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A Dosimetric Evaluation of Increasing Scalp Sparing Between Varied Energy Photon Beams and MLC Blocking Techniques Among Whole-Brain Irradiation Patients

Addah Riebschleger
Grand Valley State University

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Grand Valley State University

Graduate Medical Dosimetry Program

Abstract

Introduction

Whole brain radiation therapy (WBRT) is one of the most effective ways to treat brain metastases. Whole brain radiation therapy is typically planned 3D conformal with a right lateral and left lateral beam arrangement using a 6 mega voltage (MV) beam energy. Lower energy photon beams distribute a greater dose at surface level compared to higher energy photon beams. Using a higher energy photon beam (15 MV) to treat WBRT patients may reduce dose to the scalp and improve the patient's overall quality of life (QOL).

Methods

The study is a retrospective dosimetric analysis of 10 randomly selected whole brain radiation therapy patients. Each patient had four plans created to compare 6 MV vs 15 MV photon energy as well as a scalp-sparing technique vs an open field technique. Dose to critical structures and scalp were fabricated and analyzed by the principle investigator due to a lack of IRB approval. A paired T-Test was performed using IBM-SPSS Statistics software to test for significance between the means of the groups.

Results

The results indicated statistically significant lower dose levels to the scalp on the 15 MV plans and on the scalp sparing plans compared to the 6 MV plans and open field technique plans. Dose coverage to the brain was higher on 15 MV plans and open field technique plans compared to the 6 MV plans and scalp-sparing technique plans. Lens and Optic nerves displayed statistically significant lower doses at 6 MV compared to 15 MV, while Parotids displayed statistically significant lower doses at 15 Mv compared to 6 MV. Lens and Parotids had statistically significant lower doses on scalp-sparing technique plans compared to the open field technique.

Conclusion

Significant dose reduction to the scalp can be accomplished by using a Scalp-sparing technique and/or by using a higher energy photon beam (15 MV), while maintaining adequate coverage to the brain. Critical structure doses were not clinically significant between plans and remained within their allotted tolerances. Future studies should be pursued to examine clinical hair loss and overall quality of loss due to this dose reduction to the scalp.

Introduction

It is estimated that in 2020, there will be 1,806,590 new cancer cases for adults in the United States alone (National Cancer Institute, 2020). Mayo Clinic (n.d.) estimates that roughly 10-30% of all cancer cases metastasize to the brain. With these statistics, that amounts to an annual incidence of 180,659 to 541,977 patients diagnosed with metastatic brain cancer per year, making them 10 times more common than primary brain tumors and the most common intracranial neoplasms in adults (Khan et al., 2016). Fortunately, whole brain radiation therapy (WBRT) is one of the most effective ways to treat brain metastases and prophylaxis for microscopic disease known as prophylaxis intracranial irradiation (PCI). PCI is utilized as a prevention tool to increase survival rates for those at a high risk of developing brain metastases from cancers that typically metastasize i.e., small cell lung cancer (McTyre et al., 2013). Brain metastases occur when cancerous cells travel through the bloodstream or the lymph nodes to the brain and begin to multiply. These cells are named after the primary cancer's location (National Cancer Institute, 2015). Lung, breast, and melanoma cancers are the most common types of cancer to metastasize to the brain (Giglio & Gilbert, 2010). Brain metastases are most commonly found in the brain parenchyma. The cranium, dura, and leptomeninges are other less common sites of metastases (Nayak et al., 2012).

Simulation of Whole Brain Treatments

Simulation is a very important aspect of the treatment planning process. The biggest priorities of simulation are reproducible patient position and immobilization (Khan et al., 2016). Simulation of WBRT treatments are done in the supine position with the patient's arms at their sides. A head rest is used to make sure the patient's head is not tilted. A thermoplastic immobilization device is then made and is formed individually to each patient's head. Reference markers are applied directly to the outside of the mask, in line with the lasers, to indicate the location of isocenter (Le et al., 2018). The use of these reference markers allows the radiation therapist to produce an accurate replication of the patient's position during simulation for treatment, so that the dose is being treated to the correct target.

Standard Treatment Information

Whole brain radiation therapy is typically planned 3D conformal with a right lateral and left lateral beam arrangement. The standard prescription for brain metastases is 3 Gray (Gy) for 10 fractions using a 6 mega voltage (MV) beam energy. There is at least 1-2 cm of flash surrounding the anterior, superior and posterior sides of the skull. The inferior border is set in the intervertebral space between Cervical Vertebrae 1 (C1) and Cervical Vertebrae 2 (C2) with a 1 cm block margin posteriorly. The base of the skull, also, has a 1 cm margin block. These borders ensure the whole brain is treated and includes the entire skull and scalp. The lenses are blocked with a face block of 1 cm margin on the middle cranial (Khan et al., 2016).

Although 3D conformal is the most common treatment technique for WBRT, intensity-modulated radiation therapy (IMRT) is also another treatment technique that can be utilized. IMRT allows the dosimetrist to modulate the dose distribution. This higher level of accuracy allows the dosimetrist to be able to "sculpt" their dose distribution so that minimal radiation is administered to healthy nearby critical structures, such as the brain stem, parotids, and the hippocampus (Bucci et al., 2005).

Critical Structures Side Effects

An advantage with the use of IMRT is noted to be the preservation of the hippocampal function. Gondi et al. (2010) provided a clinical trial that demonstrated a significant neurocognitive decline in memory and learning starting at four months post radiation treatment in whole brain radiation therapy. His later research states that by using IMRT, they were able to avoid the neural-component of the hippocampus and preserve the neural stem cells that are associated with memory function, thus increasing the overall memory function of the patients post therapy (2016).

