Utilizing a patient specific silicone bolus fabricated using a 3D printed mold negative for enhanced head and neck radiation therapy set-up in treatment of the posterior scalp

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BACKGROUND

Bolus martial is used in radiation therapy to ensure adequate surface dose for the treatment of superficial tumors [1]. While conventional flat-sheet bolus is effective on uniform surfaces, its conformity often underperforms when used on irregular anatomical sites such as the posterior scalp. Despite intervention from the radiation oncology team, cutting, taping, and reshaping the bolus to customize the bolus, air gaps that can compromise dosimetric accuracy are often still observed [2]. Traditional immobilization methods while in the supine position for posterior scalp treatments may utilize a 3 point mask thermoplastic mask, plastic headrest, and cushion. These tools may further distort the bolus positioning leading to folding, sliding and other variations between fractions. Previous studies have demonstrated the feasibility of custom silicone bolus for full skull and anterior scalp treatments [3,4]. However there is a gap in the literature specifically addressing the posterior scalp and crown of the head applications.

This study investigates the feasibility of creating a patient specific silicone bolus using a 3D printed mold negative and evaluates fit, reproducibility and dosimetric performance compared to conventional bolus sheets.

METHODS

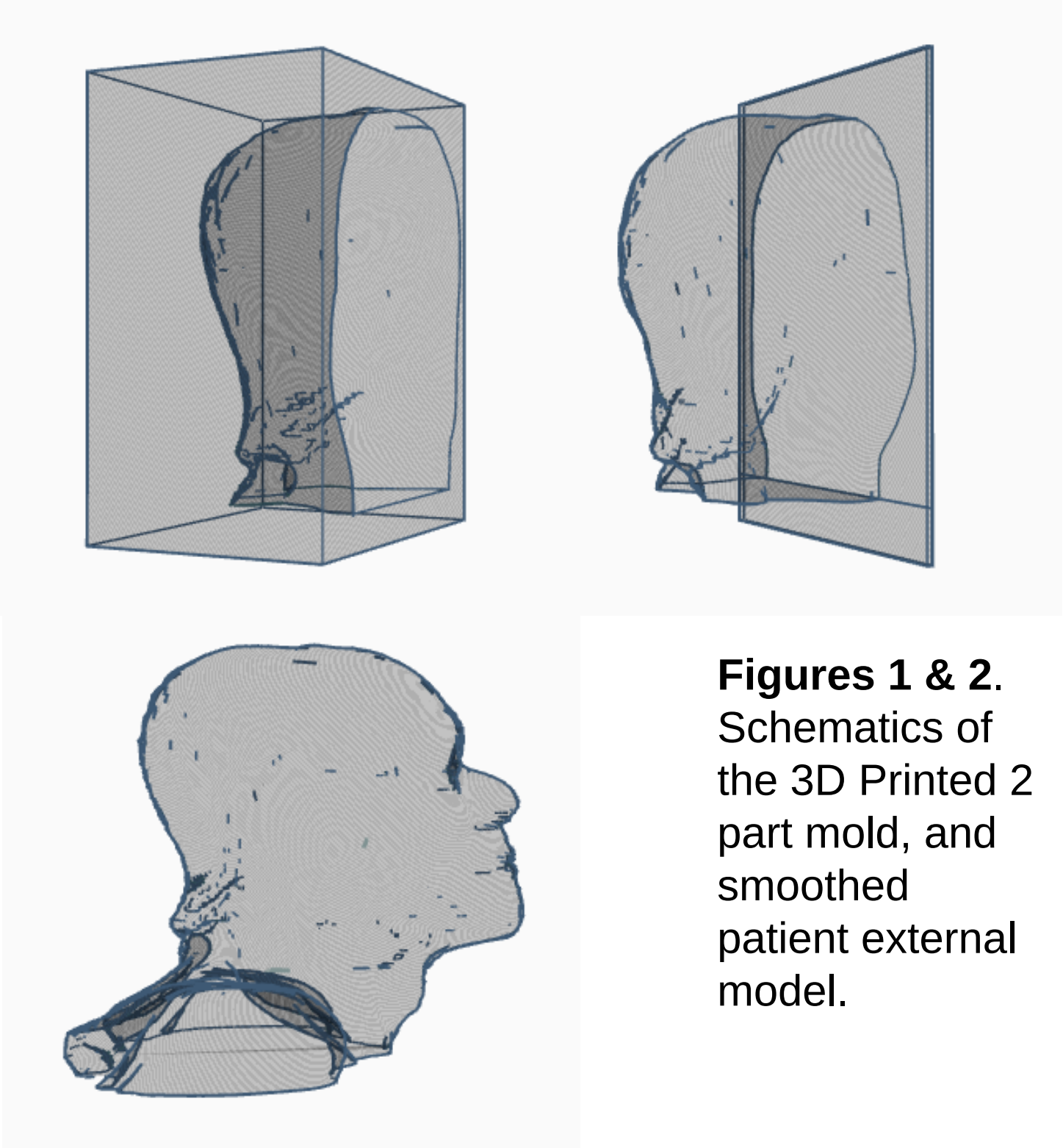
A retrospective CT dataset was used to design a custom mold, where the external or body contour was isolated and converted into an STL file. This file was imported into a 3D modeling software where the scalp was digitally reconstructed and smoothed to reduce any outlining segmentation data points. The modified model was then used to create a two-part negative mold designed to cover the targeted treatment area 3D printed using PLA filament. Biocompatible silicone was mixed and poured into the cavity and left to cure at room temperature, forming a customized bolus that was completely custom fit to the patient's anatomy.

