

A Case Study: Application of 3D Printed Thermoplastic Polyurethane Filament Bolus Device for Enhanced Radiation Therapy Delivery.



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Purpose

This study investigates the application and advantages of 3D printed, patient-specific bolus for the purpose of optimizing dose distribution, improving treatment setup, and enhancing quality assurance in radiotherapy.

Materials/Methods

A 3D-printed patient-specific bolus was designed and fabricated for a Volumetric Modulated Arc Therapy (VMAT) plan treating squamous cell carcinoma of the nasal septum/vestibule using commercially available Thermoplastic Polyurethane (TPU) filament as tissue equivalent material. The custom bolus was designed in the Eclipse treatment planning system (TPS) and fabricated using a commercially available 3D printer. [Figures 1,2]

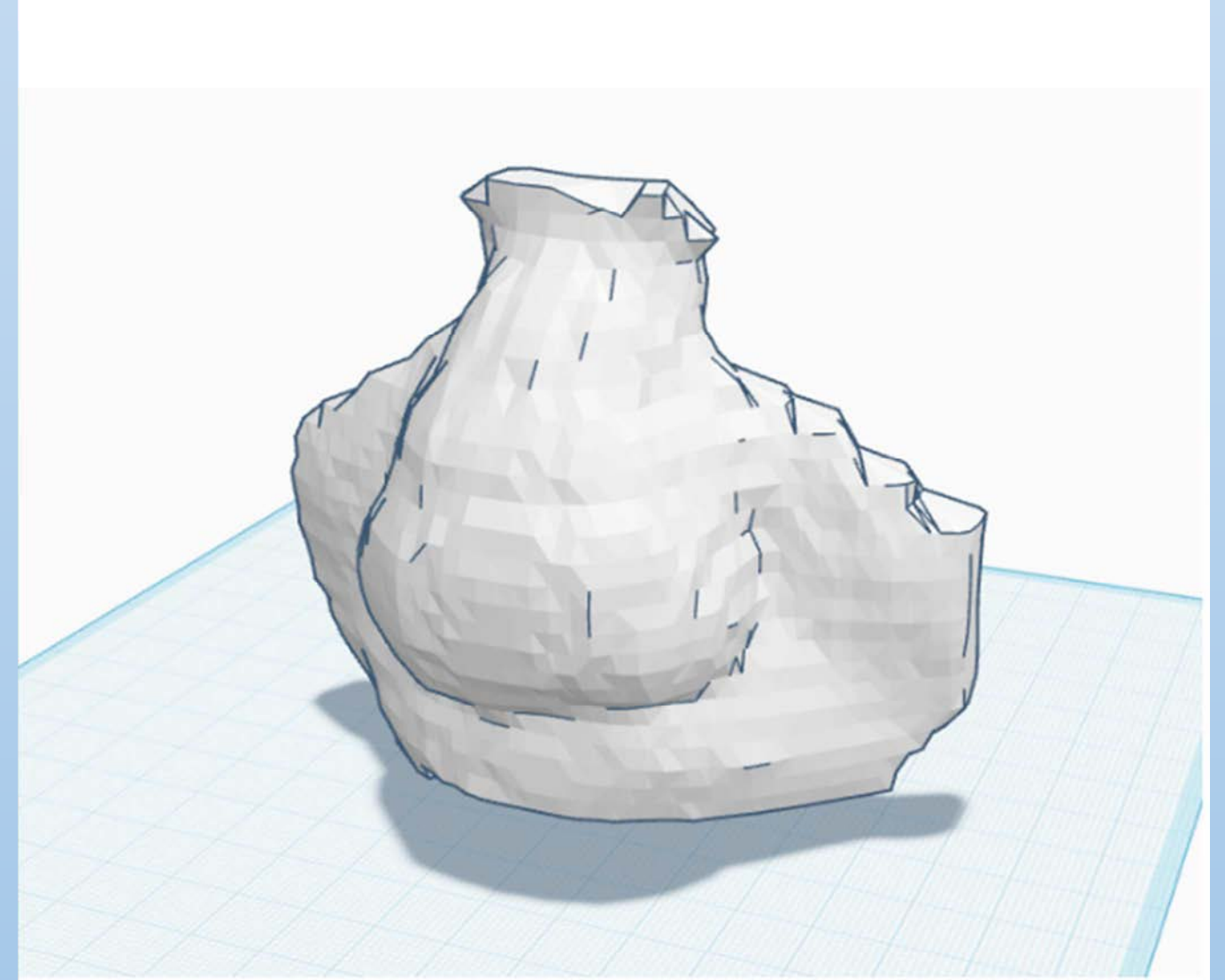


Figure 1. Model of bolus in 3D printer software

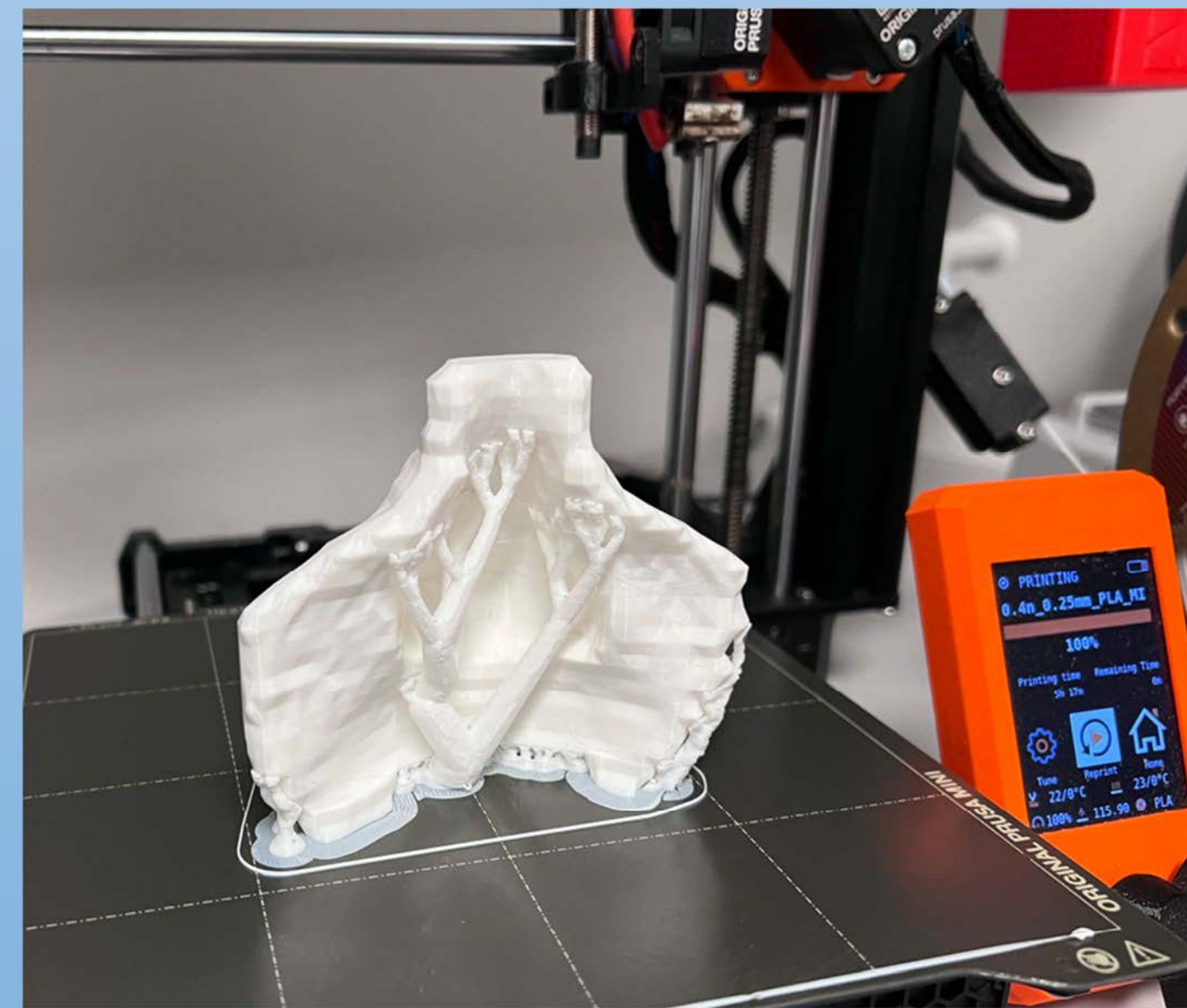


Figure 2. Custom bolus fabricated on a 3D printer with Thermoplastic Polyurethane filament (TPU)

After fabrication, the bolus had its edges smoothed out. [Figures 3,4] Patient underwent a second CT scan with the 3D-printed bolus in place. [Figures 5,6]

A comparison of dose volume histograms (DVHs) was done between plans generated using TPS bolus and 3D-printed bolus. Assessments in dose distribution, target coverage, and normal tissue sparing were evaluated. Evaluation of setup consistency was done by review of cone-beam CT (CBCT) registration to simulation CT.