There are several other critical structures that play a key role in side effects experienced after WBRT: the optic nerves, the lens, and the scalp. The optic nerves have a maximum dose of 54 Gy for standard fractionation doses of 1.8 to 2 Gy/fraction(fx) (Marks et al., 2010). Once the optic nerves begin to get close to a max dose of 50 Gy, the chances of Radiation-induced Optic Neuropathy (RION) increases. RION is presumed to be caused by the degradation of endothelial cells by radiation, specifically, the vascular endothelial cells in the optic nerve. Radiation-induced optic neuropathy runs a low risk for doses under 50 Gy, 5% risk at doses between 50-60 Gy, and 30% risk for doses above 60Gy (Danesh-Meyer, 2008). In WBRT treatments, that maximum dose of 54 Gy decreases to 37.5 Gy because of the increase to 3Gy/fx (Jiang et al., 2019). Cataracts are a side effect from radiation dose to the lens and has a dose-effect relationship with age. The fibers in the eye begin to break down in as little as 2 Gy. It is recommended to keep the maximum dose of the total lenses between 5 to 10 Gy (Scoccianti et al., 2015). There is a 33% risk of the development of cataracts after 8 years when administering a dose of 2.5 to 6.5 Gy. This statistic doubles to a 66% risk in a period of 4 years if dosed to 6.5 to 11.5 Gy (Jeganathan et al., 2011).

One of the most noticeable side effects with whole brain radiation treatment, and what patients have considered having the greatest impact on their quality of life (QOL), is hair loss (De Puysseleyr et al., 2014). According to the Common Terminology Criteria for Adverse Events (CTCAE v4.0), alopecia grading is categorized into 3 groups. Group 0 is equivalent to no observed hair loss. Group 1 is equivalent to 50% or less of hair loss, it is noted that patients in this group may still need a different hair style to cover hair loss. Group 3 is equivalent to hair loss over 50%, a wig or hair piece may be necessary for this group (National Cancer Institute, n.d.). Previous studies conducted in regard to alopecia have observed that Grade 1 alopecia occurs around a max radiation dose of 30 Gy and Grade 2 is around a max radiation dose of 46 Gy (Lawenda et al., 2004). Scoccianti (2020) stated that doses between 16-20 Gy generate G1 alopecia that is generally recoverable. Keeping the dose max of the scalp below 30 Gy would reduce the risk of the occurrence of alopecia. Metz et al. (2004) investigated radiation-induced alopecia in their study where they applied a gel called 'Temporal' to the patients' heads pre-radiation treatment and assessed hair retention post-treatment. The objective of their study was to discover a new way to protect the hair follicles during whole brain radiation therapy. The study found that moderate to almost full hair retention was observed in 3 of the 5 patients, with very minimal adverse effects, because of the application of Temporal.

Dosimetrists have also utilized a multi-leaf collimator (MLC) blocking technique known as a "scalp block" to reduce the hair loss effect on patients by reducing scalp dose. The MLC blocking technique known as a scalp block is used in the treatment of brain metastases. The brain parenchyma is treated with a 1-cm block margin that completely encompasses the skull but does not include the C-2 (Khan et al., 2016). This 1-cm block margin blocks the scalp to protect the hair follicles from excessive radiation dose. Howel & Huberts (2012) conducted a study on the efficiency of the scalp block in regard to scalp dose. They compared an open parallel opposed lateral fields treatment plan (the conventional 3D technique) to three scalp block fields, each with a different amount of centimeter margin encompassing the total brain volume. All three scalp block treatment plans had significant reduction of total scalp dose compared to the open field plan, without reducing dose to the total brain volume. They concluded that this significant decrease could potentially reduce the onset of alopecia in WBRT patients.

Beam Energy

Different amounts of dose are distributed at the surface between different energy beams. Lower energy beams, such as 6 MV, distribute a greater dose at the surface compared to an 18 MV energy beam due the beam's build up region (Klein et al., 2003). Yu et al. (2003) studied the percent maximum dose at three different layers of the skin between varied energy beams. There was very little difference in the percent of maximum dose at the skin's basal layer at .07 mm between 6 MV and 18 MV. It is at the 1 mm (dermal layer) and 1 cm (subcutaneous layer) that the percent maximum dose significantly began to differ. The 6 MV photon beams have a percent maximum dose of roughly 20% higher than the 18 MV photon beams. Hair follicles are approximately 5 mm below the scalp (De Puysseleyr et al., 2014). This leads to the idea that where the percent of maximum dose differs the greatest between the two energies, is the depth that hair follicles are being radiated. The most common way to treat WBRT is with a beam energy of 6 MV, but because of Yu et al. (2003) there is reason to believe that a higher energy beam could be more beneficial by increasing scalp sparing. Saweda et al. (2020) performed a dosimetric evaluation of the reduction of alopecia by varying the energy of the photon beams. They did not investigate what impact the energy beams may have had on any critical structures nearby, nor did they compare varying MLC techniques. Their study consisted of 10 patients and four plans per patient: 6MV vs 15 MV, with Field in Field (FiF) vs without FiF. They discovered that by using the 15MV with Fif and without FiF, there was sufficient coverage and a lower scalp dose than the 6MV. They inferred that the 15MV photon beam may lower the occurrence of alopecia, but due to it being a dosimetric evaluation they were unable to evaluate if the lower scalp dose would cause an improvement in the patients' quality of life.

