ORIGINAL ARTICLE

Evaluating the Effect of the Silicone Prosthesis on the Photon Dose Distribution in Radiation Therapy of Breast Cancer

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Abstract

Purpose: Breast cancer is the most common malignancy among women which in some cases is followed by breast reconstructions. The objective of the experimental study is to investigate the effect of the silicone prosthesis implementation on the dose distribution of radiotherapy.

Materials and Methods: Initially CT images of 7 mastectomy breast patients with silicone prosthesis were imported to the Monaco treatment planning system. A treatment plan consisting of two tangential photon fields with a prescription dose of 50Gy was arranged. To study the effect and water equivalency of silicone prosthesis, dose distribution of treatment plan was acquired in two conditions: 1) considering the real electron density of silicone prosthesis; 2) modifying (Relative electron density) RED of silicone prosthesis to 1 to virtually assume it as soft tissue (water). The results were then compared by VeriSoft software to evaluate the gamma index.

Results: The obtained results indicated that the RED for the silicon prosthesis varies between 0.7 and 1.14 while the RED for soft tissue is approximately 1. Also, the Dose-volume histogram curves for both conditions indicated that the minimum and maximum differences ranged from 1% to 4%. The significant differences might be due to the presence of the air cavity or bubbles in the silicone prosthesis implementation or air voxels between prostheses and soft tissue.

Conclusion: The obtained results showed that if there is no air cavity in silicone prosthesis and the surgery is performed in a way that no volume of air is left between the prosthesis and breast tissue, the effect and presence of silicone prosthesis will be similar to soft tissue (water).

Keywords: Radiotherapy; Silicone Prosthesis; Dose Distribution; Breast Cancer.

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1. Introduction

Breast cancer is the most common malignancy among women all over the world [1, 2]. Based on the type of breast cancer, different therapeutic methods have been used, including a combination of surgery, chemotherapy, hormonal therapy, biological therapy, and radiation therapy [3-7]. Among these methods, mastectomy or lumpectomy followed by several fractions of radiotherapy is a standard method for breast cancer treatment [8, 9]. Since both techniques remove breast cancer, breast tissue reconstruction is essential to physical, emotional, and psychological recovery [10]. Therefore, a prosthetic implant containing silicone is proposed to maintain its appearance and tissue replacement [11].

Due to the possible locoregional recurrence of breast cancer, the effect of the dose distribution and absorbed dose at the silicone prosthesis following external irradiation of the breast tissue is needed to be investigated. Thereby, Krishnan et al. evaluated the absorbed dose distribution for 1.25-15 MV photon beams in silicone breast prosthesis [12]. They also investigated the mean absorbed dose for both with- and without-prosthesis implementation in the water phantom. Finally, they presented that the maximum difference was 2% for 6 MV photon beams while there was no significant difference in 15 MV photon beams. Klein and Kuske also investigated the effect of the photon dose distribution on a mammographic phantom (prosthesis breast tissue) [13]. They also compared the calculated absorbed dose with four commercial prostheses (silicon, silicon-polyurethane, a triglyceride within the silicon, and a bio-oncotic gel within silicon-polyurethane) irradiating by a Varian Clinac 6/100* linear accelerator (with the dose rate of 60 Gy/MU) in the 10×10 cm^2 field size. Finally, the results of the ion chamber indicated no significant differences in depth dose curves. Another treatment modality used for breast cancer includes using a High Dose Rate (HDR) brachytherapy or MammoSite procedure. Since the physical placement of a MammoSite balloon was similar to the silicone breast implementation, the interface dosimetry in this treatment procedure is needed to be correctly investigated [14,15]. Cheng *et al.* studied the dosimetry at the interface between the breast tissue and a high Z-material in the MammoSite treatment technique [16]. They also investigated the effect of the lack of inhomogeneity material in this method using experimental dose perturbation distribution and Monte Carlo (MC) simulation. The comparative results of the Dose Perturbation Factor (DPF) between the measured dose distribution and MC calculation indicated that for distances more than one mm from the balloon surface, there was no significant effect on the DPF in the MammoSite procedures. Sari et al. investigated the effect of photon dose distribution of breast reconstruction prosthesis in breast cancer radiotherapy [10]. They used a female-equivalent chest phantom encompassing a silicone prosthetic breast phantom. Besides, the measured data by Thermoluminescent Dosimeter (TLD) was compared with the Treatment Planning System (TPS). Finally, their results indicated that there was no significant difference in the dose distribution of a 6 MV photon beam for reconstructed breasts. Moreover, few studies have investigated the effects of the electron density of silicone prostheses on the photon dose distribution in breast radiotherapy [10, 12-14, 16]. Reviewing the previously published papers shows that evaluating the effects of silicon prosthesis on breast cases was always of interest in radiotherapy clinics. However, among all these studies, the lack of a quantitative analysis of the dependence of dose distribution to RED of silicon prosthesis is clear. The results of such evaluation might be useful where for any reason 2D conventional treatment, which assumes all tissues as water, is preferred and there is no available treatment planning system to check the effects, attenuation, and soft tissue equivalency of silicon prosthesis prior to treatment. On the other hand, there are some commercial treatment planning systems with various dose calculation algorithms which are not able to do an accurate calculation in tissue inhomogeneities. Therefore, apart from obtaining quantitative information of dose distribution on tissues around breast prosthesis, the results of such study will be applicable for radiotherapy department manipulating with those kinds of treatment planning systems.