Figure 3. Excess materials were removed from printed bolus. Sharp edges were smoothed out and rounded off.

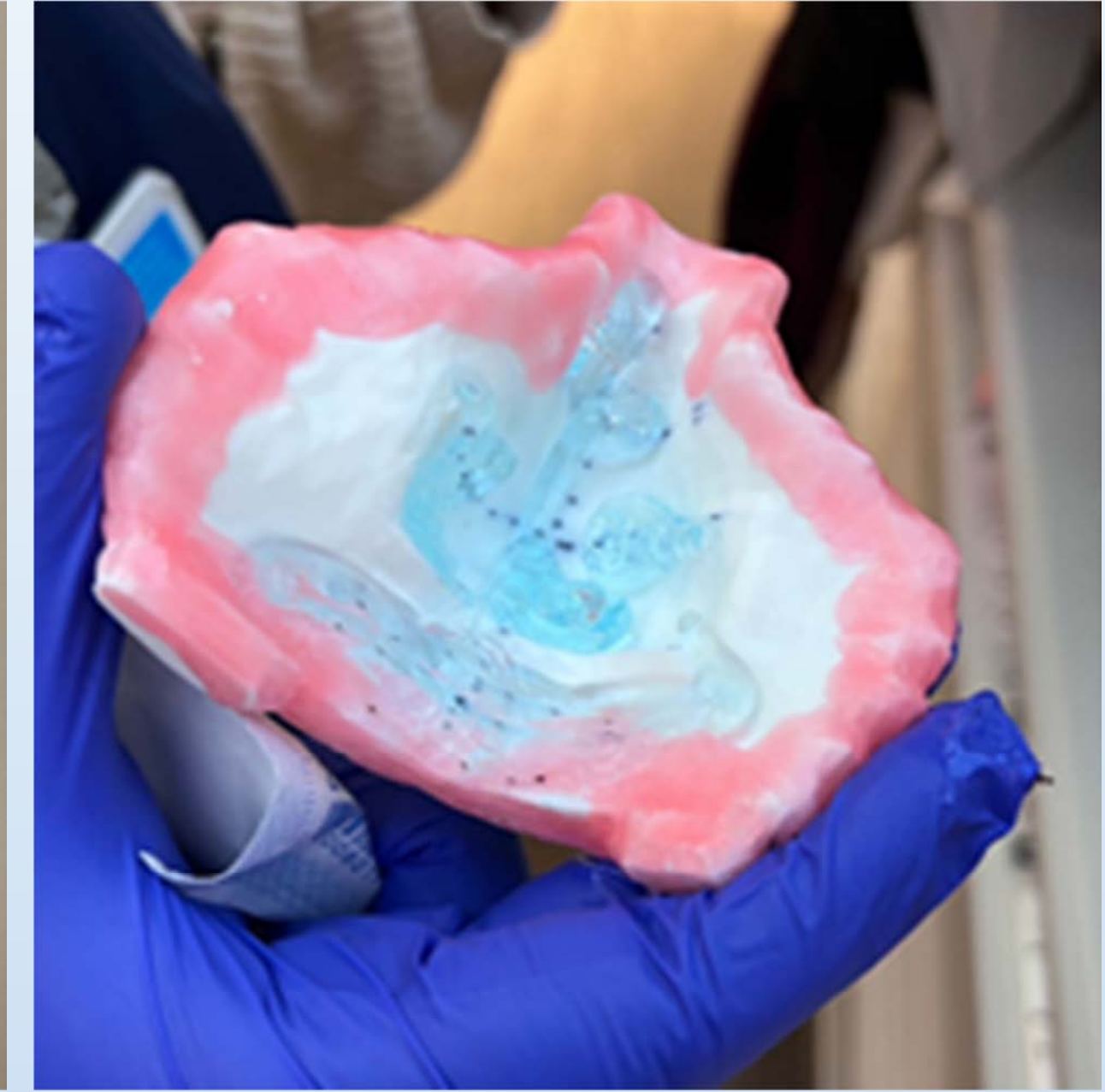


Figure 4. Edges covered with wax material to smooth edges against skin. Water equivalent gel added to reduce air gaps between bolus and skin.



