3D-Printed Headrest for Frameless Gamma Knife Radiosurgery: Design and Validation

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Introduction

Frameless Gamma Knife stereotactic radiosurgery (SRS) uses a moldable headrest with a thermoplastic mask for patient immobilization. The patient-specific mask and headrest used for immobilization are created during the patient's treatment simulation on the Gamma Knife unit. Creation of the headrest during simulation can be challenging, especially for centers with limited experience in creating radiotherapy immobilization, with the primary challenge being able to mold the patient headrest within the geometrical limitations of the Gamma Knife imaging and treatment system. The purpose of this study was to design and validate a 3D-printed headrest for frameless Gamma Knife SRS that can overcome these difficulties.

Figure 1: Standardized headrest 3D-Printed in polylactic acid in Gamma Knife frameless adapter.

Methods and Materials

A headrest 3D model designed to fit within the frameless adapter was 3D-printed (Figure 1). Dosimetric properties of the 3D-printed headrest and a standard-of-care moldable headrest were compared by delivering a Gamma Knife treatment to an anthropomorphic head phantom fitted with an ionization chamber and radiochromic film (Figure 2). Ionization measurements were compared to assess headrest attenuation and a gamma index was calculated to compare the film dose distributions. A volunteer study was conducted to assess the immobilization efficacy of the 3D-printed headrest compared to the moldable headrest. Five volunteers had their head motion tracked by a surface tracking system while immobilized in each headrest for 20 minutes (Figure 3). The recorded motion data was used to calculate the average volunteer movement and a paired t-test was performed.

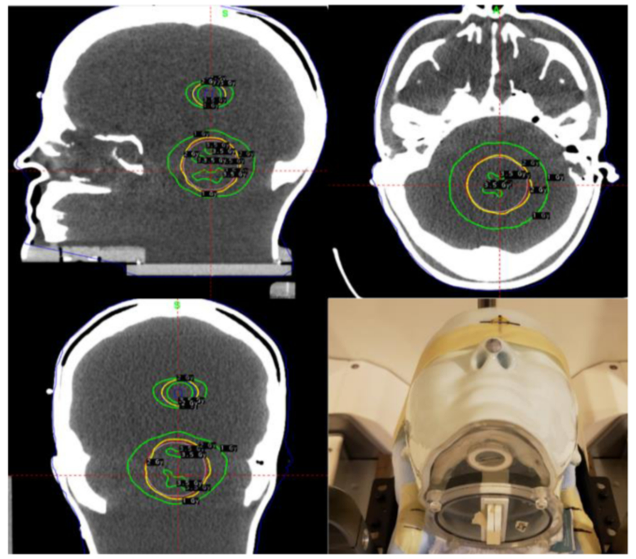

Figure 2: Renderings of treatment plan used for the dosimetric film comparison. Bottom left: phantom in the standard-of-care headrest.

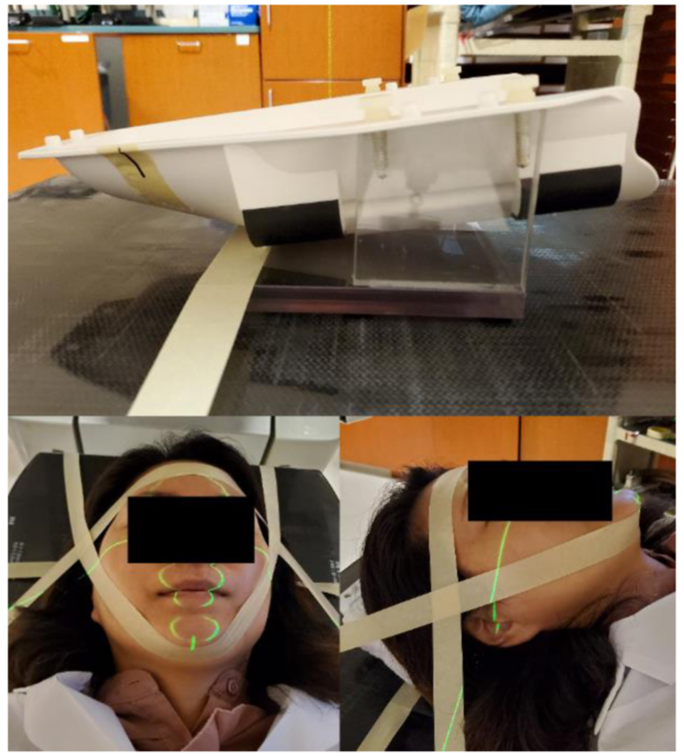

Figure 3: Top: Jig used to support headrests for comparison in VisionRT immobilization study. Bottom: Images of tape immobilization used for volunteer study.

