PTV margins for Gamma Knife Icon Frameless Treatment : A Validation Study

P. Diagaradjane[1], E.Y.Han[1], D. Luo[1], Y. Ding[1], G. Kalaitzakis[2], E. Zoros[3], K. Zourarli[3], T. Boursianis[2], E. Pappas[4], Z. Wen[1], J. Wong[1] and T. Briere[1]

[1]Department of Radiation Physics, The UT MD Anderson Cancer Center, Houston, Texas, USA
[2] Department of Medical Physics, University of Crete, Heraklion, Crete, Greece
[3] Medical Physics Laboratory, Medical School, National and Kapodistrian University of Athens, Athens 115 27, Greece
[4] Department of Biomedical Sciences, Radiology & Radiotherapy Sector, University of West Attica, Athens, Greece

JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Gamma Knife Icon with integrated cone beam computed tomography (CBCT) and a high-definition motion management (HDMM) has opened up new perspective in the Gamma Knife treatment regimens by eliminating the need for a stereotactic head frame and extending the options **to multi-fractional treatment regimens using frameless mask-based immobilization** for

i. Large tumors and,
ii. Cases involving a postoperative surgical cavity (>4 cm)

where, multi-fraction treatment regimens with small doses/fractions are desirable.

Despite promising outcomes, very limited studies have focused on the PTV margin study through the volumetric evaluation of dose distribution and the impact of intra-fraction patient motion.

AIM

Here, we sought to **evaluate the impact of patient motion** (monitored using external surrogate) on the intracranial volumetric dose distribution and **validating our PTV margin expansion** scheme of 1 mm around the gross target volume (GTV) with an exception of 1.5 mm in the superior and inferior direction for the following clinical scenarios:

i. Motion that is just below the threshold limit (1.5 mm) of HDMM with no plan adaptation and,
ii. Frequent treatment interruptions with motion beyond HDMM threshold, with a reference scenario being no head motion.

METHOD

Reference PseudoPatient^R Prime head phantom (Rtsafe, Athens, Greece), a 3D-printed anatomical replica created using the CT image of a human head, with inserts for **(a) ionization chamber, (b) film and, (c) cylindrical gel** were used for 1D, 2D and 3D dose calculations.

Clinical scenarios were simulated using a custom built translational stage, remotely controlled from treatment console.

PTV1 (center of the sensitive volume of ionization chamber) and **PTV2** (5 cm inferior to the center of PTV1) with target volumes of 3.98 cm^3 and 4.32 cm^3 were defined within the intracranial space of the head phantom. The prescription doses were set to **6 Gy to the 50 % IDL**.

TMR10 (Leksell Gamma Plan) & convolution algorithm with 1 mm^3 dose grid were used to evaluate dose calculation accuracy against the measured values.

RESULTS

Ionization Chamber (1D measurements)

GK plan algorithm Dose Calculation Vs Ion Chamber measurements.

Algorithm	Measurement	Plan	% difference
TMR 10	3.77 Gy	4.00 Gy	**5.75 %**
Convolution	4.00 Gy	3.95 Gy	**1.25 %**

- Dose calculations using AAPM Task Group 21
- P_{TP}, P_{pol}, and P_{ion} were measured using the same phantom
- K_q estimated as 1.001, assuming homogeneity phantom.

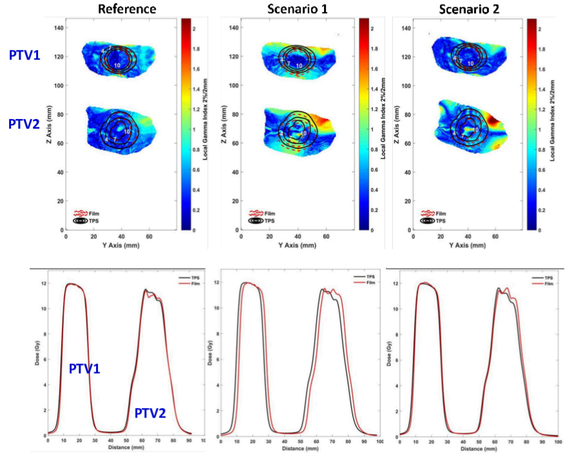
Calculated dose (Convolution) Vs Ion Chamber measurements

Convolution planned dose	Ionization chamber measurements					
	Reference		Scenario 1		Scenario 2	
	Dose	% diff	Dose	% diff	Dose	% diff
11.9 Gy	12.1 Gy	**2.3**	12.1 Gy	**2.3**	12.2 Gy	**2.8**

Reference PseudoPatient^R head phantom with remote controlled translational assembly and ion chamber insert

EBT3 Film (2D measurements)

