Dosimetric evaluation of three partial breast irradiation devices and the dosimetric effect of tissue thickness surrounding a multi-lumen partial breast applicator

Jordyn Ashle Detwiler

Medical University of Ohio

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Dosimetric Evaluation of Three Partial Breast Irradiation Devices and the Dosimetric Effect of Tissue Thickness Surrounding a Multi-Lumen Partial Breast Applicator

by

Jordyn Ashle Detwiler

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science in Biomedical Science Degree in Medical Physics

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December 2010
An Abstract of

Dosimetric Evaluation of Three Partial Breast Irradiation Devices and the Dosimetric Effect of Tissue Thickness Surrounding a Multi-Lumen Partial Breast Applicator

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September 2010

Many High Dose Rate treatment planning systems that are in use fail to correct for heterogeneities. If the treatment planning system does not correct for heterogeneities, it would assume that the patient is receiving full scatter when in reality, the patient will possibly be underdosed. A 1cm diameter planning target volume for a lumpectomy cavity could extend beyond the skin or chest wall for the patient and could be a great problem when it comes to treatment with the MammoSite® single lumen breast applicator. A previous Monte Carlo study tested 3 MammoSite® balloon sizes at various depths beyond the planning target volume to see how much tissue would be needed to achieve full scatter. The results showed that on average, if there was no tissue beyond the prescription line of 1cm there would be a 10% dose reduction for the breast – skin interface.

The purpose of this study is to use the Strut Adjusted Volume Implant (SAVI) multi-lumen breast applicator to re-create the measurements done with the MammoSite® balloon and expand these measurements to include tissue thicknesses less than the PTV.
Previous simulations with the MammoSite® were done using Monte Carlo, with tissue thicknesses beyond the planning target volume of 0 – 10cm. This study will re-create these measurements using Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and also take measurements below the prescription line of 1cm due to the ability of the SAVI applicator to adjust dose to the skin.
For my family, who have supported me endlessly and always find the time to talk and give me great words of encouragement.
Acknowledgements

This thesis would not have been possible without the loving support of my mother, father, and stepmother who continuously help me in all of my endeavors. I am grateful for all they have done and without them; I would not be who I am today. It is through them that I have learned how faith, love, discipline, and hard work can shape a person’s life.

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Chapter 1

Introduction

Whole Breast Irradiation (WBI) has been a widely studied radiation therapy treatment that has proved successful for qualifying women with breast cancer. After many significant trials and studies, it has been publicized that there are no significant differences between breast conservative surgeries with radiation versus mastectomy. Some of the major advantages of breast conserving therapy (BCT) are improved cosmetic results and reduced psychological and emotional trauma compared to mastectomy (Wazer D., 2006). Before discussing the measurements completed for this thesis, a brief discussion of whole breast irradiation, partial breast irradiation and the various components of will be presented.

1.1 Whole Breast Irradiation versus Partial Breast Irradiation

WBI usually involves the treatment of the tumor bed plus a margin. This margin involves the treatment of the entire ipsilateral breast, which would receive a primary treatment of 45 Gy– 50.4 Gy plus a boost treatment of 1cm – 2cm around the
lumpectomy cavity for an additional 8 to 10 fractions. The primary area would be treated five times a week, with the breast receiving 180 cGy – 200 cGy per treatment.

The boost given for WBI is based on the principle that higher doses of radiation therapy should be given to the tumor bed in an attempt to control smaller areas of cancer that may have been left behind after removal of the tumor (Vicini F., 2009). The entire margin for WBI is established to eliminate other possible areas of cancer in remote areas of the breast. On average, this treatment lasts 5 to 7 weeks. Due to the length of the treatment, the age of the patient, and the distance to a center that offers radiation therapy, some patients will have difficulty receiving this treatment (Wazer D., 2006). In addition to these issues, adding adjuvant chemotherapy into the treatment plan there can be considerable delays in treatment. Approximately 10% - 40% of patients who qualify for BCT actually receive it (Wazer D., 2006).

However, depending on the size of the tumor and nodal status it has also been shown that some women do not have to receive this lengthy external radiation treatment and can instead receive an accelerated radiation treatment known as Accelerated Partial Breast Irradiation (APBI) or Partial Breast Irradiation (PBI). APBI delivers 34 Gy – 38.5 Gy in 5 days, with 340 cGy – 385 cGy per fraction. This treatment alone has been questioned and multiple studies have been done to test the efficacy of APBI. Five-year results from the majority of these studies have demonstrated local control rates in the breast comparable to those observed after traditional WBI (Wazer D., 2006). Whereas WBI usually irradiates the entire ipsilateral breast, APBI will only irradiate the tissue surrounding the lumpectomy cavity with a much smaller margin. APBI involves 4 possible treatment options: three-dimensional conformal radiotherapy (3D-CRT),
intraoperative radiotherapy with electrons or kV x-rays, high dose rate (HDR) multiple catheter brachytherapy, and HDR balloon brachytherapy. Furthermore, another type of brachytherapy known as low dose rate (LDR) has also been utilized and practiced mainly in Europe (Wazer D., 2006). However, most clinical experience with APBI has been accumulated with multi-catheter brachytherapy, MammoSite® Single Lumen (balloon brachytherapy), and 3D-CRT (Wazer D., 2006).

1.1.1 Types of Partial Breast Irradiation

Intraoperative radiation therapy (IORT) with electrons offers an additional treatment method of delivering radiation in an accelerated manner. However, there are not as many studies done with IORT involving APBI with electrons. One phase III trial compared standard WBI to a 21 Gy IORT single fraction (Vicini F., 2009). Another study used IORT as a single 5 Gy boost treatment using kV x-rays (Vicini F., 2009). A study at the University of Toledo Medical Center (formerly the Medical College of Ohio) stated that the efficacy of IORT concurrent with the lumpectomy in the primary treatment of early-stage breast cancer suggested that even local recurrences following conventional conservative treatments might be dealt with effectively and expeditiously by means of local excision plus IORT (Merrick H., 2003). It goes on to further say that this treatment could prove to be much less disfiguring than mastectomy. However, there needs to be further studies to test the efficacy of this type of treatment.

