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

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ABSTRACT

Introduction: Siliconeprosthetic implants are commonlyutilizedfor tissue replacement and breast augmentation after mastectomy. On the other hand, some patients require adjuvant radiotherapy in order to preventlocal-regional recurrence and increment ofthe 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 theprosthetic breast phantom and the female-equivalent mathematical chest phantom. A Computerized Tomographybased treatment planning was performedusing 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 lighttelemetry (LTM) reader.

Results: Statistical comparisons were performed between the absorbed dosesassessed by the TLDs and the TPS calculations forthe same sites. Our initial resultsdemonstratedanacceptable agreement (P=0.064) between the treatment planning data and the measurements. The mean difference between the TPS and TLD resultswas 1.99%.The obtained findings showed that radiotherapy is compatible withsilicone gel prosthesis.

Conclusion: It could be concludedthat the siliconbreast prosthesis has no clinicallysignificant effectondistribution 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 implantsare used for cosmetic breast augmentation and tissue replacement in mastectomycases during the treatment course ofbreast cancer.The prosthetic implants generally consist of a transparent silicone material within a soft and thin silicone envelope.However, a simple question exists regardinga patient who hasundergone breast reconstruction:"How does the implant affectthe absorbed dose distribution?".

Impact of thesilicone breast prosthesison the absorbed dose distribution for electron and photon beamswas evaluated by Krishnan et al.in1983. The range of energy for electron and photon beams was 9-20 MeV and 1.25-15 MV, respectively. The meanabsorbed dose was measured and compared between the two conditions of with and without prosthesisforthe water phantom.Results showed that the difference between the Central axis percentage depth dose valuesfor 15 MV photon beams was not significant. The maximum difference was 2% of the maximum dose in water, andin case of 6 MV beams, the maximum difference in central axis dose was 4.5% of the maximum dose in water [1].

Kuske et al. in a study to assessthe tumor condition andtreatment 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 thatradiotherapy and breast reconstruction were compatible;however,the time of radiotherapy,the radiotherapy technique (e.g., using layer or box bolus), and the reconstructive procedure were determiningforthe cosmeticaspects 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,implantswere irradiated by the Varian Clinac 61100 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 cm^2 and 60 Gy, respectively.The chamberwas used in two positions relative to the beam, which were alsodistal or proximal to the implant. The measurement point was defined as the chamber plate in thproximal position of the beam and was maintained at isocenter.

These measurements were performed from the implant interface to thedepth 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 measurementsindicatedno significant alterationsin depth doses away from the implants [3].

Regarding the mentioned points and the literature, aim of the current studywas 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 envelopeswere made of siliconewiththe volume of 270 cc. The dimensions of the used implants were as fallow: 11.3 cm inwidth (the largest diameter) and 3.4 cmin depth that introduced a high profile round type. The silicone gel consists of polydimethylsiloxane $[(CH_3)_2SiO]_n$, 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,weusedaprosthetic breast phantom and ahalf of thefemale-equivalentmathematical phantom of chest slab thatcomposed of the organs fabricated based on dimensions of an average woman [4]. The sizeof 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 phantomshad 41 and 40 sheets, respectively, and were made ofPlexiglas material(tissue-equivalent).In order to simulate the anatomical positionsof organs in the thorax phantom, the thickness of the Plexiglas layer was considered as 2 mm. Similarly, the breast phantom includedPlexiglas ring layers with internal dimeters 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 cm^3 in the X, Y, and Z directions, respectively(Figure 1).The prosthetic breast phantom was put on the phantom that represented half of woman chest.