Dose Distribution and Sagittal Profile comparison

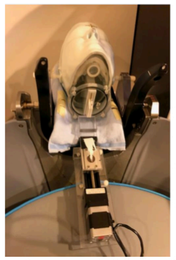


EBT3 Film (2D measurements)- Contd

Gamma index comparison with TPS-calculated dose distributions with various gamma passing criteria at 10% low-dose threshold

	Passing Criteria	Reference	Scenario1	Scenario2
PTV1	2% / 1 mm	57.8	38.2	74.4
	2% / 2 mm	**96.1**	**82.6**	**96.6**
	2% / 3 mm	99.7	98.4	99.9
PTV2	2% / 1 mm	69.3	37.0	47.2
	2% / 2 mm	**96.2**	**71.5**	**83.5**
	2% / 3 mm	100.0	95.9	95.6

- Significantly reduced passing rate at 2% / 1 mm is attributed to the film to CT co-registration uncertainty limit of 1.5 mm.
- At passing criteria of 2 % / 2mm,
  - the lower passing rate in Scenario 1 when compared to Scenario 2 **is attributed to the patient motion to threshold limit of HDMM**.
  - The overall lower passing rate of PTV2 when compared to PTV1 **is attributed to the deviation of isodose patterns with composite shots.**



Reference PseudoPatient^R head phantom with remote controlled translational assembly and Film insert (Sagittal and coronal options)

Gel (3D measurements)

- Vinylpyrrolidone-based (VIP) polymer gels containing N-vinylpyrrolidone, cross-linker N, N′-methylene-bisacrylamide and gelatin in a water environment.
- Polymer gels were equilibrated to the MRI scanner room temperature immediately after irradiation and MRI scans were acquired 24 hours after irradiation.
- T2 image scans were acquired using : repetition time = 4230 ms, echo time = 40, 353, 931, 1380 ms, pixel size = 1.4 × 1.4 mm^2, slice thickness = 2.0 mm.
- R2 maps (R2 = 1/T2), which are linearly related to the radiation dose (Gy), were post-processed and converted to 3D dose distributions.

Reference PseudoPatient^R Prime head phantom with remote controlled translational assembly and Gel insert

Image registration of the post-irradiation MR images of the phantom with gel inserts with the TPS plan demonstrating the coincidence of target (irradiated volume) with the TPS IDL in (a) transverse (b) sagittal and (c) coronal planes.

RESULTS

Gel (3D measurements)- Contd

Measured dose volume metrics, D_{95} Vs TPS calculated dose

Target	Estimated D_{95} values						
	TPS	Reference		Scenario 1		Scenario 2	
		Measured	Difference	Measured	Difference	Measured	Difference
PTV1	76.3%	78.1%	+1.9	76.2%	0.0	77.5%	+1.3
PTV2	62.0%	67.6%	+5.6	66.6%	+4.7	65.1%	+3.1

Gamma index comparison with TPS-calculated dose distributions with 2%/2mm passing criteria at 10% low-dose threshold

	Reference	Scenario1	Scenario2
PTV1	99.6	99.21	99.3
PTV2	100.0	100.0	98.4

- Measured D95 values are higher than the TPS calculated dose by up to 5.6 %.
- Better Gamma passing rate for both PTV1 and PTV2 suggests that 3D dose volume measurements confirm the validity of the current margin recipe.

CONCLUSION

- Our current clinical margin scheme is adequate for typical patient intrafractional motion during frameless mask-based Gamma Knife treatments.
- Volumetric dose distribution analysis using 3D dosimetry such as gel is more beneficial to validate PTV margins to ensure optimal target coverage.
- An end-to-end 3D dosimetry would provides the opportunity to modify the margin recipe to maintain target coverage and to protect organs at risk (OARs) for improved patient care.

REFERENCES

- Task Group 21, R.T.C., AAPM. A protocol for the determination of absorbed dose from high-energy photon and electron beams. *Medical Physics* **10**:741-71; 1983
- Han, E.Y. et al. Dosimetric validation of the Gamma Knife® IconTM plan adaptation and high-definition motion management system with a motorized anthropomorphic head phantom. *Journal of Radiosurgery and SBRT* **6**:217-26; 2019.
- Rojas-Villabona, A et al. Investigation of dosimetric differences between the TMR 10 and convolution algorithm for Gamma Knife stereotactic radiosurgery. *J Appl Clin Med Phys* **17**:217-29; 2016.
- Makris, D.N.;Pappas, E.P.;Zoros, E.; et al. Characterization of a novel 3D printed patient specific phantom for quality assurance in cranial stereotactic radiosurgery applications. *Physics in medicine and biology* **64**:105009; 2019.
- Luo D, et al. Use of uniform shots for robust planning of mask-based treatment in Gamma Knife ICON. Physica Medica 73:135-157; 2020.

CONTACT INFORMATION

Parmeswaran Diagaradjane – parmesh@mdanderson.org
Eun Young Han – Ehan@mdanderson.org