Cureus

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Abstract
Published 03/06/2024

Evaluation of Fractionated Stereotactic Radiosurgery (FSRS) Treatment Plan Quality for Large Brain Metastases: Intercomparison across Multiple Stereotactic Platforms

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Categories: Medical Physics, Radiation Oncology
Keywords: brain metastases

How to cite this abstract
Tolakanahalli R, La Rosa A, Kotecha R, et al. (March 06, 2024) Evaluation of Fractionated Stereotactic Radiosurgery (FSRS) Treatment Plan Quality for Large Brain Metastases: Intercomparison across Multiple Stereotactic Platforms. Cureus 16(3): a1116

Abstract

Objectives:

There is a broad spectrum of dedicated radiosurgery platforms available to treat brain metastasis. However, a comprehensive comparison of plan quality metrics using modern treatment planning systems specific to large brain metastases has not been performed to date. The objective of this study was to compare dosimetric parameters of Gamma Knife® (GK) treatment plans against CyberKnife® (CK), volumetric modulated arc therapy (VMAT) on conventional c-arm linac, MR-guided linac (MRL), and ZAP-X for large (> 2 cm) intracranial metastases.

Methods:

Ten consecutive patients with intact brain metastases, previously treated on GK with FSRS (27 Gy in 3 fractions), were re-planned with CK, VMAT, MRL intensity-modulated radiation therapy (IMRT), and ZAP-X systems. Plans were optimized not to exceed organ-at-risk (OAR) dose constraints and achieve a minimum target coverage (TC) of ⩾ 99.5% while maximizing the Paddick conformity index (PCI) and gradient index (GI), while minimizing beam-on time (BOT), in this order of importance. Plan quality metrics and delivery parameters (PCI, GI, BOT, brain V20Gy and V12Gy)) were compared between GK and each respective platform for all patients using a paired Wilcoxon signed rank test ($p < 0.05$) to determine statistical significance.

Results:

The average largest linear dimension and volumes of GTVs were 2.57 ± 0.52 cm and 10.40 ± 6.38 cc, respectively. All GK plans satisfied clinical goals with a median PCI [Interquartile range] of 0.93 [0.90-0.94], median GI of 2.52 [2.50-2.58], median brain Dmean dose of 1.3 Gy, and a median D0.03cc dose within the GTV of 51.10 Gy [49.95-51.28]. PCIs of GK plans were significantly higher than CK (0.93 [0.90-0.94] vs. 0.90 [0.85-0.94]; $p < 0.05$) and ZAP-X (0.88 [0.79-0.92]; $p < 0.01$) but not significantly different than VMAT plans (0.96 [0.91-0.97]; p=0.13) and MRL plans (0.93 [0.92-0.95]; p=0.23). GIs of GK plans (2.52 [2.50-2.58]) were significantly higher than CK (3.11 [2.86-3.43]; $p < 0.01$) and MRL plans (3.56 [3.28-3.59]; $p < 0.01$) and lower than ZAP-X (2.37 [2.34-2.55]; $p < 0.05$); not statistically significantly different when compared to VMAT plans (2.72 [2.54-3.09]; p=0.06). The average normal brain receiving 20 Gy (V20Gy) with GK (14.42 ± 9.61 cc) was significantly lower as compared to CK and MRL plans (17.05 ± 9.95 cc and 16.91 ± 10.82 cc; $p < 0.05$), while no statistical significance was found in comparison to VMAT (14.66 ± 9.41 cc; p=0.65) and ZAP-X (14.63 ± 9.36 cc; p=0.17). The average normal brain receiving 12 Gy (V12Gy) with GK (26.53 ± 17.86 cc) was also significantly lower as compared to CK, VMAT, and MRL (31.75 ± 17.39 cc, 29.31 ± 18.54 cc, and 39.65 ± 26.42 cc, respectively; $p < 0.05$), and not statistically significantly different as compared to ZAP-X plans (26.96 ± 17.64 cc; p=0.65). Median GK BOT (33.89 min [31.58-35.94 min]) was significantly longer than CK, VMAT, and MRL (25.00 min [23.00-27.75 min], 3.45 min [3.27-4.02 min], and 7.16 min [6.17-7.66 min], respectively; $p < 0.05$) and shorter than ZAP-X (36.38 min [35.07-46.99 min]; $p < 0.05$).

Conclusion(s):

GK plans resulted in similar or improved conformity and gradient indices compared to the other platforms, except for ZAP-X which resulted in a better GI. However, GK showed longer treatment times compared to

other platforms, except for ZAP-X, which could be a consideration in clinical practice for technology selection. Considering all plans were specifically created without setup margins to assess the dosimetric capabilities of each platform, the choice of radiosurgery platform hinges on specific treatment goals, patient characteristics, and clinical constraints, which underscore the imperative of a nuanced approach to technique selection.