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# Size-Stratified Dosimetric Impact of Gamma Knife Lightning Inverse Planning for Brain Metastases in Real-World Practice

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## Abstract

Objectives: To compare the real-world dosimetric parameters of Gamma Knife radiosurgery plans for brain metastases before and after the adoption of Lightning inverse planning, with results stratified by lesion size.

Methods: We conducted a retrospective cohort study at a single high-volume Gamma Knife center, analyzing consecutive intact brain metastases from lung or breast primaries treated between 2020 and 2024. Postoperative cavities were excluded. Lesions were categorized as 'pre-Lightning' (treated before January 1, 2022, prior to Lightning inverse planning integration) or 'Lightning-era' (treated on/after January 1, 2022, following integration). Key dosimetric data—including tumor volume, coverage (conformity), selectivity, gradient index (GI), prescription isodose level, and beam-on time (BOT)—were extracted from all plans. Lesions were stratified by volume: small ( < 1 cc), medium (1–4 cc), and large (>4 cc). Statistical comparisons were then performed to assess differences in these parameters between the pre-Lightning and Lightning-era cohorts.

Results: We identified 640 brain metastases (pre-Lightning: 362; Lightning: 278) with comparable size distributions between cohorts (small: 281 vs 209; medium: 53 vs 50; large: 28 vs 22).

Overall (across all lesions), Lightning plans demonstrated significantly higher selectivity (0.570 vs 0.510; p< 0.001) and gradient index (GI) (4.38 vs 3.55; p< 0.001), with an increased mean prescription isodose level (70% vs 60%; p< 0.001). Coverage remained very high and similar (0.995 vs 0.990; p=0.057), while beam-on time (BOT) trended longer post-Lightning (20.22 vs 18.10 min; p=0.131).

When stratified by size:

Small lesions ( < 1 cc): Showed higher GI (4.9 vs 3.7; p< 0.001), selectivity (0.503 vs 0.455; p< 0.001), and prescription isodose levels (74% vs 62%; p< 0.001) post-Lightning. Treatment time also significantly increased (16.1 vs 12.1 minutes; p=0.018).

Medium lesions (1–4 cc): Demonstrated improved selectivity (0.615 vs 0.562; p=0.012) and a modest increase in GI (4.21 vs 3.78; p=0.041), with consistently high coverage (0.995 vs 0.993; p=0.42). Prescription isodose levels were higher (p < 0.001), while BOT was not significantly different (21.0 vs 19.6 minutes; p=0.19).

Large lesions (>4 cc): Exhibited increased selectivity (0.712 vs 0.658; p=0.010) with very high and similar coverage (0.992 vs 0.988; p=0.11). GI (4.02 vs 3.86; p=0.27), prescription isodose levels (p=0.12), and BOT (28.3 vs 27.5 minutes; p=0.61) showed no significant difference.

Conclusion(s): In routine clinical use, Lightning adoption was associated with a size-dependent pattern. For medium/large lesions, plans demonstrated improved selectivity without worsening GI or prolonging treatment time, supporting its integration for these sizes. For small lesions ( < 1 cc), however, provider-selected plans shifted toward higher isodose prescriptions and greater selectivity (indicating less high-dose exposure to normal brain). This came with a trade-off of higher GI (implying larger volumes of normal tissue received 50% of the prescription dose) and longer BOT, consistent with provider choices prioritizing conformity and prescription strategy. Coverage remained consistently high across eras. These findings underscore that real-world outcomes reflect provider-driven plan selection and optimization priorities. The clinical impact of this trade-off in small lesions—particularly regarding local control and radiation toxicity—requires prospective evaluation and longer-term follow-up.