3D-CRT often involves the treatment of the lumpectomy cavity with a margin surrounding the cavity of 1cm – 2cm. With the non-invasive external beam treatment option, beams can be adjusted to achieve the desired dose distribution. The fractionation scheme for external PBI is 38.5 Gy in 10 fractions, although this scheme has been varied
for other trials (Vicini F., 2009). Some radiobiologic models suggest that this
tractionation schedule should produce an acceptable control rate in the breast and have
comparable late effects as with brachytherapy. These models also estimate that the
proposed radiation scheme should provide a biologically equivalent dose (BED) of 45 Gy
in 1.8 Gy fractions (Vicini F., 2009). In contrast to brachytherapy, there will be more
normal tissue receiving dose, and depending on the beam’s orientation in reference to the
lumpectomy cavity, there could be an increased dose given to critical structures such as
the heart and lung. Another possible problem with 3D-CRT is re-creating treatment
setup. The margin around the lumpectomy cavity must be large enough to account for
internal motion such as breathing, and since the breast can easily be shifted, the patient
may not necessarily be in the original setup. This could create significant errors in the
treatment plan and cause the efficacy of the treatment to decrease, while also increasing
the amount of normal tissue that receives radiation dose.

Low Dose Rate (LDR) Brachytherapy has also been used as a boost to external-
beam whole breast irradiation. LDR utilizes $^{192}$Ir or $^{125}$I sources. In one study $^{192}$Ir
ribbons were used to deliver a dose of 45 Gy, while in another study ribbons of $^{125}$I were
used to deliver a dose of 50Gy. With LDR brachytherapy, the dose rates are much lower,
with a rate of .5Gy/hr for $^{192}$Ir and .52Gy/hr for $^{125}$I (Wazer D., 2006). These implants
are not permanent, and will remain within the patient until the prescription dose is
achieved. Other types of LDR breast implants include permanent implants using $^{103}$Pd
sources, however the temporary implants usually give more control over the placement of
the sources (Wazer D., 2006). The temporary implants would also require the patient to
remain in the treatment area of the clinic until the treatment was complete. With a dose
rate of .5Gy/hr and a prescription of 45Gy, the patient would have to remain in the hospital for over 3 days. This would create unnecessary exposure to personnel, and keeping dose as low as reasonably achievable would be more difficult when compared to other partial breast treatments. LDR was popular in Europe, however in the United States it is rare that a patient would receive a boost treatment with LDR brachytherapy.

1.1.2 High Dose Rate Brachytherapy

The next two types of PBI treatments involve using High Dose Rate Brachytherapy (HDR) with multi catheters or balloon brachytherapy. HDR brachytherapy uses a single Iridium-192 source that has been produced by neutron bombardment in a nuclear reactor that has a half-life of 73.8 days (Nath R.). Ir-192 has a high specific activity, meaning the source can be much smaller and still have a large activity. It decays by beta and gamma emissions and has an average gamma energy of 0.37 MeV. The beta emissions for treatment planning purposes are not taken into account. The Ir-192 source is welded onto the tip of a wire that can be retracted into a primary storage safe container within a remote afterloading system. Remote afterloading, developed in the 1960’s, improves radiation control and improves patient care (Glasgow G., 1993). Remote afterloading significantly reduces the exposure to the physicists, radiation oncologists, radiation therapists, and other staff that must be present during a HDR treatment. With a remote afterloading system there is less probability of errors such as misplacing radioactive sources or losing the sources, which can occur with manual afterloading (Glasgow G., 1993). With the remote afterloading system, the Ir-192 source wire will extend to specified positions for the treatment, and dwell for a specific amount of time determined by the treatment planning system. This remote system must be checked daily before any
treatment to make sure that the wire is going to the correct place and for the specified period of time. Other items, such as door interlocks, emergency interlocks, and speaker and camera systems should be checked each day prior to treatment because emergencies can occur. If there is such an emergency, the source can be retracted manually, or the wire can be cut and placed in a mobile emergency shielded container by long handled forceps (Glasgow G., 1993).

HDR brachytherapy involving multi catheters was the original APBI technique and has generated clinical experience with the longest follow-up duration (Wazer D., 2006). This involves many catheters that can be placed in the breast of a patient to deliver a certain amount of radiation to the specified treatment area. The catheters are attached to the remote afterloader that will send out a radioactive source to a specific distance within the catheter. The source will dwell for a certain amount of time in each catheter and produce the desired dose distribution within the breast. The planning for this treatment is time consuming and treatment can be painful for the patient. However, when margins are properly established and there are stricter patient selection criteria, one study found that the 3- to 5-year breast recurrence rates ranged from 1% to 5% with this type of treatment (Wazer D., 2006). Another study evaluated the value of interstitial brachytherapy alone in the treatment of low risk breast cancer patients with regard to local control, side effects, and cosmesis. 176 patients with low risk breast cancer were selected for the study, with tumor sizes less than 3cm, resection margins clear by at least 2mm, no lymph node metastasis, and the age was greater than 35 years. Results from this German-Austrian multicenter phase II trial concluded that brachytherapy, as a monotherapy in low-risk breast cancer patients after breast conserving surgery is an
effective, precise treatment modality without perioperative morbidity, low acute, mild late toxicity, and yields good to excellent cosmetic results (Strnad V., 2004).

Due to the excellent results with multi catheter brachytherapy, other interstitial type implants have also been created. This would involve balloon brachytherapy, where a balloon is inserted into the lumpectomy cavity of a patient. Instead of having multi catheters, a balloon would enter through a single entry within the patient’s breast. This balloon has a central lumen or tube where the radioactive source can dwell. This balloon is inflated with contrast so that it can be seen on a computed tomography (CT) scan and the lumen will be contoured in a treatment planning system. The original balloon was MammoSite®, with one single lumen in the center of the balloon. The MammoSite® balloon when inflated with a contrast solution will expand to the full size of the lumpectomy cavity, and will give a near symmetric dose distribution. Treatment with MammoSite® is less invasive than the multi catheter option, and is still capable of producing desirable results. For treatment with MammoSite®, the usual margins are 1 cm beyond the inflated balloon for the planning target volume (PTV).

