Case study of a bolus helmet used to maintain optic chiasm and nerve sparing while improving target coverage using IMPT

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ABSTRACT

The purpose of this study was to examine if the use of a bolus helmet when treating the head with intensity modulated proton therapy (IMPT) will maintain organs at risk (OAR) sparing while improving the clinical target volume (CTV) coverage. A bolus helmet is a device that aims to improve on the traditionally used range shifter in proton therapy by improving dose distribution characteristics. Ten patients were retrospectively selected who had 2 separate treatment planning scans performed, a scan with the bolus helmet and a second scan without. Plans were created using both scans. Dose to organs at risk (OAR) including the left optic nerve, right optic nerve, optic chiasm, and normal brain minus CTV (brain-CTV), as well as CTV coverage were compared between the 2 plans. The use of the bolus helmet displayed lower mean OAR doses as well as higher CTV coverage, suggesting that use of the bolus helmet provides benefit when treating the head with IMPT.

Keywords: IMPT, Bolus Helmet, Range Shifter, Optic Chiasm, Optic Nerves

INTRODUCTION

Radiation induced optic neuropathy (RION) is a prominent complicating factor in radiation treatment planning. Radiation induced optic neuropathy occurs when dose beyond acceptable limits reaches optic structures such as the chiasm and nerves. According to Ali et al,[1] the 2 most influential factors in causing RION are total dose delivered and fractionation. Established guidelines define low risk for RION at doses < 50 Gy but increasing risk at doses near 60 Gy.[1,2] Despite the defined thresholds, it has been established that RION toxicities have been found retrospectively in patients receiving ≤55 Gy and continued efforts should be made to decrease dose to optic structures.[2,3] Beyond RION, dose to optic structures is shown to cause other notable ophthalmic effects such as glaucoma and cataracts, which are sometimes associated

with neurocognitive changes. These side effects can have severe long-term implications such as vision impairment or blindness.[3] Currently, there are no effective treatments available to reverse the effects of RION, further increasing the importance of lowering dose as much as possible to these structures.[1]

The use of proton therapy has been a welcome advancement in the challenging treatment planning of head and neck cancers. By delivering maximum dose at the Bragg peak, protons deposit less entrance dose than photons. In addition, protons exhibit steep dose fall-off with minimal exit dose.[1] Despite these improvements, radiation dose to surrounding structures is still an area of concern. Typically, proton plans are prescribed to clinical target volumes (CTVs) as opposed to photon plans which are prescribed to planning target volumes (PTVs). Due to the location of many head and neck cancers, CTVs often border or overlap contoured organs at risk (OAR) structures such as the optic chiasm and nerves; thus, increasing toxicities.[4] Regard for these side effects can lead to difficult decisions in sacrificing CTV coverage versus keeping dose below recommended levels to optic OAR.[5] As such, further techniques for decreasing optic OAR dose beyond standard proton treatments would prove beneficial.[3]

One development in the field of proton therapy has been the use of custom range shifters. Due to the nature of proton depth dose characteristics, protons need to pass through several centimeters of tissue before depositing dose. With tumors located in the head, CTVs are often located near the skin surface, making it difficult to receive appropriate dose. To offset proton's lack of superficial dose, external range shifters are attached to the head of the gantry, acting as a tissue compensator, and decreasing the range of proton travel.[6] Though successful in shifting the effective dose closer to the skin surface, drawbacks of range shifters include issues with machine

clearance resulting from the size of the apparatus, increased spot size, and increased penumbra due to the distance of the range shifter to the patient.[6]

To correct for some of the drawbacks of the collimator-attached range shifter, the concept of a universal non-patient specific bolus was developed.[6,7] The bolus device discussed in this study is an intra-departmentally created 3-dimensional printed bolus helmet covers the entirety of the patient's head or treatment area (Figure 1, 2). The bolus helmet aims to improve the concept of the range shifter by interacting with the beam immediately above the patient surface. Thus, the distance from the bolus material to the patient surface is reduced and spot size is decreased with a sharper penumbra.[6] Due to these factors, the bolus helmet allows for improved target coverage with decreased dose to surrounding OAR.[6]

