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Abstract

Evaluation and Clinical Use of Monte Carlo Secondary Dose Calculation for Robotic SRS/SBRT

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Objectives: Patient-specific quality assurance (QA) for robotic SRS/SBRT is a demanding task. Recently, the first commercial solution for Monte Carlo (MC)-based secondary dose verification has become available. We report on pre-clinical evaluation, sensitivity analysis of quality metrics and practical use of this novel method after verification of 152 plans.

Methods: MC source models for fixed/variable circular (5-60 mm) and multi-leaf (MLC, max. 11.5x10 cm2) collimators were derived from water tank measurements and imported to the MC software installed on an in-house virtual server platform. Consistency with the treatment planning system (TPS) dose calculation algorithms (Ray-Tracing - RT; Finite Size Pencil Beam - FSPB; MC) was assessed by comparing dose distributions of 34 single fields of different size and shape in an artificial water box. For verification of clinical plans, 3D Gamma analysis settings of 2%/1mm (global, 5% dose cut-off) were chosen. To establish tolerance levels, three clinical cases (#1: 0.3 cc acoustic neuroma; #2: 10 cc brain metastasis; #3: 113 cc prostate PTV) were selected. Plan errors were artificially introduced by rescaling monitor units (+/-5% in 1% increments) and altering the density model. Sensitivity of overall 3D Gamma analysis, PTV mean dose and PTV-specific Gamma analysis to these manipulations was evaluated.

Results: For circular single beams and quadratic MLC segments up to 7x7 cm2, TPS and secondary MC calculations were consistent. The known asymmetry in larger MLC fields was correctly reproduced by the TPS FSPB but not secondary MC. Compared to FSPB and secondary MC, the TPS MC engine underestimated absolute dose of MLC fields by ~1% due to a TPS software anomaly. In sensitivity analysis, all manipulated plans met a 95% pass rate limit for overall Gamma analysis. A 90% pass rate for PTV-specific Gamma analysis was not reached by cases #2 and #3 for >=3% dose manipulation and an air/water density model, but exceeded by case #1 with the smallest target in all scenarios. Expectedly, MC-reported PTV mean dose scaled linearly with dose manipulation. One of 152 clinical plans slightly failed the 95% pass rate limit for overall Gamma analysis due to inappropriate use of RT for a thoracic spine metastasis ("human error"), which caused incorrect dose values in lung tissue. Three cases failed the 90% pass rate limit for PTV-specific Gamma analysis and a +/-3% difference limit for PTV mean dose. All three problematic plans shared use of the variable circular collimator, field diameters of 12.5 mm or smaller, and TPS MC calculation. Further tests with this parameter

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combination revealed a potential dose overestimation of TPS MC in comparison to both TPS RT and secondary MC calculation.

Conclusions: MC secondary dose calculation was successfully introduced to the clinical QA routine. Limitations and volume dependence of Gamma analysis criteria need to be carefully considered when establishing tolerance levels. MC-based verification of clinical cases provided evidence for a problematic plan class and triggered a root cause analysis.