Quality of Life (QOL)

In a study done by Slotman et al. (2009) they examined the short-term health-related Quality of Life of patients with extensive-disease small-cell lung cancer who received PCI. Hair loss had the biggest difference in means amongst all other factors, indicating it was one of the factors that affected their QOL the greatest. The researchers indicate that the incidence of brain metastases decreased, and overall survival was increased, but it was at the cost of the patient's QOL with the loss of their hair. This raises the question that why can't the patient have both dose coverage and the reduction of scalp dose?

Comparison of Treatment Plans

Several studies have been done investigating that very question of having both dose coverage and the reduction of scalp dose, but with the approach of a different treatment technique instead of the conventional 3D conformal technique i.e., IMRT, volumetric-modulated arc therapy (VMAT), and Tomotherapy. Welsh et al. (2005) compared Tomotherapy vs IMRT, as well as compared Tomotherapy to conformal 3D WBRT. They concluded that Tomotherapy has sufficient skin sparing and still maintained the coverage needed. De Puysseleyr et al. (2014) investigated temporary alopecia by comparing VMAT WBRT to 3D conformal WBRT. Their results showed that VMAT WBRT had reduced the mean subcutaneous dose by 20.5%, potentially reducing the risk of alopecia in comparison to conventional WBRT. Finally, Kao et al. (2015) compared conventional lateral opposed fields with MLC's vs IMRT amongst WBRT patients. They defined scalp as skin + 3 mm depth. They concluded that 27% of patients preserved at least 50% of their hair with IMRT. IMRT also reduced the scalp dose compared to conventional WBRT from 26.2 Gy to 16.4 Gy. These other treatment options reduce scalp dose more efficiently than 3D conformal, but 3D conformal is more beneficial in comparison to them and should be utilized due to cost and time efficiency. There are several countries, an example being Japan, that do not allow the use of insurance to cover IMRT or VMAT treatments. As well, patients receiving 3D conformal treatments are often able to start their treatment quicker than those being planned using IMRT/VMAT. This is beneficial to patients who are experiencing more, and or a quicker onset of, symptoms due to their metastases (Sawada et al., 2020).

Purpose of the Study

In this study, the researcher is examining the gap in research between different energy beams and different MLC blocking techniques on scalp dose in consideration with doses to the critical structures. There is no study that included both beam energy and critical structure evaluation at the same time. There also have been no studies published that compare different energy beams against different MLC techniques. Does MLC blocking techniques or varying beam energy have a significant impact on increasing scalp sparing? The purpose of this study is to investigate if using higher energy beam and or different MLC blocking techniques can still give adequate coverage to the patient while reducing scalp dose. It is also to evaluate if it does reduce the scalp dose, if other critical structures then have a higher dose. The research goal is that increasing energy beams will reduce scalp dose and not have a significant impact on critical structures, so that WBRT patients can have a better probability of not losing their hair post treatment.

Two hypotheses are being tested:

Null Hypothesis (Ho): Beam energy does not have a significant impact on scalp dose among whole brain radiation patients.

Alternative Hypothesis (Ha): Beam energy does have a significant impact on scalp dose among whole brain radiation patients.

Null Hypothesis (Ho): MLC techniques do not have a significant impact on scalp dose among whole brain radiation patients.

Alternative Hypothesis (Ha): MLC techniques do have a significant impact on scalp dose among whole brain radiation patients.

Methods

Subjects

This is a retrospective study that is based on the population of WBRT patients at a Midwest institution over the past two years. The population sample was randomly chosen to reduce bias. A total of ten patients were selected. This study assesses only physical dose distributions; therefore, a small sample size is appropriate. Each patient already received and completed their prescribed course of treatment and only the patient's CT scan was used for the study. Inclusion and exclusion criteria for patient selection is listed below.

Inclusion Criteria:

- WBRT treatment due to Metastatic Disease
- Population age > 18
- Patient at the Midwest institution within the past two years of study

Exclusion Criteria:

- WBRT treatment as a form of preventative care i.e. the treatment of:
    - Leukemia
    - Lymphoma
- "Vulnerable" populations in accordance with Midwest institution guidelines
    - Hospitalized patients
    - Terminally ill, traumatized, comatose patients
    - Students and employees
    - Residents of institutions (mentally ill, prison inmates)
    - Normal volunteers
    - Minorities
    - Non-viable fetus and dead fetal material

Ethical Considerations

This is a retrospective study. IRB approval was sought after for this study. The protocol for the research project was submitted to a suitably constituted ethics committee, but due to time constraint of the paper, IRB approval was not gained. Methods and research design for this project was based strictly on had IRB approval been granted in a timely manner. All data for this project was fabricated based on dose trends by the Principle Investigator. No current or past patient data was used during the course of this study. No patient data was accessed by any other personnel during the course of this study. Patient information was not used or disclosed to others except as required by law, for oversight of the research, or for the other research that would be permitted by HIPPA.

Instrumentation

Patients were immobilized with a standard head and neck board indexed to F1 on the table. A ‘B’ head rest and a 3-point mask was used, that attached to the board. Big Bore CT (Philips Medical Systems) was used to take Computed Tomography (CT) image sets for the treatment planning. CT image sets were taken with a 2 mm slice thickness. No contrast material was used. Contouring and treatment planning was completed via Eclipse treatment planning system (Varian Medical System). Dose calculation was completed with an analytical anisotropic algorithm (AAA) in Eclipse.

