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Treatment plan quality comparison between ZAP-Axon optimizer and Leksell Gamma Knife Lightning optimizer for large single brain metastasis

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ABSTRACT

Purpose: Stereotactic radiosurgery (SRS) plan optimization requires balancing high-quality dosimetry and treatment efficiency. This study compares treatment plan quality between the recently launched ZAP-Axon optimizer and the Leksell Gamma Knife (GK) Lightning optimizer for large single metastatic brain tumors treated with volume-staged SRS.

Methods: Ten (n=10) patients treated with staged SRS using Gamma Knife were selected. The first stage treatment plans were independently recomputed using ZAP-Axon and GK Lightning optimizers. Isocenters (ZAP-Axon) or shots (GK Lightning) were automatically placed, and no manual adjustments were made before or after the optimizers were run. Optimization time per iteration (sec) was recorded for each system. Dosimetric metrics such as prescription isodose line (Rx IDL, %), target coverage (COV, %), Paddick conformity index (PCI), gradient index (GI) and delivery time estimates (min) were compared.

Results: Mean (minimum – maximum) target volume was 5.200 cc (3.038 cc - 8.329 cc) and prescription dose was 15 Gy in a single fraction. Mean COV, Rx IDL, GI, PCI and delivery time estimates for ZAP-Axon vs. GK Lightning were 99.6% vs. 99.7% (P<0.05), 57.3% vs. 52.9% (P<0.05), 2.42 vs. 2.55 (P<0.05), 0.93 vs. 0.93 (P=0.4151), and 39.6 min vs. 35.1 min with GK reference dose rate of 3.0 Gy/min (P=0.1480), respectively. Mean optimization times per iteration were 290.2 sec for ZAP-Axon vs. 36.6 sec for GK Lightning (P<0.05).

Conclusion: Minimal but statistically significant differences between the two optimizers were observed for COV, mean max dose, and GI, which are unlikely to be of clinical significance. PCI and delivery time estimates were similar for both optimizers. Optimization per iteration was more efficient with Lightning due to image resolution and dose grid size differences between CT images (ZAP-Axon) and MR images (GK Lightning). Future studies incorporating total planning time comparison with expert manual adjustments may further demonstrate planning efficiency.

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INTRODUCTION

One of the most common treatment strategies for brain metastasis (BM) is stereotactic radiosurgery (SRS) or fractionated SRS (FSRS).[1] Large BM >2 cm is typically treated with FSRS, staged SRS, pre-operative SRS/FSRS, or post-operative SRS/FSRS.[2]

Leksell GammaPlan® (LGP, Elekta AB) has evolved over decades. In 2020, a novel inverse planning optimizer called fast inverse planning, commercially referred to as Lightning, was released. The Lightning dose optimizer utilizes sector-duration optimization (convex) using linear programing to enhance planning efficiency. Previous studies demonstrated that Lighting promptly generates plans which require minimal to no manual adjustment and there is minimal inter-planner plan quality variability regardless of planner's experience.[3-5] For dose calculations, LGP uses a tissue-maximum-ratio (TMR) based algorithm, that is, TMR 10, which models the head as water and does not account for heterogeneity.

The ZAP-X has a dedicated treatment planning system (TPS) and its TPS has also evolved over the past few years. A recently launched new TPS application, named ZAP-Axon®, deploys a new optimization algorithm (Krylov optimizer) that uses a quadratic cost function and handles more beams than the older versions (Legacy TPS and Advanced Workspace). Because the Krylov optimizer leverages an iterative solver to address the convex problem, the optimization time is faster than the older versions. For dose calculations, ZAP-X TPS uses an Analytic Ray Tracing algorithm which accounts for heterogeneity based on one-dimensional equivalent path length scaling. Table 1 compares the Leksell Gamma Knife (LGK) Lightning and ZAP-Axon Krylov algorithms.

While several treatment planning studies using the LGK Lightning dose optimizer have been published, to the best of our knowledge, similar studies using ZAP-Axon have not yet been published. In this study, SRS treatment plan quality between ZAP-Axon Krylov optimizer and LGK Lighting optimizer is compared for single large intact brain metastatic lesions.

Table 1. Comparison of LGK Lightning and ZAP-Axon Krylov algorithms

	LGK Lightning	ZAP-Axon Krylov
Dose calculation algorithm	TMR 10 (heterogeneity uncorrected)	Analytic Ray Tracing (heterogeneity corrected)
Planning algorithm	Linear convex	Linear convex
Cost function	Linear	Quadratic
Solving method	Direct	Iterative

MEMTHODS AND MATERIALS

Ten (n=10) SRS patients, who were treated using Gamma Knife, were selected for this study. The patients had a single, large BM and received staged SRS to the gross tumor volume to 15 Gy in one fraction per stage. The first of the 2-stage treatment was chosen.

The 10 clinical cases were replanned in ZAP-Axon per our institutional SRS planning guidelines. For treatment planning, two steps were executed. First, after proper parameter settings (Isocenter Count limit,

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Path Density, Collimator Overlap, Small Target Diameter and Target Dilation), target packing ran for automated isocenter placement (Figure 1 (a)). Second, the optimizer ran with relevant parameter settings (Interior-100% Max, Interior-100% Min, Ext. 1 mm Max, Ext. 2 mm Max, and Ext. 5 mm Max) (Figure 1 (a)). Before optimization, the Krylov optimizer was enabled. To minimize planner dependence on planning, no manual adjustments were made after optimization was completed; that is to say, no isocenter was moved, added, or deleted, no collimator size was manually changed, or no dose was scaled. The two steps were repeated until target coverage (TC), Paddick conformity index (PCI), treatment time, and gradient index (GI) were achieved in order of this importance. Our institutional SRS/FSRS planning guidelines include TC ≥99.5% receiving prescription dose or higher, PCI as close to 1.0 as possible, GI ≤3.0 and a prescription isodose line (Rx IDL) ≥50% and ≤93%.