1.1.3 Phase III Trials Evaluating Whole Breast Irradiation and Partial Breast Irradiation

Each of these APBI treatments have been widely monitored in the protocol given by the National Surgical Adjuvant Breast and Bowel Project Protocol B-39 (NSABP) and the Radiation Therapy Oncology Group (RTOG) Protocol 0413, a randomized phase III study of conventional whole breast irradiation versus partial breast irradiation for women with Stage 0, I, or II breast cancer which establishes suggested treatment parameters and a quality assurance program for patients under treatment with APBI.
This trial evaluates the effectiveness of PBI compared to WBI in providing equivalent local tumor control in the breast following lumpectomy for early stage breast cancer. Patients that qualified for this protocol must have stage 0, I, or II invasive adenocarcinoma of the breast with no metastatic disease. If stage II, the tumor size must be 3 cm or less. Women must have undergone a lumpectomy with the margins of the resected specimen histologically free of cancer including ductal carcinoma in situ (DCIS). For patients with positive axillary nodes, eligibility is restricted to those with 0 to 3 positive axillary nodes. Other criteria involved disease stage, menopausal status, hormone receptor status, and intention to receive chemotherapy. These patients were randomized to receive either WBI or PBI. If the patient received WBI, they would receive 50 Gy – 50.4 Gy to the whole breast followed by an optional external beam boost to add to 60 Gy – 66.6 Gy. If the patient received PBI, they would receive either 34Gy in 3.4 Gy fractions using interstitial multi-catheter brachytherapy, or 34 Gy in 3.4 Gy factions using the MammoSite® balloon catheter, or 38.5 Gy in 3.85 Gy fractions using 3D conformal external beam radiation. For all PBI techniques, radiation therapy was given to tissue surrounding the lumpectomy cavity only, with a fractional separation of at least 6 hours, for a total of 10 treatments given over 5 days. This phase III trial is designed to establish the equivalency in local control and overall survival of PBI to WBI, establish the equivalency in cosmetic outcome between the two treatment approaches, and analyze potential differences in fatigue, treatment-related symptoms, and convenience of care among patients undergoing PBI versus WBI. This protocol is still being used in many treatment facilities today in hopes that there will be a large Phase III trial evaluating the effectiveness of PBI versus WBI.
Chapter 2

Multi-Lumen PBI Applicators versus MammoSite® Single Lumen (SL)

It is very clear that the MammoSite® treatment option enables women to receive a shorter radiation treatment thus being able to return quickly to their normal lives. However, there are certain parameters that are required for this treatment that some women cannot satisfy. When looking at the lumpectomy cavity on a CT, the preferred skin to balloon spacing is 7mm, and if there is less than 3 consecutive CT slices that have less than 5 mm balloon to skin spacing, the patient will not qualify (Vicini F. et al, 2009). Other dosimetric parameters such as tissue-balloon conformance, balloon symmetry, and the percentage of uninvolved normal breast are also taken into account when using the MammoSite® applicator. These parameters are to protect other parts of the tissue that are not involved with the area of treatment and should receive dose that is less than the PTV (Vicini F. et al, 2009). For tissue-balloon conformance, the lumpectomy cavity surface should be in direct contact with the entire balloon surface assuring maximum prescription dose coverage of the PTV. Often, the balloon will not conform completely to the lumpectomy cavity and there could be air or fluid between the cavity and balloon.
This results in a tissue-balloon conformance that is undesirable, and could potentially create problems with the dose distribution in the PTV. The volume of air or seroma must be less than 10% of the PTV. The balloon can also get pushed against the chest wall creating an asymmetry in the balloon; instead of having a perfectly spherical balloon, it could be misshapen. Normal balloon symmetry should not deviate more than 2mm of the expected dimensions of the balloon. For uninvolved normal breast, less than 60% of the whole breast volume should receive no more than 50% of the prescribed dose (Vicini F. et al, 2009). All of these criteria can be found in the NSABP B-39 RTOG Protocol 0413.

With a single catheter applicator such as the MammoSite® balloon, there are little options when it comes to optimizing the dose that is delivered to the PTV. The MammoSite® applicator sometimes does not produce the desired result within the PTV. The single lumen applicator is capable of producing only a symmetric dose distribution, and if the balloon happens to be asymmetric there is a chance of significantly under dosing or overdosing the PTV. This potential overdose could result in problems with the skin surface or ribs. New options in balloon type brachytherapy include treatment with single entry multi catheter devices that could eliminate these problems, while decreasing the skin dose and still achieve the targeted dose to the PTV.

2.1 Dosimetric comparison of 3 multi-lumen applicators versus MammoSite®

This study compares 3 multi-lumen applicators that can be used for treatment of breast cancer using HDR brachytherapy; these are the MammoSite® Multi-Lumen (ML, Hologic, Inc.), Contura™ (Senorx Inc.), and the Strut Adjusted Volume Implant (SAVI™, Cianna Medical, Inc.). Each of these applicators have the ability to modify the
dose further than the original MammoSite® balloon due to the addition of 3 – 10 lumens. The MammoSite® ML has 3 additional lumens surrounding the central lumen with 1 variable balloon size of 4 – 5 cm, and the lumens are still within a balloon inflated with contrast solution. The Contura™ applicator has 4 additional lumens surrounding the central lumen, but offers 2 balloon sizes, a 4 – 5 cm or 4.5 – 6 cm variable balloon. The SAVI™ consists of a central strut surrounded by 6, 8, or 10 peripheral struts depending on the size of the device (Manoharan S., 2010). The SAVI™ has the ability to treat a varying volume ranging from 8 to 90cm³, which is a much larger range when compared with any of the other applicators. This device can be collapsed and expanded by an expansion tool attached to the central strut and is expanded after placement within the lumpectomy cavity. Whereas the other applicators are inflated with a contrast solution, the SAVI™ applicator is not, and has an air cavity. However over the time of treatment, the cavity surrounding the SAVI™ can partially be filled with fluid or the tissue could expand within the struts. An image depicting each applicator is shown below in figure 2-1.
Figure 2-1: Four different types of HDR Partial Breast Irradiation Single Entry Applicators. The SAVI™ applicator is the only applicator that is not surrounded by a balloon. Each strut can be expanded within the lumpectomy cavity using an expansion tool, whereas the original MammoSite®, MammoSite® ML, and Contura™ applicators are already in place within a balloon that can be inflated with a contrast solution.

Choosing one applicator over another can be considerably difficult. Coming to an agreement on an applicator with the surgeon, radiation oncologist, and physicist can become a challenge. There are many important qualities to look for when choosing a multi-lumen applicator. When implementing one of these devices into a clinic, many qualities need to be investigated, including how well each applicator can modify the dose to areas that do not need to be treated. A brief comparison was done to determine which of these three applicators had the greatest ability to adjust the dose to the PTV.
When looking to compare these applicators, certain parameters needed to be considered. The parameters for this comparison included dose asymmetry, defined as the dose at 1 cm from the device in a direction of asymmetry divided by the prescription dose, and other objective parameters to quantify minimum and maximum dose within the PTV given from NSABP B-39 RTOG 0413. The other parameters that were used in this comparison include the volume of tissue receiving more than 150% of the dose (V150) which must be less than 50 cm³, the volume receiving 200% of the dose (V200) which must be less than 10 cm³, the dose to the target volume which must be greater than 90% of the prescription dose (D90), and the skin dose which must be less than 145% of the prescription dose. The V150 and V200 are used to ensure that the acceptable dose homogeneity is not exceeded while striving to achieve the targeted dose, and these parameters are not specified on balloon size (Vicini F. et al, 2009). They represent a general rule to follow when looking at the MammoSite® treatment plan. The PTV also needed to receive 340 cGy (±5%) while one area of the PTV had a maximum point of asymmetry. In this comparison, each of these parameters was looked at to determine which applicator is more capable at adjusting the dose.

