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A dosimetric analysis of the aeroform™ tissue expander in radiation therapy

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Original Article

Abstract

Purpose: The aim of this study is to evaluate the effects of the metallic reservoir and the use of gas within the Aeroform™ tissue expander with respect to the radiation dose distribution. **Methods**: Dosimetric effects of using a metallic reservoir within a breast tissue expander during external beam radiotherapy were investigated. To view the internal components of the reservoir, it was removed from the tissue expander and imaged on a Varian AS500 electronic portal imager. To calculate the relative density of each component within the reservoir, an ionization chamber within solid water was used to measure the dose and compared to a simulation within the Pinnacle treatment planning system (TPS). To examine the relative dose profile along the length of the reservoir, the reservoir was exposed on EBT3 film and analyzed using SNC Patient™. In-vivo Dosimetry was performed using a RANDO® Woman phantom. Thermo-luminescent dosimeters were placed within the wax bolus enveloping the tissue expander. **Results:** Imaging the reservoir on the electronic portal imager revealed it consists of 3 distinct components. The densities assigned in the TPS, which resulted in calculated doses which matched the measured doses were; Section 1 = 0 g/cm^3, Section 2 = 2.8 g/cm^3 and Section 3 = 0.7 g/cm^3. Relative dose reductions were observed due to the metallic case; Section 1 = 20%, Section 2 = 40% and Section 3 = 30%. Entrance doses ranged from 2.39 - 2.53 Gy for both the medial and lateral beams. Exit doses ranging from 1.10 - 1.71 Gy were observed in both beams. There was a significant difference in measured and calculated doses at exit locations in the beam. **Conclusion**: Dosimetric effects due to the metallic reservoir within the Aeroform breast tissue expander have been demonstrated and have been observed to be significant. To increase the dosimetric accuracy when contouring, individual components of the reservoir should be distinguished. Our in-vivo experiment showed that dose homogeneity was difficult due to the metallic reservoir and we recommend stringent patient dose monitoring when using this expander during radiotherapy.

Keywords: Aeroform; Tissue Expander; Metal; Radiotherapy; Contour

Introduction

Immediate reconstruction after a mastectomy in breast cancer patients may markedly improve a woman's quality of life by enhancing body image, cosmetic outcome, and overall psychological well-being.[1,2] Consequently, mastectomy or nipple sparing mastectomy (NSM) combined with immediate breast reconstruction with either temporary tissue expander/implant reconstruction or autologous tissue reconstruction, has been performed for an increasing numbers of patients. However, the presence of a reconstruction may complicate the planning for radiation therapy as well as increase the risk of long-term complications related to radiotherapy treatment, which may impact the cosmetic outcome.[3-5] The role of adjuvant post-mastectomy radiotherapy (PMRT) is now well established for locally advanced and node positive breast cancer with level 1 evidence from the Early Breast Cancer Trialists' Collaborative Group (EBCTCG) meta-analysis demonstrating an improvement in loco-regional

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control and overall survival.[6] Even patients with 1-3 nodes will benefit from PMRT with outcome survival improved by 7.9% at 20 years. As such the decision to undergo immediate reconstruction and the need to deliver PMRT will present immediate and future challenges to both patients and their care givers.

When a patient requires PMRT or where the role of external RT is uncertain before mastectomy, a saline filled tissue expander may be placed at the time of definitive surgery. This allows for re-expansion of collapsed breast skin and maintenance of the skin envelope on the first stage of a two-stage implant reconstruction or a delayed autologous reconstruction after radiation therapy while awaiting assessment of the final pathology. If PMRT is recommended, radiation therapy is delivered with the temporary tissue expander in place. Gradual expansion of the skin is accomplished by the injection of saline into the expander using a metal-backed magnetically locatable port. This can be a lengthy process, involving several disruptive and often uncomfortable saline injections over weeks. In an effort to provide the patient with a more comfortable, gradual tissue expansion process that they control, a breast tissue expansion system consisting of a CO_2-filled tissue expander (AeroForm™) and a handheld radio-frequency dosage controller has been devised. The dosage controller communicates with the expander and allows the patient to self-administer 10 cc doses of CO_2 from a reservoir within the expander [7] obviating needle punctures to achieve expansion. The purpose of this investigation is to evaluate the effects of the metallic reservoir and the use of gas within the Aeroform™ tissue expander with respect to the radiation dose distribution.

