

Comparative Evaluation of Dose Delivery Precision Using SGRT and Stereoscopic Image-Guided Radiosurgery for the Treatment of Trigeminal Neuralgia

Javad Rahimian, Ph.D.*
Southern California Permanente Medical Group, Los Angeles, California 90027

Purpose

Trigeminal neuralgia radiosurgery demands submillimeter accuracy: the nerve is only 3–4 mm wide, treated with a 4 mm cone at doses near 90 Gy, so small positioning errors can meaningfully affect coverage and dose. This study **theoretically** compared targeting precision for three setups at 100 cm SAD—SGRT alone, stereoscopic IGRS alone, and combined SGRT+IGRS—using a Gaussian beam model (10XFFF, 4 mm cone) to assess how residual translational and rotational errors affect central dose to a 3 mm nerve target.

Materials and Methods

Treatment planning targeted the trigeminal nerve, a 3 mm diameter (1.5 mm radius) structure, centered at isocenter and prescribed 90 Gy using a 10 MV FFF beam through a 4 mm cone at 100 cm SAD, delivered via 8 non-coplanar arcs with couch angles every 20° from 270° to 90°. Guidance accuracy was modeled across four scenarios: loose SGRT (± 1.0 mm / $\pm 1.0^\circ$), tight SGRT (± 0.8 mm / $\pm 0.8^\circ$), typical IGRS (± 0.5 mm / $\pm 0.5^\circ$), and high-precision IGRS (± 0.2 mm / $\pm 0.2^\circ$), as well as a combined workflow using IGRS with continuous SGRT monitoring. The dose distribution was modeled as a Gaussian approximation (Figure 2), $D(r) = D_0 \cdot \exp[-r^2/(2\sigma^2)]$, with a 4 mm 50% dose diameter corresponding to a Gaussian width (σ) of 1.70 mm. Rotational shift was calculated as $d_{\text{rot}} = r_t \cdot \theta$, combined with translational error as $d = \sqrt{d_{\text{trans}}^2 + d_{\text{rot}}^2}$, giving a relative dose of $D/D_0 = \exp[-d^2/(2\sigma^2)]$ and a delivered dose of $D = 90 \times (D/D_0)$. The target was modeled as a rigid body, with gantry/collimator isocentricities not included and target deformation neglected. The study endpoint was geometric and dosimetric accuracy, aimed at comparing the relative performance of SGRT and IGRS.

Results

Table 1. Geometric and dosimetric accuracy comparison for trigeminal radiosurgery (3 mm target, 4 mm cone, 90 Gy prescription)

Guidance method	Trans. (mm)	Rot. (°)	Combined error (mm)	Error (% of target)	Rel. dose (%)	Delivered (Gy)	Dose loss (Gy)
SGRT (loose)	1.0	1.0	1.000	33.3%	84.1	75.7	14.3
SGRT (tight)	0.8	0.8	0.800	26.7%	89.6	80.7	9.3
IGRS (typical)	0.5	0.5	0.500	16.7%	95.8	86.2	3.8
IGRS (high precision)	0.2	0.2	0.200	6.7%	99.3	89.4	0.6
IGRS + SGRT	0.2	0.2	0.200	6.7%	99.3	89.4	0.6

Table 1. Comparison of geometric localization accuracy and predicted dosimetric performance for trigeminal radiosurgery delivered with a 4 mm cone and 90 Gy prescription dose. Results demonstrated progressive improvement in targeting accuracy and dose fidelity as residual positioning uncertainty decreased from SGRT-only thresholds to high-precision stereoscopic image guidance.

Conclusion

1. Translational uncertainty is the **dominant contributor** to targeting error for trigeminal radiosurgery delivered at isocenter. 2. Rotational errors contribute minimally due to the small size of the target and its proximity to the rotational center. 3. SGRT alone with a 1 mm/1° tolerance may theoretically reduce delivered central dose to approximately 75.7 Gy (84.1% of prescription). 4. Stereoscopic IGRS with 0.2 mm/0.2° residual uncertainty maintains approximately 89.4 Gy (99.3% of prescription). 5. Stereoscopic image guidance improves geometric targeting accuracy by approximately **five-fold** compared with SGRT alone.

