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The Air Gap Effect Between a Bolus and the Skin Surface for Chest Wall Irradiation

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Abstract

Introduction

Planning technique and bolus choice are important aspects in planning chest wall irradiation (CWI). Many previous studies have tested various combinations of photon energies, electron energies, bolus types and sizes, air gaps sizes, and treatment methods. This study aims to assess the effect of smaller, clinically relevant air gap sizes on specific chest wall treatments using a variety of common bolus types.

Methods

Due to the Covid-19 pandemic, no data was able to be collected and was instead fabricated by the researcher. Four different treatment plans were created on a phantom patient using various energies of photons (6MV and 10MV) and electrons (9MeV and 12MeV) using the version 15 eclipse planning system. All treatment plans were tested with five different types of bolus: superflab, elastogel, steel brass, custom aquaplast, and wet towel. Air gaps of sizes 0cm, 0.3cm, 0.5cm, 0.7cm, and 1cm were introduced between the bolus and phantom surface.

Results

Statistical analysis was performed as t-tests with a Bonferroni correction for multiple testing. P-value of significance is p=0.0125 and the only air gap of significance was 1cm (p=0.0029). Of the bolus types, steel brass and custom aquaplast displayed the largest doses while wet towel displayed the lowest doses.

Conclusion

As the air gap size increased, the more significant the difference in dose to the chest wall. Small air gaps are not clinically detrimental to CWI's, while larger air gaps starting at 1cm pose a significant difference. Steel brass and custom aquaplast are good choices of bolus when treating a chest wall for optimal coverage of the target.

Introduction

In women, the most common type of cancer is breast cancer[9]. Though breast cancer is most common in women, the malignancy is second to lung cancer by way of mortality. Annually, there are around 230,000 new diagnoses of breast cancer, which is responsible for more than 40,000 deaths[9]. When treating breast cancer, the main three treatment options utilized are: surgery, chemotherapy, and radiation therapy[9]. These techniques are used in a variety of ways depending on stage and grade of the cancer. Most commonly, surgery is the initial treatment followed by chemotherapy and finished with radiation therapy[9].

There are many types of surgeries which can be performed to eradicate breast neoplasms. These surgical options include a lumpectomy, total mastectomy, radical mastectomy, modified radical mastectomy, and lymphadenectomy[9]. A lumpectomy is often referred to as a breast-conserving surgery where only the tumor and an area of sub-clinical disease is removed, followed by adjuvant radiation therapy; this is considered the most cosmetically appealing surgery[9]. Lumpectomies are not options used in all stages of breast cancer, and are generally utilized on patients diagnosed in the earlier stages[9]. For patients diagnosed in the later stages the first option is a total mastectomy, a complete surgical resection of breast tissue[9]. Patients in the earlier stages may also opt for this surgery as a prophylactic precaution, especially for those who are high-risk and/or present the BRCA1 and BRCA2 mutations[9]. A radical mastectomy removes the breast, overlying skin, pectoralis muscles, and all the axillary lymph nodes[9]. The modified radical mastectomy removes the breast and spares the pectoralis muscles by only removing the underlying fascia with level I and II axillary lymph nodes[9]. This method results in less toxicities and complications but both methods are not commonly used[9]. Lymphadenectomy in regards to breast cancer only removes level I and II of the axillary lymph nodes[9]. These surgeries are typically followed by chemotherapy.

Chemotherapy is a systemic treatment which introduces cytotoxic drugs into the body. These cytotoxic drugs target cancer cells to weaken and/or kill them. The treatments are given intravenously over several hours. There are several different types of chemotherapy agents that can be used. Doctors may prescribe a single drug or a "cocktail" which consists of multiple drugs together. The most common chemotherapy drugs used in the treatment of breast cancer are 5-FU, cyclophosphamide, and methotrexate. Cycles of chemotherapy treatments take place once a week to once every three weeks and patients may undergo treatment for three to six months depending on the stage of cancer. Once patients complete their chemotherapy cycle, a referral to radiation oncology for radiation therapy is close to follow.

When breast cancer patients present to radiation oncology, there are different treatment plans to be created based on the type of surgery the patient underwent. Patients who only had a lumpectomy procedure and still retain a breast receive whole breast irradiation (WBI)[2]. WBI fractionation follows a scheme of 28 fractions at 1.8 Gy per day to a total of 50.4 Gy; this is the conventional fractionation[9]. Patients may also receive a hypofractionated regimen. Hypofractionation is "the use of dose fractions substantially larger than the conventional level around 2 Gy"[9]. A hypofractionated WBI consists of 17 fractions at 2.65 Gy per day to a total of 45 Gy[9].

For a patient who has undergone a mastectomy, they then typically receive chest wall irradiation (CWI)[2]. The conventional fractionation for a CWI is 2 Gray (Gy) per day to a dose of 50 Gy[9]. The doctor may also prescribe a hypofractionated regimen of 2.65 Gy per day to a dose of 42.5 Gy[9]. Conventional fractionation is the most commonly used method. The chest wall should receive a dose no higher than 108% of the planned prescription during a CWI[9]. Limiting the dose to a level of 108% or under aids in meeting the lung constraint "to equal to or less than 30% of the prescribed dose and to limit the volume of heart to equal to or less than 5% of the prescribed dose"[9].