The silicone bolus was scanned using a Philips CT machine, the images were then uploaded to the Eclipse treatment planning system for quantitative analysis. The dosimetrists evaluated the bolus fit, both visually and virtually within the planning software by assessing the presence and volume of air gaps at the patient surface. For comparison, a standard flat-sheet bolus was also scanned under the same conditions.

Treatment plans for both bolus types were generated using the same beam parameters and prescription to aid in dosimetric evaluation. Surface dose, dose uniformity and PTV coverage were assessed using isodose line distribution and dose volume histograms (DVHs) compared between plans.

To validate the surface dose under the silicone bolus, optically stimulated luminescence dosimeters (OSLDs) were placed directly on the surface of a 3D printed phantom that was filled with water, and the posterior scalp was then covered with the silicone bolus. The plan was delivered using a 6MV beam from a Varian TrueBeam linear accelerator and readings were recorded and analyzed.

MODEL



Figures 1 & 2. Schematics of the 3D Printed 2 part mold, and smoothed patient external model.

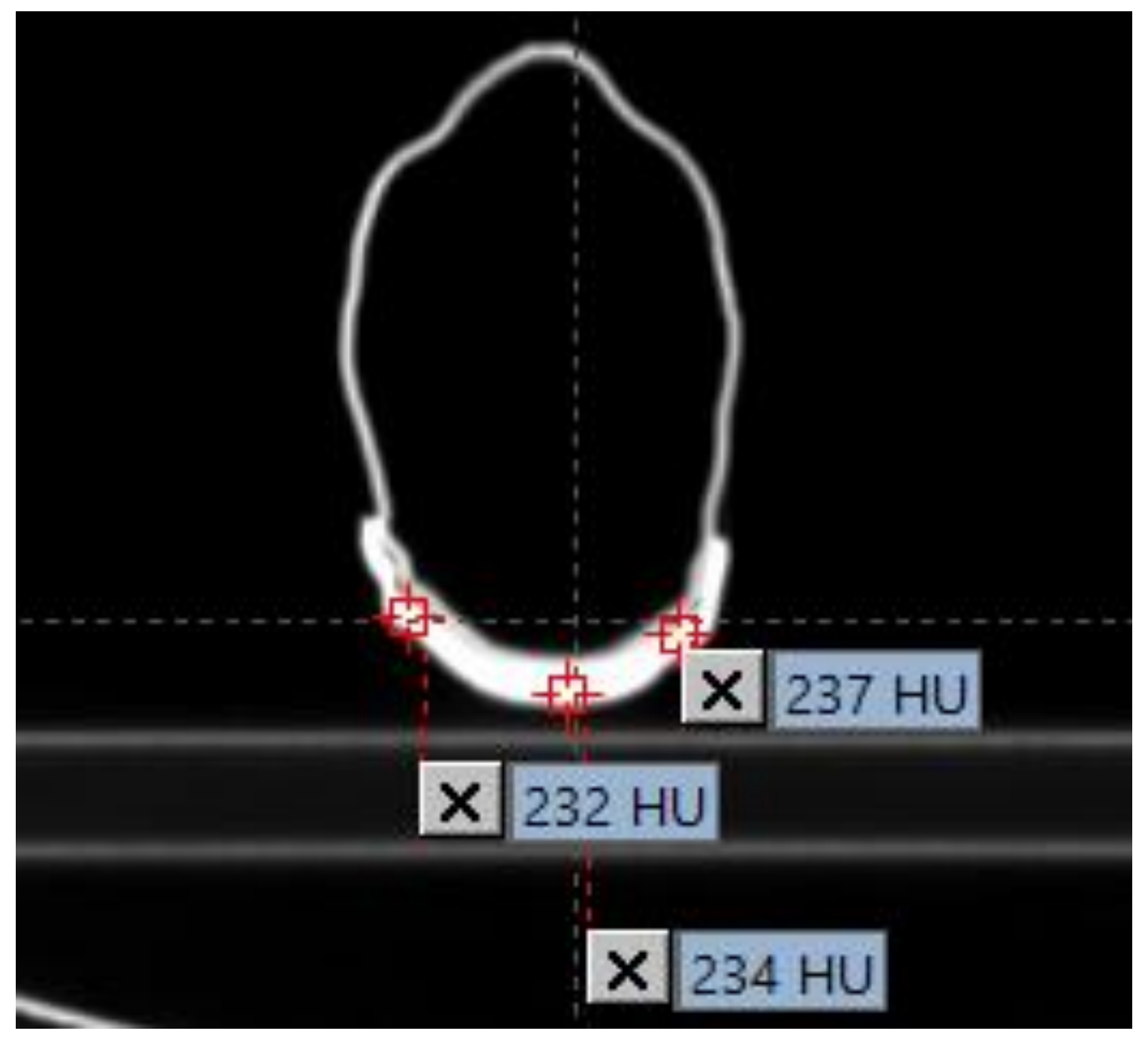


Figure 3. CT scan of 3D printed phantom and silicone bolus used to determine Hounsfield units

Figure 4. 3D printed Head and Neck Phantom with silicone bolus at CT SIM

RESULTS

Quantitative analysis from axial CT slices of the 3D printed phantom with traditional bolus, and custom silicone bolus revealed that in the inferior region the traditional bolus showed larger and more frequent air gaps. The research team measured the gaps using a virtual ruler. Measured gaps were 0.40cm, 0.65cm, and 0.64cm for the traditional bolus. In contrast, the silicone bolus displayed significantly smaller gaps in the same region, measuring 0.10cm, 0.0cm, and 0.20cm Researchers then generated treatment plans for both the traditional and silicone bolus using a prescription of 200 cGy x 1 Fraction, 3 arcs with anterior avoidance sectors from 60 to 300 degrees. Isodose lines displayed consistent conformity across both plans. The dose volume histogram (DVH) showed that the traditional bolus plan yielded a PTV coverage of 99.7%, while the silicone bolts plan achieved a slightly higher coverage of 99.8% The plan was delivered on a TrueBeam Linac for OSLD measurement. After irradiation the doses from the OSLD's measured 194.720 cGy and 193.559 cGy, indicating a deviation of less than 3% from the prescribed dose.