In order to create this comparison there needed to be a way of optimizing the dose to the PTV to create a symmetric dose distribution and then adjusting one side of the dose to create an area of asymmetry. To do this, four points surrounding the PTV were created. The dose was initially symmetric in the treatment planning system, so that each point was receiving 340 cGy. This mimicked an original MammoSite® plan. From this point, a separate plan was created to push the optimization further, making the dose asymmetric. This idea was applied to each applicator. Using this technique, the
MammoSite® ML resulted in a dose asymmetry of 12.2% compared to 13% for Contura, and 52% with the SAVI applicator. Images of each applicator and their dose distributions can be seen in figures below.

![Figure 2-2](image)

**Figure 2-2**: The MammoSite® ML applicator. The four points of symmetry can be seen on the image. The points *sym 1*, *sym 2*, and *sym 3*, are receiving 340cGy (±5%) while the point *asym* is receiving the least amount of dose. The light blue isodose line represents the prescription dose of 340cGy. The red line represents the PTV. From the image, it can be seen that the dose surrounding the *asym* point is reduced compared to the other 3 points. The same points were placed around the other multi-lumen applicators. The MammoSite® ML applicator resulted in a dose asymmetry of 12.2%.
Figure 2-3: The Contura™ applicator. The same theory was idea was applied to this applicator, resulting in a dose asymmetry of 13.0%.

Figure 2-4: The SAVI™ applicator. It is clear that the SAVI has the greatest ability to adjust dose to the PTV to avoid critical structures if necessary. The dose asymmetry was 52%.
A recently published abstract compared MammoSite® ML and Contura and also concluded that these two applicators produce similar results when there are larger distances from the skin and/or chest wall (Liang X., 2010). However, for smaller breast sizes when the balloon is much closer to the skin, Contura was able to achieve better skin sparing (Liang X., 2010). Each of these applicators can also satisfy the parameters discussed above, which were also evaluated during the dosimetric comparison. Table 2-1 below shows these values for each of the applicators and if they are within the passing criteria of the protocol. It can be noted that some of the applicators do not pass the criteria specified by the NSABP B-39 RTOG 0413 protocol. However, these plans were only made to determine how far the dose could be pushed from the PTV. The plan could have been further adjusted to pass these criteria. The MammoSite® ML may have the greatest trouble passing the V200 because it already has the least ability to adjust the dose.

Table 2-1: NSABP Parameters applied to MammoSite® ML, Contura™, and SAVI™, and the dose asymmetry for each applicator. Dose asymmetry is defined as the prescription dose divided by the dose at a point of asymmetry. Observing the passing criteria listed above, each applicator passes the V150, while the MammoSite® ML and SAVI™ applicators do not pass the V200. The treatment plan however could be easily adjusted so that these criteria would be acceptable.

<table>
<thead>
<tr>
<th></th>
<th>V150 (cm³)</th>
<th>V200 (cm³)</th>
<th>Dose Asymmetry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MammoSite® ML</td>
<td>35.7</td>
<td>10.5</td>
<td>12.2</td>
</tr>
<tr>
<td>Contura™</td>
<td>21.7</td>
<td>5.4</td>
<td>13.0</td>
</tr>
<tr>
<td>SAVI™</td>
<td>24.8</td>
<td>12.5</td>
<td>52.0</td>
</tr>
</tbody>
</table>

2.2 Disadvantages of Multi-Lumen and MammoSite® SL Applicators

It has been shown that with a multi-lumen applicator the dose to the chest wall and or skin can be significantly decreased while still achieving the desired dose distribution
within the PTV. This means that skin dose will no longer be an issue and more women will qualify for APBI with these types of applicators. However, with a multi-lumen applicator the planning can become quite complex and time consuming. There are more lumens that must be contoured in the treatment planning system, and the balloon could possibly get twisted within the lumpectomy cavity when compared with the initial CT plan. This could result in treating normal breast tissue that should not have been treated. There could also be potential errors with placing the correct catheter into the afterloader. The VariSource (Varian Medical Systems, Palo Alto, CA) afterloader allows the placement of over 20 catheters. There is a chance that a catheter could be in the wrong channel number and overlooked, therefore the complex plan to adjust the dose to the skin or chest wall could in fact be invalidated.

Another issue with multi-lumen applicators involves the VariSource remote afterloader system and the number of cycles used, or how many times the source is extended into a catheter. Each time the source extends and retracts counts as one cycle. So each catheter used would count as one cycle. For structural integrity reasons, there is a limit on the number of cycles the Ir-192 wire can have before it is replaced, and if this number is exceeded, the source will not extend. Having a multi-lumen applicator will cause the wire to go through these cycles much more quickly than with a MammoSite® single lumen (SL) balloon. Another potential issue exists for the MammoSite® SL, MammoSite® ML, and Contura balloons involving radiographic contrast. One study measured dose perturbations induced by the presence of radiographic contrast inside the MammoSite® balloon (Kirk M. et al, 2004). This study concluded that as the radius of the balloon increases, as well as a higher contrast concentration within the balloon, the
dose perturbation increases (Kirk M. et al, 2004). Another study performing similar experiments resulted in a 5% error in dose reduction (Zhang Z. et al, 2007). This can occur with any of the balloon type applicators and could contribute to a significant dose reduction. Other problems arise with the SAVI™ applicator involving inverted struts and the fact that this applicator is not inflated with contrast but filled with air, and tissue can get caught between the applicator and cause tissue invagination (Richardson S., 2010), (Manoharan S., 2010).
Chapter 3

The Strut Adjusted Volume Implant (SAVI)

It is clear that the SAVI™ applicator has the greatest ability to adjust dose given to tissue outside of the PTV. With the number of women who cannot qualify for treatment with the MammoSite® SL because of tumor beds close to the skin or for having smaller breasts, these women could now qualify for treatment with the SAVI™ applicator.

3.1 Previous Research Involving the SAVI™ Applicator

There have been numerous studies and comparisons for women that have been treated with SAVI™, and more recently, research testing the dosimetric effects of the air cavity. Yashar et al reported early clinical experience by treating 30 patients with SAVI™ with a median follow up of 12 months. It was concluded that the dosimetry was outstanding when looking at V90, V150, and V200, with no local recurrences to date. Nearly half of the candidates for this study did not qualify for other single entry brachytherapy devices due to skin spacing or breast size (Yashar C., 2009).

