The Effect of Breast Reconstruction Prosthesis on Photon Dose Distribution in Breast Cancer Radiotherapy

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ABSTRACT

Introduction: Silicone prosthetic implants are commonly utilized for tissue replacement and breast augmentation after mastectomy. On the other hand, some patients require adjuvant radiotherapy in order to prevent local-regional recurrence and increment of the overall survival. In case of recurrence, the radiation oncologist might have to irradiate the prosthesis. The aim of this study was to evaluate the effect of silicone prosthesis on photon dose distribution in breast radiotherapy.

Materials and Methods: The experimental dosimetry was performed using the prosthetic breast phantom and the female-equivalent mathematical chest phantom. A Computerized Tomography based treatment planning was performed using a phantom and by CorePlan Treatment Planning System (TPS). For measuring the absorbed dose, thermoluminescent dosimeter (TLD) chips (GR-207A) were used. Multiple irradiations were completed for all the TLD positions, and the dose absorbed by the TLDs was read by a light telemetry (LTM) reader.

Results: Statistical comparisons were performed between the absorbed doses assessed by the TLDs and the TPS calculations for the same sites. Our initial results demonstrated an acceptable agreement (P=0.064) between the treatment planning data and the measurements. The mean difference between the TPS and TLD results was 1.99%. The obtained findings showed that radiotherapy is compatible with silicone gel prosthesis.

Conclusion: It could be concluded that the silicone breast prosthesis has no clinically significant effect on the distribution of a 6 MV photon beam for reconstructed breasts.

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Introduction

Since breast reconstruction is of particular importance in the physical, emotional, and psychological recovery of women, prosthetic implants are used for cosmetic breast augmentation and tissue replacement in mastectomy cases during the treatment course of breast cancer. The prosthetic implants generally consist of a transparent silicone material, within a soft and thin silicone envelope. However, a simple question exists regarding a patient who has undergone breast reconstruction: “How does the implant affect the absorbed dose distribution?”.

Impact of the silicone breast prosthesis on the absorbed dose distribution for electron and photon beams was evaluated by Krishnan et al. in 1983. The range of energy for electron and photon beams was 9-20 MeV and 1.25-15 MV, respectively. The mean absorbed dose was measured and compared between the two conditions of with and without prosthesis for the water phantom. Results showed that the difference between the Central axis percentage depth dose values for 15 MV photon beams was not significant. The maximum difference was 2% of the maximum dose in water [1].

Kuske et al. in a study to assess the tumor condition and treatment complications, cosmetics optimization, and patients’ satisfaction, evaluated 72 reconstructed breast patients after radiotherapy. Thermoluminescent dosimeter (TLD) chips and a parallel plate chamber were used for measuring the depth dose in an interface phantom. The results indicated that radiotherapy and breast reconstruction were compatible; however, the time of radiotherapy, the radiotherapy technique (e.g., using a layer or box bolus), and the reconstructive procedure were determining factors for the cosmetic aspects and minimizing the complications [2].

The effect of prosthesis on dose distribution around the breast tissue was evaluated by Klein and

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Kuske (1993). In their work, the thin window parallel-plate ionization chamber and TLDs were used to quantify the variation of dose distribution. A mammographic phantom, that resembles mammary tissue in different features, was compared with four commercial prostheses, namely two silicone gel fillers in combination with two different shells.

In the aforementioned study, implants were irradiated by the Varian Clinac 6100 linear accelerator. All measurements were made with a constant source-to-surface distance (SSD) of 100 cm. For the measurement step, the field size and dose were set at 10×10 cm² and 60 Gy, respectively. The chamber was used in two positions relative to the beam, which were also distal or proximal to the implant. The measurement point was defined as the chamber plate in the proximal position of the beam and was maintained at isocenter.

These measurements were performed from the implant interface to the depth of 1.0 cm proximal and 1.5 cm distal for all implants. The TLD measurements were also performed along the central plane of the beam at the locations duplicating the apex, medial, and lateral borders. The results of ion chamber measurements indicated no significant alterations in depth doses away from the implants [3].