In planning CWI's, it is typical for a bolus to be placed on the skin and used for daily treatment. A bolus is a tissue equivalent material used to attenuate some of the dose and bring the distribution closer to the skin surface. Lower photon energies are preferable for chest wall treatments because their maximum depth of penetration (dmax) is lower than other higher energies. A 6MV photon beam has a dmax of 1.5cm, which means that the 100% isodose line will be reach a depth of 1.5cm. The chest wall is in close proximity to the skin making it a superficial target, adding a bolus helps raise the 100% isodose line closer to the skin surface. The 100% isodose line should not go beyond the chest wall into normal health tissue but border the edge. When treating a chest wall patient, issues often arise between the bolus and the patient's surface. Following a mastectomy procedure, the patient's surface is generally not smooth but presents with ridges and groves[9]. When the bolus is placed on the patient's rigid and grooved surface, the bolus is not flush but instead has small gaps between the bolus and skin, called air gaps.

Introducing an air gap into a radiation treatment plan can affect the efficacy of the plan. Radiation moves through air more easily than when interacting with a medium as the tissues, muscles, and bone of the body. Each medium of the body consists of a different density; the denser the medium the harder it is for radiation to penetrate deeper, and the less dense the medium the easier it is for radiation to penetrate further. In air, radiation does not interact but moves about freely, scattering and losing energy with no pointed direction. When small air gaps are present during treatment, a small decrease in surface dose may be observed[4]. This is evident in a study testing skin dose from unwanted air gaps which used a 6MV photon beam to treat the surface of a water phantom with air gap sizes of 0.2cm, 0.4cm, and 1cm between two bolus types of wax and Med-tec[4]. Results saw a significant reduction in dose of 0-4% with a 0.4cm air gap and a 10% reduction in dose with a 1cm air gap[4]. Having the presence of an air gap of 0.4cm to 1cm has shown a drastic decrease in skin dose; a 10% reduction changes the prescribed 100% dose to 90% which severely affects the daily biological effect of radiation treatments.

More extreme air gap instances have been studied, testing air gaps of sizes 1cm , 3cm, and 6cm; larger decreases in surface dose were observed in this case[1]. In this study, 9 types of bolus were tested. Most of the boluses had a thickness of 0.5cm, and only two had a thickness of 0.3cm[1]. A total of 4 energies were used: 6MeV, 9MeV, 16MeV, and 18MV, the goal was to evaluate the effect of a wider variety of higher energies on larger air gaps[1]. The expected result from the study was a decrease in skin dose throughout all tests, but an increase in skin dose was observed for some of the 3cm and 6cm air gaps for certain bolus types[1]. Air gap sizes of 3cm and 6cm are not likely to occur clinically but could be overlooked when treating a patient with reconstructed breasts or breast implants which create large slopes in the breast contour. The unique aspect of this study was the test on a wide variety of electron energies.

Another study tested only electron energies of 4.5, 6, 7.5, 9, and 12MeV on a phantom patient with elastogel bolus of size 0.5cm and 1cm at various angles of 0, 15, 30, 45, 60, and 75 degrees[5]. No air gap was introduced between the phantom surface and the bolus. The novel approach is the angles of incidence at which the beam strikes the bolus in this study. The overall purpose was "to determine the effect of bolus to the surface dose in oblique electron incidences"[5]. Findings showed a decreased dose at the surface with increase in the angle of the incidence, “especially with the usage of thick bolus with low energies under the highly oblique incidence angles” of 60 and 75 degrees[5]. While electrons are an optimal choice to treat the chest wall, due to the shallow nature of the treatment, the steep angles reduce the efficacy of the treatment. but bolus has been shown to decrease the surface dose with increasing treatment angles when bolus is present[5]. All of these different factors of energy, bolus size, and angle of incidence are important factors in chest wall planning.

In the treatment of chest walls, different plan methods can be utilized to reach the same objective. Conventional methods of tangential chest wall fields with a field in field (FIF) technique using photons is the most common type of treatment plan[9]. FIF is a subset of a larger treatment field; multileaf collimators block a part of the larger field that has a high dose region in order to reduce the overdosed areas while maintaining coverage of the target[9].

Another treatment option is volumetric modulated arc therapy (VMAT). For a one-sided CWI, a common VMAT treatment includes two partial arcs to gain optimal conformality[7]. A study investigating the “dosimetric outcome of tangential partial arc VMAT treatments” in the first “large group of mastectomy and breast conservation patients” ever performed revealed that the efficacy of this technique in optimal and conformal coverage as well as minimal organ at risk (OAR) dose[7]. Quandaries have risen about the effect an air gap has between a conventional FIF plan and VMAT plan of the chest wall[3].

A study set out to answer this specific question by comparing conventional FIF plans to VMAT plans using 6MV, a single 0.5cm bolus, and air gaps of 0.5cm and 1cm[3]. Results favored conventional FIF plans which had a minimal variation in dose when an air gap is present[3]. The conformality of the VMAT plan is thought to reduce the dose to the skin surface more significantly when an air gap is introduced than for a conventional plan[3]. For CWI, VMAT planning is not a preferable choice due to the rigid skin surface of the patient post-mastectomy; air gaps are likely to occur and VMAT plans reduce in dose in the presence of air.