Due to the non-commercial status of the bolus helmet, use is currently limited leading to a dearth of published data on its true effectiveness. The problem is that traditional proton therapy planning techniques sacrifice CTV prescription coverage to meet dose tolerances of the optic chiasm and nerves. Initial review of the bolus helmet suggests an ability to maintain OAR dose while improving CTV coverage.[6] The purpose of this study was to determine if the addition of the bolus helmet maintained optic chiasm and nerve sparing while improving the CTV prescription coverage in treatments to the head. The researchers' goal was to demonstrate that use of the bolus helmet will improve the volume of primary CTV receiving 95% of the prescription dose ($V_{95\%}$), and 100% of the prescription dose ($V_{100\%}$) compared to plans without the use of the bolus helmet. Additional goals included showing improved dose to the volume of CTV receiving 95% of the prescribed dose or less ($CV_{95\%}$), as well as improved minimum dose to the primary CTV. Researchers will further examine if dose will decrease to the left optic

nerve, right optic nerve, optic chiasm, and normal brain outside of the CTV (brain-CTV) in plans using the bolus helmet when compared to plans not using the bolus helmet.

CASE DESCRIPTION

Patient selection & setup

All plans examined in this study were created at the time of initial treatment planning and were retrospectively reviewed. Patients included were treated for primary cancers of either the brain or head and neck region with CTVs located near optic structures. All patients selected were treated using intensity modulated proton therapy (IMPT). To qualify for inclusion, the CTV location had to be adjacent to the optic chiasm and nerves. Patients also required 2 separate planning scans, with and without placement of the bolus helmet, at the time of simulation.

Simulation was performed using either a Siemens SOMATOM Definition AS 20 or SOMATOM Definition AS 64 CT scanner (Siemens Medical Solutions, Munich, Germany) in a headfirst, supine position. Immobilization included use of an Orfit thermoplastic mask (Orfit Industries, Wijnegem, Belgium) and a Klarity Cushion neck rest (Klarity Medical Products, Heath, Ohio). Three-point marks were placed on the mask for setup purposes. The bolus helmet planning scan was obtained using a 1.0 mm slice thickness, whereas the non-bolus helmet scan used a 2.0 mm slice thickness.

Target delineation

Target delineation was performed using Eclipse treatment planning software (Varian Medical Systems, Palo Alto, California). Physicians delineated the CTV as well as OAR including the optic chiasm and nerves with CT and MR guidance. The brain volume was contoured by a physician or a certified medical dosimetrist. The brain-CTV structure consisted of the normal brain tissue with the area of the CTV cropped away with no additional margin.

Treatment planning

All treatment plans were designed using a pencil beam technique. Treatment planning was performed using the nonlinear universal proton optimizer (NUPO) calculation model with Eclipse version 13.7 or 15.6 planning software. The primary planning goal for all cases was to spare dose to optic structures, at the expense of CTV prescription coverage if needed. The secondary planning goal was prescription CTV coverage. The prescription varied from a total dose of 50.4 Gy to 70 Gy. Plans that did not use the bolus helmet instead used a nozzle-mounted range shifter. Beam arrangement was not standardized, and the optimal technique was used for each patient. Factors that influenced field design included avoiding beam entrance through OAR, consideration of robustness due to uncertainties, and the location of biologic dose enhancement. The number of fields was dependent on the size and location of the target. The number of beams used was limited to reduce the amount of low dose to the normal tissues. Physical dose and biologic dose were assessed during plan evaluation. A fast GPU-based Monte Carlo calculation algorithm was used as a secondary check of the treatment planning software and to calculate the biologic dose based on relative biological effectiveness and linear energy transfer.[8]

Organs at risk dose limits for this study were obtained from departmental guidelines. The planning objective for the optic chiasm and nerves was for 0.03 - 0.1 cubic centimeters (cc) to receive less than 54 Gy, depending on physician request. Minimizing the volume of the optic chiasm and nerves receiving 50 and 60 Gy were further planning objectives. The dose to the brain-CTV was reported with the intent to keep the dose as low as reasonably achievable. The goal for all plans reviewed was for 95% of the CTV to receive 100% prescription dose.

Statistical analysis

Ten patients met criteria for selection in this study. Due to the small patient sample size, descriptive statistics were used in evaluating plan comparisons. Mean and mean percent differences were used to evaluate variations in dose delivered to the OAR and CTV coverage between the two plans.