Research Design

Each patient had four plans created: scalp sparing technique with a beam energy of 6MV (SS6X), scalp sparing technique with a beam energy of 15MV (SS15X), conventional technique with a beam energy of 6MV (CT6X), and conventional technique with a beam energy of 15MV (CT15X). The scalp sparing technique’s field borders included the treatment of the brain parenchyma with a 1-cm block margin that completely encompasses the skull but does not include the C-2. The conventional technique’s field borders included at least 1-2 cm of flash surrounding the anterior, superior and posterior sides of the skull. The inferior border was set to the intervertebral space between C1 and C2 with a 1 cm block margin posteriorly and at the base of the skull. The brain, lens, optic nerves, and parotids were delineated for each patient by following the RTOG atlas. The scalp contour was based on Kao et al.’s (2015) study that concluded the scalp was skin plus 3 mm depth as to include hair follicles from the level of the canthi to the inferior border (between C1 and C2). All treatment plans consisted of two opposed lateral photon beams. The gantry was angled a few degrees anteriorly for lens sparing. All plans had a prescription dose of 30 Gy in 10 fractions. Data collected included the maximum dose to the lens, optic nerves, parotids, scalp, the mean PTV, PTV D95, and the mean scalp doses.

Statistical Data Analysis

In order to test for statistical significance amongst energy levels and MLC techniques, a paired T-test was used to analyze if there was a significant difference between the two means within each subject. A significance level of $p \leq .05$ was used. Dose-volume histograms were assumed to be normally distributed. All the statistical tests were performed using the IBM-SPSS Statistics software (Statistical Package for Social Science, version 26).

Results

The goal of this study is to evaluate whether higher energy beams and/or different MLC blocking techniques can reduce scalp dose, while maintaining adequate coverage to the PTV. If by reducing the scalp dose, the investigator examined whether critical structures would then be negatively impacted by receiving a higher dose. No outliers were reported and/or removed from this study.

Lens

The lens' max dose was evaluated on all four plans. All four plans found significant results. As shown in Figure 1., Scalp Sparing (SS) 6x reported a significantly lower max dose than the conventional technique (CT) 6x (M = -.60500, SD= .37340), t(9) = -5.124, p<.001. SS 15x reported a significantly lower max dose than CT 15x (M = -.81900, SD = .42202), t(9) = -6.137, p<.00<.05. SS 6x reported a significantly lower max dose than SS 15x (M = -.95500, SD = .91979), t(9) = -3.283, p<.009. CT 6x reported a significantly lower max dose than CT 15x (M = -1.16900, SD = .82209), t(9) = -4.497, p<.001. The lens on SS6x plan had a max dose range of

2.65 Gy to 5.8 Gy, with a mean of 4.052 Gy. On the SS15x plan, the max dose to the lens had a range of 2.94 Gy to 8.06 Gy, with a mean of 5.007 Gy. The lens on the CT6x plan had a max dose range of 2.88 Gy to 5.82 Gy, with a mean of 4.675 Gy. On the CT15x plan, the max dose to the lens had a range of 3.35 Gy to 8.64 Gy with a mean of 5.8260 Gy.

Optic Nerves

The Optic Nerves' max dose was evaluated on all four plans. All plans found significant results besides plan SS 15x vs CT 15x. As shown in Figure 2., SS 6x reported a significantly higher max dose than CT 6x (M = .17600, SD = .15443), t(9) = 3.604, p<.006. SS 15x and CT 15x did not differ significantly in max dose, (M = .02500, SD = .28957), t(9) = .273, p= .791. SS 6x reported a significantly lower max dose than SS 15x (M = -.45500, SD = .34452), t(9) = -4.176, p<.002. CT 6x reported a significantly lower max dose than CT 15x (M = -.60600, SD = .28084), t(9) = -6.824, p<.00<.05. The optic nerves on SS6x plan had a max dose range of 2.65 Gy to 5.8 Gy, with a mean of 4.052 Gy. On the SS15x plan, the max dose to the optic nerves had a range of 2.94 Gy to 8.06 Gy, with a mean of 5.007 The optic nerves on the CT6x plan had a max dose range of 2.88 Gy to 5.82 Gy, with a mean of 4.675 Gy. On the CT15x plan, the max dose to the optic nerves had a range of 3.35 Gy to 8.64 Gy with a mean of 5.8260 Gy.

Parotids

The Parotids' mean dose was evaluated on all four plans. All four plans found significant results. As shown in Figure 3., SS 6x reported a significantly lower mean dose than CT 6x, (M = -.53100, SD =.46467), t(9) = -3.614, p=.006. SS 15x reported a significantly lower mean dose than CT 15x (M = -.62100, SD = .47976), t(9) = -4.093, p = .003. SS 6x reported a significantly higher mean dose than SS 15x (M =.31300, SD = .21261), t(9) = 4.656, p=.001. CT 6x reported a significantly higher mean dose than CT 15x (M = .22300, SD = .19687), t(9) = 3.582, p=.006. The parotids on SS6x plan had a mean dose range of 4.71 Gy to 13.28 Gy, with a mean of 8.986 Gy. On the SS15x plan, the mean dose to the parotids had a range of 4.59 Gy to 12.66 Gy, with a mean of 8.673. The parotids on the CT6x plan had a mean dose range of 4.81 Gy to 14.48 Gy, with a mean of 9.517 Gy. On the CT15x plan, the mean dose to the parotids had a range of 4.75 Gy to 13.97 Gy with a mean of 9.2940 Gy.