Discussion

In trigeminal radiosurgery, rotational uncertainty contributes little to geometric error given the small, isocenter-positioned target: for a 3 mm target, $d_{\text{rot}} = 1.5 \times (\pi/180) = 0.026$ mm per degree of rotation. Translational uncertainty therefore dominates. SGRT alone, with a 1 mm tolerance, permits geometric error approaching one-third of the target diameter, delivering only about 84% of the prescribed central dose. Stereoscopic IGRS (0.2 mm/0.2°) reduces this uncertainty to roughly 6.7% of target diameter and preserves about 99% of intended dose, with repeated imaging at each couch angle limiting setup drift and systematic error. Adding SGRT for continuous intrafraction monitoring further improves robustness through beam-interruption capability. While actual 10 MV FFF cone profiles aren't perfectly Gaussian, this approximation offers a transparent, reproducible way to compare the relative dosimetric impact of positioning uncertainty.

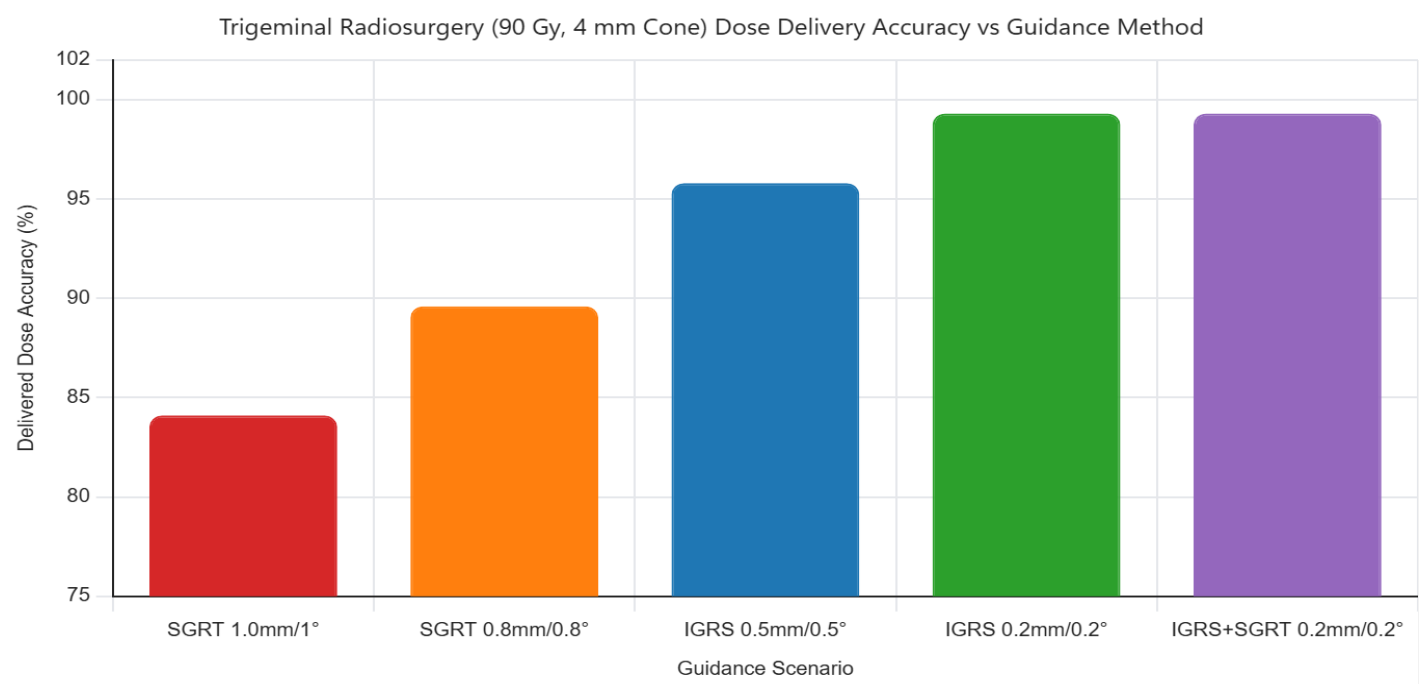


Figure 1. Predicted dose delivery accuracy for a 3 mm trigeminal nerve target treated with a 4 mm cone and 90 Gy prescription dose at 100 cm SAD. Dose accuracy was estimated using a Gaussian beam approximation ($\sigma = 1.70$ mm). Progressive reductions in residual positioning uncertainty from SGRT-only thresholds (1.0 mm/1°) to high-precision stereoscopic image guidance (0.2 mm/0.2°) resulted in improved target dose fidelity from 84.1% to 99.3% of prescription dose.