Therefore, to cover all above-mentioned needs, the present study follows the main goals, including:

1. Evaluating the photon dose distribution using the Monaco treatment planning system under two conditions (with real RED of silicon prosthesis and modified RED to virtually assume it as water,

2. Analyzing Gamma index and dose comparison of these two situations using VeriSoft (patient plan verification) software.

2. Materials and Methods

2.1. Database and Properties

In this experimental study, the CT scans of seven mastectomy breast cancer patients with the surgery of silicone prosthesis implant were used. To acquire CT images, patients were scanned with an Aquilion 64 multidetector (Toshiba Medical, Japan) with 64 detector rows and a protocol for isotropic voxels (0.5-mm increments, 0.75 mm pitch, 240 mm FOV, 120kV and 225 mAs) in headfirst supine position with the contralateral arm extended above the head. To reproduce patient position and minimize their movement during CT imaging and treatment, the immobilization device was also used. Images were then imported to the Monaco treatment planning system.

It should also be mentioned that in order to conserve ethics in this study, patients' information was used anonymously. The silicone breast prostheses were made of polydimethylsiloxane $[C_2H_6OSi]_n$ with a density of 965 kg/m^3 and an effective atomic number of 10.37 [17]. The composition of the polydimethylsiloxane, also known as dimethylpolysiloxane or dimethicone, included 37.87% silicon, 32.39% carbon, 21.57% oxygen, and 8.156% hydrogen. More information about the features of each patient is also reported in Table 1.

2.2. Photon Dose Distribution

As mentioned earlier, the Monaco treatment planning system (Elekta, USA) [18] was used to investigate the effect of silicone prosthesis on the photon dose distribution. Monaco TPS employs Collapsed Cone (CC) and Monte Carlo algorithms to calculate high precision dose distribution. It should be noted that the CT number for the Relative Electron Density conversion (CT-RED curve) must be determined before commissioning a treatment planning system [19]. Therefore, applying a correct CT-RED curve, the dose distribution of breast tissue was determined under two conditions: 1) with the actual RED of the silicone prosthesis obtained from the CT-RED curve, and 2) with the correction in the RED number of the silicone prosthesis to assume it as water equivalent. A 50 Gy photon beam dose at two different angles known as the tangential method was applied to calculate the 6MV dose distribution and Dose-volume histogram (DVH) curve. Analyzing the obtained results was done by VeriSoft (PTW, Germany) application [20].

2.3. VeriSoft Analysis

VeriSoft software is a patient plan verification software providing a wide range of standard and advanced tools for dose-measurement, dose-comparison, visualization, and evaluation. It can also be used in IMRT, VMAT, or SRS/SBRT treatment plans with the capacity of being integrated with the dose reconstruction algorithms to verify standard and non-standard clinical parameters such as non-coplanar beams, large fields, and extremely off-axis lying target volumes or treatments with multiple energies [20-22]. In this study, the VeriSoft analysis was used for Gamma index determination, dose-comparison, and dose evaluation.