Scalp

The Scalp max and mean doses were evaluated on all four plans. All plans in regard to both Scalp categories found significant results. As shown in Figure 4., SS 6x reported a significantly higher max dose than SS 15x, (M = 2.43800, SD = .62675), t(9) = 12.301, p<.00<.05. CT 6x reported a significantly higher max dose than CT 15x, (M = 2.88300, SD = .54577), t(9) = 16.704, p<.00<.05. SS 6x reported a significantly lower max dose than CT 6x, dose (M = -3.72600, SD = .74430), t(9) = -15.831, p<.00<.05. SS 15x reported a significantly lower max dose than CT 15x, (M = -3.28100, SD = .78970), t(9) = -13.138, p<.00<.05.

As shown in Figure 5., SS 6x reported a significantly higher mean dose than SS 15x, (M = .82000, SD = .13824), t(9) = 18.757, p<.00<.05. CT 6x reported a significantly higher mean dose than CT 15x, (M = 1.53200, SD = .07627), t(9) = 63.516, p<.00<.05. SS 6x reported a significantly lower mean dose than CT 6x, dose (M = -5.83500, SD = .47540), t(9) = -38.813, p<.00<.05. SS 15x reported a significantly lower mean dose than CT 15x, (M = -5.12300, SD = .39727), t(9) = -40.779, p<.00<.05.

Brain

The PTV mean, D95, and 3D dose max were evaluated on all four plans. Both plans found significant results in regard to energy beam comparison in all three categories. Only plan

SS 6x vs CT 6x did not find significant results in two of the three categories in regard to MLC techniques.

The maximum, minimum, mean, and standard deviation for all four plans of each category can be found in Table 1. SS 6x reported a significantly lower PTV mean dose (M = -.22200, SD = .25112, t(9) = 02.796)) and D95 dose (M = -1.30000, SD = .64118, t(9) = -6.412)), while a significantly higher max dose (M = 1.28000, SD = .64429, t(9) = 6.282)) than SS 15x, p<.00<.05. CT 6x reported a significantly lower PTV mean dose (M = -.36700, SD = .08341, t(9) = -13.914)) and D95 dose (M = -1.54000, SD = .55618, t(9) = -8.756)), while a significantly higher max dose (M = 4.00000, SD = .83931, t(9) = 15.071)) than CT 15x, p<.00<.05. SS 6x vs CT 6x for PTV mean dose (M = .05000, SD = .20923) did not differ significantly, t(9) = .756, p = .461. SS 6x vs CT 6x for D95 (M = -.09000, SD = .36040) did not differ significantly, t(9) = -.790, p = .450. SS 6x reported a significantly lower max dose than CT 6x (M = -4.83000, SD = .64127), t(9) = -23.818, p<.00<.05. SS 15x reported a significantly lower PTV mean dose (M = -.09500, SD = .04197, t(9) = -7.159)), D95 dose (M = -.33000, SD = .17670, t(9) = -5.096)), and max dose (M = -2.11000, SD = .48178, t(9) = -13.850)) than CT 15x, p<.00<.05.

Discussion

All critical structures in all plans remained within their tolerances as referenced by QUANTEC (2010). There was no clinical significance in regard to brain coverage between any of the four plans. Scalp Sparing plans significantly reduced the dose to the scalp compared to the open field technique plans. In addition, scalp dose was also reduced when using a higher energy photon such as 15 MV compared to using a lower energy photon beam i.e., 6 MV.

Critical Structures (Lens, Optic Nerves, Parotids)

All critical structures displayed statistically significant results between the plans. Although, this is not to say that these results were clinically significant. QUANTEC (2010) protocol was followed for the lens, optic nerves, and parotids during planning evaluation. Per Quantec protocol, the max dose that the lens can receive is 7 Gy to reduce the risk of Cataracts, although the fibers in the eye begin to break down in as little as 2 Gy. To reduce the risk of Optic Neuropathy to less than 3%, optic nerves can not exceed a max dose greater than 55 Gy. Finally, in order to preserve long-term salivary function by reducing the risk xerostomia, the Parotids must not be greater than a mean of 25 Gy. The ranges, means, and standard deviations for all three critical structures can be found in Table 2.

The max dose to the lens was evaluated on all four plans. The 6x plans were statistically significantly better than the 15x plans, as well as the scalp sparing plans were statistically significantly better than the conventional field technique plans. When evaluating the ranges, both 6x plans had a max range of 5.8-5.82, which are in tolerance of the max dose of 7 Gy, whereas the 15x plans had a max range of 8.06-8.64 Gy which is slightly over the tolerance of 7 Gy, increasing the patients' risk of cataracts. This difference could be due to the increased scatter that occurs at higher photon energies, causing the lens to absorb more dose on the 15x plans compared to the 6x plans (Wang et al., 2002). When comparing the SS vs the CT plans, it is noted there is a statistical significant difference, but when evaluating the range max's, as well as their means, there is no clinical significance between the two plans as they still fall within their tolerances.

This clinical significance analysis was done for the optic nerves and parotids as well. Although a statistically significant difference was found between the 6x plans and the 15x plans in regard to the optic nerves, all plans' maxes ranged between 31.05 to 31.40, which is significantly under the QUANTEC max dose needed of <55 Gy. When evaluating the Partoids, an explanation as to why the 15x plans were statistically significantly better the 6x plans could be due to dose build up. The parotid gland is roughly 3.4 cm deep from the surface of skin (Jousse-Joulin, 2010). When examining a percent depth dose (PDD) chart, the dose max occurs at roughly 1.62 cm for 6 MV beams and 2.65 cm for 15 MV photon beams (Ibrahim et al., 2018). This means that there is less absorbed dose until it gets deeper into the parotids for the 15 MV plan compared to the 6 MV plan. All four plans have mean max doses' that are below the tolerance limit of 25 Gy, making all plans treatable plans in regard to parotid sparing.