Methods and Materials

The Aeroform™ (manufactured by AirXpanders™) patient-controlled tissue expander consists of an anatomically shaped outer silicone shell and an inner metallic reservoir of compressed carbon dioxide. The surgeon and/or patient increases the volume of the expander by using a wireless handheld controller to release the carbon dioxide from the metallic reservoir (**Figure 1**).

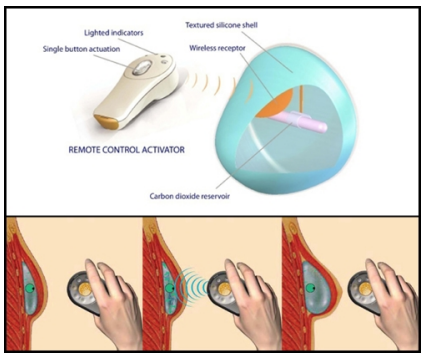

FIG. 1: An illustration of the AirXpander™ system taken from http://www.airxpanders.com/.

The 850 cc expander model LP130-850 Large was used for this study, with the outer shell expanded to 400 cc capacity. The material of the metallic reservoir case is stainless steel. The reservoir is unable to be opened and hence the internal components, materials and its impact on the delivery of radiation are unknown for the purpose of this study.

Dosimetric studies using film were performed using GafchromicTM EBT3 film [8], SNC Patient™ software v6.0 and PTW RW3 solid water.[9] SNC Patient™ by Sun Nuclear is a software which provides tools for planar dose analysis. Gafchromic™ EBT3 film is a self-developing, radiosensitive film.

Ion chamber measurements were performed without the outer shell using a Scanditronix™ CC13 ionization chamber [10] and PTW RW3 solid water.

In-vivo dosimetry measurements were performed using LiF:Mg thermo-luminescent dosimeters (TLD), a RANDO® [11] woman and fabric-backed gel. TLD results were later compared to dose calculations in Pinnacle$^{3™}$ v9.2 using the Collapsed-Cone Convolution (CCC) algorithm.

To view the internal components of the metallic reservoir, the reservoir was removed from the tissue expander unit (**Figure 2**) and exposed on a Varian AS500 portal dosimeter.

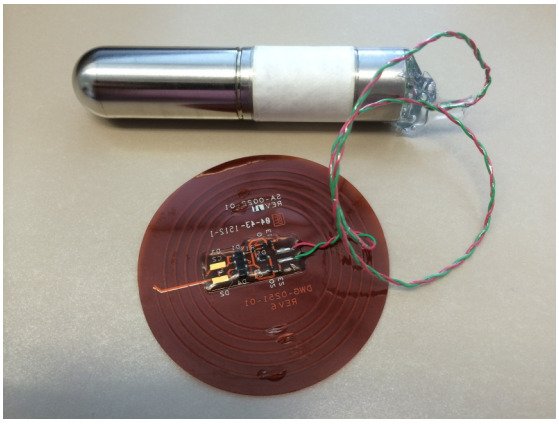

FIG. 2: The metallic reservoir and the signal receiver removed from within the AirXpander breast tissue expander system.

Pseudo Density of the Reservoir Components

The dosimetric accuracy around the metallic reservoir modelled in the treatment planning system is significantly dependent on accurate contouring and assigning the correct densities. In this scenario, it was difficult to assign a density to an unknown component of an unknown material. Therefore, for the purpose of an initial dose calculation, an arbitrary estimate of the density was assigned to each component of the reservoir. The metallic stainless steel casing was assigned a density of 8.0 g/cm^3 and gas was assigned a density of 0.0 g/cm^3. A CC13 ionization chamber was placed in RW3 solid water at 1.5 cm depth, 100 cm source-to-surface distance (SSD) to the surface of the phantom. A single 6 MV beam at

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gantry 0° delivered 100 monitor units (MU) with a field size of 10 cm x 10 cm. The metallic reservoir was removed from the tissue expander unit and placed flat on the solid water. The chamber was placed directly under each component of the reservoir and a measurement was obtained (**Figure 3**). Using an MV image of the reservoir as a visual guide, the contoured reservoir in the treatment planning system was then assigned a density, which resulted in a planned dose that matched the measured reading.

FIG. 3: An ion chamber placed in RW3 directly under the gas chamber of the metallic reservoir.

Film Dosimetry Measurements

To obtain a dose profile and measure the attenuation of the beam through the metallic reservoir, EBT3 film was placed in solid water at 1.5 cm depth. A single 6 MV beam at gantry 0° and 100cm SSD, delivered 200 MU for a 15 x 15 cm field size (**Figure 4**). The exposed film was scanned into the computer and analysed using SNC Patient™ software. The breast expander unit and reservoir were still intact was placed on the surface with the reservoir at the centre of the field.

