Cureus

Single and Multiple Brain Metastases Radiosurgery with Coplanar Arcs: A Lexicographic Optimization-Based Planning Comprehensive Evaluation

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Abstract
Published 03/06/2024

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Categories: Medical Physics, Radiation Oncology
Keywords: brain metastases

How to cite this abstract
Trivellato S, Pellegrini R, Daniotti M, et al. (March 06, 2024) Single and Multiple Brain Metastases Radiosurgery with Coplanar Arcs: A Lexicographic Optimization-Based Planning Comprehensive Evaluation. Cureus 16(3): a1162

Abstract

Objectives:

This study validated a not yet commercially available fully-automated lexicographic optimization planning system (LOps) for both single (SL) and multiple lesions (ML) intracranial stereotactic radiosurgery (SRS) with coplanar arcs.

Methods:

Forty-three consecutive SRS plans (21 Gy/1 fx) delivered between November 2019 and August 2022 were retrospectively selected and automatically re-planned by LOps: 24 of them has 1 lesion, 13 had 2 lesions, 4 had 3 lesions, and 2 had 4 lesions. An a-priori assigned priority list, Wish List (WL), was needed to guide the sequential LO: it represents a dialogue between the radiation oncologist and the planner, setting hard constraints and following objectives that must be translated into one or more cost functions associated with the contoured structures. Their definition is part of the so-called tuning process, a multi-step iterative method on a subset of patients (tuning set) that goes on until the optimized plans satisfy the defined clinical protocol without affecting plan delivery accuracy. A tuning set of 4 patients was necessary to achieve each robust WL, for SL-plans (SLp) and ML-plans (MLp). While in manual plans (MP), the arc setup is a planner's free choice, the WL was tuned to use 2 coplanar arcs of 140° and 360° for SLp and MLp, respectively. The only planner's manual interaction is the choice of the start angle in SLp to reduce the involved brain volume. A collimator rotation was set at 0° and 90° for counter-clockwise and clockwise arcs, respectively. After fluence LO, a Monte Carlo calculation (MCc) is performed with a 1 mm-dose grid and 0.5%-statistical uncertainty. A target coverage as high as possible was requested, with at least 80% of the prescription dose covering 99% of the PTV. The main criteria for SLp approval was a brain V12Gy< 10 cm3. In MLp this criterion can be overcome to get the minimum target coverage. The remaining 35 SRS plans (20 SLp and 15 MLp) were automatically re-planned (testing set, AP). AP were compared in terms of dose-volume constraints, conformality, monitor units (MUs) and modulation complexity score (MCS). Statistical significance was assessed by performing the parametric t-test or the non-parametric Wilcoxon rank-sum test. Delivery time and accuracy (local gamma analysis (2%/2mm)) were verified by pre-treatment QA.

Results:

SLp registered a median GTV and PTV of 0.69 [0.08-2.47] cm3 and 2.00 [0.67-6.42] cm3, respectively. On the other hand, the selected ML patients registered a median GTV and PTV of 0.20 [0.01-3.19] cm3 and 0.84 [0.18-6.31] cm3 on a single lesion-basis, respectively. The median MLp total GTV and PTV was 0.46 [0.12-3.48] cm3 and 2.07 [0.79-1.61] cm3, respectively. Each WL-tuning took 3 days. Overall median MP and AP MCc time can be estimated at 8 hours and 3 hours, respectively. Statistically significant increases in SLp and MLp target coverages was registered (median GTV_D98%: +2.9% SLp, +5.4% MLp, median PTV_D98%: +4.4% SLp, +10.8% MLp). A significant improvement in PTV Paddick's conformity index has been registered in both SLp and MLp ($p< 0.01$). AP showed a not statistically significant and clinically acceptable higher median brain V12Gy (SLp: MP 6.9 cm3, AP 7.5 cm3; MLp: MP 8.7 cm3, AP 10.3 cm3). Other organs at risk were never significantly interested by clinically relevant doses. The SLp registered a lower median MU number (-5.8%) with a comparable median delivery time (MP 2.0 min, AP 1.9 min) while MLp were obtained with a significantly higher median number of MU (+9.8%) and longer delivery time (MP 3.5 min, AP 4.4 min). MCS

resulted significantly higher for AP (e.g. SLP: MP 0.24 [0.17 – 0.37], AP 0.46 [0.31 – 0.55]. This complexity difference did not affect gamma passing rates (p>0.5).

Conclusion(s):

The novel LOps produced high-quality clinically acceptable SRS SL and ML plans with coplanar arcs significantly reducing the overall planning time from about one working day for one MP to about 3 hours for one AP. Together with comparable OAR sparing, the target coverage was significantly increased and the plan deliverability was preserved. Radiation oncologists' blind choice is on going to also evaluate plan clinical acceptability. Here presented planning times and dosimetric results suggest the possibility to treat SL and ML SRS patients from CT simulation to plan delivery in a one-day session.