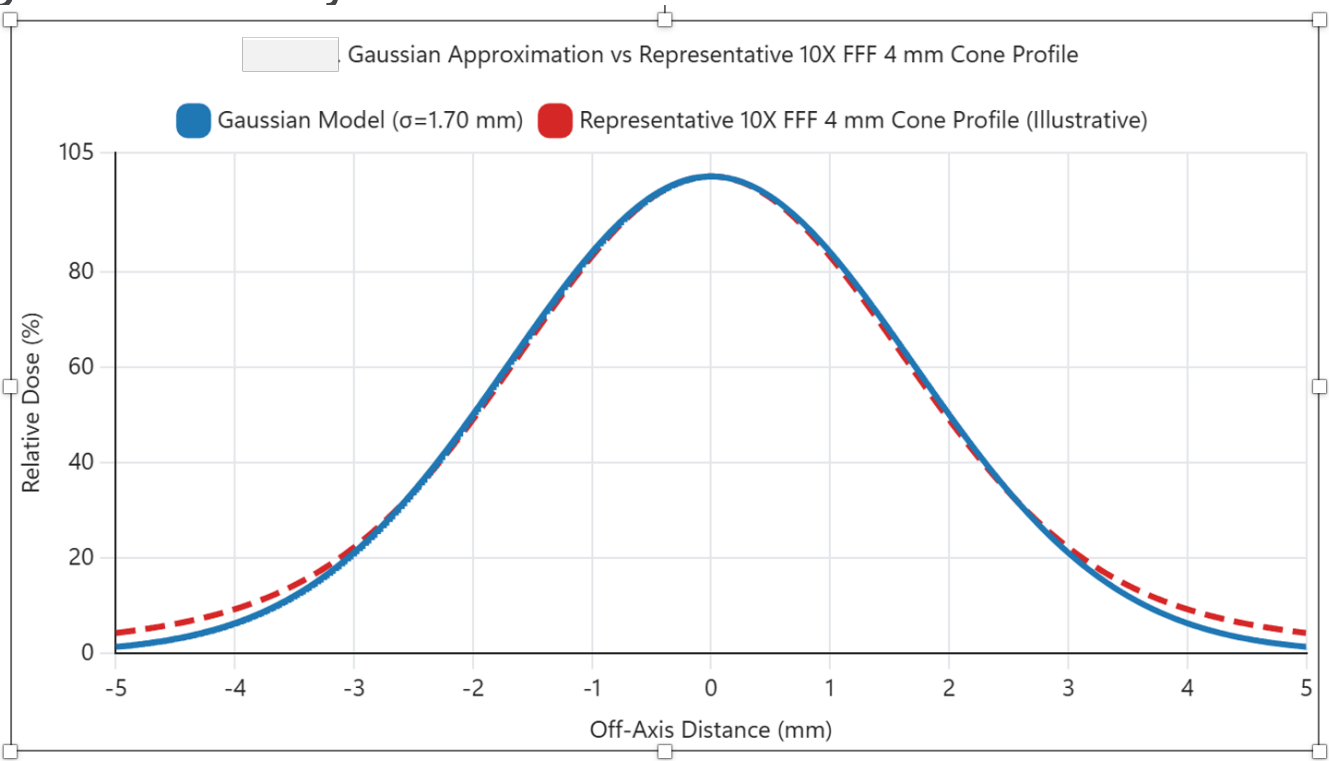


Figure 2. Blue solid curve: Gaussian model used in the dose-accuracy calculations ($\sigma = 1.70$ mm). Red dashed curve: A representative illustrative 10X FFF 4 mm cone profile,

*:Javad.X.Rahimian@KP.Org