Figure 5. 3D bolus aligned to existing marks on mask.



Figure 6. Bolus secured down with tape.

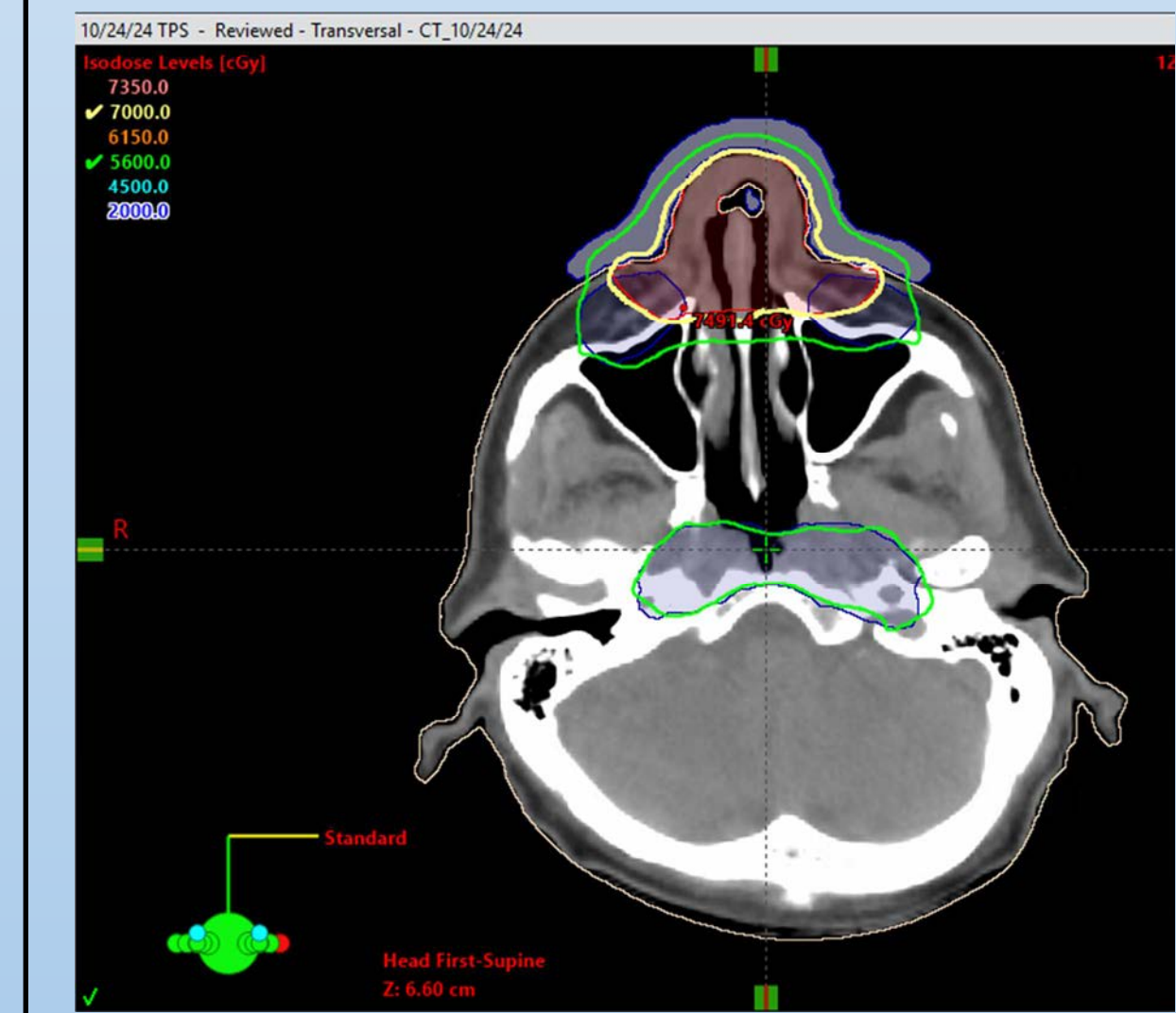


Figure 7. Calculated plan on CT with TPS bolus.

