estimations were first compared with the results reported by Zehtabian et al. and those obtained from *F4 tally [4]. Our results were consistent with the estimations of the mentioned study.

To investigate the effect of phantom material on dose distribution, eight phantoms with different material compositions were simulated as shown in Figure 2. In this study, different phantoms containing different materials, i.e. mean adipose (m1) and mean glandular (m2) tissues, breast tissue defined by International Commission on Radiation Units and Measurements Report 44 (ICRU-44) (m3) and normal breast tissues (a mean combination of 20% gland and 80% adipose as suggested in TG-186) (m4) were used. Finally, the dose distribution inside the phantom materials was compared with that of homogeneous water phantom, as recommended by TG-43.

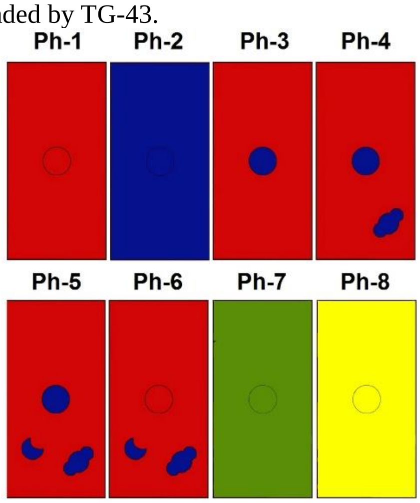

Figure 2. Simulation geometry of the breast (mean adipose tissue (red), mean glandular tissue (blue), ICRU-44 breast tissue (green), and normal breast tissue (yellow)) for Ph-1 to Ph-8 phantoms.

Study on patients

Several real tissue compositions were considered for the breast in addition to previous materials (m1 to m4). The real composition of breast tissue was obtained from computed tomography (CT) images of five patients with ages and sizes in a random manner. The CT scan images of the breast were used to define the uniform breast tissue compositions with real mass ratio of adipose and glandular tissues. It is directly noted by TG-186 that if reliably distinguished materials were not accessible, a uniform material composed of a mixed of adipose and glandular tissue should be assigned as the whole breast [28].

The CT images of five patients were segmented based on CT number in each slice for tissues with different density ranges using Amira Software. This software creates a 3-dimensional volume from these segmented areas in all slices containing the breast.

The volume percentages of adipose and glandular tissues of the patient breasts were obtained and mass percentage for these tissues were calculated. A mean homogeneous tissue was defined for each patient. The dose distribution in the homogeneous phantoms composed of these tissues was obtained using Monte Carlo simulation and compared with the dose distribution in water phantom.

Results

Phantom dosimetry

The dose distribution inside the homogeneous water phantom obtained from the results of Monte Carlo simulation is demonstrated in Figure 3. For a better distinction between the doses obtained from different phantoms, the difference percentage between the doses in water (D_w) and other phantoms (D_m) were calculated for all points in the breast using Equation 1.

$$\%Difference = \frac{D_m - D_w}{D_w} \times 100 \qquad (1)$$

The maximum and mean values of absolute percentage difference (Max and Mean, respectively) were calculated throughout the dose distribution of each phantom. Furthermore, as demonstrated in Figure 4a, 14 dosimetry points were selected to show the obtained results in each phantom. Difference percentages in selected points and Max and Mean values are shown in Table 2. Percentage difference for ph-5 and ph-7 phantoms are plotted in figures 4b and 4c, respectively.

A sphere was considered at the center of the phantoms as planning target volume (PTV) for a better estimation. The dose volume histogram (DVH) analysis was applied to provide an appropriate dosimetric comparison for PTV coverage in eight phantoms. The comparison of the parameters obtained from the DVHs such as D50, D75, D90, and D95 for different phantoms is revealed in Table 3.