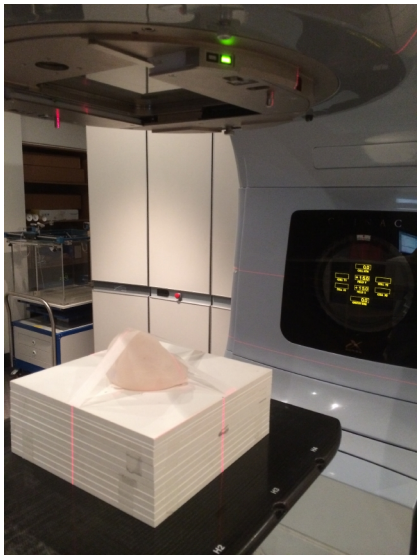

FIG. 4: The Aeroform™ breast tissue expander system on RW3 solid water with the metallic reservoir at the beam centre.

In-Vivo Dosimetry Using a RANDO® Woman

A RANDO® woman was simulated on a breast board with the Aeroform™ breast tissue expander unit attached as shown in **Figure 5**. The expander was placed on the RANDO® with the length of the metallic reservoir in the long axis in the transverse direction.

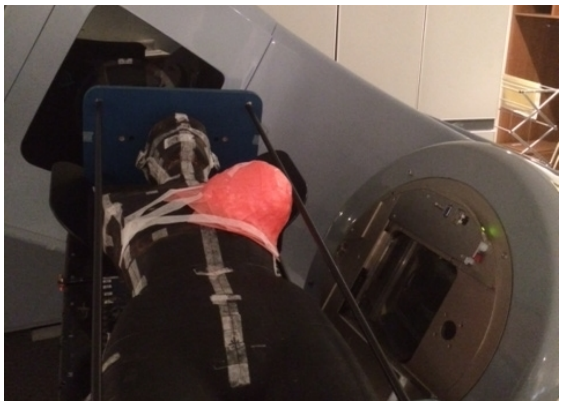

FIG. 5: The Aeroform™ breast tissue expander system with wax bolus on a RANDO® woman.

An average of 1.5 cm of thermoplastic wax was moulded over the expander to simulate breast tissue. The RANDO® woman was scanned using computed tomography (CT) and imported into the treatment planning system. The PTV was created from a contour of the wax bolus, minus the breast tissue expander, contracted 5 mm from the bolus surface and 5 mm from the lung and posterior beam edge (**Figure 6**).

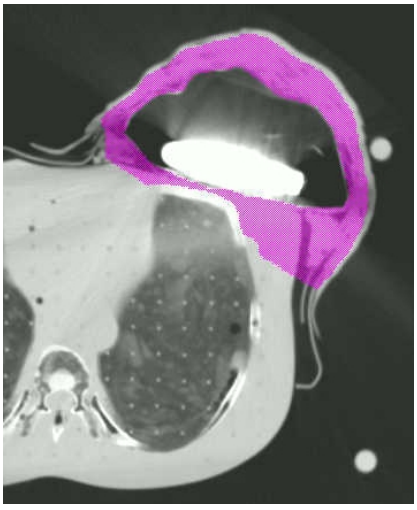

FIG. 6: An illustration of the mean PTV defined in this experiment.

A 6 MV parallel-opposed oblique technique was used to deliver 200 MU. TLDs were placed beneath the metallic expander and on the surface of the expander to measure the skin entrance and exit dose (**Figure 7**). This experiment was repeated twice and the results were averaged.

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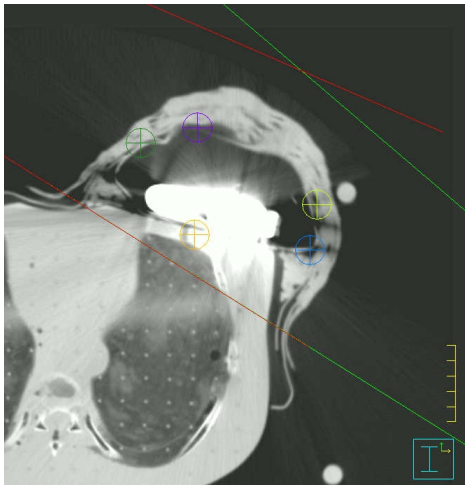

FIG. 7: A CT image slice of the Aeroform breast tissue expander system. The treatment comprises of a pair of parallel-opposed beams. For each beam, the entrance dose at two positions and exit dose at two positions are measured.