Susan L. Richardson and Ramiro Pino (2010) studied how the air inside the SAVI™ applicator changes the delivered dose from the homogeneously calculated dose. This study compared a SAVI™ applicator filled with air, and water. Depending on the
size of the SAVI™ applicator used, the arrangement of the sources, and the dwell times, the magnitude of the dosimetric effect will change. Their results indicated that the dose at 1cm away from the water-air boundary is 9% higher than if the applicator was filled with water. Their general conclusion was with the SAVI applicator, with the air cavity the dosimetric effect ranges from 3% - 9% (Richardson S., 2010).

3.2 Verifying a Monte Carlo N-Particle Study with SAVI™ and a MOSFET Dosimeter System

Along with the error presented with an air cavity instead of a water-inflated balloon, there can still be significant errors with the measurements of the SAVI applicator. These concerns for error stem from an earlier study done with a MammoSite® SL balloon using Monte Carlo N-Particle (MCNP) simulations (Kassas B., 2006). This MCNP study was done based on a number of HDR treatment planning systems that fail to correct for heterogeneities within the patient and outside of the patient’s CT scan (Kassas B., 2006).

This can be a great problem when it comes to treatment with the MammoSite® SL applicator, as the prescription line is 1cm away from the balloon surface. If the balloon surface is less than 1cm from the skin or chest wall, then the PTV would extend into the air or lung. If the treatment planning system does not correct for heterogeneities, it would assume that outside and inside the patient is water. This could potentially create a significant difference in the predicted dose distribution. This study, performed by Kassas et al predicted how much difference in dose there would be 0 – 10cm beyond the prescription line for a breast-tissue interface and breast-lung interface. To compare these measurements, a dose modification factor, defined as the ratio of the dose rate at the prescription distance of 1cm from the balloon’s surface with full scatter using the
modeled water phantom, to the dose rate with a finite tissue thickness (0 – 10cm) beyond the prescription line was formed. Thus, a dose modification factor of 1 would mean that full scatter contribution was achieved and the PTV received the correct dose. It can also be noted that breast tissue extending beyond 5cm is very rare for these types of treatments, however this study was extended to 10cm to show how much tissue beyond the prescription line would be needed to achieve the full scatter dose. These measurements were done for 3 balloon sizes of 4cm, 5cm, and 6cm.

The results of this study for the breast-skin interface when there was no tissue beyond the prescription line of 1cm were 1.098, 1.112, and 1.132 for the 4cm, 5cm, and 6cm balloon. This means that on average there would be a 10% dose reduction at the breast-skin interface if the surface of the balloon was 1cm away from the interface (Kassas B., 2006). These simulations also showed that 5cm of breast tissue beyond the prescription line would still not result in a full scatter contribution. Simulations were also done for the breast-lung interface that also resulted in an underdose as high as 6% - 9% (Kassas B., 2006).

As quoted in this study, “Because the Associations of Physicists in Medicine Task Group 40 recommendation for intracavitary brachytherapy allows for ±15% in the delivery of the prescribed dose rather than the ±5% limit expected for external beam therapy, the reduction in the dose resulting from the lack of full scatter coupled with the reduction from the use of high atomic number contrast material (which causes a dose rate reduction in the range of 1% - 6%) can result in considerable uncertainty” (Kassas B., 2006). This treatment is intended to irradiate the area surrounding the lumpectomy cavity to 1cm, however if there is more than 15% of an underdose due to contrast and lack of
heterogeneity correction in the treatment planning system there could be reason to look into the significance of these findings.

Although with the SAVI™ there does not exist a dose difference due to contrast, there is a significant difference in the dose due to the air cavity. It is the goal of this research to verify these previous theoretical calculations done by Kassas et al, using the SAVI applicator instead of the MammoSite® SL. However instead of using MCNP, metal oxide semiconductor field effect transistors (MOSFETs) will be used.
Chapter 4

Materials and Methods

This experiment further tests the MCNP results achieved by Kassas et al using MOSFETs and the SAVI™ applicator. When planning to re-create these measurements, there needed to be a way to accurately measure the dose delivered at a certain point within the water phantom that was used. This requirement is stressed because the water phantom is mimicking the breast-tissue interface, where a measurement will be taken on the tissue (water) surface, or underneath the tissue surface. It was decided that measurements would be taken with MOSFET dosimeters, because they have been widely used for dosimetric measurements in radiation therapy and were readily available in the clinic (Rosenfeld, 2002).

The major advantage of the MOSFET detector is that it provides a direct reading with a very small active area. The size of the MOSFET enables point dose measurements to be taken, and it also offers a simple dose read-out. MOSFET dosimeters are dose-rate independent, and have the ability to store accumulated dose that can be read at a later point in time (Soubra M., 1994, Rosenfeld, 2002). The sensitivity can also be adjusted by changing the bias voltage. The greater the fraction of charge collected, the higher the sensitivity. A MOSFET consists of a P-type silicon semiconductor substrate, a layer of insulating oxide, and a metal gate (Bhattacharyya, 2009). The MOSFET generates
electron-hole pairs in the oxide part of the MOSFET when hit with ionizing radiation. The generation of this electron-hole pair creates a charge, which moves in the direction of the Silicon interface where the charge is trapped. This trapped charge shifts the gate threshold voltage and after the MOSFET is exposed, the gate threshold voltage can be measured by applying constant source-drain current, with which the accumulated dose is read. The shift in the gate threshold is a reasonably linear measure of the dose (Soubra M., 1994).

4.1 Materials Used

All measurements were performed with either the Best® Medical TN-502RD standard MOSFET dosimeter or the TN-502RDM micro MOSFET dosimeter. Measurements were taken by attaching the MOSFET to the Thomson and Nielsen MOSFET 20 Reader, and power and bias supply, show in the figures below.

Figure 4-1: The Thomson and Nielsen MOSFET 20 Reader and power and bias supply.
The TN502RD MOSFET detector is a dual bias detector that consists of two identical MOSFETs fabricated on the same silicon chip operating at two different gate biases. This dual MOSFET achieves better sensitivity and reproducibility when compared with a single MOSFET detector (Soubra M., 1994). A MOSFET detector with two identical MOSFETs on the same silicon chip will also decrease the temperature dependence of the threshold voltage. The pair is operated with different bias voltages, and the temperature dependence is offset by using the difference in their responses to indicate measured dose (Knoll, 2000).
Ryosuke Kohno et al. performed a dosimetric evaluation of this specific MOSFET detector for clinical application in photon therapy evaluating reproducibility, dose-rate effect, accumulated-dose effect, fading effect, angular dependence, accuracy in tissue-maximum ratio, and total scatter factor. The estimate of reproducibility for this MOSFET was found to be 1.9% while the true reproducibility was between 1.5 and 3.3% with a confidence level of 90%. An angular dependence of the MOSFET was within ±3.0% for each energy level tested. These MOSFETs also showed a fading effect of .9% after being read 20 minutes after irradiation (Kohno R., 2008). Each of these errors should be noted when determining the accuracy of the MOSFET dosimeters for HDR brachytherapy.

