2026 JOINT AAPM | COMP MEETING
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Implementation of RayStation Photon Monte Carlo As a Method to Initiate Clinical Expertise for MR-Guided Adaptive Radiotherapy

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Abstract

Our department will introduce a MR-Guided Adaptive Radiation Therapy (MRgART) this year, which introduces several changes our clinic. The Elekta Unity solution relies on a Monte Carlo (MC) photon dose calculation algorithm. Previously, our clinicians had minimal familiarity with Monte Carlo dose distributions and how they might differ from conventional dose distributions they are more familiar with. Compared with conventional algorithms such as convolution–superposition, or collapsed cone, MC methods more accurately model radiation transport in heterogeneous media. Our previously under-utilized tool: RayStation photon Monte Carlo algorithm was commissioned and assessed as a tool to ease the transition to adaptive for workflow and clinical decision-making by providing context for expected workflow and evaluation differences.

Introduction

In MR-guided adaptive radiotherapy, daily dose recalculation and plan evaluation are performed on updated patient anatomy under clinically constrained timelines. The use of Monte Carlo (MC) dose calculation, as recommended for MR-linac systems, introduces systematic differences relative to conventional algorithms, particularly in heterogeneous tissues, at air–tissue interfaces, and for small or highly modulated fields. Clinician familiarity with these MC-specific dose characteristics is essential to accurately interpret changes in target coverage and organ-at-risk dose during online adaptation. Understanding when observed dose differences reflect true anatomical change versus expected algorithm behavior supports consistent plan acceptance, normalization, and adaptive decision thresholds. As MC becomes the standard calculation engine in MR-guided adaptive workflows, this knowledge directly improves clinical confidence, reduces uncertainty during time-critical adaptive sessions, and facilitates safe and effective implementation of adaptive radiotherapy.

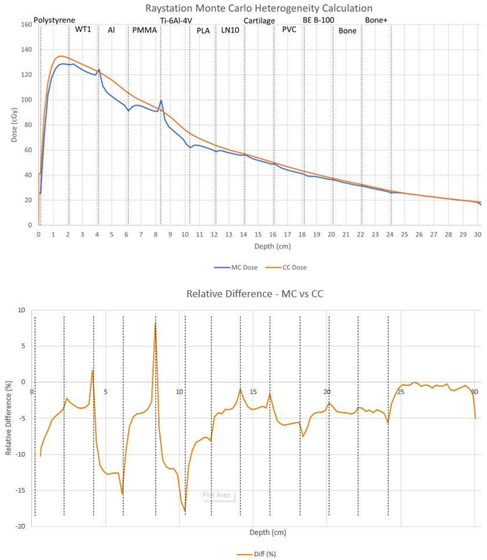

Figure 1. (a) Percentage depth dose, and (b) dose calculations difference measurements in heterogeneous phantoms.

Methods and Materials

Photon Monte Carlo dose calculation in RayStation was evaluated in the context of common clinical scenarios, including lung, head and neck, and stereotactic treatments, where tissue heterogeneity and small field effects are significant. Twenty-seven plans were selected randomly from recently completed treatments. The plans compared across various anatomical sites and treatment planning techniques including SRS, SBRT, and IMRT. Comparisons were made to conventional dose calculation approaches typically used in photon planning. Dose calculation time was compared between the two algorithms to prepare clinicians for timing expectations that would need to be considered within the adaptive workflow. Dose-difference comparisons were made between the two plans composed of three components: qualitative analysis of the differences between dose depositions; quantitative analysis of differences between DVH data; and binary analysis of pass/fail on our set of clinical goals templates related to the prescription and plan. With this latter group, the analysis was made to determine if based on the difference in clinical goal outcome a different clinical decision would have been made which will be denoted as a significantly different acceptability (Figure 4).
For commissioning, tests were conducted in heterogeneous phantoms to derive dose differences in various materials between Monte Carlo and Collapsed-cone methods (Figure 1).

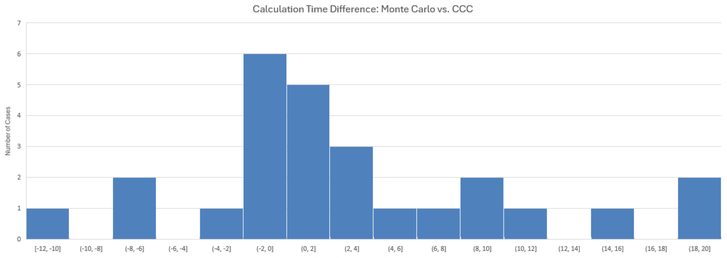

Figure 3. Histogram of cases binned into two second intervals denoting calculation time interval differences between Monte Carlo and CCC. One outlier case with high grid resolution excluded for clarity.