Results

Figure 8 shows an image acquired by a Varian AS500 portal dosimeter, which shows the internal components of the metallic reservoir. The manufacturer has not disclosed the exact function of each component, however it is assumed the compressed gas is stored in the chamber indicated by the dark void in the first section of the reservoir. The second and third section of the reservoir forms the components which allow for the compressed gas to be released into the expander. Each section is numbered accordingly for the purpose of the following experiments.

FIG. 8: An image of the internal components of the metallic reservoir within the AirXpander™ system, taken by a Varian™ AS500 portal dosimeter.

Pseudo Density of the Reservoir Components

The density assigned to Sections 2 and 3, which resulted in matched calculated and measured readings, were 2.8 g/cm^3 and 0.7 g/cm^3 respectively. These results are tabulated in **Table 1**.

Film Dosimetry Measurements

The scanned film was analysed in absolute dose mode and normalized to 200 cGy. **Figure 10** shows the dose profile along the length of the metallic reservoir as shown by the green line in **Figure 9**.

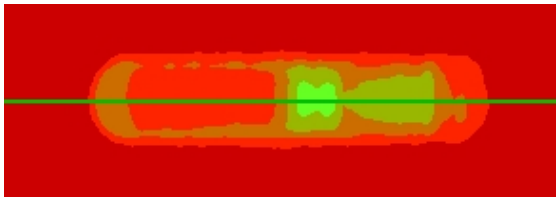

FIG. 9: A film scan imported into SNC Patient software.

A dose reduction of approximately 20% was observed at the tip of the gas chamber. A maximum dose reduction of 40% was observed in the high density region at Section 2 and a reduction of 30% was observed in Section 3 of the metallic reservoir. The observed reductions in dose were consistent with data previously published.[12]

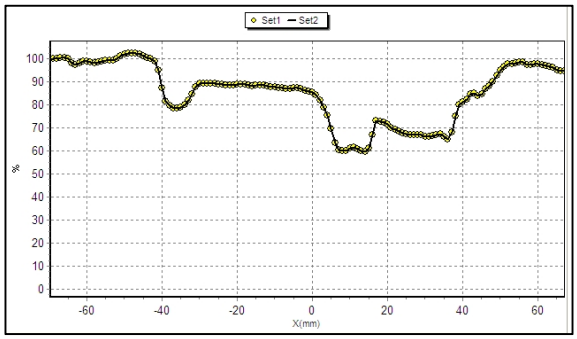

FIG. 10: A line dose profile of the metallic reservoir using Relative Dose mode.

In-Vivo Dosimetry Using a RANDO® Woman

In-vivo measurements using TLDs were performed and compared with Pinnacle3™ v9.2. TLD were placed in positions as shown in **Figure 6**. Measurements for this experiment are summarized in **Table 2**. Entrance doses ranged from 2.39 – 2.53 Gy for both the medial and lateral beams. Exit doses ranging from 1.10 to 1.71 Gy were observed in both beams.

Percentage differences between measured and calculated doses varied from -1.8 to 14.6%. For the medial beam at the locations 2 and 4, higher differences between measured and calculated doses were observed compared to locations 1 and 3. This may be due to either inaccurate positioning of the TLD on a curved surface or contributed by the uncertainty in modelling at the air/tissue interface. A higher difference between both calculated and measured doses were observed in the lateral exit beam at locations 1 and 2 compared to entrance locations 3 and 4. This may be due to the uncertainty contributed to the attenuation of the beam as it passes through high density materials. Moni *et al.* has published an average difference between the measured and calculated dose of -3.0% [12] using OSLDs placed at a similar location to the lateral beam exit 1 and 2.

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TABLE 1: The density assigned to the internal components of each section of the reservoir.

Reservoir Section	Initial Average Density reported by TPS (g/cm³)	Assigned Internal Component Density (g/cm³)	Measured Dose(Gy)	Calculated Dose (Gy)	Calculated Dose (Gy) if Overridden as 8.0 g/cm³
1	1.50	0	0.92	0.92	0.52
2	3.06	2.8	0.73	0.73	0.58
3	3.06	0.7	0.82	0.82	0.57

TABLE 2: Measured TLD doses compared to Pinnacle3™ v9.2 dose calculations.