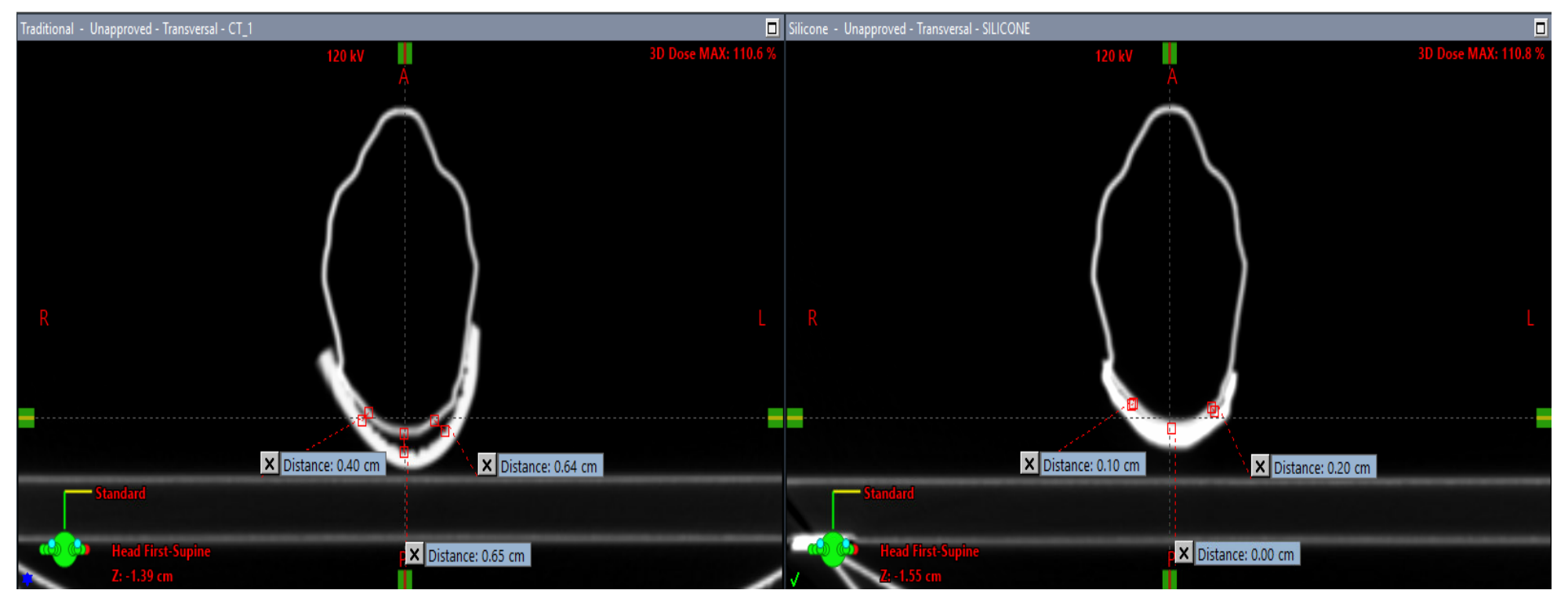


Figure 5. Digital measurement of air gaps comparison between CT scans of 3D printed phantom with traditional and silicone bolus