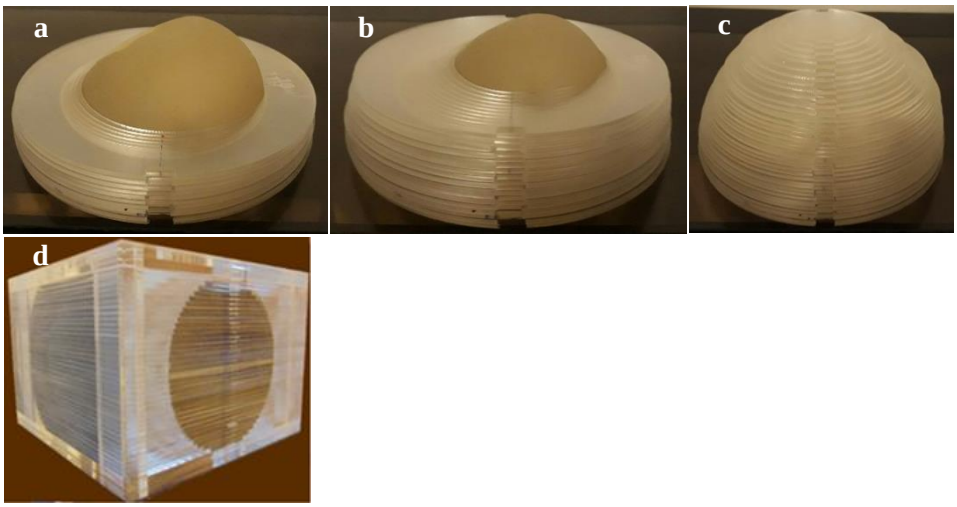

Figure 1. a,b, and c) Prosthetic breast phantom built in this study. d) Half of a female chest phantom,chest wall, and lung.

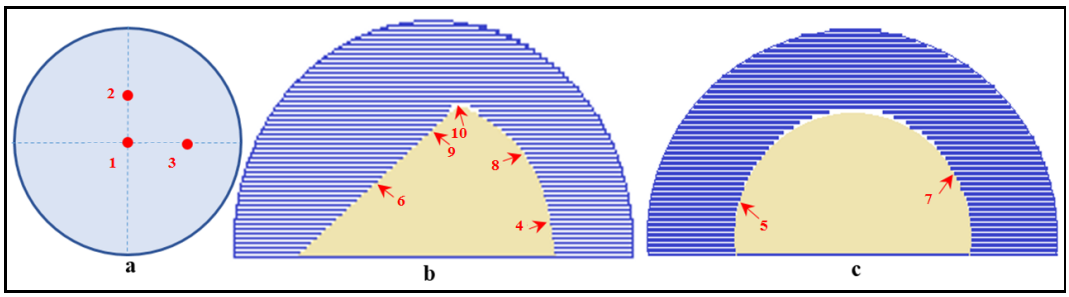

Figure 2. The TLD chips location in the prosthetic breast phantom. a) Position of TLDs 1, 2, and 3 (under silicone prosthesis). b) Position of TLDs 4, 6, 8, 9, and 10 (x=0). c) Position of TLD 5 and 7 (y=0).

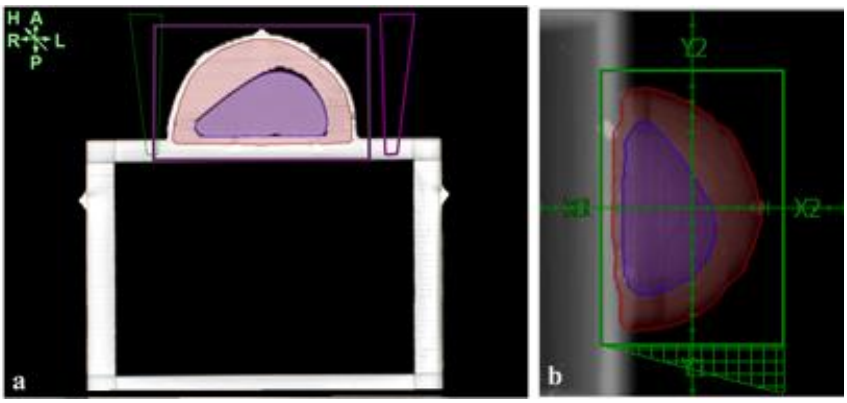

Figure 3. Phantom irradiation setup. The opposite 100 cGy photon beam delivered to a 12×18 cm^2 field with 100 cm SSD and gantry of 88° and 272° with 15° wedge.