Regarding the mentioned points and the literature, the aim of the current study was to evaluate the impacts of a silastic prosthesis on photon dose distribution in breast cancer radiotherapy.

Materials and Methods

The evaluated implants in this study were as different gel fillers and shell materials. The prosthesis and their envelopes were made of silicon with the volume of 270 cc. The dimensions of the used implants were as follow: 11.3 cm in width (the largest diameter) and 3.4 cm in depth that introduced a high profile round type. The silicone gel consists of polydimethylsiloxane [(CH₃)₂SiO]ₙ with specific gravity of 0.98 g·cm⁻³. Composition of the used silicone gel was 8.156% hydrogen, 32.39% carbon, 21.57% oxygen, and 37.87% silicon. The envelope had a thickness of 1.5 g·cm⁻² and was made of 80% silicon.

In this study, we used a prosthetic breast phantom and a half of the female-equivalent mathematical phantom of chest slab that composed of the organs fabricated based on dimensions of an average woman [4]. The size of organs was referred to an anthropomorphic chest phantom introduced by Scutt [5]. A new prosthetic breast phantom was made in the present work to simulate the actual conditions, measure the accurate dose by TLDs, determine an exact isodose, and reduce the errors.

The breast and thorax phantom had 41 and 40 sheets, respectively, and were made of Plexiglas material (tissue-equivalent). In order to simulate the anatomical positions of organs in the thorax phantom, the thickness of the Plexiglas layer was considered as 2 mm. Similarly, the breast phantom included Plexiglas ring layers with internal diameters of 16 cm, in which the prosthesis was inserted.

According to the International Commission on Radiological Protection publication 23 [6], the lung was fabricated in cylindrical form, 18 cm in diameter and 28 cm in height, and was made of a type of cork with a density of 0.297 g·cm⁻³. The chest wall thickness was 2 cm and the hemi-thorax dimensions were 30×30×28 cm³ in the X, Y, and Z directions, respectively (Figure 1). The prosthetic breast phantom was put on the phantom that represented half of a woman chest.

Figure 1. a,b, and c) Prosthetic breast phantom built in this study. d) Half of a female chest phantom, chest wall, and lung.
The effect of a prosthesis on the photon dose distribution was studied by Fateme Sari et al. in their research published in the Iranian Journal of Medical Physics. The study aimed to understand how the placement of a silicone prosthesis might alter the dose distribution of a 100 cGy photon beam delivered to a 12×18 cm² field with a 100 cm SSD and gantry angles of 88° and 272° with a 15° wedge.

The dose was measured using 12 thermoluminescent dosimeters manufactured by Fimel Co. (Fimel, Velizy, France). This product measured 4.5×0.8 mm² and is almost equivalent to the tissue because lithium fluoride is doped by Mg, Cu, and P (commercially known as GR-207A). For reducing the background radiation, the manufacturer recommended annealing the TLDs at approximately 240°C for 10 min [7].

The TLDs were placed on a Perspex slab at the depth of 5 cm to take the whole scatter radiation. All the TLDs were exposed with 6 MV photons generated by Siemens Primus linear accelerator at the dose of 100 cGy (SSD=100 cm and field size=10×10 cm²). The element correction coefficient (ECC) was calculated using equation 1:

\[
\text{ECC}_i = \frac{<\text{TLD}>}{\text{TLD}_i} \tag{1}
\]

Where \(<\text{TLD}>\) and TLD\(_i\) are the average of the TLDs and individual readings, respectively [7,8].

The silicone prosthesis was inserted into the breast phantom and the dose value was determined by 12 TLDs. The chips were placed between the breast implant and the specific Plexiglas layer representing the subcutaneous muscle flap. Specifically, 3 TLDs were placed directly under the prosthesis at the first surface layer, which was in the breast part of the phantom. Moreover, the TLD numbers 4 to 9 were placed in the inner wall of layers 5, 10, 14, 17, 20, and 24 on the superficial surface of the prosthesis, and TLD 10 was located at the upper surface of the implant. In addition, two TLDs were used for background measurements. The experiment arrangement is schematically shown in Figure 2.