Gamma index analysis considered for this study included a 2D gamma index in the axial direction analysis. Also, the results of the dose distributions for two conditions (with and without the modification in the electron density of the silicone prosthesis implementation) were imported

Table 1. The features of the case studies

Case Number	Laterality	Surgical Procedure	Cosmetic Result	Clinical Status
Number 1	Left Breast	Mastectomy	Good	cancer
Number 2	Left Breast	Reconstruction	Excellent	cancer
Number 3	Left Breast	Mastectomy	Good	cancer
Number 4	Left Breast	Mastectomy	Poor	cancer
Number 5	Left Breast	Reconstruction	Excellent	cancer
Number 6	Left Breast	Reconstruction	Excellent	cancer
Number 7	Right Breast	Reconstruction	Excellent	cancer

into the VeriSoft software to compare dose values under threshold gamma index> 3%/3 mm. The VeriSoft outputs were represented through high dose gradient points when there was a significant difference between the two conditions. The results of the study depicted as DVH curves for seven studied patients are shown in Figure 1.

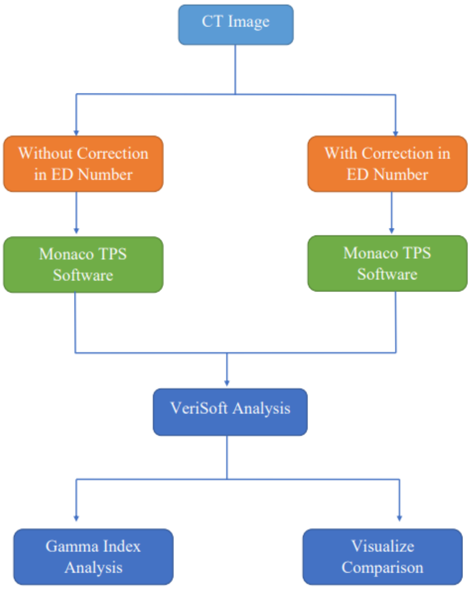

Figure 1. The flowchart of the proposed method in this study

3. Results

In radiation treatment planning, a Dose-Volume Histogram (DVH) summarized 3D dose distributions in a 2D graphical format under two types of the template; differential DVH and the cumulative DVH. In the present study, the cumulative DVH was used to plot the dose histogram. The horizontal axis in the DVH represents the volume referring to the target of radiation treatment, including a healthy organ nearby a target or an arbitrary structure while the vertical axis rising from the DVH demonstrates bin doses. The differences in RED between silicon prosthesis and soft tissue are reported in Table 2. Besides, the results of the DVH curve obtained from Monaco TPS software are shown in Figure 2. According to Figure 2, the red solid lines and red dash lines belong to without- and with-RED modification situations, respectively. Since the DVH analysis cannot provide spatial information about a particular structure receiving a dose, the VeriSoft analysis was used for dose-comparison, visualization, and evaluation [23].

The results of the dose comparison between two conditions obtained by VeriSoft analysis are reported in Figure 3. As it is shown in Figure 3, there were several high and low dose gradient points representing the difference between these two conditions. The concept of colors in Figure 3 is based on the gamma index of 3%/3mm, showing that the red color is unacceptable and represents a significant difference between the two treatment plans. The yellow color (acceptable) shows that the difference between the two plans is smaller than the gamma index. The green color (acceptable) shows that there is no difference between the two treatment plans.