The dose was measuredusing 12 thermoluminescent dosimetersmanufactured by Fimel Co. (Fimel, Velizy, France).This product measured 4.5×0.8 $mm^2$and is almostequivalent to the tissue becauselithium fluoride isdoped by Mg, Cu, and P (commercially known as GR-207A).For reducing the background radiation, the manufacturer recommendationto anneal the TLDs at approximately240˚C for 10 min [7] was respected.The TLDs were placed on a Perspex slab at the depth of 5cm, so totake the whole scatter radiation.All the TLDs were exposed with 6 MV photonsgenerated by SiemensPrimus linear accelerator at thedose of 100 cGy(SSD=100 cm and field size=10×10 cm^2). The element correction coefficient (ECC)was calculated using equation 1:

$$ECC_i = \frac{<TLD>}{TLDi} \quad (1)$$

Where <TLD> and TLD_i are average of the TLDs readings and individual readings, respectively [7,8].

The silicone prosthesis was inserted intothe breast phantom and the dose value was determined by 12 TLDs. The chipswere 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 TLDs 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 Figure2.

The Computerized Tomography (CT) scanning images were takenin order to determine the volume of breast and prosthesis. Three-dimensional treatment planning was executed on the CTimages of prosthetic breast phantom by CorePlan (Figure 3).

According to the plan, the prosthetic breast phantom was irradiated with a dose of 100 cGy using medial and lateral tangential fields with gantry angles of 88˚ and 272˚,and a 15˚wedge. All evaluations were performed with a constant SSDequivalent of 95.24 cm, and the field sizewas set at 12×18 cm^2on the surface. All irradiations were conducted using photons from the SiemensPrimus linear accelerator with a nominal accelerating potential of 6 MV. The experiment procedure wasperformed in triplicates.

After exposing, all the TLD chips were read out by the LTM reader (Fimel, Velizy, France)withtheir ECCs taken into consideration.The mean dose ofeach TLD was calculated and then compared withresults of the TPSat 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 plottedfor 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.

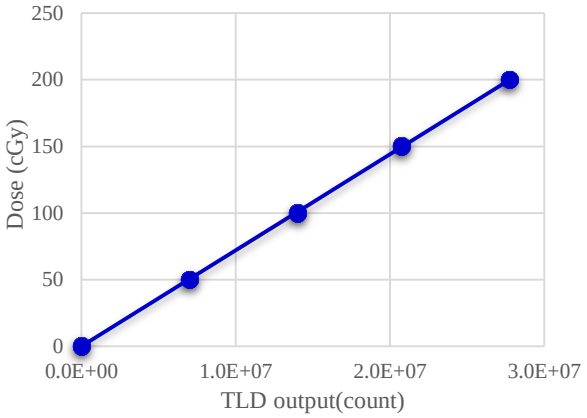

Figure 4. TLD dose-response curve

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

Measurement points	TLD	TPS	Mean difference between TLD & TPS
1	97.23±2.02	98.69	1.50
2	98.24±2.19	99.03	0.80
3	97.17±2.30	99.88	2.79
4	103.16±1.63	105.64	2.40
5	101.26±1.66	103.18	1.90
6	99.29±1.10	101.71	2.44
7	98.69±2.14	98.54	0.15
8	100.37±1.97	103.92	3.54
9	97.94±2.63	98.76	0.84
10	98.66±1.73	102.54	3.93
Average	99.20±1.94	101.19	1.99

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 Figure3. Table 1 demonstrates thecomparisons and the results.

The treatment planning system showed that D_{max} (maximum dose), D_{min} (minimum dose), and D_{ave} (average dose) were obtained as 112.91 cGy, 67.81 cGy, and 102.44 cGy in theprosthetic breast (PTV), respectively. Additionally, D_{max}, D_{min}, and D_{ave} were measuredas 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 theprosthetic 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 andradiotherapyshould be used again for the local recurrence within the reconstructed breast.

In thestudy performed byKrishnan 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 flue at this location. The observationsshowed 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 flue fromthe prosthesis increased, while a reduction was observed in the electron flue 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 flue.

The dose reduction in the interfaceregion might be due to deposition of theelectron energy. On the other hand, since the electron flue elevates, the dose builds up to the maximum limit gradually. The increase in electron flue could be attributed to the improvedflue of the photon that leaves the silicon prosthesis [1].

Klein and Kuske(1993) indicated that the differencebetweenscattering and absorption wasrelated 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 changeas the quantitative and qualitative tests, theresults 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 ondistribution of theradiation 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 efficiencywas strongly dependenton 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 studywith other dosimeters (e.g., ionization chamber) was not possibleconsidering 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 ahigh 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 indicated1.99% difference(which is well within the clinically acceptable limits) betweenthe values of the two methods was observed.