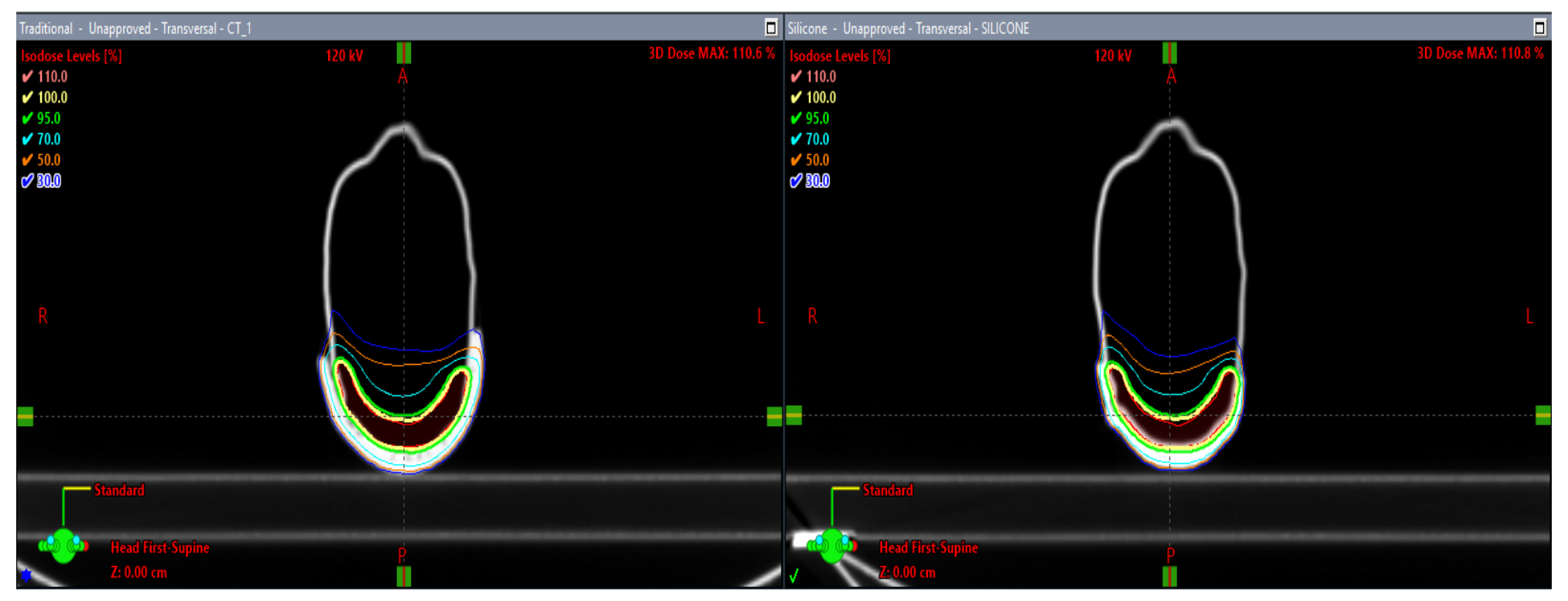


Figure 6. Isodose line distribution comparison between plans generated using traditional and silicone bolus on 3D printed phantom.