Finally, the results of the gamma index calculated by VeriSoft analysis are reported in Table 3. As shown in Table 3, more than 90% of similar points are selected to

Table 2. Relative Electron Density (RED) of silicon prosthesis and soft tissue

Number of Cases	Silicon Prosthesis			Soft Tissue
	Minimum RED Number	Maximum RED Number	Average RED Number	Average RED Value
Patient Number 1	0.190	1.094	0.849	1
Patient Number 2	0.734	1.198	1.060	1
Patient Number 3	1.001	1.105	1.052	1
Patient Number 4	0.850	1.095	0.856	1
Patient Number 5	0.198	1.204	1.073	1
Patient Number 6	1.026	1.104	1.073	1
Patient Number 7	0.903	1.185	1.070	1

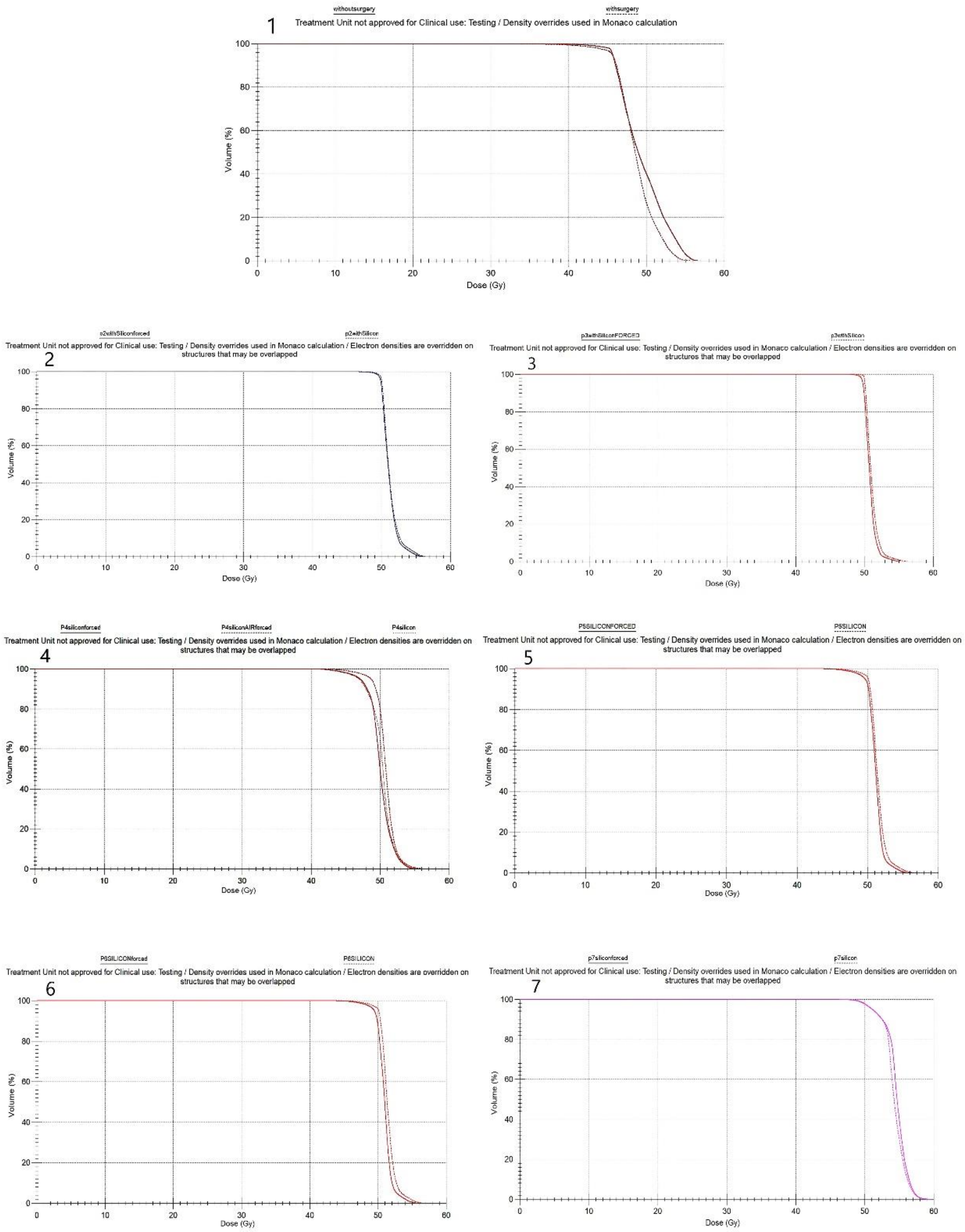

Figure 2. The DVH curve calculated by the Monaco TPS software (the red line for without any correction in the RED number and the red dash line for correction in the electron density number)

calculate and determine the average 3D gamma index and the percentage of similarity between the two conditions.

