Ann Med Res 2020;27(5):1645-9

Annals of Medical Research

DOI: 10.5455/annalsmedres.2019.12.800

Original Article

Experimental and Monte Carlo evaluation of effects of temporary tissue expanders (TTE) on radiotherapy dose distribution

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Abstract

Aim: The purpose of this study was to model the metallic port which included samarium cobalt magnet in breast tissue expanders and to improve the accuracy of dose calculations with nanoDot optically stimulated luminescence dosimeter (nanoDot OSLD) measurements.

Material and Methods: Mentor TTE (Temporary Tissue expander) (at a depth of 3 cm) was modeled by DOSXYZnrc Monte Carlo code and the nanoDot OSLD were used for dose measurements in solid water phantoms.

Results: In present study, dose increases in tissue at 3 cm due to the backscatter of electrons was 16.3% for metallic port at 6 MV using the Monte Carlo method. It was observed 12 % in the experimental results. Additionally, while the decrease in dose behind the port was 17.4 % by Monte Carlo program code, it was observed 25.8 % in the experimental results

Conclusions: In present study, the low dose region remains in saline solution within the tissue expander. It can be negligible clinically. In a clinical setting, the breast patients are treated with tangent beam fields. It was thought that unless the frontal direct field was not used in clinics for these patients, the dose reduction and dose increase would not do not play a role in influencing the treatment.

Keywords: Breast cancer; metallic port; NanoDot OSLD; radiotherapy dose distribution; temporary tissue expander

INTRODUCTION

Breast cancer is the most common type of cancer in women (1). The loss of a breast can be a traumatic experience for women who have undergone a mastectomy. Breast reconstruction provides psychosocial as well as aesthetic benefits. Temporary Tissue expanders (TTE) and implants are now commonly used in breast reconstruction. The purpose of using temporary tissue expanders is to expand the skin and tissues after mastectomy (2). The breast reconstruction requires two stages: a (TTE) is placed in a submuscular pocket during the first operation. After sufficient healing has occurred, the expander is filled with saline in a serial fashion over several weeks or months to the desired volume. Then, after there has been sufficient expansion, TTE is removed and a permanent saline or silicone implant is replaced. There is a magnet structure that allows the injection site to be found from outside. There are also metallic constructions to prevent accidental drilling of the TTE. All of these metallics and magnet structures in TTE are called metallic ports. It is not clear how this metallic port influences the dose distribution during radiotherapy.

There are few studies in the literature related to the effect of TTE on the radiotherapy dose distribution. Moni et al. investigated the effect of TTE on the radiotherapy dose distribution using TLD and EBT3 film dosimetry for 6 MV photon energy (3). Damast et al. also investigated the effect of TTE using TLD and EBT3 film dosimetry and reported dose reductions of up to 22% at 2.2 cm deep to the port using film dosimetry and TLD (4). Strang et al. investigated the effect of metallic port on radiotherapy dose distribution using TLD for 6 MV and 18 MV photon energies and 9 and 12 MeV electron energies and showed no significant dose variations over the port using TLD for 6 MV (5). Additionally, Asena et al. investigated the effect of the metallic port for the tangential treatment field and the electron boost field and reported that no backscatter dose enhancements in the radiochromic film (6). Chatzigiannis et al performed Monte Carlo simulations using CT images of a patient implanted with a McGhan Style 133 (Inamed/Allergan) tissue expander and found that an increasing dose about 9 and 12% at 2 mm away from the magnet surface for 6 and 18 MV photons, respectively (7). Trombetta et al. performed Monte Carlo simulations to investigate the

Received: 04.12.2019 **Accepted:** 25.04.2020 **Available online:** 11.06.2020
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dosimetric effects of an IMP (internal metallic port) with a 6 MV photon beam and observed the decrease in dose was 13% behind the metallic port using Monte Carlo method (8). Park et al. investigated whether clinically relevant dose-volumetric parameters were affected by the IMP in a TTE using Monte Carlo methods (9). All the previous studies were developed using only one type of tissue expander (McGhan Inamed/Allergan). It is thought that the TTEs which include different material have different effects. The different geometry and composition of the metallic port (Mentor TTE, Santa Barbara, CA) may affect breast radiotherapy treatment. Additionally, the in vivo measurements, which were performed on the patient skin in previous studies, were insufficient to evaluate the effect of TTE on the dose distribution inside a patient body (4).