RESULTS

CTV coverage

The $V_{95\%}$, $V_{100\%}$, $CV_{95\%}$ and minimum dose for the primary CTV were evaluated in this study (Table 1). The sample mean $V_{95\%}$ metric was 99.6% with the bolus helmet plans and 99.0% for the non-bolus helmet plans, resulting in a mean percent different of 0.6%. The sample mean of the $V_{100\%}$ metric was 93.8% with the bolus helmet plans and 89.8% for the non-bolus helmet plans resulting in a mean percent difference of 4%. The sample mean $CV_{95\%}$ metric (reported in cc) resulted in a mean value of 0.464 cc on the bolus helmet plans and 1.133 cc for the non-bolus helmet plans. The mean minimum CTV dose was 85.5% with the bolus helmet plans, compared to 82.9% for the non-bolus helmet plans, resulting in a mean percent difference of 2.6%. All categories evaluated indicated improved CTV coverage for the bolus helmet plans when compared to the non-bolus helmet plans (Figure 3).

Optic nerve metrics

In evaluation of the mean dose to the left optic nerve, the sample mean for the bolus helmet plans was 25.58 Gy compared to 29.21 Gy for the non-bolus helmet plans, a difference of 13.25% (Table 2). Regarding the maximum dose to the left optic nerve, the mean maximum dose was 41.76 Gy with the bolus helmet plans compared to 44.98 Gy for the non-bolus helmet plans, resulting in a mean percent difference of 7.42%. Both the mean dose and maximum dose metrics indicated lower left optic nerve dose delivered with use of the bolus helmet (Figure 4).

For the evaluation of mean dose to the right optic nerve, the sample mean was 22.68 Gy for the bolus helmet plans compared to 28.25 Gy for the non-bolus helmet plans with a mean percent difference of 21.87% (Table 2). The bolus helmet mean maximum dose was 35.73 Gy compared to 40.16 Gy for the non-bolus helmet plans, a difference of 11.67%. Both categories indicate lower dose to the right optic nerve with use of the bolus helmet.

Optic chiasm metrics

For the evaluation of the mean dose to the optic chiasm, the sample mean for the bolus helmet plans was 21.73 Gy compared to 26.01 Gy for the non-bolus helmet plans for a mean percent difference of 17.93% (Table 2). The mean maximum dose was 35.35 Gy for the bolus helmet plans and 40.64 Gy for the non-bolus helmet plans, a difference of 13.92%. These values display lower optic chiasm dose with use of the bolus helmet.

Brain-CTV metrics

In evaluation of the mean dose to the brain-CTV, the sample mean was 3.67 Gy for the bolus helmet plans and 4.66 Gy for the non-bolus helmet plans with a mean percent difference of 23.77% (Table 2). The mean maximum dose delivered was 62.14 Gy for the bolus helmet plans compared to 62.46 Gy for the non-bolus helmet plans, indicating a marginal 0.51% mean difference in favor of the bolus helmet plans. Both the mean dose and maximum dose to the brain-CTV were lowered with use of the bolus helmet (Figure 5).

DISCUSSION

Examination of the CTV metrics indicate plan improvements with use of the bolus helmet. Though the $V_{95\%}$ showed a minor improvement of 0.6%, all other criteria displayed notable CTV improvement. The $V_{100\%}$ with a mean increase of 4%, and the minimum CTV with a mean increase of 2.6%, both displayed worthwhile gains in CTV coverage. Consistent with the

other target coverage metrics in this study, the mean $CV_{95\%}$ was 0.464 cc when the bolus helmet was used versus 1.133 cc when the bolus helmet was not used. These metrics indicating improved CTV coverage with use of the bolus helmet are consistent with Mundy et al.[9] Of the 10 patients examined, non-bolus helmet plans displayed improved $V_{95\%}$ coverage in only 2 plans, and $V_{100\%}$ improvements were observed in 3 plans. Further examination into the specifics of these plans provided additional insight. In 1 such case where the non-bolus helmet plan had higher CTV coverage, the patient began treatments with the non-bolus helmet plan seen in this study. Due to side effects to the lacrimal glands, the patient was replanned with use of the bolus helmet but with instruction to sacrifice prior CTV coverage to ensure sparing of the lacrimal glands. This provides an example where the data shows lower CTV coverage with use of the bolus helmet, but because of physician instruction.

Notably reduced dose to OAR was also observed with use of the bolus helmet (Table 2). For the OAR examined, the reduction of the mean percent difference of the mean OAR dose ranged from 13.25% to 23.77%. The reduction in maximum dose was negligible for the brain-CTV anatomy analyzed but resulted in a mean percent difference between 7.42% and 13.92% lower for all other structures.