In regard to the different treatment methods, there are also various types of bolus that can be used to achieve the same goal. Knowing which bolus to use for a specific treatment as for a chest wall treatment is important. Traditionally, materials as wet towels, wet gauze, and elastogel have been used to obtain the most conformality for a chest wall treatment[1]. The issue with wet towels and gauze is that reproducing the amount of water in the material each day has been inconsistent and, therefore, will not have the same bolus effect each day[1]. Elastogel may seem more conformal by having the ability to stick to a patient but is hard to conform to small groves and extreme ridges[6].

New techniques have been introduced to make bolus more conformal. One method is with steel brass bolus which has mesh detail to make conformality easier[1]. Aquaplast bolus has also been used to make a custom bolus for a patient in a simulation at the center using a solid slab of aquaplast[6]. Another technique, mesh aquaplast, has been used; but solid has been found to be a more effective form of bolus[6]. The most conformal of the three is 3D printed bolus which is ordered and made to a patient's specific contour[8]. This is also the most expensive with a lengthy wait period to receive the bolus. The other boluses are more readily available.

The purpose of this study is to assess the effect of an air gap on specific chest wall treatments using various types of bolus. There are five different types of bolus involved in this study: superflab, elastogel, steel brass, custom aquaplast, and wet towel. The chest wall plans will be created for different energies of photons and electrons using the same tangential angles and a 0.5cm thickness of bolus. Photon energies of 6MV and 10MV are utilized as well as electron energies of 9MeV and 12MeV. The angles of incidence for each chest wall plan are set at 310 degrees for the medial field and 130 degrees for the lateral field. Different sizes of air gaps, 0.3cm, 0.5cm, 0.7cm, and 1cm, will be introduced during treatment delivery and compared to a treatment with no air gap. All tests will be run on a phantom patient.

Null hypothesis (H_0): The size of an air gap and bolus type will have no effect on the dose to a chest wall treatment plan.

Alternative hypothesis (H_a): The size of an air gap and bolus type will have an effect on the dose to a chest wall treatment plan.

Methods

Due to the limitations of the Covid-19 pandemic the data obtained in this study was fabricated by the researcher. No treatments were performed on a phantom patient during the data collection period so no dose measurements were actually obtained. This study should not be published.

In this study, a phantom was utilized for the chest wall treatments. All the chest wall plans were created for the phantom using the version 15 eclipse planning system. Two photon plans of energies 6MV and 10MV, as well as two electron plans of energies 9MeV and 12MeV were designed. Each plan was tested with several types of bolus: superflab, elastogel, steel brass, custom aquaplast, and wet towel. When the plans were delivered out on the machine, air gaps of 0.3cm, 0.5cm, 0.7cm, and 1cm were introduced between the bolus and the phantom surface.

IRB

This study did not require IRB approval. No patient data was accessed and all tests were conducted on a phantom patient.

Photon Plans

Two photon plans were created, one with all 6MV and the other with all 10MV. The tangent angles chosen for all of the tangential fields of the differing plans were at 310 degrees for the medial field and 130 degrees for the lateral field. The jaws for each field were set 2cm superiorly and inferiorly the chest wall, half beam blocked to the ribs, and included 3cm of flash anteriorly. The multi-leaf collimators blocked the entire heart and blocked the lungs to include no more than 2cm in width. A 0.5cm bolus was generated to the size of the entire treatment field within the treatment system and linked to each treatment field. The plans were then calculated. Once each plan was calculated, they were normalized so that the 100% isodose line was just posterior to the contour of the chest wall and anterior to the rib cage. The field in field technique was then utilized to reduce the max point dose to below 108%. The plans were all prescribed to a dose fractionation scheme of 2 Gy per fraction to a total dose of 50 Gy.

Electron Plans

Two different electron plans were crafted using energies of 9MeV and 12MeV. The tangential angles were set at 310 degrees for the medial field and 130 degrees for the lateral field. The electron blocks were set to the same dimensions as the photon plans and the same 0.5cm bolus, described above, was attached to each field of each electron plan. The 9MeV plan was normalized to the 90% isodose line and the 12MeV plan was normalized to the 95% isodose line. These normalization values were selected to move the depth of dmax posteriorly to the chest wall and anterior to the ribcage.

Air Gap

In order to introduce the air gap for treatment, hollowed out styrofoam blocks were crafted. The styrofoam used had a density of 50kg/m^3. Each styrofoam block was shaped to the contour of the phantom's chest wall, beyond the dimensions of the treatment field, and cut to the desired thickness of our introduced air gaps: 0.3cm, 0.5cm, 0.7cm, and 1cm. The styrofoam blocks were made larger than the treatment field because once each block was hollowed out the borders of the block were each 2cm thick to have a ledge to fashion the bolus to.