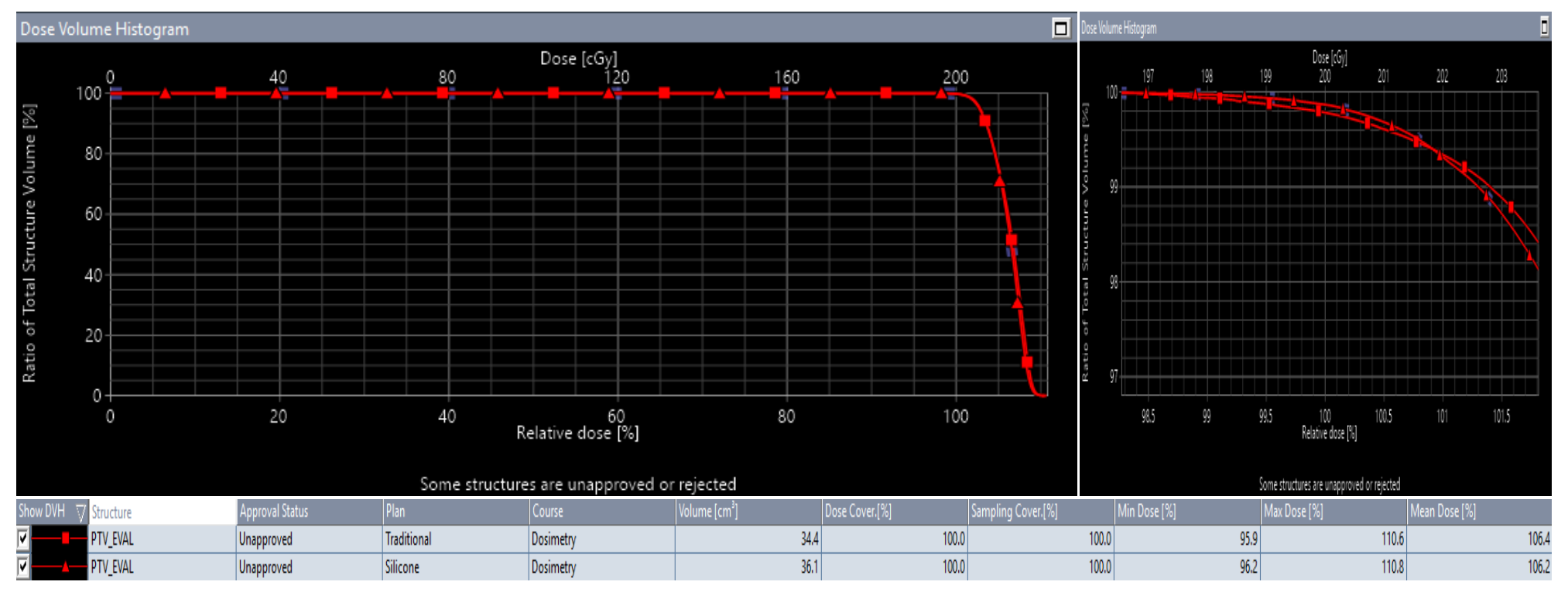
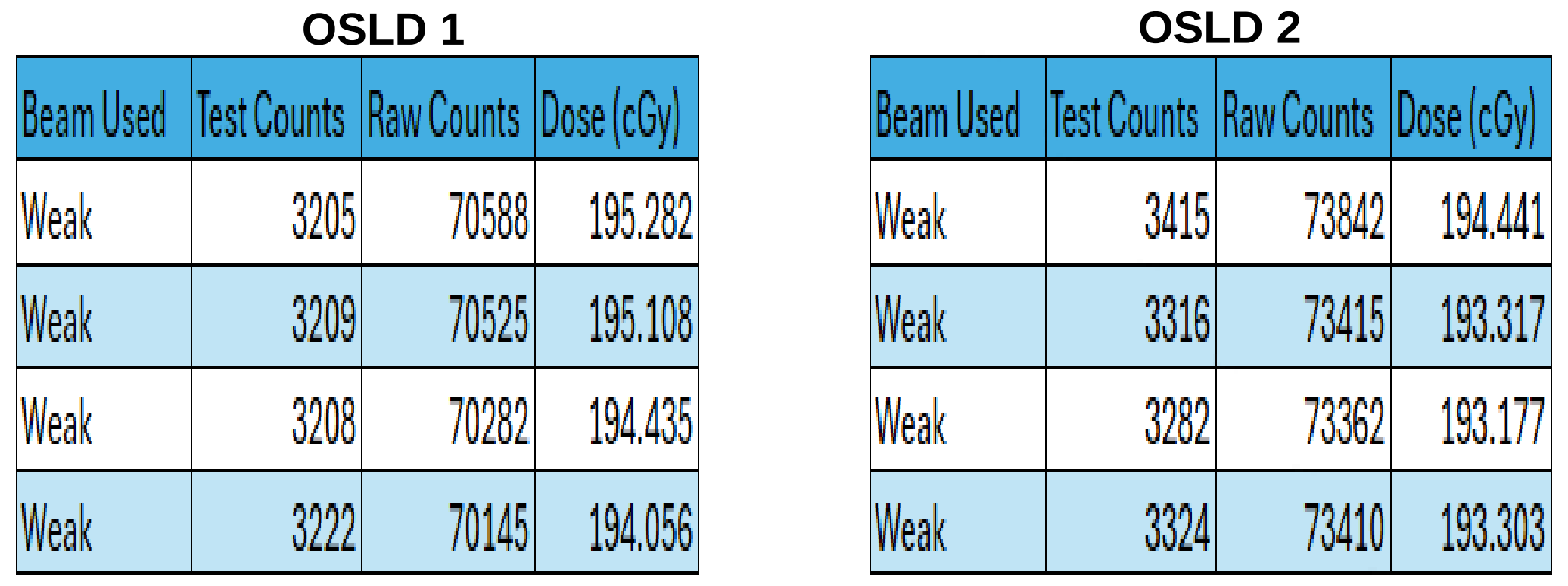