Considering curative doses greater than 50 Gy may involve sacrificing CTV coverage to keep OAR dose to acceptable levels, this data has important dosimetric implications.[5] By increasing CTV coverage while also decreasing OAR dose, the initial findings of this case study indicate the ability of the bolus helmet to improve plans compared to those using the traditional proton range shifter. With side effects caused by dose to optic structures being potentially severe, any reduction in dose is worthwhile.[3] The findings of improved CTV coverage along with reduced OAR coverage are supported by Mundy et al.[9]

CONCLUSION

Researchers in this study aimed to address the issue of traditional proton therapy planning sacrificing CTV coverage to maintain acceptable dose levels to optic OAR such as the optic nerves, optic chiasm, and brain-CTV. Researchers investigated if the addition of a bolus helmet would lead to improved treatment plans. Noting the decrease of dose to the optic nerves, chiasm, and brain-CTV, with the simultaneous increase in CTV coverage, use of the bolus helmet should be explored for proton therapy treatments to the head.

Limitations of this study to consider include a small sample size of 10 patients. Though worthwhile in gathering initial trends, a larger grouping of patients would provide more impactful data. All plans examined were retrospective and not all variables were known as to what criteria were prioritized in each plan. Future research recommendations would be to examine a larger sample size. Standard planning guidelines implemented would help decrease the human variability from plan to plan. Ideally the same medical dosimetrist would complete both plans to maintain the integrity of plan comparison. Based on the study findings, additional research would be beneficial as initial data indicate favorable results with use of the bolus helmet for treatments to the head with IMPT.

FIGURES

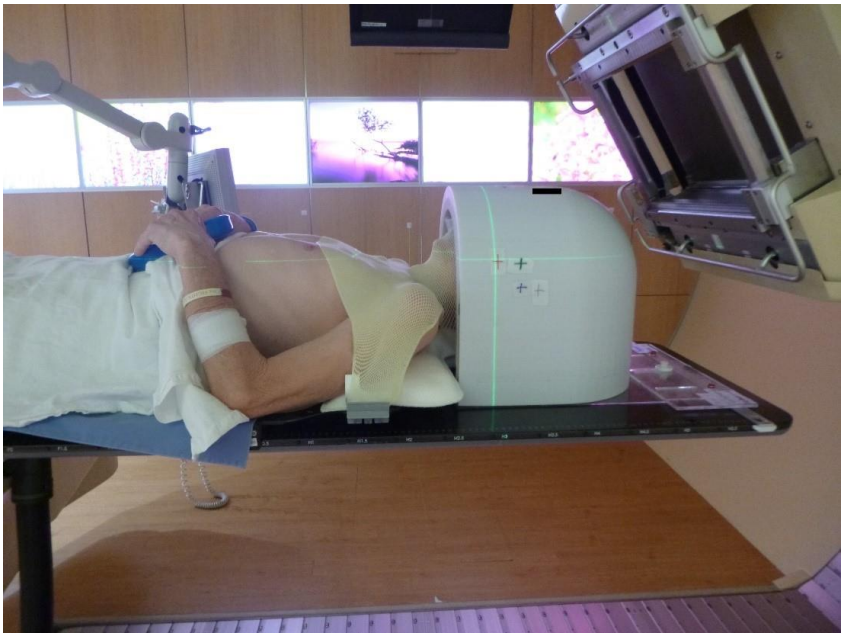

Fig. 1. A patient in treatment position with the bolus helmet in place.

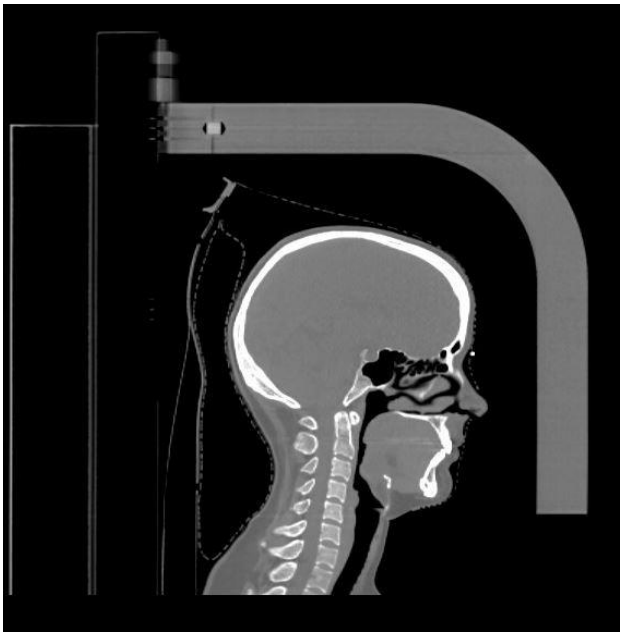

Fig. 2. A sagittal view of a patient immobilized using a custom Klarity Cushion neck rest and Orfit thermoplastic mask, with bolus helmet placed over head.