Bolus

This study tested five types of bolus: superflab, elastogel, steel brass, custom aquaplast, and wet towel. All of the bolus types were used at an equivalent thickness of 0.5cm. The superflab, elastogel, and steel brass were left in the original shape and dimensions from the manufacturer. The custom aquaplast bolus was made in the simulation room by heating a solid sheet of 0.5cm aquaplast in the water bath and placed on the phantom's chest wall, cut to the dimensions of the treatment borders, and shaped to the contour. The material was then left to dry for 30 minutes to ensure the bolus was properly set. The wet towel bolus was made from the larger towels provided to the radiation oncology department, which were folded in half and fully soaked in water for thirty seconds. The towel was then rung out once to ensure the towel was not dripping from excess water. The wet towel measured 0.5cm thick.

Diode Measurements

Measurements from each treatment were acquired from diode readings. For each treatment, a diode was placed in the center of the treatment field. The center of the treatment field was permanently marked on the phantom prior to the start of testing to ensure a consistent placement of the diode with every treatment. For each of the planned treatment plans, a control test was performed to get a base dose reading on each type of bolus with no air gap. The air gaps were then introduced to each plan and type of bolus. The readings from all the plans were compiled into tables; a total of five tables were created for the various types of air gap sizes.

Results

The objective of this study is to evaluate the effect of an air gap on specific chest wall treatments using various types of bolus. By introducing an air gap between the bolus and the patient surface, there is a better understanding of how radiation interacts with air gaps within chest wall treatments. Four plans with various photon and electron energies were created for a phantom patient. The dose of each plan was then measured on a linear accelerator with a diode for each air gap size and every bolus type. The daily dose for the CWI was 200 cGy.

<u>No Air Gap (Control)</u>

The average dose to the chest wall for the 6MV plan was 205.5 cGy. The 10MV plan received an average dose of 210.5 cGy. Electron energies of 9Mev and 12MeV saw average doses of 201.5 cGy and 204.5 cGy. The results of the subsequent tests with air gaps were compared to the control results using t-tests with a Bonferroni correction for multiple testing, see tables and figures in the appendix. The p-value of significance is p (0.5/4) = 0.0125 because four tests were conducted. All of these statistical results were obtained from a statistical consult at Grand Valley State University using the IBM SAS version 9.4 system.

<u>0.3cm Air Gap</u>

The average dose to the chest wall for the 6MV plan was 204.7 cGy. The 10MV plan received an average dose of 210.1 cGy. Electron energies of 9Mev and 12MeV saw average doses of 200.8 cGy and 203.8 cGy. The t-test revealed a p-value of 0.5232 when compared to the control which is not significant.

<u>0.5cm Air Gap</u>

The average dose to the chest wall for the 6MV plan was 204.2 cGy. The 10MV plan received an average dose of 209.5 cGy. Electron energies of 9Mev and 12MeV saw average doses of 200.2 cGy and 203.3 cGy. A p-value of 0.2552 was the result of 0cm vs. 0.5cm air gap and like the 0.3cm p-value is not significant.

0.7cm Air Gap

The average dose to the chest wall for the 6MV plan was 203.2 cGy. The 10MV plan received an average dose of 208.6 cGy. Electron energies of 9Mev and 12MeV saw average doses of 199.3 cGy and 202.3 cGy. The t-test ran computed a p-value of 0.0518 and is again not significant.

1cm Air Gap

The average dose to the chest wall for the 6MV plan was 201.8 cGy. The 10MV plan received an average dose of 207.4 cGy. Electron energies of 9Mev and 12MeV saw average doses of 198.1 cGy and 201.1 cGy. The final p-value of demonstrated a significant value of 0.0029.

Bolus Type

From the control plans, the range of variance in dose between the types of bolus was between a 0.1 cGy to a 0.8 cGy difference. Among the control bolus types, steel brass was observed to have a higher dose for 6MV and 10MV at 205.9 cGy and 211.0 cGy. Amid the electron energies, steel brass and custom aquaplast tied for the highest dose with 201.9 cGy for 9MeV and 204.7 cGy for 12MeV. Within the various air gap dose values steel brass and custom aquaplast continued to tie for highest dose as well as switch between highest dose for various energies among differing air gap levels. The only air gap level where steel brass displayed the highest dose across all of the energies was for the 0.7cm air gap. For the 1cm air gap the highest doses amidst the bolus types switches between steel brass and custom aquaplast. Steel brass is higher for the 10MV and 12MeV energies while custom aquaplast is higher for the 6MV and 9MeV energies. Throughout all of the plan energies wet towel displayed the lowest dose.

Discussion

The purpose of this study was to evaluate the presence of an air gap between a bolus and a phantom surface in order to assess the dosimetric effect for specific CWI treatments. The introduction of an air gap below the bolus material can reduce the dose to the skin surface. Past research has continually shown a decrease in the dose received at the skin when an air gap exists.