The Computerized Tomography (CT) scanning images were taken in order to determine the volume of breast and prosthesis. The experiment procedure was performed in triplicates.

After exposing all the TLD chips, they were read out by the LTM reader (Fimel, Velizy, France) with their ECCs taken into consideration. The mean dose of each TLD was calculated and then compared with results of the TPS at the equivalent locations. The data analysis was performed using the independent samples t-test by the SPSS software version 22. P-values of less than 0.05 were considered as statistically significant.
Results

Firstly, the calibration curve (the TLD response versus the absorbed dose) was plotted for the 6MV radiation energy (Figure 4). Range of the doses was 50-200 cGy in the 50 cGy steps. As shown in Figure 4, the response of TLDs was linear in this dose range.

![Figure 4. TLD dose-response curve](image)

Table 1. Comparison between Treatment Planning System (TPS) and experimental dosimetry (TLD) results

<table>
<thead>
<tr>
<th>Measurement points</th>
<th>TLD</th>
<th>TPS</th>
<th>Mean difference between TLD &amp; TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>97.23±2.02</td>
<td>98.69</td>
<td>1.50</td>
</tr>
<tr>
<td>2</td>
<td>98.24±2.19</td>
<td>99.03</td>
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<td>3</td>
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<td>4</td>
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<td>5</td>
<td>101.26±1.66</td>
<td>103.18</td>
<td>1.90</td>
</tr>
<tr>
<td>6</td>
<td>99.29±1.10</td>
<td>101.71</td>
<td>2.44</td>
</tr>
<tr>
<td>7</td>
<td>98.69±2.14</td>
<td>98.54</td>
<td>0.15</td>
</tr>
<tr>
<td>8</td>
<td>100.37±1.97</td>
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<td>3.54</td>
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<td>10</td>
<td>98.66±1.73</td>
<td>102.54</td>
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</tr>
<tr>
<td>Average</td>
<td>99.20±1.94</td>
<td>101.19</td>
<td>1.99</td>
</tr>
</tbody>
</table>

The measured dose value of TLDs and their related locations are shown in Figure 2. The expected value of TPS and the image are also shown in Figure 3. Table 1 demonstrates the comparison and the results.

The treatment planning system showed that $D_{\text{max}}$ (maximum dose), $D_{\text{min}}$ (minimum dose), and $D_{\text{ave}}$ (average dose) were obtained as 112.91 cGy, 67.81 cGy, and 102.44 cGy in the prosthesis breast (PTV), respectively. Additionally, $D_{\text{max}}$, $D_{\text{min}}$, and $D_{\text{ave}}$ were measured as 107.37 cGy, 98.87 cGy, and 102.39 cGy in the prosthesis, respectively. Furthermore, the treatment planning results showed that $D_{95}$ (dose to 95% of the PTV) and $D_{50}$ (dose to 50% of the PTV) were measured as 96.32% and 100%, respectively in the prosthesis breast.

Discussion

In some patients who undergo breast reconstruction, breast cancer tends to recur in the region of silicone implant on the chest wall. In these cases, the radiation oncologist is faced with the task of satisfactory treatment for these lesions and radiotherapy should be used again for the local recurrence within the reconstructed breast.

In the study performed by Krishnan et al., the results showed that presence of the implant did not affect the dose delivered by 6 and 15 MV X-rays significantly. The small buildup of dose at the water-prosthesis interface for the beams of photon may be due to the discontinuity in photon-produced electron fluence at this location. The observations showed that compared to water, fewer photons (approximately 4% and 3% fewer photons in 6 and 15 MV beams, respectively) were attenuated by the prosthesis at the water-prosthesis interface. Therefore, the photon fluence from the prosthesis increased, while a reduction was observed in the electron fluence after leaving the prosthesis. Therefore, after replacing the prosthesis at the water-prosthesis interface, as equal thickness of water, the photon flow was bigger than the electron fluence.

