Target localization uncertainty in Gamma Knife SRS: Comparison of three frame-based workflows

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Purpose and Objective

Frame-based Gamma Knife radiosurgery is clinically implemented by (i) performing a patient MRI scan after attaching the Leksell stereotactic frame incorporating the N-shaped fiducials (hereinafter, "MR-only" workflow) or (ii) acquiring a CT scan with the frame and performing an anatomy-based co-registration with the MRI (hereinafter, "MR/CT" workflow). Moreover, (iii) the mean image method has been proposed for MR distortion correction in MR-only procedures (non-clinical, hereinafter "MR-corrected" workflow). In all cases, the target(s) are registered to the Leksell stereotactic space (LSS) by identifying the N-shaped fiducials. This phantom study evaluates and compares the localization uncertainties stemming from registration and inherent MR image distortions.

Materials and Methods

A custom-made acrylic-based spherical container was filled with 3D polymer gel dosimeter. The phantom was CT-scanned with the Leksell frame on. A treatment plan of 26 individual 4mm-shots was prepared and delivered. Shot centers directly defined in the Leksell stereotactic space (LSS) served as reference target positions (Fig.1). The irradiated phantom was also T2w-imaged at 1.5T, with the frame on. An extra reversed gradient polarity MR series was acquired to implement the mean image distortion correction method. Targets were independently contoured in the GammaPlan TPS by exploiting the radiation-induced MRI contrast on all images relevant to the three workflows (Fig.1). TPS-calculated structures and corresponding transformation matrices were exported and processed using in-house routines. Target centroids were first calculated in the dicom coordinate system and then co-registered to the LSS by applying the TPS-calculated transformation(s), following each one of the three workflows, independently. Calculated centroid locations were compared to reference positions for uncertainty evaluation.

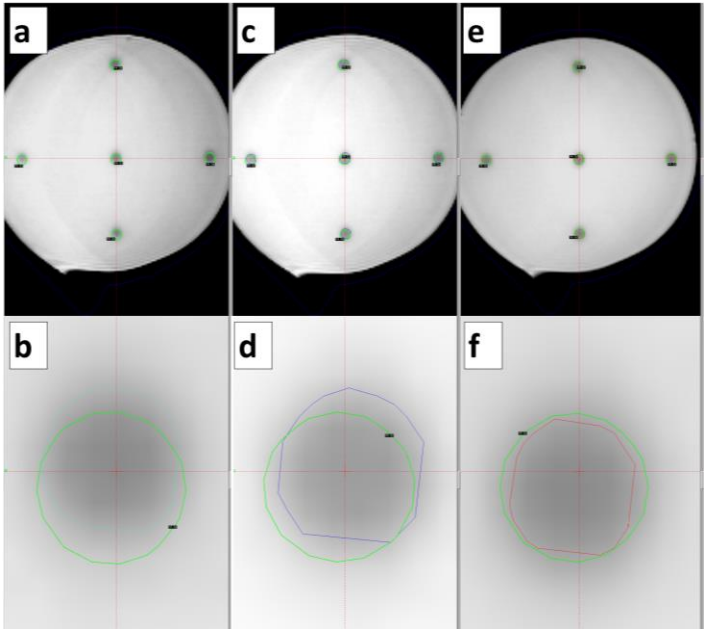

Fig. 1. Screenshots of the GammaPlan treatment planning system depicting a transversal MR slice of the irradiated phantom intersecting 5 Gamma Knife shots, after performing the spatial co-registration to the Leksell Stereotactic Space (LSS), following the (a),(b) MR-only, (c),(d) MR/CT and (e),(f) MR-corrected workflows. To increase visibility, the central GK shot is enlarged in the bottom row panels (b),(d),(f). Legend: green solid line: the 14-Gy isodose for each shot delivered (corresponding centroids serving as reference points); light blue, dark blue and red lines: contours of the automatically generated target structures, defined using the radiation induced polymerization areas, for the assessment of target localization accuracy, following the MR-only, MC/CT and MR-corrected workflows, respectively. All data shown are registered to the LSS coordinate system.

Results and Conclusion

Spatial offsets were seen in all workflows (Fig.1). For MR-only, a 0.8mm median spatial uncertainty was estimated, with a max of 1.2mm and great dependence on target location. Reduced uncertainties (median 0.6mm, max 0.9mm) were calculated for the MR/CT workflow (Table 1). The MR-corrected approach performed best with median/max uncertainties of 0.2mm/0.4mm (Table 1).

For both clinically used workflows, target localization uncertainty may compromise treatment efficiency, especially for tiny lesions distant from isocenter. MR distortion correction can improve target localization accuracy in MR-only workflows.

Table 1. Summary of the phantom study results. Median and maximum offset between reference and evaluated centroids in the LSS, related to all 26 GK shots and three workflows. Legend: x, y, z correspond to the normal axes of the Leksell Stereotactic Space (LSS); x: Left-Right direction; y: Posterior-Anterior direction; z: Inferior-Superior direction; R: the Radial distance between reference and evaluated points

	Median absolute offset (mm)				Maximum absolute offset (mm)			
	Δx	Δy	Δz	R	Δx	Δy	Δz	R
MR-only	0.0	0.7	0.4	0.8	0.1	1.1	0.8	1.2
MR/CT	0.2	0.4	0.1	0.6	0.7	0.9	0.4	0.9
MR-corr.	0.1	0.1	0.0	0.2	0.4	0.4	0.2	0.5

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