Air Gap

Small air gaps are a common occurrence in daily clinical procedure. The overall goal is to avoid them as much as possible; unfortunately, air gaps still occur due to the nature of the grooved chest wall surface following a mastectomy procedure. Of the air gaps tested in this study, the only significant difference in dose received to the chest wall was with a 1cm bolus. Other findings in a related study have found that in the presence of a 1cm air gap a reduction of 10% of dose to the skin can be seen[4]. In the same study, a significant drop of 0-4% was seen with 0.4cm air gap[4]. Due to the previous research the significant difference in dose with a 1cm air gap is consistent with past findings. Inconsistent data is seen from this study for results on the 0.5cm and 0.7cm air gaps. From the finding, in a previous study, of a significant difference on a 0.4cm air gap the expected results would be a level of significance for air gaps larger than 0.4cm[4].

On a related note, a pattern can be seen in the computed p-values that lends some explanation to the noted discrepancy. As the air gaps increase in size, the p-values tend to decrease in size moving towards a state of significance. Statistical significance is true at 1cm but the lower air gap levels a somewhat close to significance. The continual decrease in p-values shows the gradual effect of an air gap on the treatment dose. The larger the air gap size the more significant the difference in dose to the chest wall.

Bolus Type

The collection of data was too small to be able to run statistical analysis on the difference between the bolus types. However, from reviewing the data, speculation can be made from observation of patterns. The most consistent pattern in the continual lowest doses among the wet towel bolus between energies and bolus type. The low dose results show that wet towel is an ineffective material when used to absorb dose and raise the 100% isodose line closer to the skin. While the towel used in this study was folded and soaked in a consistent manner, other techniques may not be so precise. Towel types may differ in size and thickness, and may not be uniform from clinic to clinic. The soaking procedure may also change from person to person, changing the overall thickness and density. Even if the towel is soaked in the same manner every treatment there is no way of testing that the water density will be the same from day to day and during treatment the water has been known to leak out of the towel. While the measurements of the wet towel thickness in this study were 0.5cm, the true equivalent thickness seems to be less by the low dose readings to the skin.

On the other end of the spectrum, the bolus types that read the highest dose were for steel brass and custom aquaplast. Throughout the air gap sizes and energies these two exchanged between the highest dose and often resulted in equal values. There is no statistically notable difference between the two, but the data suggests there is a clinical difference. Both offer a high quality of conformality to the chest wall due to the small interlaced fastenings of steel brass and unique moldable properties of the custom aquaplast but the difference lies in dose interaction. Steel brass presents an elevated risk for neutron contamination due to the high density of the material. Neutron contamination is an undesirable reaction that should be avoided from treatment due to the increased skin reactions. For this reason, custom aquaplast would be the better bolus material clinically since the difference in dose between the two is minimal.

Photon and Electron Energies

Energies of 6MV and 10MV were used for the photon chest wall plans. Previous studies as the study by Boman and a study by Bjork have only steered toward using 6MV beams when testing photon energies on CWI's. In a more dramatic study that mainly focused on electron energies, an 18MV photon beam was used[1]. The 10MV photon energy took a new approach on previous studies and from the control group is evident of a higher dose to the skin of about 5 cGy when compared to the 6MV treatment. Using this higher dose may be more beneficial clinically having the higher dose could increase the biological effectiveness of the treatment. Also, with the common existence of air gaps, which reduce the dose, losing part of the dose will not have much of an effect with a slightly higher daily dose.

Between the electron energies of 9MeV and 12Mev, like the photon energies, the higher energy of 12MeV displayed a higher dose to the skin of about 3 cGy. In comparison to the photon plans each electron energy resulted in lower doses to the skin. While the higher 12MeV energy is better between the electron energies, 10MV provides the largest dose to the skin overall. Photon energies in comparison to electron energies often provide a higher and more consistent daily dose. This is due to the shallower depth of dispersion more sporadic nature of electrons which can either increase or decrease skin dose[1]. Electrons scatter more often in their path of travel than photons do. Evidence of this phenomenon is clear in a study by Alford which shows an increase of skin dose for a 9MeV beam when an air gap of 1cm was present[1]. All in all, a larger photon beam of 10MV is a better beam selection over electron energies and the photon energy of 6MV.

Limitations and Future Research

The most prominent limitation of this study is the use of fake data for the results. Running the tests on an actual treatment machine would lend a better understanding of the true effect an air gap has between the patient surface and a bolus. Another limitation was the inability to statistically analyze the differences between the various bolus materials. Not enough data was collected to analyze the differences between the various bolus materials. A future study should include gathering repeated measurements to use the average for statistical analysis.

Moving forward, there are many doorways to explore modifying and improving this study for the benefit of future research. A larger variety of photon and electron energies can be utilized especially integrating and comparing the larger energies of each beam type to the lower energies. From the outcomes observed on the significance of the 1cm air gap, larger air gaps that are still clinically relevant as 1.2cm to 2cm could be added assessments. In regards to the planning techniques, modifications in the treatment plans could prove useful. Making small tweaks to the incident angles; instead of having the same angles for the medial and lateral beams differences of 5 degrees could be tested. The method of planning could be explored by comparing the VMAT planning technique to photon and electron energy plans. New and innovative ideas still exist in this research.

Conclusion

Many choices go into planning a CWI between bolus type, bolus thickness, beam energy, tangential angles, etc. and once out on the treatment machine errors can occur. Air gaps are frequently spotted between the patient surface and bolus for treatment. From this study it is evident that if an air gap of 1cm is present significant decreases in skin dose can occur. While a significant difference was not found in air gap sizes of 0.3cm to 0.7cm, it was shown that the dose does decrease with an increasing air gap.