Typically, the prosthesis areparticularly used for breast reconstruction or augmentation, and silicone implants contain materials of a higher atomic number (Z) compared to the human tissue, whichmay potentially affect the radiation dose distribution within the breast [3,9]. But, our findings do not demonstrate a statistically significant differencebetweenthe calculated andmeasured 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)whichis consideredacceptable.

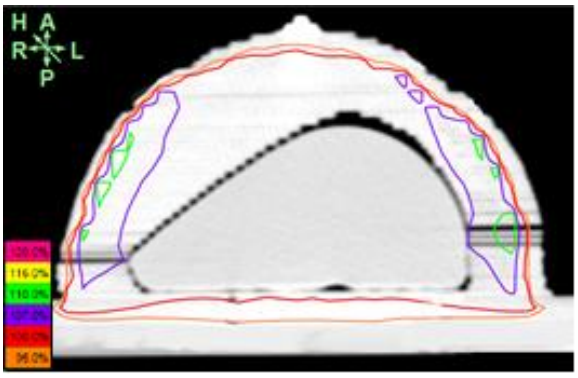

Figure 5. Treatment planning report in one of the phantom CT-scan slices. Slice of breast, prosthesis and isodose curves of 110% (green), 107% (violet), 100% (red), and 95% (orange) are shown in this picture.

The hot points betweenskinand prosthesis envelopecause dermalburningwhich 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 mayresult in leakage or rupture, which necessitates the urgent removal of theprosthesis.

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 a100% isodose curve (red curve) covered it completely.

Conclusion

The obtained findings show that the radiotherapy treatment and use of silicone gel prosthesiscould be compatible. When conducting the 6 MV photon dosimetry,presence of thesilicone 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 3Dconformal radiotherapy andsuitable treatment planning tobe applied in order to reduce the recurrence of malignancyand minimizing the relevant complications.

References

1. Krishnan L, George F, Mansfield C and Krishnan E. Effect of silicon gel breast prosthesis on electron and photon dose distributions. Medical Physics. 1983;10:96-9.DOI: 10.1118/1.595279.
2. KuskePR, Schuster R, Klein EE, Young L, Perez C ,Fineberg B. Radiotherapy and breast reconstruction: clinical results and dosimetry. Int. J. Radiation Oncology Biol. Phys. 1991 Jul 1;21(2):339-46.DOI: 10.3978/j.issn.2227-684X.2012.05.02.
3. Klein EE, Kuske PR. Changes in photon dose distributions due to breast prostheses. Int J Radiat Oncol Biol Phys.1993;25:541-9.DOI: 10.1016/0360-3016(93)90078-A.
4. Oshaghi M, Sadeghi M, Mahdavi SR, Shirazi AR. Dosimetry of MammoSite applicator: Comparison between Monte Carlo simulation, measurements, and treatment planning calculation. Journal of Cancer Research and Therapeutics.2013;9:224.DOI: 10.4103/0973-1482.113361.
5. Scutt D, Lancaster GA, Manning JT. Breast asymmetry and predisposition to breast cancer. Breast Cancer Res.2006;8:(2): R14.DOI: 10.1186/bcr1388.
6. International Commision on Radiological Protection. Report of the Task Group on Reference Man, ICRP publication 23. Oxford: Pergamon Press;1975.
7. Banaee N and Nedaie H.A. Evaluating the effect of energy on calibration of thermoluminescent dosimeters 7-LiF:Mg,Cu,P (GR-207A). International Journal of Radiation Research.2013;11:51-4.

8. Bahreyni Toossi MT, Rajab Bolookat E, Salek R, Layegh M. Dose measurements of parotid glands and spinal cord in conventional treatment of nasopharyngeal carcinoma using rando phantom and thermoluminescent dosimeters. Iranian Journal of Medical Physics. 2015;12(2):78-84.DOI: 10.22038/ijmp.2015.4769.
9. Chu FC, Kaufmann TP, Dawson GA, Kim YS, Rajaratnam S, Hoffman LA. Radiation therapy of cancer in prosthetically augmented or reconstructed breasts. Radiology.1992;185:429-33.DOI: 10.1148/radiology.185.2.1410349.