Brain/Scalp

As shown in Table 1, all plans were statistically significant in regard to the brain's coverage, but no plan was clinically significant. All plans produced would be considered a treatable plan when analyzing dose coverage in the brain. All 15 MV and open field technique plans had higher radiation doses than their counter 6 MV and scalp sparing plans, but all plans fell within the required guidelines for treatment. The PTV-means were.317 Gy apart between the lowest dose plan and highest dose plan. The D95 was evaluated and even the plan with the least coverage (SS6x) was still greater than the required 95% for a minimum dose with a minimum dose of 97.60% and a mean of 99.13%. Finally, when evaluating the dose max, both the scalp sparing plans and CT15x plan have means that fall below the recommended dose metrics hot spot of 110%. The scalp sparing 15 MV plan is the only plan with a dose max maximum range of less than 110% (109%), making it the superior plan out of the four plans in regard to dose max.

As shown in Figure 4 and Figure 5, significant differences were found amongst all plans in regard to scalp max dose and the scalp mean dose. The scalp max and mean were significantly lower on the scalp sparing plans and 15x plans compared to the conventional technique plans and 6x plans. Lawenda et al. (2004) observed Grade 1 hair loss occurring around a max dose of 30 Gy. SS6x, SS15x, and CT15x, all had scalp max means below 30 Gy. When combining the scalp sparing technique and 15 MV, there is an observed scalp max maximum range of 27.80 Gy, making SS15x the only plan that falls below that 30 Gy cut off. The same was found when evaluating the scalp mean plans. Scoccianti (2020) stated that doses between 16-20 Gy generate G1 alopecia that is generally recoverable. Both scalp sparing plans had scalp mean maximum range below 16 Gy, compared to the conventional field technique plans that both were over 16 Gy. When combining the scalp sparing technique with the 15 MV energy beam in a plan (SS15x), it produced the lowest minimum, maximum, and mean amongst all four plans. It could be assumed that by combining the scalp sparing technique with a higher energy, there is potential to reduce hair loss completely.

There have been previous studies that evaluated different energy beams with WBRT patients, but no previous studies have evaluated the critical structure constraints in addition to that, nor differing MLC technique. The results of this study are consistent with the study done by Sawada et al. (2020) who discovered that by using the 15MV there was sufficient coverage and a lower scalp dose than the 6MV plan.

Bias/Limitations

The largest limitation to this study was the lack of IRB approval. This limitation caused the fabrication of results based on the principle investigator's assessment on what they assumed the trends to be, resulting ultimately in it being based on their own bias. QOL could only be assumed and could not be accurately assessed because this was not a clinical trial and did not have real-time results based on plans. Had the project been granted IRB approval, random error could have occurred due to the small sample size of originally ten patients. With IRB approval, results would have been more accurately evaluated and conclusions could have been drawn between the plans more confidently.

Conclusion

In conclusion, photon energy and MLC techniques have a significant effect on the amount of radiation dose received in WBRT patients. By using a higher energy photon beam, and or, using the scalp sparing MLC technique, it can significantly decrease the dose to the scalp, while not compromising critical structures. As such, the use of the higher photon energy does not compromise the overall brain coverage. Although critical structure doses were statistically significant between plans, there was no clinical significance between the plans based on their doses still falling within the range of their tolerances. Due to the fabrication of results, future studies should be done to assess if the trends assumed were accurate and are important in order to truly assess an increase of QOL based on the results. Future studies could include assessing a higher energy photon beam (18X) to see if scalp dose could be reduced further. A clinical trial could be conducted in order to assess hair loss efficiently and accurately in WBRT patients based on the different plans created.

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Figure 1. Lens Scalp Sparing vs Conventional; Lens 6x vs 15x