The dose reduction in the interfaceregion might be due to deposition of the electron energy. On the other hand, since the electron fluence elevates, the dose builds up to the maximum limit gradually. The increase in electron fluence could be attributed to the improved fluence of the photon that leaves the silicon prosthesis.

Klein and Kuske (1993) indicated that the difference between scattering and absorption was related to the elemental composition (atomic number) and was not under the influence of implants physical density [3].

The prosthesis physical changes after exposures were evaluated by tonometry and color changes as the quantitative and qualitative tests, the results of which indicated the "hardening" and "yellowing" of the implants. All the implants exhibited change in color after 50 Gy, and the bio oncotic gel became significantly less formable after the irradiation. The data indicated that radiation affected the prosthesis, but the prosthesis did not have any effect on the distribution of the radiation beams [3].

This observation presented a detailed analysis of the potential impact of the in-dwelling silicone gel prosthesis on radiotherapy dose distribution in breast radiotherapy. In this study, X-ray dose of 100 cGy was delivered to the phantom which was not consistent with the common practice in breast radiotherapy (i.e., 200 cGy). We used predominantly relative dose distribution and absolute dose was not important in this regard, however, the absolute dose for irradiation was in the range of clinical use.
There was some invalidities with TLDs, but their efficiency was strongly dependent on the calibration method and thermal treatment, and we tried to keep invalidity at the lowest level. Additionally, designing and making a phantom like the one used in this study with other dosimeters (e.g., ionization chamber) was not possible considering the cost and labor, because the detectors were distributed on three dimensions and simultaneously.

The results of this study showed that silicone prosthesis did not significantly affect the dose distribution and the reconstructed breasts can receive the prescribed dose with a high confidence. Our initial results were demonstrative of an acceptable agreement (p=0.064) between those measured in the experimental dosimetry via TLD and those calculated from TPS results; however, as the results indicated 1.99% difference (which is well within the clinically acceptable limits) between the values of the two methods was observed.

Typically, the prosthesis are particularly used for breast reconstruction or augmentation, and silicone implants contain materials of a higher atomic number (Z) compared to the human tissue, which may potentially affect the radiation dose distribution within the breast [3,9]. But, our findings do not demonstrate a statistically significant difference between the calculated and measured doses.

The main goal of external beam radiotherapy includes 95% coverage of the PTV by 95-107% of the prescribed dose (PD). In the present study, the dose volume histogram (DVH) in treatment planning showed the D_{95} as 96.32% in prosthetic breast (PTV) which is considered acceptable.

Figure 5. Treatment planning report in one of the phantom CT-scan slices. Slice of breast, prosthesis and isodose curves of 110% (green), 107% (violet), 100% (red), and 95% (orange) are shown in this picture.

The hot points between skin and prosthesis envelope cause dermal burning which might lead in prosthesis ejection. Prosthesis ejection during or after the radiotherapy causes impaired treatment process and undesirable cosmetic consequences. Furthermore, the hot points on the prosthesis may result in leakage or rupture, which necessitates the urgent removal of the prosthesis.

In the current study, the phantom dosimetry data demonstrated no hot (isodose curve > 110%) or cold spots due to the prosthesis, which might lead in excess fibrosis or tumor recurrence (Figure 5). In conclusion, the suitable treatment planning can eliminate or reduce the hot points: The prosthetic breast (PTV) had suitable dose covering because a 100% isodose curve (red curve) covered it completely.

Conclusion

The obtained findings show that the radiotherapy treatment and use of silicone gel prosthesis could be compatible. When conducting the 6 MV photon dosimetry, presence of the silicone gel prosthesis does not result in a clinically significant effect when compared to the intact breast.

In conclusion, we recommend the modern conformal techniques such as 3D conformal radiotherapy and suitable treatment planning to be applied in order to reduce the recurrence of malignancy and minimizing the relevant complications.

References