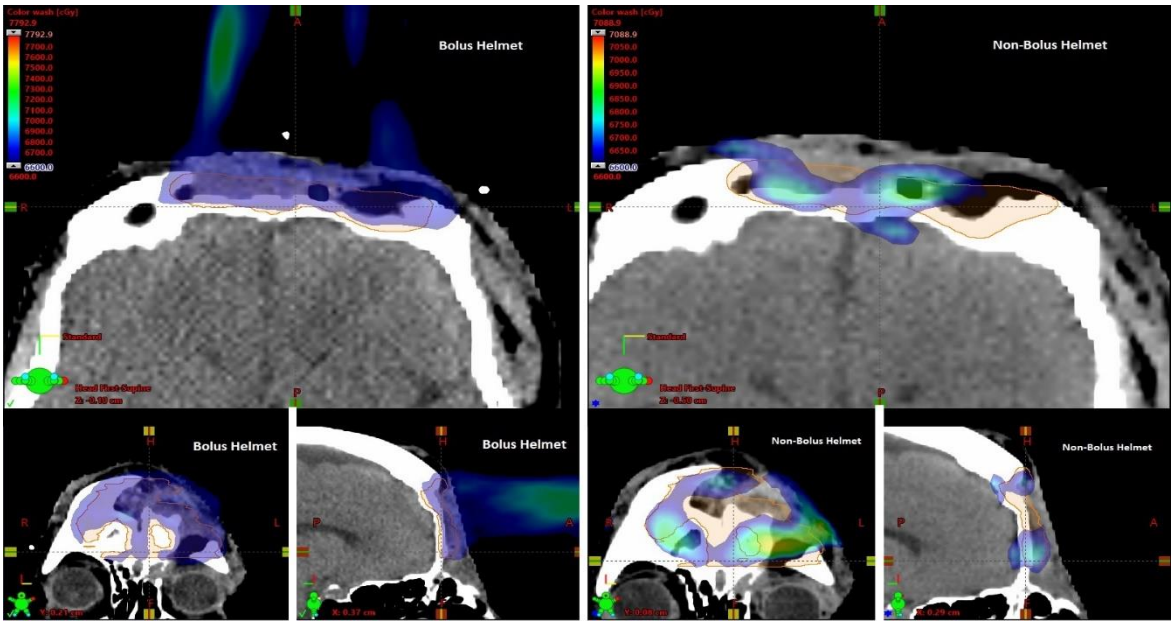

Fig 3. An example of axial, sagittal, and coronal views of improved clinical target volume coverage with use of the bolus helmet (left) versus without the use of the bolus helmet (right).

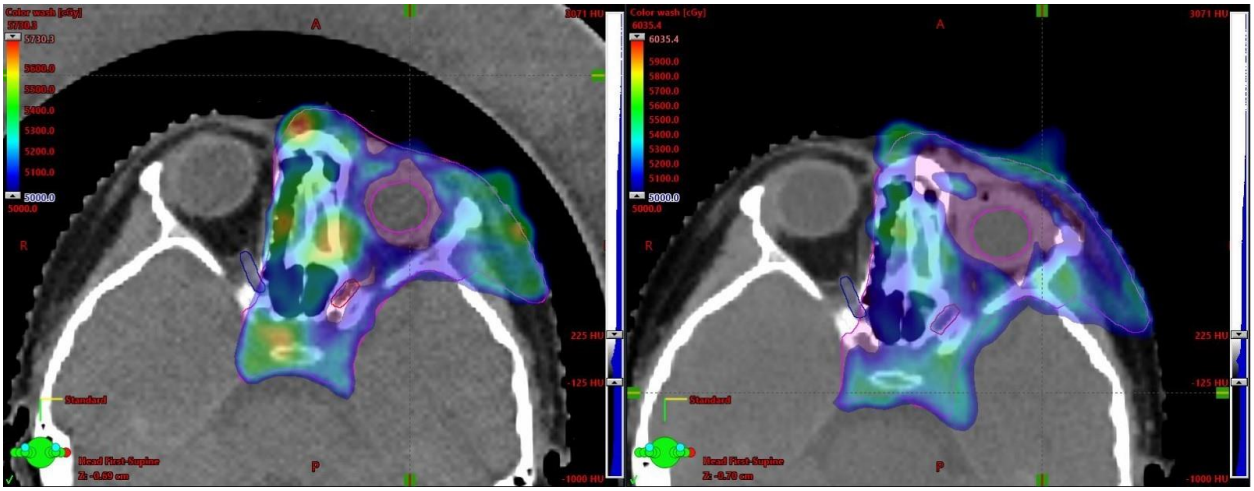

Fig. 4. An example of an axial view comparison of improved left optic nerve sparing with use of the bolus helmet (left) versus decreased sparing without the use of the bolus helmet (right). The 50 Gy dose level is displayed in colorwash.