4. Discussion

In some patients undergoing breast reconstruction to maintain their appearance and tissue replacement, breast cancer also tends to recur in the region of silicone implants. In these cases, radiotherapy should be used again for the treatment of the recurring region [10]. Therefore, the effects of silicone prosthesis on the photon dose distribution in breast radiotherapy need to be investigated. In radiotherapy clinics, it is always assumed that silicone prosthesis is always water equivalent. Considering the chemical formula and effective atomic number of this compound [17] shows that a quantitative comparison between dose distribution of a real silicone prosthesis and a forced RED silicone prosthesis to virtually assume it as water is needed. The results of such eval uation will provide information of beam attenuation, water equivalency, and dose distribution of remaining breast tissues during radiotherapy. It might be useful where for any reason 2D conventional treatment, which assumes all tissues as water, is preferred and there is no available treatment planning system to check the effects, attenuation, and soft tissue equivalency of silicon prosthesis prior to the treatment. On the other hand, there are some commercial treatment planning systems with various dose calculation algorithms which are not able to do an accurate calculation in tissue inhomogeneities. Therefore, apart from obtaining quantitative information of dose distribution on tissues around breast prosthesis, the results of such study will be applicable for radiotherapy department manipulating with those kinds of treatment planning systems.

The majority of the prior studies indicated that there were no significant differences between the dose

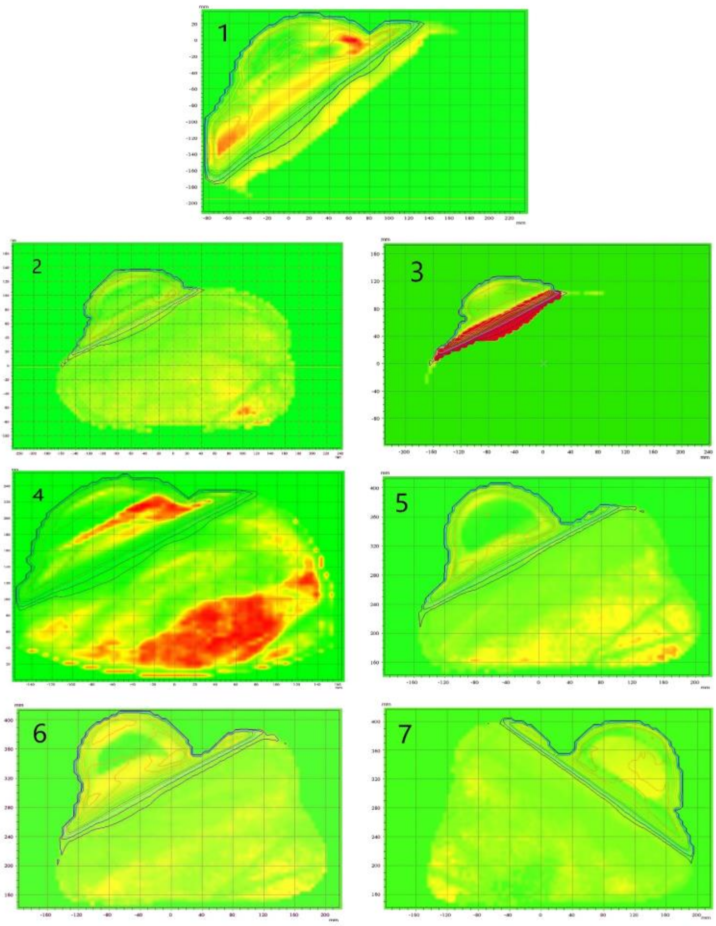

Figure 3. The results of the comparison between two conditions by using the VeriSoft analysis in the axial direction