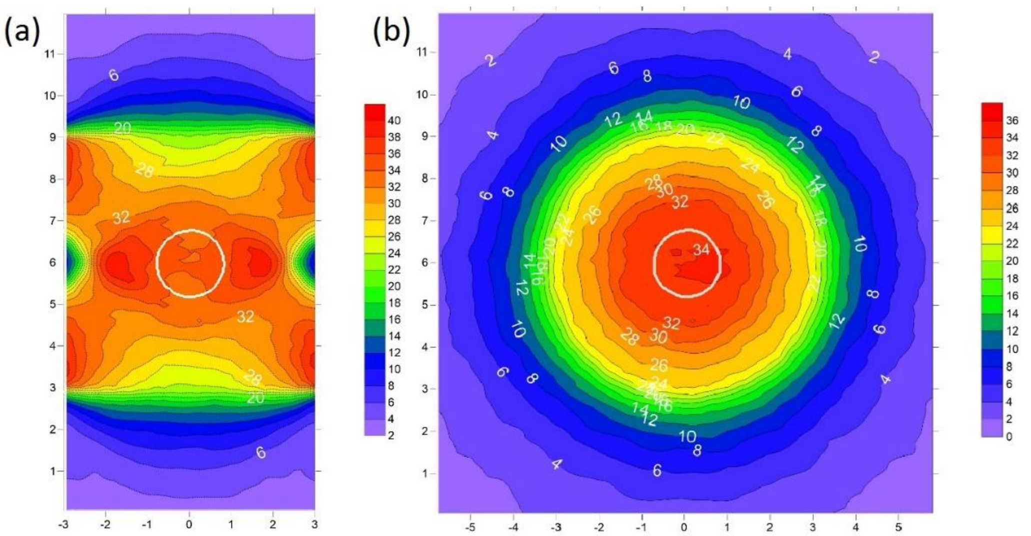

Figure 3. The isodose plots inside the water phantom for the radiation of AccuBoost device (Gy) in a) X-Z direction and b) Y-Z direction

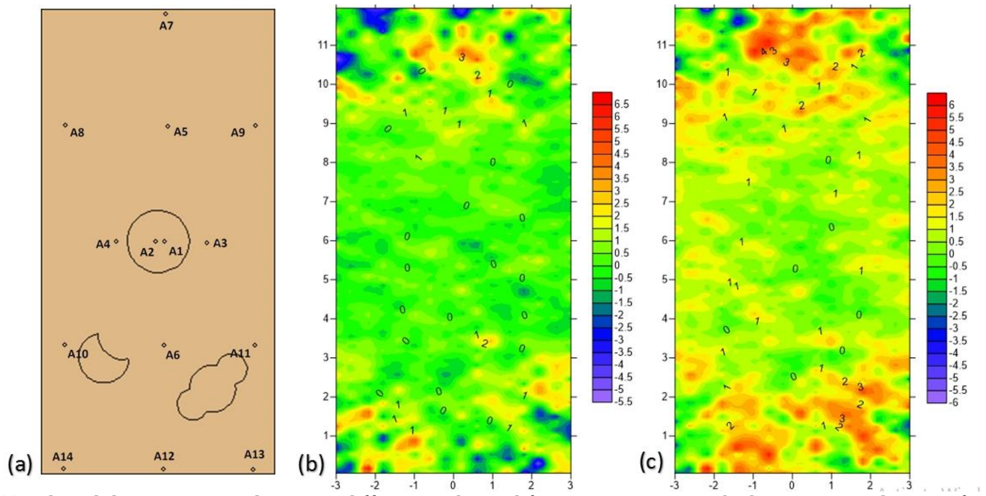

Figure 4. (a) Selected dosimetric point locations; differences obtained from Equation 1 into the breast in X-Z direction for (b) ph-5; and (c) ph-7 phantoms.

Table 2. The percentage difference between the dose distribution inside eight phantoms and that of water

	Ph-1	Ph-2	Ph-3	Ph-4	Ph-5	Ph-6	Ph-7	Ph-8
A1	0.48	0.5	-0.12	-0.11	-0.09	-0.12	1.39	0.55
A2	0.47	0.44	0.8	0.78	0.8	0.75	0.45	0.86
A3	0.53	0.43	-0.53	-0.51	-0.53	-0.6	0.61	0.14
A4	1.24	0.89	0.16	0.14	0.09	0.23	0.36	0.61
A5	0.66	0.55	-0.25	-0.21	-0.19	-0.38	0.84	0.14
A6	-0.48	-0.52	-0.94	-0.88	-1.03	-1.2	-0.87	-0.43
A7	-2.57	-1.34	-4.44	-4.41	-4.49	-4.53	-3.27	-3.71
A8	2.87	3.02	1.69	1.61	1.6	1.56	3.15	2.29
A9	-0.1	0.1	-0.25	-0.26	-0.2	-0.38	1.01	0.38
A10	1.11	1.02	1.32	1.32	1.38	1.18	1.68	0.72
A11	1.4	1.64	1.69	1.75	1.68	1.55	2.1	1.55
A12	1.07	1.52	-0.42	-0.49	-0.32	-0.59	0.97	-1.85
A13	4.85	4.41	3.46	3.52	3.43	3.55	3.88	3.86
A14	-1.72	0.74	-1.11	-0.96	-1.02	-1.12	-1.73	-1.5
Max	6.52	6.86	8.57	8.69	8.35	8.39	7.6	8.56
Mean	1.17	1.17	1.05	1.04	1.04	1.03	1.32	1.05
S*	1.05	1.02	0.99	0.99	0.99	0.98	1.14	0.95

* Type A standard uncertainty

Table 3. Dosimetry parameters (Gy) obtained from the dose volume histogram analysis for planning target volume

Dosimetric Parameters (Gy)	Phantoms							
	Water phantom	Ph-1	Ph-2	Ph-3	Ph-4	Ph-5	Ph-7	Ph-8
D50	33.92	33.94	34.09	33.8	33.81	33.81	34.14	33.97
D75	31.91	32.02	31.94	31.96	31.96	31.94	31.98	32.03
D90	31.33	31.51	31.48	31.52	31.52	31.51	31.39	31.42
D95	30.9	31.29	31.22	31.13	31.14	31.15	31.11	31.22

Patient dosimetry

The information obtained from the CT images of the five patients are shown in Table 4. Monte Carlo simulations were performed using homogeneous phantoms. The elemental composition of the homogeneous phantom (patient1- patient5) used for simulation of each patient is shown in Table 5. The mass ratios obtained from CT images were included about 10-30% glandular and 70-90% adipose tissues that was near the mean ratios suggested by TG-186. The results of dosimetric consideration for patients are presented in table 6 and 7.