The 10 cases were also replanned in LGP (v.11.4.2) using the Lightning optimizer. In the dose optimizer (Figure 1(b)), prescription dose, proper maximum dose to the target, number of fractions (one or three, only for mask fixation configuration) were entered and the TC box was enabled. Low dose (LD) and BOT settings ranging from 0.00 to 1.00 each were selected. The optimizer ran repeatedly with different LD/BOT combinations until TC, PCI, BOT and GI were achieved in order of this importance. No manual adjustments were made after optimization completion.

Plan quality metrics were noted for each group. For Krylov plans, PCI, GI, TC (%), Rx IDL (%), treatment time (=gantry motion + beam-on + intrafraction imaging) (min), number of isocenters, and number of beams were recorded. For Lightning plans, PCI, GI, TC (%), Rx IDL (%), sBOT (scaled BOT to dose rate of 3.0 Gy/min) (min) and number of shots were recorded.

Statistical analysis was performed to compare plan quality metrics between Krylov plans and Lightning plans for each group. Considering small sample size (n = 10), a Wilcoxon matched pairs test was performed. A *p-value* <0.05 was considered statistically significant.

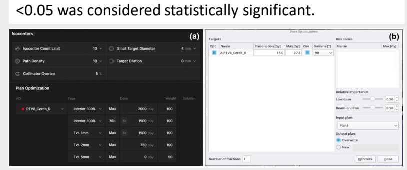

Figure 1. (a) Examples of parameter settings for (a) ZAP-Axon Krylov optimizer and (b) LGK Lightning optimizer for a single, large intact brain metastatic lesion

RESULTS

The mean (minimum - maximum) target volume was 5.200 cc (3.038 cc - 8.329 cc). The mean COV, Rx IDL, GI, PCI and delivery time for ZAP-Axon vs. GK Lightning were 99.6% vs. 99.7% (p <0.05), 57.3% vs. 52.9% (p <0.05), 2.42 vs. 2.55 (p <0.05), 0.93 vs. 0.93 (p = 0.4151), and 39.6 min vs. 35.1 min with GK reference dose rate of 3.0 Gy/min (p = 0.1480), respectively. The mean optimization times per iteration were 290.2 sec for ZAP-Axon vs. 36.6 sec for GK Lightning (p <0.05). While COV, Rx IDL,

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GI and optimization time were statistically different(p <0.05), PCI and delivery time were not. Figure 2 (a)-(f) shows comparisons of COV, Rx IDL, PCI, GI, delivery time (min) and optimization time per iteration (sec) between ZAP-Axon and GK Lightning, respectively. Examples of isocenter and shot placement, and examples of ZAP-Axon Krylov and LGK Lightning plans are shown in Figure 3 (a)-(b) and 4 (a)-(b), respectively.

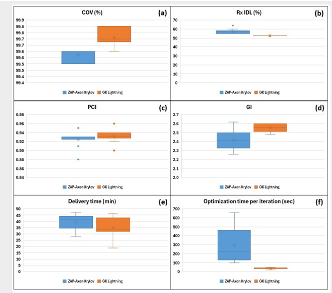

Figure 2 (a)-(f). Treatment plan quality metrics comparison between ZAP-Axon and LGK Lightning

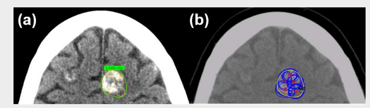

Figure 3. A representative example of (a) isocenter placement in ZAP-Axon Krylov plan and (b) shot placement in LGK Lightning plan

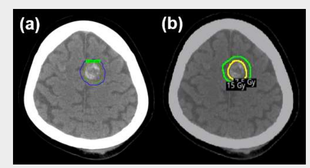

Figure 4. Axial views of a representative example of (a) ZAP-Axon plan and (b) LGK Lightning plan

CONCLUSIONS

Minimal but statistically significant differences between the two optimizers were observed for mean COV, max dose, and GI, which are unlikely to be of clinical significance. PCI and delivery time were similar for both optimizers. Optimization per iteration was more efficient with Lightning due to image resolution and dose grid size differences between CT images (ZAP-Axon Krylov) and MR images (LGK Lightning).

REFERENCES

1. Vogelbaum MA, Brown PD, Messersmith H, Brastianos PK, Burri S, Cahill D, et al. Treatment for Brain Metastases: ASCO-SNO-ASTRO Guideline. *J Clin Oncol.* 2022;40:492-512.
2. Kotecha R, Ahluwalia MS, Siomin V, McDermott MW. Surgery, stereotactic radiosurgery, and systemic therapy in the management of operable brain metastasis. *Neurol Clin.* 2022;40(2):421-436.
3. Lee YC, Wieczorek DJ, Chaswal V, Kotecha R, Hall MD, Tom MC, et al. A study on inter-planner plan quality variability using a manual planning- or Lightning dose optimizer-approach for single brain lesions treated with the Gamma Knife® Icon™. *J Appl Clin Med Phys.* 2023;24(11):e14088.
4. Spaniol M, Mai S, Zakrzewski, Ehmann M, Stieler F. Inverse planning in Gamma Knife radiosurgery: A comparative planning study. *Phys Med.* 2021;82:269-278.
5. Cui T, Kie K, Zhu J, Danish S, Weiner J, Chundury A, et al. Clinical evaluation of the Inverse Planning System Utilized in Gamma Knife Lightning. *Front Oncol.* 2022;12:832656.