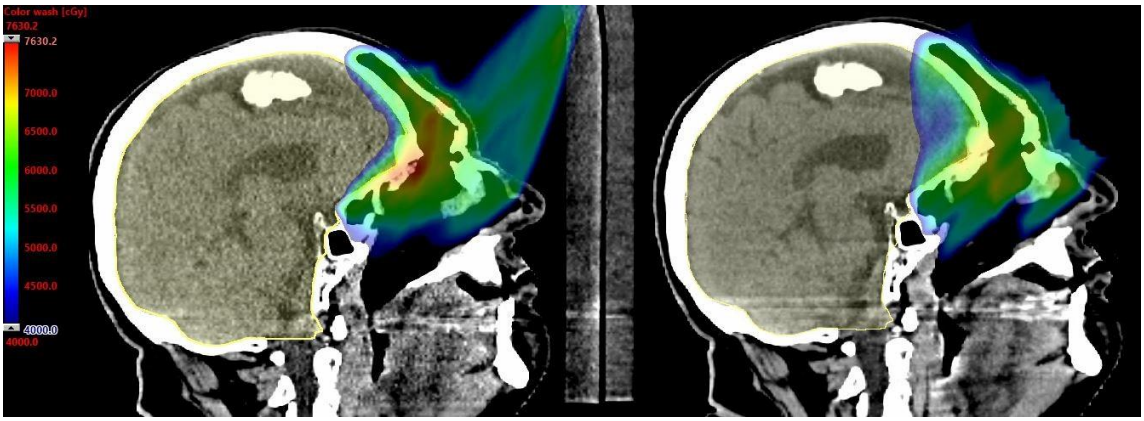

Fig. 5. A sagittal view example demonstrating better sparing of brain minus clinical target volume (yellow contour) with the use of the bolus helmet (left) versus without the use of the bolus helmet (right). The 40 Gy dose level is displayed in colorwash.

TABLES

Table 1. Study data collection of CTV and coverage of bolus helmet and non-bolus helmet plans. Mean value and mean percent differences calculated for comparison. The percentage difference favors the bolus helmet.

Metrics	Mean Value	Mean % Diff
$V_{95\%}$_BH (%)	99.6	0.6
$V_{95\%}$_No BH (%)	99.0	
$V_{100\%}$_BH (%)	93.8	4.0
$V_{100\%}$_No BH (%)	89.8	
Minimum_BH (%)	85.5	2.6
Minimum_No BH (%)	82.9	
$CV_{95\%}$_BH (cc)	0.464	N/A
$CV_{95\%}$_No BH (cc)	1.133	

CTV = Clinical target volume; BH = Bolus helmet; $V_{95\%}$ = Volume receiving 95% of the prescribed dose or more; $V_{100\%}$ = Volume receiving 100% of the prescribed dose or more; $CV_{95\%}$ = Complement volume, the volume receiving 95% of the prescribed dose or less; % diff = Percent difference; cc = Cubic centimeters

Table 2. Comparison of the sample mean of the mean dose in Gray (Gy), mean percent difference of the mean dose, mean maximum dose in Gy, and maximum dose mean percent difference. The percentage difference favors the bolus helmet in all categories.

Metrics	**Optic Nerve Left**	**Optic Nerve Right**	**Optic Chiasm**	**Brain-CTV**
Mean of Mean Dose_BH (Gy)	25.58	22.68	21.73	3.67
Mean of Mean Dose_No BH (Gy)	29.21	28.25	26.01	4.66
Mean % Difference of Mean Dose (%)	13.25	21.87	17.93	23.77
Mean Maximum Dose_BH (Gy)	41.76	35.73	35.35	62.14
Mean Maximum Dose_No BH (Gy)	44.98	40.16	40.64	62.46
Maximum Dose Mean % Difference (%)	7.42	11.67	13.92	0.51

Gy = Gray; BH = Bolus helmet; % Diff = Percent difference

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