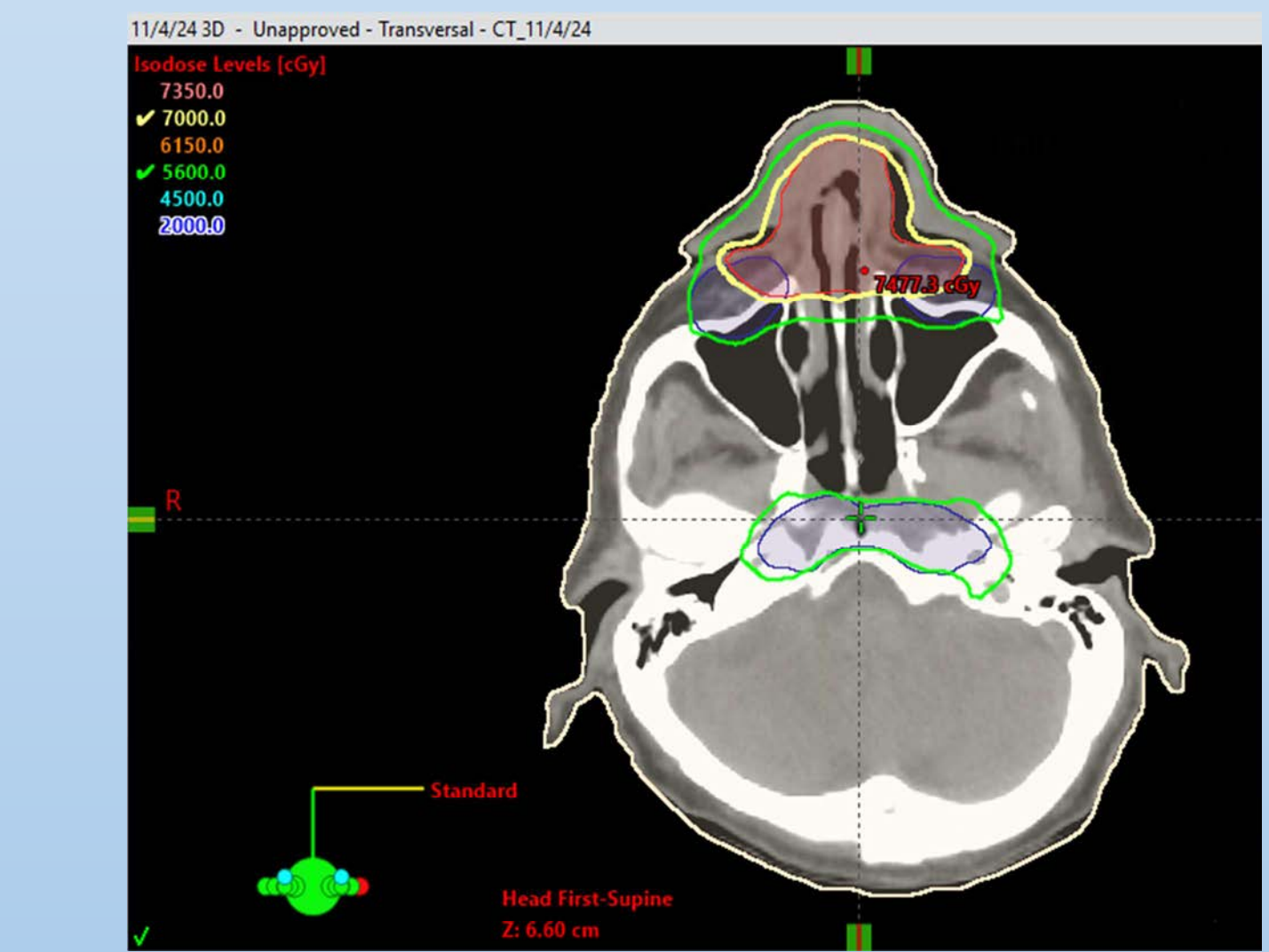


Figure 8. Calculated plan on CT with 3D printed bolus

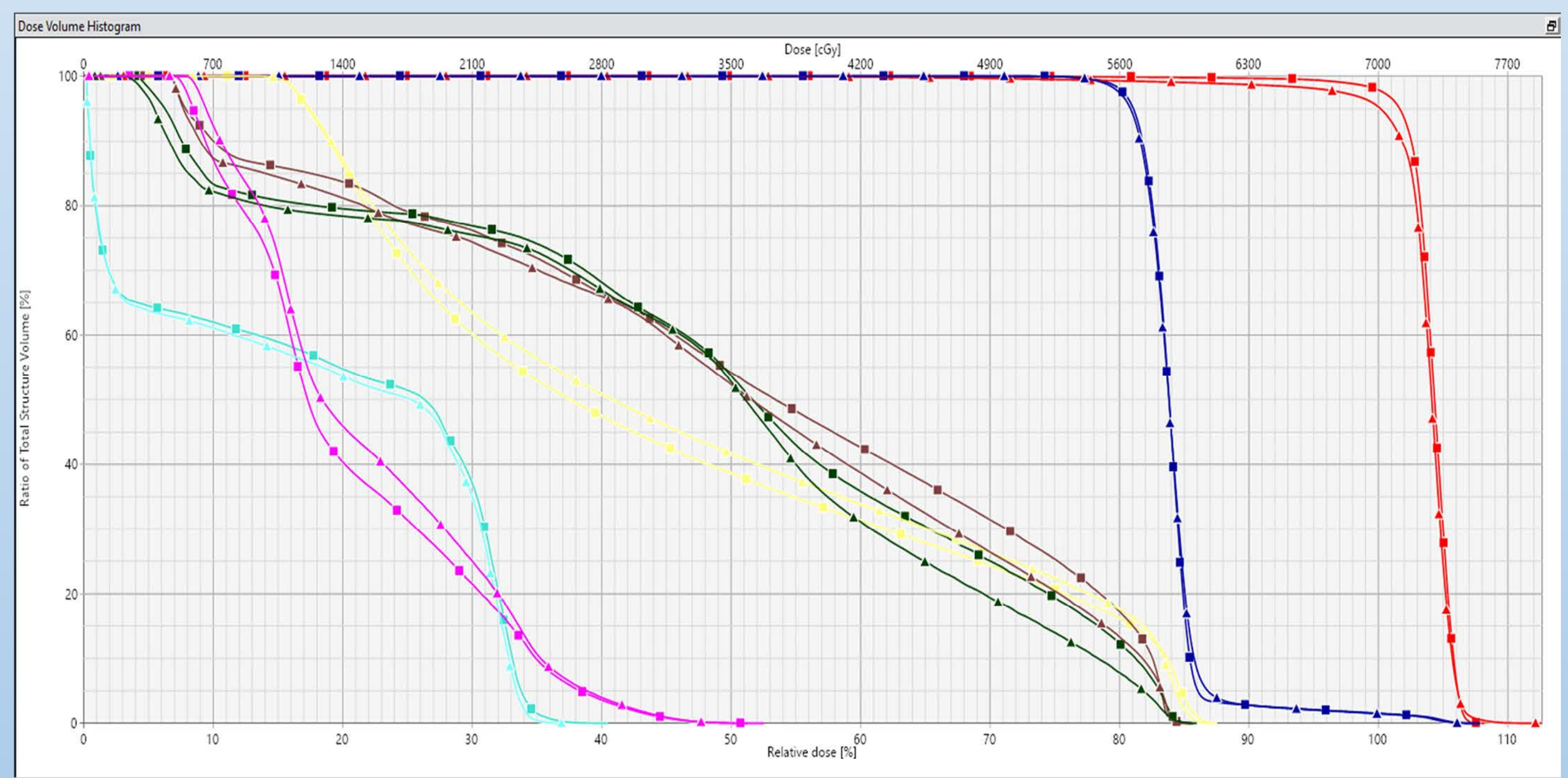


Figure 9. DVH comparison between TPS (square) and 3D bolus (triangle) plans

Results

Treatment plans

The plans using TPS generated bolus and 3D-printed bolus were calculated and compared. Isodose distribution and DVH results were reviewed.