Other materials used for these measurements include a plastic water tank with a device to hold and lower the applicator into the water, a device keep the MOSFET stationary, Varian reusable transfer guide tubes, Varian VariSource HDR system, and BrachyVision™ Treatment Planning System. To keep the MOSFET stationary, a tool was developed to keep the MOSFET at a pre-defined distance from the surface of the SAVI™ applicator. Without this device, the MOSFETs would not remain accurately above the SAVI™ applicator. This device was made from plastic materials, with a metal rod that would hold and lower the MOSFET directly over the SAVI™ applicator. It accurately kept the MOSFET in place during each measurement.

The Varian VariSource HDR system has a source consisting of two pieces of 0.34mm diameter, 2.5mm long iridium wires, encapsulated in a titanium/nickel tube of 0.59mm outer diameter and 0.34mm inner diameter (Choi C., 2009). The BrachyVision™ Treatment Planning System utilizes the American Association of
Physicists in Medicine Radiation Therapy Committee Task Group Report Number 43, which involves a calculation of dose by using

\[ D(r,\theta) = S_k A \left[ \frac{G(r,\theta)}{G(r_0,\theta_0)} \right] g(r) F(r,\theta), \]

the general formalism for a two-dimensional case, such as a cylindrical source. Where \( A \) represents the dose rate constant defined as the dose rate to water at a distance of 1cm on the transverse axis of a unit air kerma strength source in a water phantom, \( S_k \) represents the air kerma strength of the source, \( G(r,\theta) \) the geometry factor which accounts for the variation of dose due only to the spatial distribution of activity within the source, \( g(r) \) the radial dose function which accounts for the effects of absorption and scatter in the medium, and \( F(r,\theta) \), the anisotropy function which accounts for the anisotropy of dose distribution around the source. This equation was modified to account for previous flaws with older protocols (Nath R.). These older protocols were based upon photon fluence around the source in free space, whereas clinical applications require dose distributions in a scattering medium such as a patient (Nath R.). The equation above corrects this problem by a direct use of measured dose distributions produced by a source in a water equivalent medium. This however still does not correct for any other material involved with the patient treatment, such as air outside of the body, or air within the lungs, which is why many studies are performed to make sure the patient’s treatment is accurate.

4.2 Calibrating the MOSFETs

The MOSFETs were specifically calibrated for the energy spectrum of Ir-192. Before taking measurements with the SAVI™ applicator, these calibrations were completed using the MammoSite® SL balloon. The MOSFET was placed along the surface of the water-inflated balloon, and a CT scan was taken that was then imported into
BrachyVision™. Minimal contrast (less than 1%) was used for the CT scan, so that the
dose perturbation error due to contrast was negligible. The MammoSite® SL balloon
was also placed within 10cm of water so that it would achieve full scatter. This was to
ensure the conditions were accurate for the treatment planning system. From this CT,
four plans were created each with different prescriptions (20cGy, 60cGy, 100cGy, and
140cGy). Since the MOSFET was visible on the CT, a reference point was placed
directly in the center of the MOSFET. BrachyVision™ determined the dose to this point
for each plan. These plans were then exported to the treatment machine and MOSFET
measurements were taken. Because the MOSFET can be seen on the surface of the
balloon on the CT, a known dose can be delivered to the MOSFET, and a calibration
curve can be made for each reading taken. The results of this calibration for both the TN-
502RD and TN-502RDM MOSFET dosimeters can be seen in the figures below.
The TN-502RD MOSFET Calibration. A known dose from the treatment planning system, BrachyVision™ was delivered to the MOSFET. A plot of the measured reading versus the calculated dose is shown. The equation $y = 0.94x - 4.46$ was then used to correct the readings taken in the following measurements, where $x$ is the reading given from the Thomson and Nielsen MOSFET reader.

**Figure 4-3:** The TN-502RD MOSFET Calibration.
Figure 4-4: The TN-502RDM micro MOSFET calibration. This calibration was done in the same exact way as the TN-502RD MOSFET.

4.3 Waterprooﬁng the SAVI™ Applicator

In addition to calibrating the MOSFET dosimeters, the SAVI applicator must be waterproof before taking measurements. The expandable part of the SAVI applicator would normally be within the lumpectomy cavity during treatment, leaving the other part of the applicator outside of the patient in air. The ends of the applicator would be attached to waterproof catheters, which are then connected to guide tubes, which are then attached connected to the VariSource Afterloader. Due to unforeseen circumstances, the commercially manufactured waterproof catheters that connect to the SAVI™ applicator were not delivered in a timely fashion. These catheters were waterproof tubes that would connect the applicator to the VariSource connectors. Instead of using these, the reusable transfer guide tubes used for interstitial implants were used. These tubes needed to be
attached to the SAVITM, and waterproofed. This consisted of using 3 – 4 different sized heat shrink tubes to connect the transfer guide tubes to the SAVITM applicator. After all 9 lumens were attached to separate transfer guide tubes; they were submersed in water for 24 hours to confirm waterproofing. After the 24 hours were over, a measuring wire was placed through each SAVI-guide tube catheter connection. As the wire was being pulled out of the catheter, it was tested by sliding the wire across a paper napkin. If water was visible on the napkin, that specific lumen needed to be separated from the transfer guide tube, re-waterproofed, and re-submersed in the water and tested again. The waterproof test was also performed each day prior to taking measurements and attaching it to the remote afterloader. The images below show the waterproofing process.
Figure 4-5: Waterproofing the SAVI™ Applicator. Heat shrink tubing was used to attach the transfer guide tubes to the SAVI™ lumens.
4.4 **Catheter Length Measurements**

Initially when attempting to take measurements using the SAVI™ applicator, the dummy wire would retract and a blockage error would occur. This means that the dummy wire could not extend to the measured length that was in the treatment planning system.

Whereas normal catheters can be measured separately without the quick connect tube, the reusable transfer guide tubes were already attached to the quick connect tube and could
not be removed. The wire not only measured the SAVITM catheter length, but the entire length of the transfer guide tube including the quick connect tube, which added an additional distance that should not have been included in the measurement. This resulted in the blockage error when using the remote afterloader. To correct this problem, a series of single lumen single dwell measurements were taken to confirm the location of the wire. A camera was set up to film the dummy and source wire extensions to a specified location within the second lumen of the SAVITM. The planned position was to be directly in the center of the second lumen, however the camera verified that the wire was extending to the incorrect location. After a series of these measurements, and visually confirming that the distance in the applicator was incorrect, it was determined that a distance of 2.5cm needed to be subtracted from the measured length of the catheter. This was done for each lumen, and corrects for the additional length of the quick-connect tubes. The figures below show the Ir-192 source extended at the incorrect length, and the corrected length.
Figure 4-7: The SAVI™ applicator with the dummy wire extended to the incorrect length before the 2.5cm adjustment. The dummy wire is extended in the second lumen (very top lumen in picture), dwelling slightly past the intended position (center of lumen). The arrow points to the dummy wire.
Figure 4-8: The SAVI™ applicator with the dummy wire extended to the correct length, after the 2.5cm adjustment. The dummy wire is extended in the second lumen, directly in the center of the lumen, where it was told to dwell. Again, the arrow is pointing to the location of the dummy wire.

