Optimization Algorithm for Single-Isocenter VMAT Stereotactic Radiosurgery for Multiple Brain Metastases

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Categories: Medical Physics, Neurosurgery, Radiation Oncology
Keywords: stereotactic radiosurgery, srs, brain metastases, single isocenter, volumetric modulated arc therapy (vmat)

How to cite this abstract

Abstract

Objectives: Developing an optimal Stereotactic radiosurgery (SRS) plan for multiple brain metastases can be a labor intensive process. Single-isocenter multi-arc volumetrically modulated arc therapy (VMAT) has been used as an SRS technique, in which a Linear Accelerator (Linac) delivers targeted radiation along multiple arc angles as it rotates around the isocenter. Standardized arc angles without regards to patient-specific tumor anatomy may increase unnecessary exposure of normal brain to radiation due to "leakage" caused by a Multileaf Collimator’s (MLC) inability to shield the space between 2 or more tumor targets in alignment. This results in increased volume of normal brain receiving low to intermediate dose of radiation. GammaKnife and CyberKnife largely circumvent this issue by their respective platform specific treatment technique. For Linac, we have developed an optimization algorithm to intelligently choose VMAT arc angles with the aim to reduce exposure to normal brain.

Methods: For an optimal VMAT planning protocol, our optimization algorithm assumes a single isocenter with three or more arcs, each associated with a specific collimator rotation. A cost function, which simulates the amount of radiation leakage to normal brain, is computed. This is done by projecting 3D tumor locations onto 2D planes at each gantry position along an arc, followed by simulation of the MLC modulation in response to the angle-dependent 2D projections of tumor positions, and calculating the amount of normal brain exposed to radiation due to MLC leakage in a specific arc at a specific collimator angle. This is repeated for all possible combinations of arcs and collimator rotations. Ranking the cost function then enables a planner to obtain the optimal combinations of arc and collimator angles with the least leakage. Arc angles less than 15° apart are avoided in order to maintain radiosurgery dosimetry.

Results: 2 recent cases with 5 and 7 tumors were used retrospectively in generating preliminary results. Standard arcs angles are defined at couch positions of 135, 180 and 225 degrees. Optimized arc and collimator angles resulted in 1% (0.5cc), 1% (2cc), 25% (330cc) and 18% (480cc) reduction in exposure of normal brain at V75%, V50%, V25% and V10%. Due to the steep dose gradient of SRS, higher dose volumes do not change significantly. However, as expected, the optimization algorithm resulted in significant reduction in exposure at lower dose levels. Preliminary results also show optimization can be further improved by selecting segments of arc rotations that are associated with particularly low levels of exposure from...
multiple arcs. By combining these smaller segments of multiple arcs, dosimetric parameters may improve further, pending ongoing research.

Conclusions: Our single center isocenter VMAT optimization algorithm results in SRS plans that tailor to patient-specific tumor anatomy in 3D space and outperform standard protocols for treatment of multiple brain metastases. Further testing is needed in a larger series to show generalizability. In addition, we plan to improve the algorithm by exploiting 3D geometry of the tumors and incorporating low-exposure arc segments as part of the final output.