Results

The ionization chamber readings were within 0.55% for the 3D-printed and moldable headrests, and the calculated gamma index showed 98.6% of points within dose difference of 2% and 2 mm distance to agreement for the film measurement. These results demonstrate the headrests were dosimetrically equivalent within the experimental uncertainties. Average motion (± standard deviation) of the volunteers while immobilized was 1.41 ± 0.43 mm and 1.36 ± 0.51 mm for the 3D-printed and moldable headrests, respectively. The average observed volunteer motion between headrests was not statistically different, based on a p-value of 0.466.

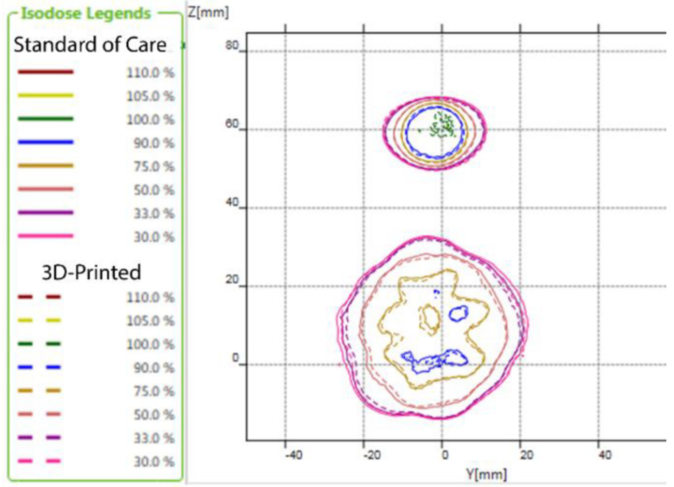

Figure 5: Results of film dosimetric comparison. Isodose comparison overlay.

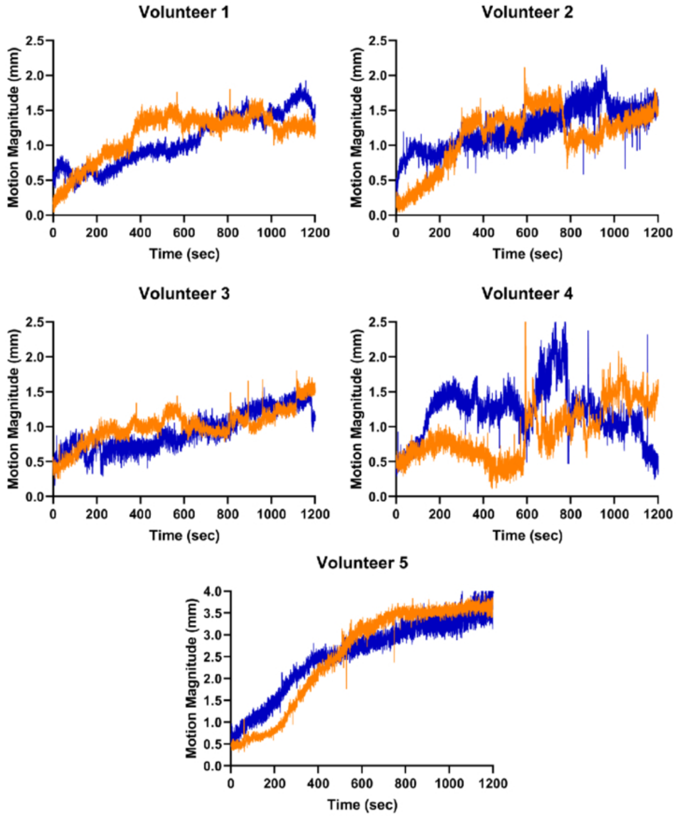

Figure 6: Plots of VisionRT recorded movement for each volunteer while immobilized in 3D-printed headrest (blue) and standard-of-care headrest (orange).

Table 1: Summary of immobilization study data

	Mean Vector Distance (mm)		Standard Deviation	
	3D-Printed	Standard-of-Care	3D-Printed	Standard-of-Care
Volunteer 1	1.30	1.15	0.28	0.42
Volunteer 2	1.08	1.14	0.38	0.34
Volunteer 3	0.93	1.02	0.28	0.25
Volunteer 4	1.19	0.93	0.38	0.40
Volunteer 5	2.55	2.55	0.84	1.15
Average	1.41	1.36	0.43	0.51
p-value	0.466			

Conclusions

A dosimetric study demonstrated the 3D-printed headrest does not negatively affect delivering the intended dose to the target as planned. An immobilization study demonstrated the 3D-printed headrest provided comparable immobilization to the current standard-of-care moldable headrest. Together, these results demonstrate that the 3D-printed headrest is suitable for use in frameless Gamma Knife treatments. Use of the 3D-printed headrest can alleviate the challenges associated with using the current standard-of-care moldable headrests. The design developed in this study can be utilized as a foundation for future research in 3D-printed patient specific headrests.