4.5 Measurements with Increasing Backscatter

After the MOSFETs were properly calibrated, and the catheter distance was corrected, measurements could finally be taken. The SAVI™ applicator was CT scanned in the water phantom with the MOSFET 1cm directly above the second lumen. Measurements were done to investigate the SAVI™ under conditions of limited backscatter. This meant creating a plan utilizing the central lumen of the SAVI™, with multiple dwell positions with increasing backscatter (water) at 0cm – 9cm beyond a PTV of 1cm. These measurements were slightly different then the simulation performed by Kassas et al. Whereas they utilized a single lumen, single dwell, in these measurements a single lumen multiple dwell plan was performed. This type of plan was performed due to a previous study involving a considerable underdosage caused by the anisotropy of a stationary...
source (Choi C., et al, 2009). This study also proposed that multiple dwell positions would improve the PTV coverage (Choi C., et al, 2009). After a plan was created, a reference point was placed where the MOSFET was located on the CT. The dose delivered to this reference point in BrachyVision™ represents the calculated dose to the MOSFET with full backscatter. This dose was then compared to the calibrated MOSFET readings to come up with a dose modification factor. The dose modification factor in this case is defined as:

$$DMF = \frac{\text{predicted by BrachyVision}}{\text{measured MOSFET in water}},$$

where the predicted dose is given from BrachyVision™ that assumes full backscatter, and is divided by the calibrated MOSFET reading measured. A dose of 100 cGy was prescribed to the PTV for these measurements. These measurements were also performed with a single lumen multiple dwell due to a previous study that

4.6 Effect of Tissue Thickness less than 1cm surrounding the SAVI™ Applicator

Since the SAVI™ applicator is capable of adjusting the dose to the skin surface to avoid overdosing the skin; the minimum skin spacing from applicator to tissue no longer has to be 7mm, as recommended with the MammoSite® SL applicator. This means women with smaller breasts, or lumpectomy cavities close to the chest wall can qualify for this treatment. However, due to the shorter distances to skin, there could be dosimetric inaccuracies involving lack of backscatter. The measurements presented here compare the dose with full backscatter as measured in BrachyVision™ to the calibrated MOSFET dose at a distance of 0.1cm – 1cm.
The SAVI™ applicator was placed within the water phantom, and lowered to 1cm below the water surface. The MOSFET was placed directly on the water surface to mimic the tissue interface. From this point, a CT was performed on the water phantom and imported into the BrachyVision™ treatment planning system. A PTV of 1cm was made, however the PTV was made to avoid the water surface by 5mm and a plan avoiding this 5mm skin contour and utilizing the other SAVI™ lumens was made. A dose of 100 cGy was prescribed to this new PTV. Reference points were placed within the CT to mimic the MOSFET at 0.1cm – 1cm and to give the calculated dose with full scatter, as seen in figure 4-9. The SAVI™ applicator was raised from 1cm - 0.1cm and MOSFET measurements were taken in 1mm increments. Again, the dose modification factor was defined as the dose at the MOSFET with full backscatter from the treatment planning system, divided by the corrected MOSFET reading.
Figure 4-9: The reference points set up within the treatment planning system. The 1cm reference point is where the MOSFET is located. From this point, reference points from 0.9cm - 0.1cm were placed directly below the 1cm reference point. Although it looks as if the other reference points are not on the surface of the water, BrachyVision™ assumes everything is water, therefore it is acceptable to place the reference points this way. However, when the actual measurements were taken, the SAVI™ applicator was raised from 1cm - 0.1cm, and the MOSFET remained on the surface of the water.
Chapter 5

Results

5.1 Results in Comparison to the Monte Carlo Study

Kassas et al found that with the MammoSite® balloon for tissue thicknesses ranging from 0cm – 10cm that there resulted in a 6% – 9% error depending on the size of the balloon. In the study presented here, the measurements were performed with MOSFETs and the SAVI™ applicator. The SAVI™ applicator’s volume was much smaller (27cm$^3$) than any of the three MammoSite® balloons used in the Monte Carlo study. The results that were achieved with the SAVI™ and the MOSFETs showed that the DMF increases as the water above the applicator decreases. Thus, as the backscatter decreases, the DMF increases. This is in agreement with the MammoSite® balloon which has a much larger dose modification factor when there is less tissue thickness beyond the PTV. The effect is similar to the SAVI™, however the DMF is about 0.08 higher with the SAVI™ when compared with the 6cm MammoSite® balloon with 0cm tissue thickness beyond the PTV. When compared with 9cm of tissue beyond the PTV the DMF with the SAVI™ is about 0.02 higher than the MammoSite® 6cm, and approximately .03 higher than the MammoSite® 4cm and 5cm. Figure 5-1 below shows the predicted values from the MCNP simulation done by Kassas et al, and figures 5-2 and 5-3 show the measured results with the MOSFET.
Figure 5-1: This figure below shows the results given in the MCNP study done by Kassas et al. The values were interpolated based on the original graph of their data which was presented in the Journal of Applied Clinical Medical Physics, Volume 7, Issue number 3. From this graph, it can be seen that as the DMF goes up, there is a larger difference in dose due to the lack of backscatter beyond the PTV of 1cm.

The figure below shows the results for varying tissue thicknesses beyond the PTV (1cm) for the TN-502RDM MOSFET dosimeter. From the graph it can be seen as the tissue thickness beyond the PTV decreases, the dose modification factor (DMF) increases, resulting in a larger error in the dose. The TN-502RD MOSFET seems to have produced a larger error for these measurements (a DMF of 1.5), and it was at first thought to be related to the placement of the MOSFET directly over the second lumen of the SAVITM. The second lumen has a radiopaque marker for identification, which could create even less of a scatter contribution to the MOSFET. These measurements were also performed with the micro MOSFET again with the SAVITM rotated so that the MOSFET
was no longer blocked by the second lumen. These results are also shown in figure 5-2. The deviations of each MOSFET reading were within ±2%. There is minimal difference between the two MOSFET readings, meaning that the radiopaque marker does not contribute to the large error in the dose measurements. Measurements were also taken with the TN-502RD MOSFET, however the measurements were sporadic and varied with each measurement taken. Even though the MOSFET was in the same location, the measurements were inconsistent, and it was assumed that the age of the MOSFET was causing this problem and not the radiopaque marker. Due to these reasons, the TN-502RD MOSFET readings are not shown.