In study, nanoDot OSLD (optically stimulated luminescence dosimeters) were used for measurements. The nanoDot is the newest innovation for single point radiation measurement for skin entrance dose assessment. Jursinic showed that the clinical use of OSLDs is feasible for in vivo dosimetric measurements in his study. The OSLDs exhibited high precision and accuracy in measuring dose, were small in size, had no energy dependence, had no dependence on angle (10).

High density materials may lead to major problems at providing an accurate dose distribution in radiotherapy (AAPM-85 report) (11). Undesirable changes on the dose distribution may affect the treatment success and may increase side effects in healthy tissues. In present study, it was aimed to investigate the effect of metallic port which included SmCo5 (samarium cobalt) magnet in TTE (Mentor) on radiotherapy dose distribution based on the Monte Carlo method and experimentally by using nanoDot OSLD.

MATERIAL and METHODS

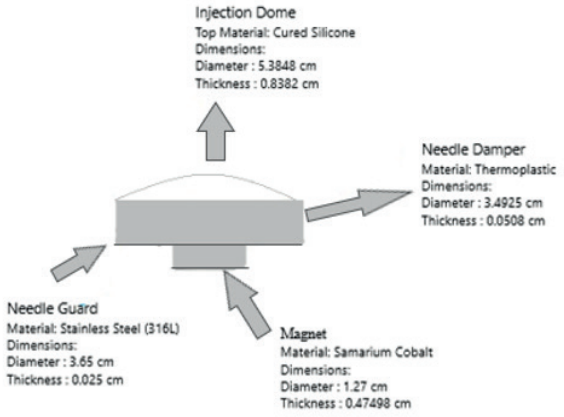

Figure 1. The structure of the metallic port

Measurements using with the metallic port removed from the TTE

In present study, the metallic port (Mentor TTE) was used for the measurements and simulated by DOSXYZnrc Monte Carlo code. This tissue expander is made of silicone elastomer and its textured surface contains an integrated injection site. It includes a rare-earth magnet (SmCo5) that is 1,27 cm in diameter and 0,47498 cm thick (Figure 1) (12).

The metallic port was removed from tissue expander (Figure 2).

Figure 2. The metallic port

After the metallic port was placed on the solid water phantom, the two nanoDot OSLDs were placed; one of them was on the metallic port (1), and the other was below the port (2). A 3 cm bolus were placed on the metallic port instead of the breast tissue (Figure 3).

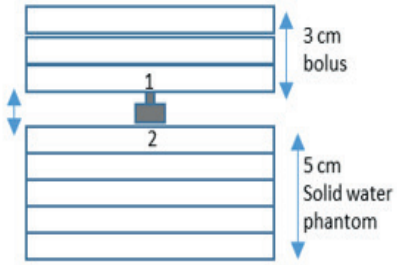

Figure 3. The set-up of measurement

The nanoDot OSLD were used to understand the radiation interaction with the metallic port (Figure 4).

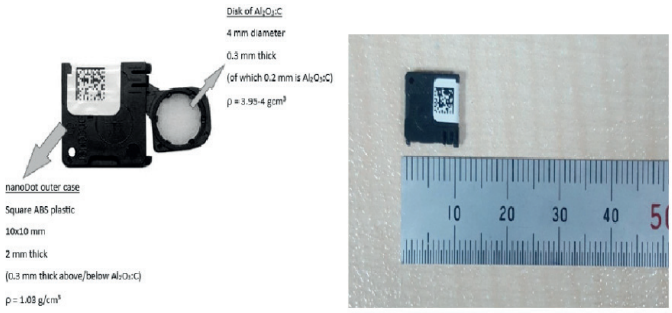

Figure 4. The nanoDot OSLD

The nanoDot OSLDs are 4 mm diameter, 0.2 mm thick plastic disks infused with aluminum oxide doped with carbon (Al_2O_3:C). The plastic has a mass density of 1.03 g/cm3 and the plastic leaves that cover the front and back of the OSLD disk are 0.3 mm thick. The mass density of

Al_2O_3:C is 3.95-4 g/cm^3. OSLDs are read with an InLight microStar reader (Landauer) (13). MicroStar reader can be used for immediate and accurate radiation dose assesments. There was no need the calibration. The MicroStar system automatically applies calibration and correction factors to the measured dose, after the energy range was selected in system.

Irradiations were performed using a Varian Clinac DHX linear accelerator. The SSD (source-skin distance) was set a distance of 100 cm and the photon energy was 6 MV. The irradiation field size was set 10 x10 cm^2 on the phantom surface. The metallic port was irradiated using single direct 10x10 cm^2 field. The prescription dose was 200 cGy. In order to compare the measurement results, the same set-up was used without the metallic port. A 1.5 cm thick bolus was placed instead of metallic port. For the same conditions, the measurements were repeated three times and the averaged.