The superior choice in beam energy is a 10MV photon beam. Larger doses can be seen in the chest wall, even in the presence of an air gap and the dose to the skin never went below the daily prescription of 200 cGy. Lastly, selecting a custom aquaplast bolus will aid in conforming to the patient, reducing air gaps, and provide the most effective bolus effect by way of skin dose when compared to other bolus types. Knowing the affect air gaps can have CWI's helps reinforce important planning choices of bolus type and beam energy.

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Table 1. No Air Gap (Control)

		Beam Energies			
		6MV	10MV	9MeV	12MeV
Bolus Type	Superflab	205.4 cGy	210.6 cGy	201.4 cGy	204.4 cGy
	Elastogel	205.4 cGy	210.7 cGy	201.3 cGy	204.4 cGy
	Steel Brass	205.9 cGy	211.0 cGy	201.9 cGy	204.7 cGy
	Custom Aquaplast	205.7 cGy	210.8 cGy	201.9 cGy	204.7 cGy
	Wet Towel	205.1 cGy	210.4 cGy	201.1 cGy	204.2 cGy

Table 2. 0.3cm Air Gap

		Beam Energies			
		6MV	10MV	9MeV	12MeV
Bolus Type	Superflab	204.7 cGy	210.0 cGy	200.8 cGy	203.9 cGy
	Elastogel	204.8 cGy	210.0 cGy	200.7 cGy	203.8 cGy
	Steel Brass	205.1 cGy	210.4 cGy	201.0 cGy	204.0 cGy
	Custom Aquaplast	204.9 cGy	210.3 cGy	201.1 cGy	203.9 cGy
	Wet Towel	204.0 cGy	209.8 cGy	200.3 cGy	203.5 cGy

Table 3. T-test 0cm vs. 0.3cm

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	38	0.64	0.5232
Satterthwaite	Unequal	37.992	0.64	0.5232

Figure 1. Distribution of Outcome of 0cm vs. 0.3cm

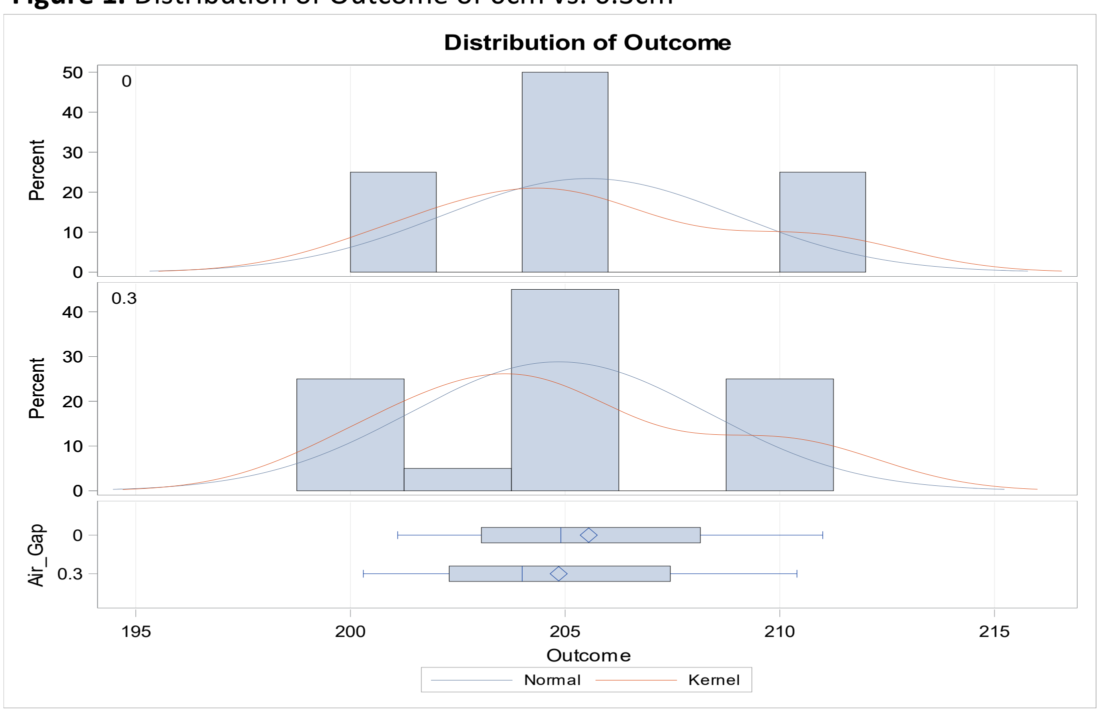

Table 4. 0.5cm Air Gap

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Beam Energies</td></tr>
<tr><td>6MV</td><td>10MV</td><td>9MeV</td><td>12MeV</td></tr>
<tr><td rowspan="5">Bolus Type</td><td>Superflab</td><td>204.1 cGy</td><td>209.6 cGy</td><td>200.2 cGy</td><td>203.3 cGy</td></tr>
<tr><td>Elastogel</td><td>204.3 cGy</td><td>209.5 cGy</td><td>200.2 cGy</td><td>203.4 cGy</td></tr>
<tr><td>Steel Brass</td><td>204.5 cGy</td><td>209.8 cGy</td><td>200.5 cGy</td><td>203.4 cGy</td></tr>
<tr><td>Custom Aquaplast</td><td>204.4 cGy</td><td>209.8 cGy</td><td>200.5 cGy</td><td>203.2 cGy</td></tr>
<tr><td>Wet Towel</td><td>203.5 cGy</td><td>209.0 cGy</td><td>199.7 cGy</td><td>203.0 cGy</td></tr>
</table>