- Dose distribution and conformity were similar between the two plans. The isodose distributions were reviewed in the CT axial planes [Figures 7,8]
- The DVH results showed similar coverage to target and sparing of local critical structures. [Figure 9]

CBCT review and analysis

Analysis of daily CBCT setup images provided validation of treatment setup accuracy and placement consistency of 3D bolus on body of patient.

- The bolus placement were evaluated using CBCT images starting from 1st fraction [Figure 10] and every 5 fractions thereafter. Visual review showed bolus located on patient as planned.
- Measurements were taken between corner edges of 3D bolus against visible bony anatomy of Nasal Septum. The plotted graph showed consistency in placement as deviations from each sampled fraction range from 0mm to 2.5mm. [Figure 11]
- Deviations were found to be within accepted daily setup tolerances. Variations in offset between 3D-printed bolus placement and body were concluded as minimal; thereby proving reproducibility.

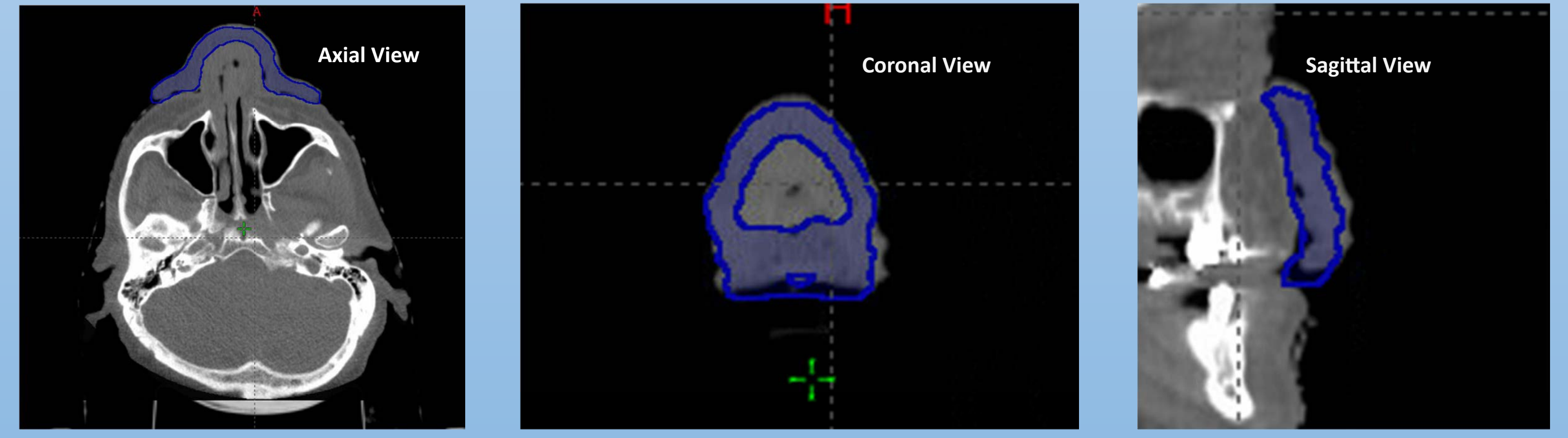


Figure 10. In Eclipse treatment planning system, 1st day CBCT overlaid on planning CT with TPS bolus outline visible. CBCT captured bolus matches well with TPS generated custom bolus outline on axial, coronal, and sagittal planes.