Table 3. The results of the comparison gamma index 3.3% between two conditions

Number of Cases	Total number of points	Total number of considered points	Average 3D Gamma Index	Similarity
Number 1	198250	177546	0.713	89.6 %
Number 2	454005	453941	0.016	100 %
Number 3	5605	5182	0.622	98.2 %
Number 4	206180	197972	0.689	96 %
Number 5	300300	299876	0.376	99.9 %
Number 6	300300	300282	0.289	100 %
Number 7	305760	305748	0.154	100 %

distribution of silicone prosthesis and water equivalent (soft) tissues. However, few studies investigated the effects of electron density on dose distribution [10, 12-14, 16, 17]. The present study considered seven patients under two conditions to evaluate the average RED value of the silicone prosthesis in breast radiotherapy and compare it to that of water. Thus, the minimum, maximum and average ranges of the RED for silicone prostheses are shown in Table 2. As shown in Table 2, the RED of silicone prostheses varied between 0.7 and 1.14.

The results of the DVH curves (Figure 2) indicate that there is no significant difference between the two studied pair cases. According to DVH curves, the maximum and minimum differences ranged from 4% to 1%, respectively, which shows that changing the RED number provided no significant effect on dose distribution.

Additionally, the observed differences in the DVH curve of patients one and four originated due to the presence of the air cavity and air voxels. This issue can also be considered as another potential issue in breast reconstruction tissue affecting the dose distribution [24, 25]. However, unacceptable cosmetic results happen since poor surgical and radiotherapeutic techniques were applied, which has been frequently observed in MammoSite dosimetry due to the presence of an air cavity near or inside of the balloon [10, 13, 17].

Since the DVH curves offer no spatial information in the dose distribution, the VeriSoft analysis has been used for visualization of the dose distribution in the axial direction, measuring the average 3D gamma index and calculating the percentage of similarity between the two conditions. The results in Table 3 represented that the significant differences were observed in patients one and four, while there were no significant differences between the two conditions in patients two, six, and seven. It should be mentioned that more than 90 percentage points were selected in order to investigate the Gamma index between two case pairs. Also, the T-test analysis was applied to determine the difference of the mean value in the two conditions from each case [26]. The results of the T-test showed more than 95% of the similarity between the two conditions. Hence, the most critical factor in silicone prosthesis of breast reconstruction affecting dose distribution is the presence of the air cavity or bubbles in or between the silicone prosthesis and breast tissue.

5. Conclusion

The results of this study showed that if there is no air cavity in silicone prosthesis and the surgery is performed in a way that no volume of air is left between the prosthesis and breast tissue, the effect and presence of silicone prosthesis will be similar to water.

References

1-Stewart BW, Kleihues P. World cancer report. 2003.

2-Toledo E, Salas-Salvadó J, Donat-Vargas C, Buil-Cosiales P, Estruch R, Ros E, et al. “Mediterranean diet and invasive breast cancer risk among women at high cardiovascular risk in the PREDIMED trial: a randomized clinical trial.” *JAMA internal medicine*; 175(11):1752-60, 2015.

3-Gärtner R, Jensen M-B, Nielsen J, Ewertz M, Kroman N, Kehlet H. “Prevalence of and factors associated with persistent pain following breast cancer surgery.” *Jama*; 302(18):1985-92, 2009.

4-Group EBCTC. “Effects of chemotherapy and hormonal therapy for early breast cancer on recurrence and 15-year survival: an overview of the randomised trials.” *The Lancet*; 365(9472):1687-717, 2005.

5-Pegram MD, Reese DM, editors. “Combined biological therapy of breast cancer using monoclonal antibodies directed against HER2/neu protein and vascular endothelial growth factor.” *Seminars in oncology*; *Elsevier*, 2002.

6-Rouzier R, Perou CM, Symmans WF, Ibrahim N, Cristofanilli M, Anderson K, et al. “Breast cancer molecular subtypes respond differently to preoperative chemotherapy.” *Clinical cancer research*; 11(16):5678-85, 2005.

7-Whelan TJ, Pignol J-P, Levine MN, Julian JA, MacKenzie R, Parpia S, et al. “Long-term results of hypofractionated radiation therapy for breast cancer.” *New England Journal of Medicine*; 362(6):513-20, 2010.