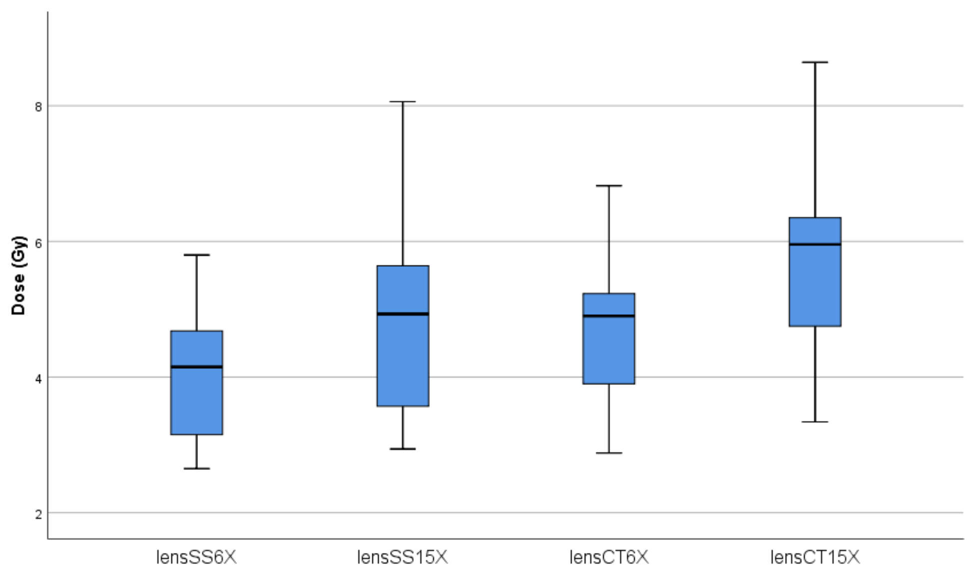

Figure 2. Optic Nerves Scalp Sparing vs Conventional; Optic Nerves 6x vs 15x

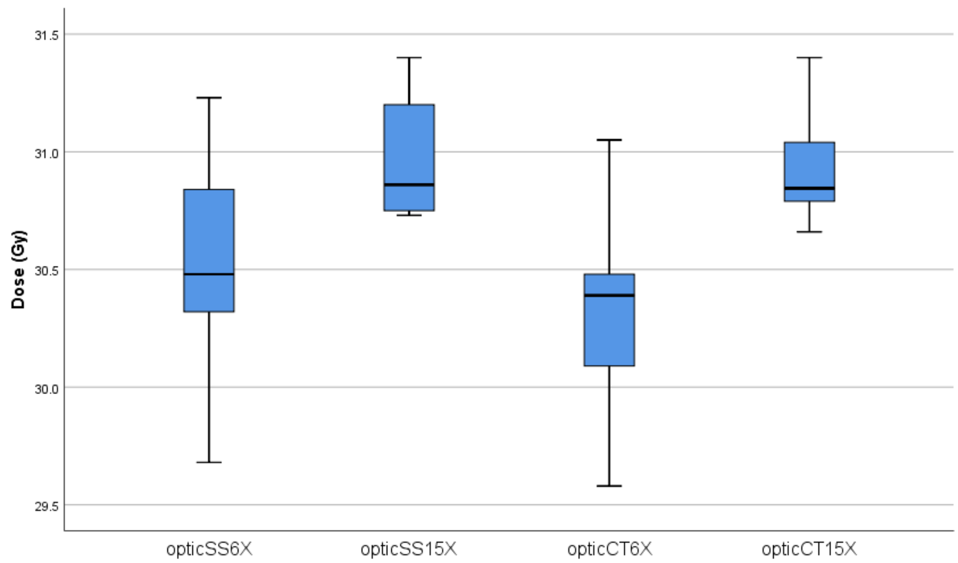

Figure 3. Parotids Scalp Sparing vs Conventional; Parotids 6x vs 15x

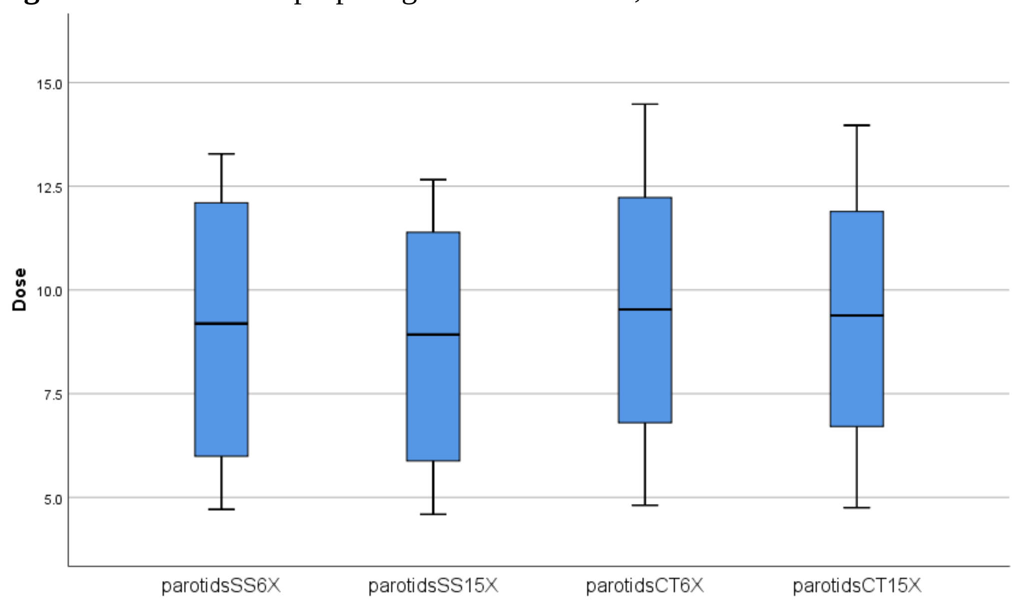

Figure 4. Scalp Max 6x vs 15x; Scalp Max Scalp Sparing vs Conventional

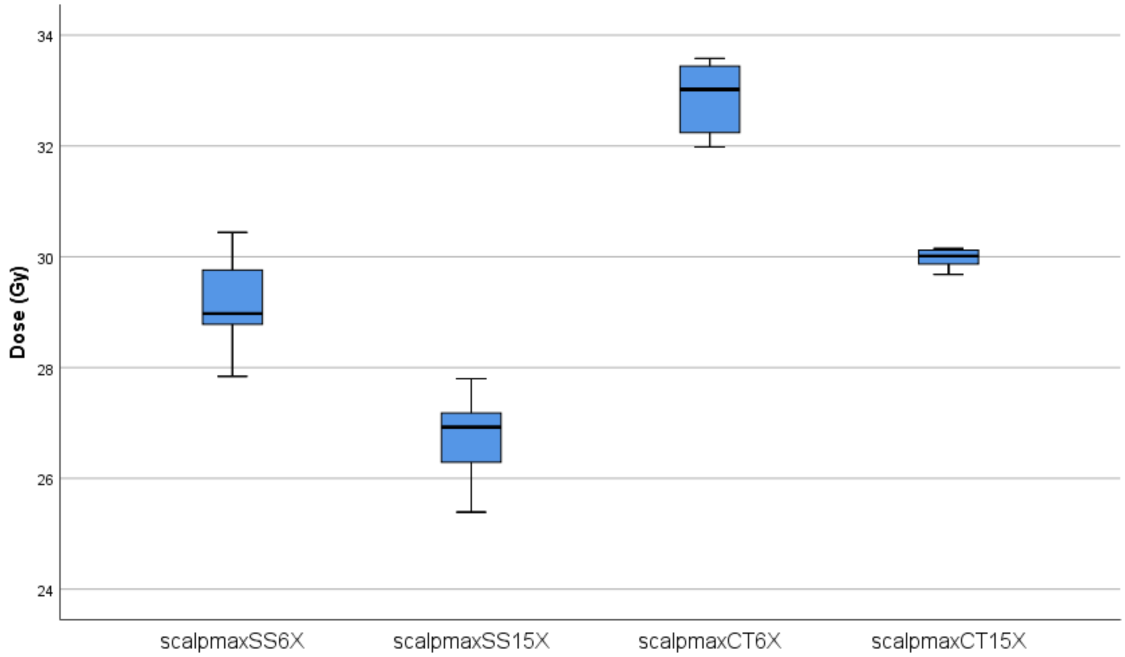

Figure 5. Scalp Mean Scalp Sparing vs Conventional; Scalp Mean 6x vs 15x

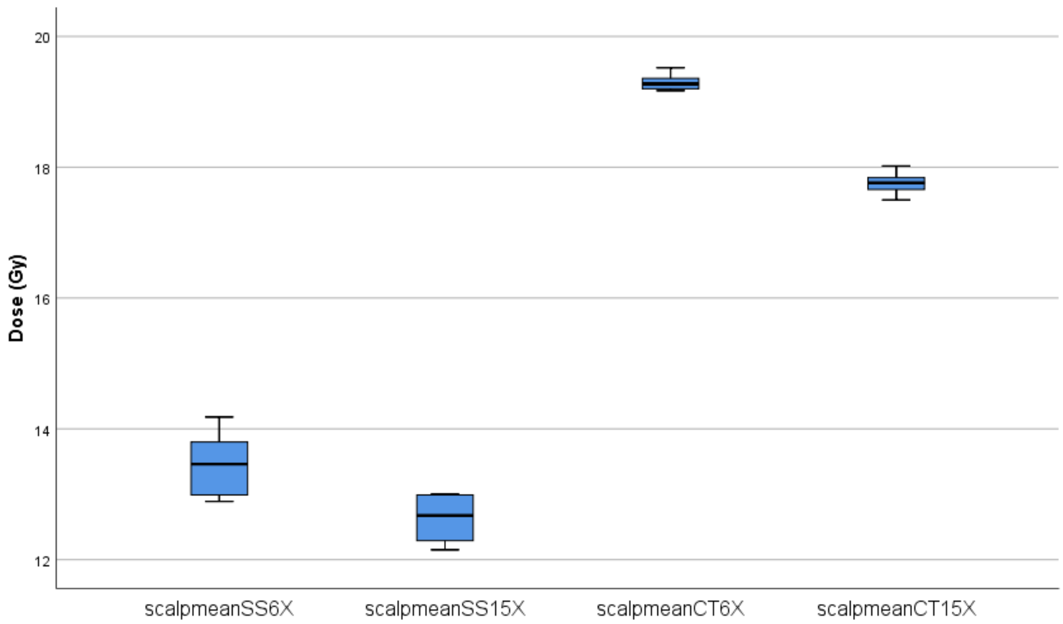

Table 1.

PTV mean, D95, and Dose Max: Minimum, Maximum, Mean, and Std. Deviation between SS/CT/6x/15x

	Minimum	Maximum	Mean	Std. Deviation
PTV-meanSS6x	30.33	31.89	30.7450	.44420
PTV-meanSS15x	30.71	31.42	30.9670	.21980

PTV-meanCT6x	30.26	31.27	30.6950	.30314
PTV-meanCT15x	30.77	31.54	31.0620	.23864
D95-SS6x	97.60	100.10	99.1300	.72732
D95-SS15x	99.80	101.00	100.4300	.41913