**Figure 5-2:** Varying the Tissue Thickness Beyond a PTV of 1cm. Measurements were taken with both the TN-502RD MOSFET and the TN-502RDM MOSFET. Only TN-502RDM measurements are shown. As water thickness beyond the PTV increases, there is more backscatter resulting in a dose much closer to the dose calculated in BrachyVision™. A larger error in the TN-502RD was thought to stem from the MOSFET dwelling above the second lumen, which contains a radiopaque marker.
Figure 5-3: A measurement of the TN-502RDM MOSFET dosimeter without being directly above the second lumen, which contains a radiopaque marker for planning purposes. The large error in the dose modification factor was thought to have partially stemmed from the MOSFETs dwelling above the second lumen. However, results from the micro MOSFET show no large changes in error, and fit within ±4% error when compared to the previous measurements shown in Figure 5-1.

5.2 Results of Tissue Thickness less than 1cm surrounding the SAVITM Applicator

Initially, it was uncertain whether the closeness of the applicator to the skin surface would create a significant increase in dose, or if the lack of backscatter would create a significant decrease in dose. It was unclear which factor would be most effective on the MOSFET dosimeter. On average for each MOSFET, there was a 9% to 11% difference in the dose when compared with the calculated dose from BrachyVisionTM. Whereas the dose modification factor previously decreased with increasing backscatter, the
measurements with tissue thickness less than 1cm remain within a deviation of 9% - 11%. The dose modification factor within ±1.3% remains constant as the SAVI™ applicator gets closer to the MOSFET dosimeter. When compared with the MammoSite® SL applicator, the DMF when there is no backscatter beyond 1cm results in a 10% to 13% difference in dose. The differences in dose at 1cm with the MammoSite® are comparable to the measurements that were taken from 0.1cm -1cm with the SAVI™ applicator. These differences in dose are significant enough to change the dose given to the skin-air interface, and should be taken into account when creating a plan within a treatment planning system that assumes a full scatter contribution, when in reality the skin receiving less dose.

**Figure 5-4:** Measurements with the TN-502RDM MOSFET on the water surface while continually decreasing the distance between the MOSFET and the SAVI™ applicator. The results are similar to the ones achieved with the TN-502RD MOSFET. The deviation of the measurements was within ±1.3%.
Chapter 6

Summary and Conclusion

It is well known that for qualifying women with breast cancer accelerated partial breast irradiation is an equivalent treatment when compared to whole breast irradiation. HDR with single entry applicators has become a very popular option because it can limit the dose to the heart and lungs. Single entry applicators have evolved; by adding multiple lumens the dose can be manipulated to achieve an asymmetric dose distribution. These new applicators allow women to be treated who were previously incapable of being treated with the MammoSite® applicator due to breast size or the location of the lumpectomy cavity. A comparison of three of these multi-lumen breast applicators shows that the dose can be manipulated by 12.2% for the MammoSite® ML, 13.0% for the Contura™ applicator, and 52% for the SAVI™ applicator. Although adding multiple lumens can adjust the dose, there are greater chances of error when compared to the original MammoSite® balloon. The addition of multiple lumens can increase setup error, and move through source cycles more rapidly. However, one thing in common with the original MammoSite® balloon that can lead to significant error involves the HDR treatment planning system that is in use. Many HDR treatment-planning systems that are in use do not take into account heterogeneities within or outside of the patient. This can lead to a considerable error in the actual dose that the patient receives.
The two different types of measurements performed showed considerable differences in dose when using a water phantom and varying the tissue thickness between the applicator and the air-tissue interface. The first measurements re-created the Monte Carlo simulations done by Kassas et al, measuring the dose at 1cm with increasing tissue thickness. The measurements were performed using the SAVI™ applicator and MOSFET dosimeters in a water tank. To approximate the MammoSite® single lumen balloon, the SAVI™ measurements were performed utilizing only the central lumen of the applicator. Using only the central lumen will create the near symmetric dose distribution that would be created with the original MammoSite®. The dose modification factor (DMF), defined as the dose at the MOSFET with full backscatter divided by the measured MOSFET dose, was shown to increase as the tissue thickness decreased. With at least 9cm of backscatter the DMF was about 1.04, which is far from receiving the full amount of scatter. It is also highly unlikely in the clinical setting that the tissue would ever extend past 5cm, which means that there is a significant reduction in the dose (about 7% dose difference at 5cm) when the tissue thickness past the PTV is small. With a deficiency of tissue thickness surrounding the PTV, it can be concluded that the surrounding tissue will receive less dose than predicted by the treatment planning system. This is in agreement with Kassas et al, who used the MammoSite® single lumen applicator to perform measurements at 1cm with increasing tissue thickness. Both measurements showed a continued decrease in the DMF as the tissue thickness increased.

The second measurements involved placing the MOSFET at the surface of the water, and varying the distance between the SAVI™ applicator and the MOSFET. Because the SAVI™ has the greatest ability to adjust dose to the skin surface and patients
no longer need to have a skin to applicator separation of greater than 5mm, these measurements were performed. Measurements ranging from 0.1cm – 1cm were taken, resulting in a 9% - 11% difference in the dose when compared with the predicted dose in BrachyVision™. Instead of an increase in the DMF as the tissue thickness decreased, these measurements showed a more consistent dose difference (on average 10%) as the applicator was moved closer to the MOSFET. As tissue thickness decreases beyond 1cm, the dose difference due to backscatter remains the same. Even though the SAVI™ applicator can adjust dose significantly to the skin surface, there is significantly less dose contributed when compared with the treatment planning system. This will create a potential underdose, and should be taken into account when determining an appropriate treatment plan. NSABP B-39 RTOG 0413 protocol also states that the skin dose should not exceed more than 145% of the prescription dose. If the treatment planning system estimates that more than 145% of the dose would be delivered to the skin, the actual dose to the skin has been determined to be on average 10% less than what the treatment planning system predicts for this specific applicator. It was shown that it does not matter how close the SAVI™ applicator is to the surface of the water, it results in an average dose difference of 10%. The SAVI™ applicator also creates a difference in dose due to the air cavity. Instead of having a balloon inflated with a contrast solution, the expanded lumpectomy cavity will contain air. Having an air cavity results in less scatter dose contribution. In combination with the 5% - 9% error due to the air cavity in the SAVI™ applicator, there could be an error larger than 15% in the dose given to the patient.
References