Beam / Location	Calculated Dose (Gy)	Average Measured Dose (Gy)	% Difference
Medial Beam Entrance 1	2.43	2.53	-3.9
Medial Beam Entrance 2	2.28	2.47	8.1
Medial Beam Exit 3	1.12	1.10	-1.8
Medial Beam Exit 4	1.86	1.68	-9.7
Lateral Beam Entrance 3	2.48	2.39	-3.8
Lateral Beam Entrance 4	2.39	2.48	3.6
Lateral Beam Exit 1	1.13	1.30	14.6
Lateral Beam Exit 2	1.86	1.71	-8.3
Under Reservoir 5 Medial Beam	1.65	1.62	-1.8
Under Reservoir 5 Lateral Beam	1.86	1.92	3.2

Discussion

Damast *et al.*[13] has found that Magna-Site™ disc ports used in McGhan Style 133 [14] breast expanders can reduce the beam transmission to as much as 78% for a 6 MV beam for certain orientations of the magnet. Thompson *et al.* [15] have also reported that the transmission of the radiation beam was reduced to 70% due to the Magna-Site™ disc port. However, Moni *et al.*[12] showed that the presence of a metallic port in the tissue expander does not significantly contribute to the high complication rates. This is mainly because any increased dose due to the metallic port is observed in the immediate vicinity of the port (< 7 mm) where the effect is mostly observed in the expander volume and not the chest wall. However, the shape of the metallic reservoir used in the Aeroform™ is cylindrical, which may present different transmission values which are dependent on the thickness of metallic material the beam traverses. Also, the location of the metallic reservoir in the Aeroform™ is proximal relative to the chest wall compared to Magna-Site™ disc ports used in the McGhan Style 133 breast tissue expander.

In this experiment, the sample provided was only expanded with 400 cc of gas. Full expansion of 850 cc of gas would have been preferred. This presented a slight difficulty in maintaining the rigidity of the expander during experiments and would have reduced the uncertainty of TLD positioning.

Since the Aeroform™ breast tissue expander is expanded with gas, the dose was prescribed to the mean planning target volume, which is the tissue around the expander. This method increases the dose inhomogeneity, which contributes to high dose gradients in the overlying tissue. One area of concern would be the increase of scatter into the breast tissue and chest wall from having a relatively large high density material in the tissue expander. Combined with the lack of tissue equivalent material in the vicinity of the metallic reservoir, this may lead to significant hot spots during radiotherapy especially in the overlying breast tissue.

Upon observing the dose distribution (**Figure 11**), the TLDs were placed in regions of high gradients due to the scattering effects of the metallic reservoir. This may have contributed to increased differences between calculated and measured doses. In this experiment, smaller differences between measured and calculated doses were observed underneath the reservoir where the dose region was more homogenous compared to all other locations. This indicated that areas adjacent to gas were more difficult to verify dosimetrically.

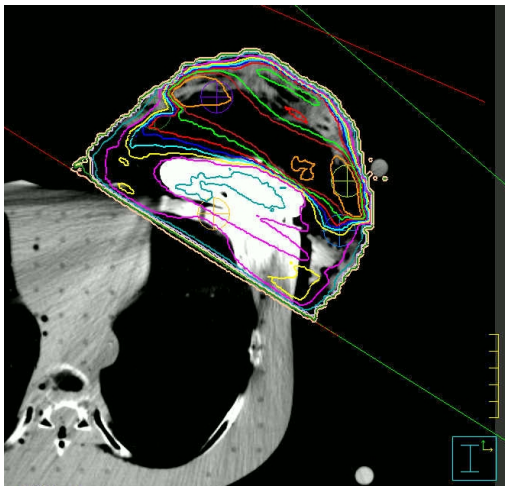

FIG. 11: A dose distribution of the Aeroform™ breast tissue expander unit in this experiment.

Conclusion

Dosimetric effects due to the metallic reservoir within the Aeroform breast tissue expander have been demonstrated and have been observed to be significant. Our investigation with the internal components of the metallic reservoir aims to increase the accuracy of assigning the physical density and physical contouring of the metallic reservoir in the treatment planning system. Our in-vivo dosimetry experiment with the RANDO® demonstrated that dose homogeneity may be difficult to achieve in the surrounding tissue. In addition it may be difficult to verify the planned dose due to the scattering effects of the reservoir. The Aeroform™ is a novel expander that may be increasingly utilised due to its inherent simplicity and ease of use. As such we welcome its introduction but recommend stringent patient dose monitoring when utilised in patients undergoing radiotherapy.

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Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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