D95-CT6x	98.00	100.20	99.2200	.74356
D95-CT15x	100.20	101.40	100.7600	.41952
Dose Max-SS6x	105.60	111.30	108.4100	1.99747
Dose Max-SS15x	105.30	109.00	107.1300	1.43531
Dose Max-CT6x	109.60	116.70	113.2400	2.52199
Dose Max-CT15x	106.90	112.10	109.2400	1.75512

Table 2.

Lens, Optic Nerves, and Parotids: Minimum, Maximum, Mean, and Std. Deviation between SS/CT/6x/15x

	Minimum	Maximum	Mean	Std. Deviation
Lens-SS6x	2.65	5.80	4.0520	1.00261
Lens-SS15x	2.94	8.06	5.0070	1.62445
Lens-CT6x	2.88	5.82	4.6570	1.08967
Lens-CT15x	3.34	8.64	5.8260	1.61680
Optic Nerves-SS6x	29.68	31.23	30.5050	.44109
Optic Nerves-SS15x	30.73	31.40	30.9600	.25303
Optic Nerves-CT6x	29.58	31.05	30.3290	.40731
Optic Nerves-CT15x	30.66	31.40	30.9350	.25687
Parotids-SS6x	4.71	13.28	8.9860	3.09772
Parotids-SS15x	4.59	12.66	8.6730	2.94474
Parotids-CT6x	4.81	14.48	9,5170	3.18391
Parotids-CT15x	4.75	13.97	9.2940	3.02030