Table 4. The percentage of adipose and glandular tissues of the five patients, as estimated from computed tomography images.

	Glandular tissue (%)	Adipose tissue (%)
Patient-1	11.5	88.5
Patient-2	27.1	72.9
Patient-3	14.9	85.1
Patient-4	10.8	89.2
Patient-5	28.9	71.1

Table 5. Elemental composition used for the simulation of each patient's breast

Materials	Elemental composition (% by mass)								Mean density (g/cm3)
	H	C	N	O	Na	S	Cl	P	
m5 (Patient-1)	11.31	56.75	0.96	30.66	0.1	0.11	0.1	0.01	0.958
m6 (Patient-2)	11.19	52.59	1.32	34.54	0.1	0.14	0.1	0.02	0.968
m7 (Patient-3)	11.28	55.84	1.05	31.51	0.1	0.11	0.1	0.01	0.96
m8 (Patient-4)	11.32	56.93	0.95	30.48	0.1	0.11	0.1	0.01	0.957
m9 (Patient-5)	11.17	52.11	1.37	35	0.1	0.13	0.1	0.02	0.97

Table 6. The difference percentage between the dose distribution inside the patient phantoms and that of water phantom

	Patient-1	Patient-2	Patient-3	Patient-4	Patient-5
A1	0.55	0.58	0.55	0.5	0.66
A2	0.66	0.81	0.76	0.85	0.72
A3	0.16	0.11	0.06	0.09	0.14
A4	0.56	0.61	0.52	0.54	0.54
A5	-0.4	-0.42	-0.31	-0.39	-0.53
A6	-0.39	-0.41	-0.63	-0.28	-0.6
A7	-3.39	-3.85	-3.35	-3.61	-4
A8	2.57	2.62	2.61	2.53	2.64
A9	-0.41	-0.41	-0.3	-0.54	-0.33
A10	0.86	0.8	0.85	0.91	0.76
A11	1.73	1.77	1.67	1.65	1.65
A12	-0.14	-1.02	-0.2	0.01	-1.2
A13	4.35	4.17	4.45	4.35	4.4
A14	-0.75	-0.94	-0.47	-1.45	-0.66
Max	7.65	7.17	7.39	7.38	7.32
Mean	1.1	1.08	1.1	1.09	1.07
S*	1	0.98	1	0.98	0.97

* Type A standard uncertainty

Table 7. Dosimetry parameters (Gy) obtained from the dose volume histogram analysis for planning target volume

Dosimetric parameters (Gy)	Phantoms				
	Patient-1	Patient-2	Patient-3	Patient-4	Patient-5
D50	34.03	34.05	34.03	34.07	34.04
D75	31.98	32.01	31.88	31.87	31.95
D90	31.44	31.37	31.41	31.41	31.37
D95	31.21	31.22	31.19	31.23	31.17

According to the results, the dose values at different positions of each phantom showed a mean percentage difference of 1% when compared with the dose at the water phantom. As revealed in Figure 4, the highest percentage differences between the doses of different compositions and water phantom were found to be about 6% near the skin. Type A standard uncertainty estimations showed about 1% deviation from the mean values.

Discussion

Based on the results of a study conducted by Wu et al., the dose of ^{192}Ir HDR brachytherapy in the bone and lung tissues was different from the water phantom [30]. In addition, the requirements of revisions in TPSs in the air and bone interferences and tissues with heterogeneity were discussed in the mentioned study [31, 32].

Regarding the results of the present study, the ignorance of real tissue compositions for possible breast materials and the breasts with heterogeneity had no significant effect on dose distribution in the breast. However, the materials with higher density differences compared to water showed greater differences in dose distribution. This fact is not valid for breast treatments by low energy sources [19, 33].

More differences were observed for water approximately near the skin that refereed to the air-tissue interference effects; nevertheless, their magnitudes were negligible. Several studies on various high dose rate ^{192}Ir brachytherapy have been performed on this issue [20].

Conclusion

According to the results of this study, the difference between the dose distributions in different breast tissues were not significant for HDR ^{192}Ir AccuBoost brachytherapy. Therefore, TG-43-based TPSs can still be used as a conservative dose approximation method without significant uncertainties in the treatment of breast cancer using HDR brachytherapy. However, in addition to phantom material considerations, requirements for comparative evaluations on the geometry and composition for real sources and applicators respect to those defined by TG-43 is necessary to have a more reliable conclusion on the measurements from TPSs.

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