Table 5. T-test 0 vs. 0.5cm

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	38	1.16	0.2552
Satterthwaite	Unequal	37.991	1.16	0.2552

Figure 2. Distribution of Outcome of 0cm vs. 0.5cm

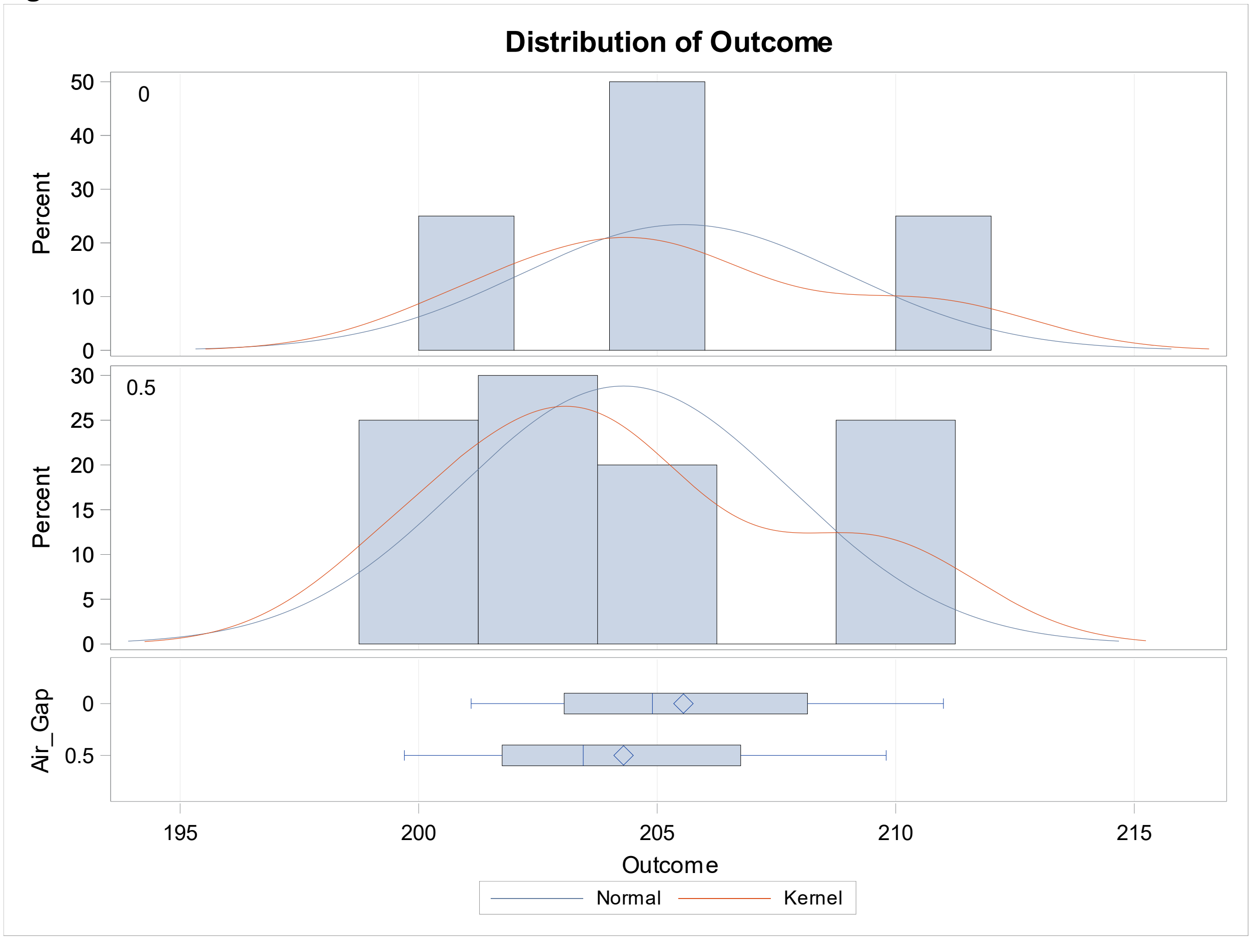

Table 6. 0.7cm Air Gap

		Beam Energies			
		6MV	10MV	9MeV	12MeV
Bolus Type	Superflab	203.2 cGy	208.7 cGy	199.4 cGy	202.3 cGy
	Elastogel	203.3 cGy	208.5 cGy	199.2 cGy	202.3 cGy
	Steel Brass	203.6 cGy	209.0 cGy	199.6 cGy	202.5 cGy
	Custom Aquaplast	203.5 cGy	208.9 cGy	199.5 cGy	202.3 cGy
	Wet Towel	202.6 cGy	208.0 cGy	198.9 cGy	202.1 cGy