Monte Carlo method

DOSXYZnrc is an EGSnrc-based Monte Carlo simulation code. This code models the transport of photons, electrons and positrons in a cartesian coordinates and stores the energy in the voxels (14).

Table 1. Physical properties of metallic port

Material	Main elements	ρ (g cm−3)
SmCo5	Sm, Co	8.40

In the present study the DOSXYZnrc user code was used to simulate the phantoms and metallic port. The point source from the front with rectangular collimation was used. The source position was located at Z=100 cm and the field was 10 x 10 cm^2 at Z= 0 cm. 0.7 MeV energy cut off for electron and 0.01 MeV for photon was set in code. The 6 MV spectrum was used in simulations. Material composition was determined by 700 icru. For depth dose, 3x10^8 histories have been followed. Statistical uncertainty of Monte Carlo results was less than 1.0 % for 3x10^8 histories. The physical properties of the metallic port used are shown in Table 1.

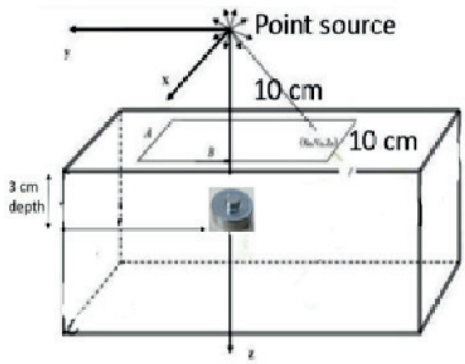

Figure 5. The phantom geometry used in DOSXYZnrc

For Monte Carlo calculations the main elements and mass density of all the elements used in the metallic port were entered into a DOSXYZnrc input file. The geometry used was a 30 x30 x30 cm3 water phantom with metallic port centered at a depth of 3 cm (Figure 5).

This depth was chosen to avoid the build-up region and to approximate a typical depth in tissue of a TTE. Percentage depth dose (PDD) curves were calculated using the data obtained for a 10 × 10 cm^2 field for 6 MV photon beam. All doses were normalized by the dose at Z = 1.5 cm. The dose differences between the Monte Carlo method dose values with metallic port and without metallic port were determined by this formula:

$$\text{Dose difference} = \frac{(\text{Dose MC(with metallic port)} - \text{Dose MC (without metallic port)})}{\text{Dose MC (without metallic port)}} \text{ x } 100 \qquad (1)$$

The dose differences between the measurements with metallic port and without metallic port were determined by this formula:

$$\text{Dose difference} = \frac{(\text{Dose OSLD(with metallic port)} - \text{Dose OSLD (without metallic port)}}{\text{Dose OSLD (without metallic port)}} \text{ x } 100 \qquad (2)$$

The dose differences between the measurements and Monte Carlo results were determined by this formula:

$$\text{Dose difference} = \frac{(\text{Dose OSLD} - \text{Dose MC})}{\text{Dose MC}} \text{ x } 100 \qquad (3)$$

RESULTS and DISCUSSION

The effects of metallic port in TTE on dose distribution were determined with two methods: nanoDot OSLD and Monte Carlo code for 6 MV photon beam. Initially, the results of the doses with metallic port and without metallic port using Monte Carlo code were compared to each other. Significant changes in the absorbed dose due to the metallic port are shown in Figure 6.