Results

Twenty-seven patient cases, covering several clinical sites with heterogeneous tissue, were recalculated using Monte Carlo with 0.1% uncertainty. Evaluating with site-specific clinical goals, 84% of plans had clinically relevant dose differences. Cases involving targets proximal to tissue-air or metal-tissue interfaces, common in H&N (Figure 2), had significant dose deviations. The use of photon Monte Carlo in RayStation resulted in clinically relevant differences in calculated dose for 84% of assessed plans, particularly in low-density tissues, at tissue–air interfaces, and for small or highly modulated fields. Target coverage was significantly different compared with the collapsed cone algorithm, while doses to organs at risk may be recalculated more accurately. These differences influenced the selection of prescription dose, plan normalization, and clinical acceptability. Advances in computing performance have reduced MC calculation times to levels compatible with clinical workflows, although they remain longer than traditional algorithms. Plan acceptability criteria were significantly different for 34% of clinical goals assessed. Time for dose computation between the two algorithms were very close, with Monte Carlo taking 2.55 seconds longer on average, or 8.86 seconds when including an outlier that took 172.89 seconds longer, which is attributable to image and dose grid resolution (Figure 3).

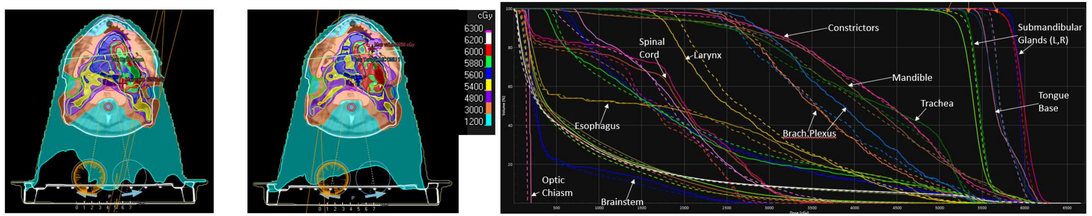

Figure 2. Example H&N plan with metal containing dental work and air gaps. (a) Dose differences are pronounced with dose calculated in tissue-metal interface. (b) DVH with OAR specific dose differences.

Discussion

The online adaptive environment provides many opportunities and challenges to the unfamiliar clinician. With the Elekta Unity MRgART workflow in particular, Monte Carlo dose optimization, presents additional challenges. Developing familiarity, and intuition of the differences with these aspects will enable faster decision making in time-sensitive workflows. The study conducted here intended to build confidence and familiarity with components of the workflow by commissioning and examining several critical aspects that will be different in this context. We found that the dose outcomes for dose calculations differ for Monte Carlo, especially in highly heterogeneous tissues such as head and neck and thorax. Time-based analysis indicated that in the majority of cases Monte Carlo dose computation was similar to CCC time, although in some cases with high dose and image resolution the computation time was significantly higher. A key decision-making tool that is expected to be utilized in the adaptive environment is clinical goals as it provides a rapid visual feedback of critical dosimetric information. Our analysis found that in the majority of cases there was at least one change in clinical goal state between MC and CCC, which we consider as the criteria for different clinical outcome or decision. There are several possibilities for this: MC randomness, the complexity of plans, the strictness of the goals, and most likely that the plans had not been optimized with MC. Alternatively, the majority of clinical goals overall remained unchanged, as there are many clinical goals for each case.

ROI/POI	Clinical goal	Current Plan dose: testmc (Pl... Result	[%]	Compare 1 Plan dose: H&N Result
PTV6000	At least 98.00 % volume at 5700 cGy dose	98.22 %	0	98.56 %
PTV6000	At most 6480 cGy dose at 0.03 cm³ volume	6684 cGy	0	6477 cGy
PTV6000	At most 6720 cGy dose at 0.03 cm³ volume	6684 cGy	0	6477 cGy
PTV5400	At least 95.00 % volume at 5130 cGy dose	98.79 %	0	99.12 %
PTV5400	At least 98.00 % volume at 5130 cGy dose	98.79 %	0	99.12 %
PTV5400...	At most 5832 cGy dose at 0.03 cm³ volume	6034 cGy	0	5984 cGy

Figure 4. Target clinical goals for representative case (R Breast). Criteria are guided by physician determined clinical outcomes and denoted both quantitatively as well as a binary of pass (green) or fail (orange). Comparison column 1 are the results with Monte Carlo calculation and column 2 is CCC.

Conclusions

The incorporation of photon Monte Carlo dose calculation in RayStation has the potential to improve dosimetric accuracy and confidence in treatment planning, particularly for anatomically complex cases. However, its adoption alters historical dose benchmarks and requires careful education and clinical judgment. When implemented thoughtfully, photon Monte Carlo can enhance clinical practice by supporting more accurate and patient-specific radiotherapy planning. Moving forward, this work will serve as the foundation for evaluating Monte Carlo dose calculations in the adaptive setting.

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