Figure 7. Graph showing the DVH comparison between plans using traditional bolus and silicon bolus



OSLD 1

Beam Used	Test Counts	Raw Counts	Dose (cGy)
Weak	3205	70588	195.282
Weak	3209	70525	195.108
Weak	3208	70282	194.435
Weak	3222	70145	194.056

OSLD 2

Beam Used	Test Counts	Raw Counts	Dose (cGy)
Weak	3415	73842	194.441
Weak	3316	73415	193.317
Weak	3282	73362	193.177
Weak	3324	73410	193.303

Figure 8. Tables showing the read outs values in cGy for two different OSLDs

DISCUSSION

After taking a CT, researchers calculated the average Hounsfield Unit of the silicone bolus calculated to be 234.33 making it more radiodense than soft tissue. Despite intervention at sim cutting, taping, and reshaping the traditional bolus larger air gaps could be seen on the CT compared to those of the silicone bolus. Through qualitative testing and evaluation, researchers observed that despite the increased radiodensity both the traditional and silicone bolus archived similar dose conformity and PTV coverage. The traditional bolus plan resulted in PTV coverage of 99.7%, and the silicone bolus plan had a .1% increase in PTV coverage at 99.8%. In vivo phantom surface dose readings using OSLD's further validated the ability to accurately deliver dose using silicone bolus. Values of the OSLDs were recorded at 194.720 cGy and 193.559 cGy closely aligned to the prescribed 200 cGy. Together these results support the feasibility of using patient specific silicone bolus for posterior scalp treatment with compromising dosimetric quality.

CONCLUSIONS

This study evaluated the dosimetric performance and clinical feasibly of a custom silicone bolus for posterior scalp treatment made from a 3D printed negative. Overall, the silicone bolus demonstrated reduced air gaps, comparable PTV coverage, and accurate surface dose measurements. This suggests is potential to improve set up reproducibility and patient comfort.

A key finding was the improved conformity of the silicone bolus to irregular anatomy, particularly the inferior of the posterior scalp region, where traditional bolus showed larger air gaps compared to the silicone bolus. Above this region folds could be observed in the traditional bolus, but it followed the phantom interface very well. This translated into comparable dose distributions, with PTV coverage of 99.8% for the silicone bolus and 99.7% for the traditional bolus. Dose surface measurements using OSLD's and a 3D printed phantom that was filled with water also confirmed the planned 200 cGy prescription with readings of 194.720 cGy and 193.559 cGy indicting accurate dose delivery.

The use of silicone bolus offers a notable improvement in the consistency of clinical set ups. Its fixed like nature allows for clear markings beneath the mask. Furthermore feedback from simulation therapists highlighted that with the silicone bolus they had reduced reliance on taping to skin or hair, which may greatly impact patient comfort during treatment.

One limited of this study is the reliance on a 3D printed phantom with overridden Hounsfield units or water to simulate human tissue, rather than in vivo application. Additionally, although the silicone cures within a few hours, the creation of the 2 part mold can be time consuming, depending on printer type and anatomical complexity.

Future research could investigate clinical use on patients, and the potential for pre simulation bolus fabrication using diagnostic CT images.

Overall, this approach offers a promising path tawrad more personalized and reproducible radiation therapy for complex surface anatomies.

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