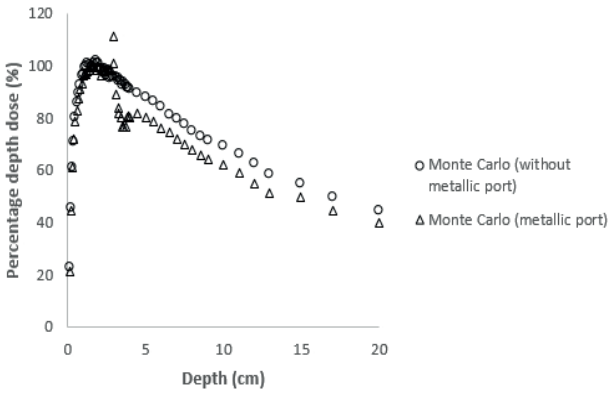

Figure 6. Comparison of the calculated PDD curves at 6 MV

In the present study, dose increases in tissue at 3 cm due to the backscatter of electrons was 16.3% for metallic port at 6 MV using the Monte Carlo method. Zabihzadeh et al. observed a dose increase of approximately 15% due to the backscatter of electrons from metallic port at 6 MV photon energy (15). Chatzigiannis et al. found that an increasing dose about 9 and 12% at 2 mm away from the magnet surface for 6 and 18 MV photons, respectively (16). High density implants can cause significant attenuation in the absorbed dose at points beyond the implants. This present study's findings showed that the decrease in dose was 17.4% behind the metalic port at 6 MV. This result was found using the Monte Carlo program code. Trombetta et al. observed the decrease in dose was 13% behind the metallic port using Monte Carlo method (8). Zabihzadeh et al. observed a dose reduction of about 10% at 5 cm distance from the backward direction of the port using Monte Carlo code (15).

The same set-up (metallic port at a 3 cm depth) was used for nanoDot OSLD measurements. Measured results are presented in Table 2.

Table 2. The results of nanoDot OSLD measurements

6MV	Dose, cGy		
Location	with port	without port	Differences (%)
Over metallic port	223	199	12.0
Behind metallic port	147	198	- 25.8

As shown in table 2, the dose increases in tissue at 3 cm (over the metallic port) due to the backscatter of electrons was 12.0% for 6 MV using nanoDot OSLD methods. The different measurement techniques were used by some researchers for this metallic port. Strang et al. showed no significant dose variations over the port using TLD for 6 MV (5). Asena et al. reported that no backscatter dose enhancements in the radiochromic film (6). Since there was not any study using nanoDot OSLD for metallic port, it could not be compared with the present study.

As shown in Table 2, the results showed that a dose reduction was 25.8% behind the metallic port using nanoDot OSLD method. Damast et al. reported dose reductions of up to 22% at 2.2 cm deep to the port using film dosimetry and TLD (4). Thompson and Morgan investigated the effect of the McGhan Style 133 tissue expander using diode dosimetry in a water phantom. The dose reduction was up to ~ 30% for a single 6 MV photon beam and the ~ 10% in a clinical case, when the irradiation was performed with two tangential beams (17).

Table 3. The differences between the results of nanoDot OSLD measurement and Monte Carlo

6MV	Dose Differences (%)		
Location	Monte Carlo	nanoDot OSLD	Differences (%)
Over metallic port	16.3	12.0	-26.3
Behind metallic port	17.4	25.8	48.3

As shown in Table 3, in view of the results, the doses calculated with Monte Carlo method were not in agreement with nanoDot OSLD measurements. There was a major difference between the results of Monte Carlo code and measurements. Although the increase in dose was 16.3 % by Monte Carlo program code, it was observed 12 % in the experimental results. Since nanoDot OSLD volume was not sufficient for scatter and backscatter measurement, scatter and backscatter radiation on dose distrubition could not be observed by nanoDot OSLD. Additionally, while the decrease in dose behind the port was 17.4 % by Monte Carlo program code, it was observed 25.8 % in the experimental results.

There can be several explanations why the consistent decreasing and increasing dose that was seen in the Monte Carlo method was not seen as significant in the nanoDot OSLD measurements. The Monte Carlo simulation does not require electronic equilibrium and has the advantage of high resolution due to small voxel size and provides accurate dose calculation. However, the measurement using nanoDot OSLD was 48.3 %, more different from other Monte Carlo results. The reason for the overestimate of dose measurement using the dosimeter is mainly due the contribution of secondary electrons scattered into the dosimeter volume. The difference between the results can be due to the variability of either different kind of sensitivity, experimental conditions and set-up errors among the dosimetric techniques. Additionally, the accuracy is advertised to be ±10% in the nanoDot OSLD measurements (18). Another explanation may be due to this accuracy on dose measurement of this measurement technique.

According to dosimetric protocols, the differences in the dose should be bellow of 5% (19). The study results were found above this value. In addition, it has been shown that the metallic port increased the skin dose due to scattering. Therefore, it is necessary to avoid frontal direct field irradiation.

CONCLUSION

In present study, the low dose region remains saline solution within the tissue expander. It can be negligible clinically. In a clinical setting, the breast patients are treated with tangent beam fields. It was thought that unless the frontal direct field was not used in clinics for these patients, the dose reduction and dose increase would not do not play a role in influencing the treatment.

Competing interests: The authors declare that they have no competing interest.

Financial Disclosure: There are no financial supports.

Ethical approval: In this type of non-human studies, we don't add the ethics committee decision.

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