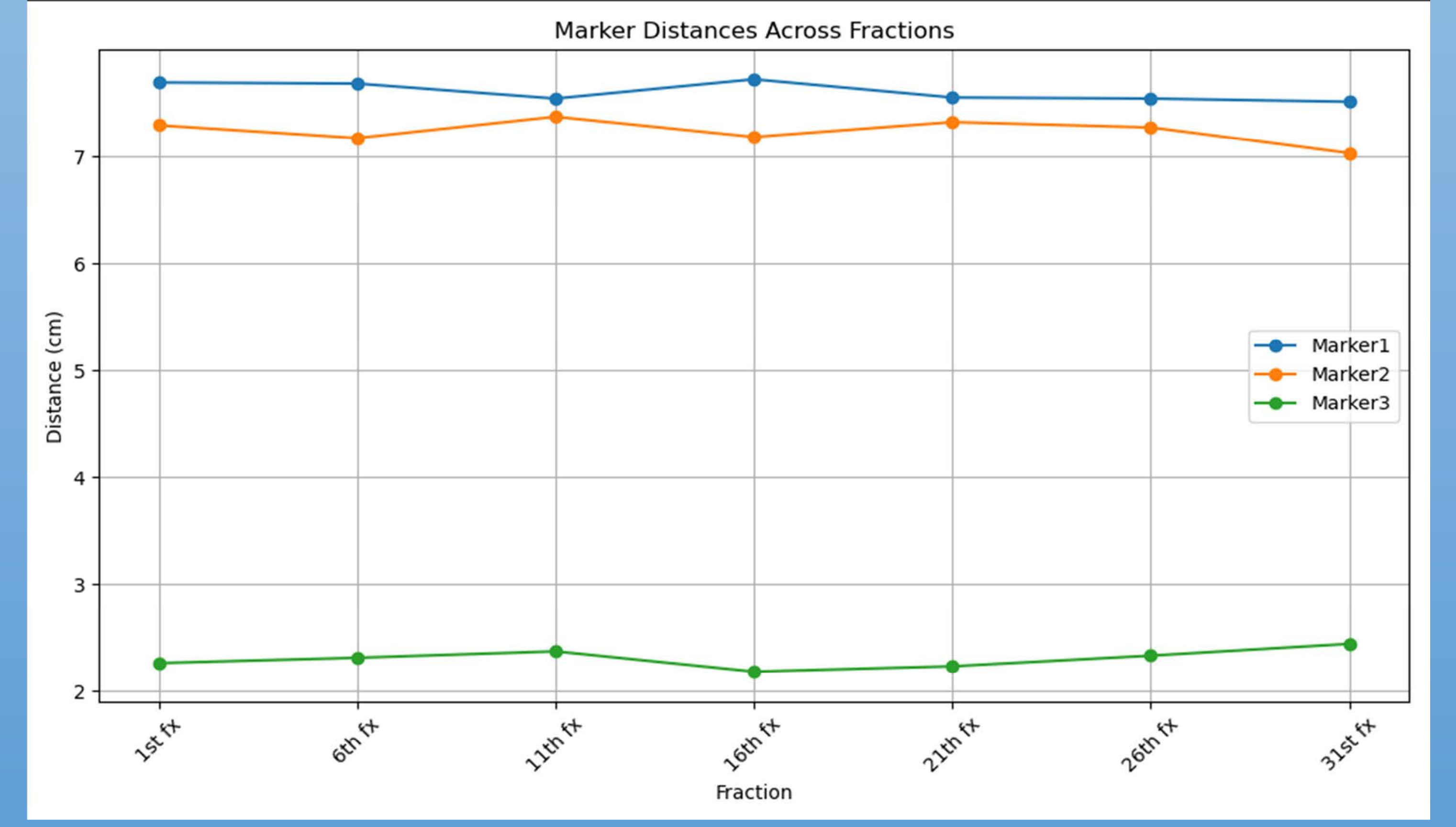


Figure 11. Graph showing distances between nasal septum to landmark points on 3D bolus.

Discussion and Conclusion

The plan calculated on CT with 3D-printed bolus showed similar dose results when compared plan with TPS-generated bolus. The results have shown similar dose conformity to target, ease, and accuracy of device fabrication, and improvements to setup reproducibility. Integrating 3D-printed devices into our treatment planning and design can improve the overall quality of radiotherapy delivery to our patients.

Pros:

- Creates more complex seamless shapes than regular bolus around irregular surfaces (i.e. nose) thus help minimize potential air gaps.
- 3D printed device could serve as a template for creating bolus using other conventional materials (i.e. Superflab)
- Re-print/re-create exact bolus in case of loss/damage
- Reduces the requirement/dependence on human dexterity/skill in manufacture

Cons:

- Higher learning curve with software and printing hardware
- Large volume bolus/structure may take up to 24 hours to print
- The edges of bolus were difficult to create smoothly along axial plane because of nature of contouring on existing TPS software
- Cannot currently do severely concave contours because of conversion limits to a 3D CAD mesh object closing the concavity
- TPU filament less flexible than conventional Superflab bolus
- Issues with fitting if patient surface changes

Future Directions

Future studies relating to 3D printing could focus on different commercially available materials for device creation, automated design algorithms, and workflow refinement for broader clinical implementation.

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