8-Fisher B, Redmond C, Poisson R, Margolese R, Wolmark N, Wickerham L, et al. “Eight-year results of a randomized clinical trial comparing total mastectomy and lumpectomy with or without irradiation in the treatment of breast cancer.” *New England Journal of Medicine*;320 (13):822-8, 1989.

9-Lasry J-CM, Margolese RG, Poisson R, Shibata H, Fleischer D, Lafleur D, et al. “Depression and body image following mastectomy and lumpectomy.” *Journal of Chronic Diseases*; 40(6):529-34, 1987.

10-Sari F, Mahdavi SR, Anbiaee R, Shirazi A. “The Effect of Breast Reconstruction Prosthesis on Photon Dose Distribution in Breast Cancer Radiotherapy.” *Iranian Journal of Medical Physics*; 14(4):251-6, 2017.

11-Chawla AK, Kachnic LA, Taghian AG, Niemierko A, Zapton DT, Powell SN. "Radiotherapy and breast reconstruction: complications and cosmesis with TRAM versus tissue expander/implant." *International Journal of Radiation Oncology* Biology* Physics*; 54(2):520-6, 2002.

12- Krishnan L, St. George FJ, Mansfield CM, Krishnan EC. "Effect of silicone gel breast prosthesis on electron and photon dose distributions." *Medical physics*; 10(1):96-9, 1983.

13- Klein E, Kuske RR. "Changes in photon dose distributions due to breast prostheses." *International Journal of Radiation Oncology• Biology• Physics*; 25(3):541-9, 1993.

14- Keisch M, Vicini F, Kuske RR, Hebert M, White J, Quiet C, et al. "Initial clinical experience with the MammoSite breast brachytherapy applicator in women with early-stage breast cancer treated with breast-conserving therapy." *International Journal of Radiation Oncology* Biology* Physics*; 55(2):289-93, 2003.

15- Streeter Jr OE, Vicini FA, Keisch M, Astrahan MA, Jozsef G, Silverstein M, et al. "MammoSite® radiation therapy system." *The Breast*; 12(6):491-6, 2003.

16- Cheng CW, Mitra R, Allen Li X, Das IJ. "Dose perturbations due to contrast medium and air in MammoSite® treatment: An experimental and Monte Carlo study." *Medical physics*; 32(7Part1):2279-87, 2005.

17- Lee J. "Breast prostheses." *BMJ*; 302: 43–4, 1991.

18- Monaco training guide. Elekta, Inc. Document ID: LTGMON051102. https://www.elekta.com/

19- Hatton J, McCurdy B, Greer PB. "Cone beam computerized tomography: the effect of calibration of the Hounsfield unit number to electron density on dose calculation accuracy for adaptive radiation therapy." *Physics in Medicine & Biology*; 54(15):N329, 2009.

20- VeriSoft training guide. PTW, Inc. https://www.ptwdosimetry.com/en/products/verisoft/

21- Hussein M, Rowshanfarzad P, Ebert MA, Nisbet A, Clark CH. "A comparison of the gamma index analysis in various commercial IMRT/VMAT QA systems." *Radiotherapy and Oncology*; 109(3):370-6, 2013.

22- Stathakis S, Myers P, Esquivel C, Mavroidis P, Papanikolaou N. "Characterization of a novel 2D array dosimeter for patient-specific quality assurance with volumetric arc therapy." *Medical physics*; 40(7):071731, 2013.

23- Drzymala R, Mohan R, Brewster L, Chu J, Goitein M, Harms W, et al. "Dose-volume histograms." *International Journal of Radiation Oncology* Biology* Physics*; 21(1):71-8, 1991.

24- Jacobson GM, Sause WT, Thomson JW, Plenk HP. "Breast irradiation following silicone gel implants." *International Journal of Radiation Oncology* Biology* Physics*; 12(5):835-8, 1986.

25- Yun JH, Diaz R, Orman AG. "Breast reconstruction and radiation therapy. Cancer control."; 25(1): 1073274818795489, 2018.

26- DeCoster J, Claypool H. Data analysis in SPSS. Retrieved October. 2004; 2:2015.