Table 7. T-test 0cm vs. 0.7cm

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	38	2.01	0.0518
Satterthwaite	Unequal	37.992	2.01	0.0518

Figure 3. Distribution of Outcome of 0cm vs. 0.7cm

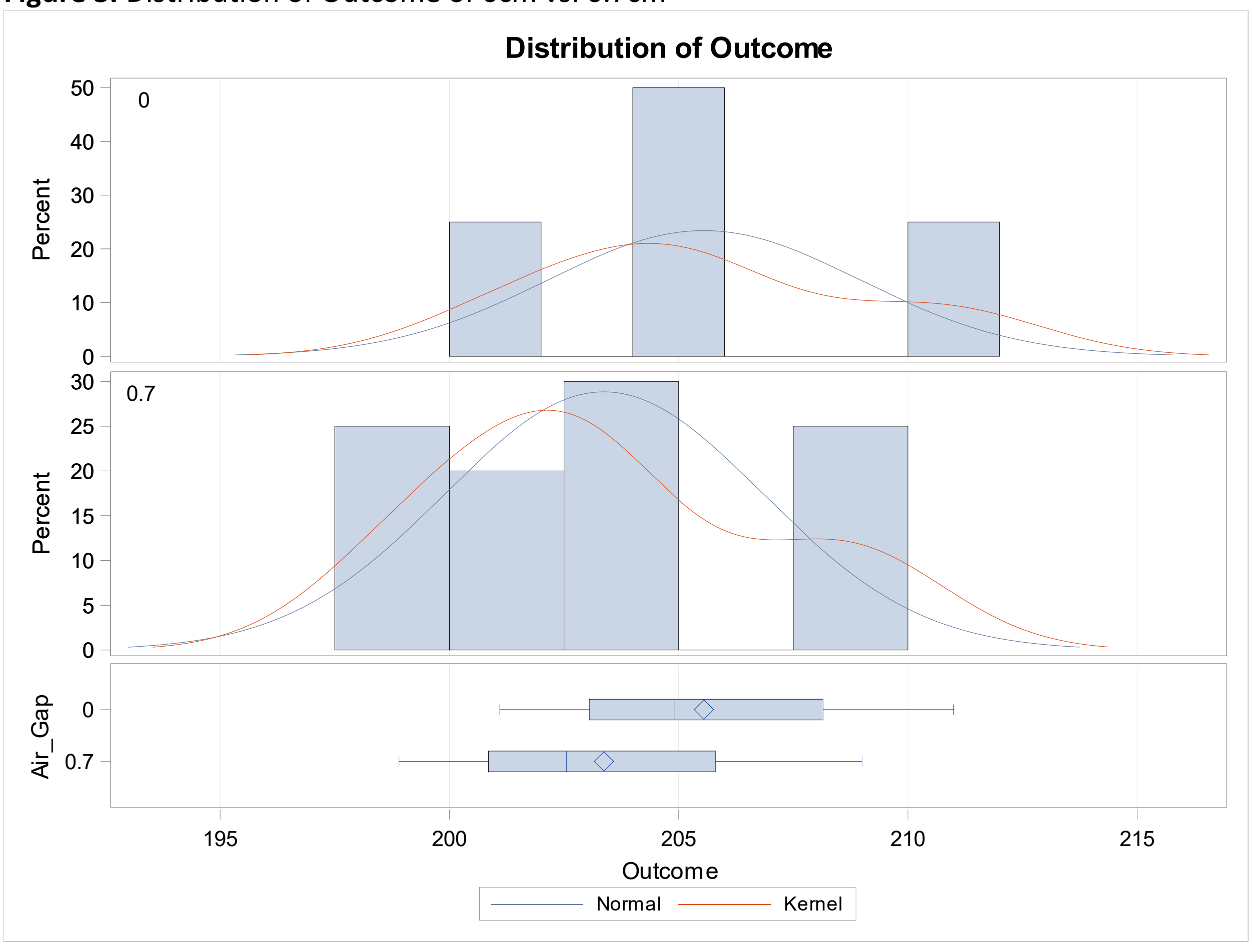

Table 8. 1cm Air Gap

		Beam Energies			
		6MV	10MV	9MeV	12MeV
Bolus Type	Superflab	201.8 cGy	207.3 cGy	198.2 cGy	201.0 cGy
	Elastogel	202.0 cGy	207.0 cGy	198.0 cGy	201.1 cGy
	Steel Brass	202.0 cGy	208.0 cGy	198.3 cGy	201.3 cGy
	Custom Aquaplast	202.1 cGy	207.7 cGy	198.4 cGy	201.2 cGy
	Wet Towel	201.2 cGy	206.9 cGy	197.6 cGy	200.7 cGy

Table 9. T-test 0cm vs. 1cm

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	38	3.19	0.0029
Satterthwaite	Unequal	37.992	3.19	0.0029

Figure 4. Distribution of Outcome of 0cm vs. 1cm