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Radiobiological Comparison of Pencil Beam- and Shot-Based Treatment Delivery Techniques in Stereotactic Radiosurgery of Intracranial Benign Lesions: Preliminary Results of a Bicentric Study

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Abstract

Objectives:

Stereotactic radiosurgery (SRS) is commonly facilitated by “step-and-shoot” irradiation techniques, comprising sequential delivery of the planed dose distribution through either isocentric radiation shots (e.g., Gamma knife) or non-isocentric pencil beams (e.g., CyberKnife). These techniques are linked to complex dose and dose rate distributions on both the spatial and temporal domains, resulting in variations in the degree of radiation-induced DNA damage repair during treatment, which, eventually, modulate the biological outcome of prolonged treatments.
In this study we aim to compare the two fundamental and most widely used techniques of SRS dose delivery, i.e., those implemented in the Gamma knife (GK) and CyberKnife (CK) systems, in terms of radiobiology using the concept of radiobiological effective dose (BED) for intracranial benign tumor treatments.

Methods:

Vestibular Schwannoma (VS) cases treated with GK-SRS in a single fraction were selected and retrospectively analyzed after corresponding data anonymization. The VS cases studied had a score of 1-3 in the Koos grading scale. A therapeutic dose of 12 Gy was prescribed in all cases. The same VS cases were replanned in a CyberKnife (model VSI) system employing the fixed collimators. For each case, the CT image series (along with the HU-to-density calibration data of the acquisition scanner) and the contoured structures utilized in GK treatment planning were used. CK treatment planning strategy resulted in clinically deliverable plans, with a sole obligation to keep the VS target coverage (by the prescription dose iso-surface) higher than 95% to match the corresponding property of GK plans.
For each case, the plan data were extracted from both GK and CK systems and used to perform independent calculations of the dose and dose rate distributions corresponding to each radiation shot (for the GK system) or irradiating beam (for the CK system) on a voxel-by-voxel basis. The calculated dosimetry data were then used to obtain corresponding BED distributions accounting for sublethal repair effects (BEDSRE), using the Millan and Canney formula [1], as revised by Pop et al [2] and employing an a/b ratio of 2.47 Gy.

Results:

A number of 15 cases were retrospectively processed. The median volume of VS tumors was 0.36 cm3 (range: 0.07 – 4.77). The median treatment time was 35 min (range: 17 – 56) and 36 min (range: 19 – 74) for the CK and GK system, respectively, exhibiting no statistically significant difference ($p = 0.34$). On the other hand, beam-on time was shorter for the CK system ($p < 0.001$) requiring a median of 13.7 min (range: 6.96 – 28.13) to deliver 12 Gy of radiation dose to the periphery of the VS targets compared to a corresponding median of 33.5 min (range: 17.3 – 70.5) for the GK system. No statistically significant difference was found in Paddick’s conformity, R50 and Selectivity indices, denoting equal plan quality, whereas GK plans were systematically associated with better Gradient Index (GI50 median values: 2.89 vs 3.77 for the GK and CK system, respectively, $p = 0.002$). Statistically significant differences were found in the mean and maximum dose delivered to the VS targets, both being higher for the GK system ($p < 0.001$). These, however, stem majorly from the different range of isodose levels utilized in each system for dose prescription. The median prescription isodose level was 64% (range: 60 – 76) and 50% (range: 50 – 65) for the CK and GK system, respectively. The minimum dose was marginally higher for the CK system (median values: 10.72 Gy vs 9.70 Gy for CK and GK, respectively, $p = 0.051$), while the minimum dose delivered to the 98% of VS volume, D98, was statistically higher for the GK system (median values: 12.20 Gy vs 11.90 Gy for GK and CK, respectively, $p < 0.001$). No statistically significant difference was found for the integral dose (median values: 5.37 mJ vs.

6.00 mJ for Ck and GK, respectively). Regarding the BED delivered to the VS targets, statistically significant differences were found in the mean and maximum BEDSRE levels reflecting those of mean and maximum dose, due mainly to the different dose prescription policy applied in the two systems. It is worth noting that, contrary to D98, no statistically significant difference was found in the minimum BEDSRE delivered to 98% of VS volume, BED98.

Conclusion(s):

Robot trajectory time is a major contributor in CK total treatment time, while for the GK system, treatment time is a function of the number of radiation shots and the activity of Co-60 sources. In terms of the marginal BED delivered to the VS targets, expressed by BED98, no statistically significant difference was found. Differences in mean and max dose and BEDSRE levels reflect the different dose prescription policy in the two SRS platforms.

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