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Abstract
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Is it Safe and Feasible to Deliver a 30-Gy Single High-Dose to Solitary Lung Lesion via SBRT on the Current Halcyon Ring Delivery System?

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Abstract

Objectives:

SBRT treatments of select lung cancer patients using SRT dedicated TrueBeam LINAC following RTOG 0915 protocol (Arm 1) for a single dose of 30-34 Gy has become a standard of care at our institution. This treatment scheme has provided excellent treatment response of 100% local control rate with no lung toxicity in a 2-year median follow up. Based on those clinical experiences, we sought to explore the safety and feasibility of using the current co-planar Halcyon ring delivery system (RDS) in delivering a single fraction 30 Gy SBRT treatment to solitary lung lesions. In doing so, potential improvements for the Halcyon RDS can be revealed to allow for more accurate treatment delivery, patient safety, and efficiency. This study further explores the full utility of the single-energy Halcyon system to expand the access of care for remote and underserved patient cohorts in the treatment of lung SBRT.

Methods:

For testing and end-to-end validation, 13 patients previously treated with a single fraction of 30 Gy to a lung lesion on the TrueBeam (6MV-FFF, 1400 MU/min) using 2-4 partial non-coplanar VMAT arcs were selected. These high-quality plans were anonymized and replanned onto the Halcyon RDS (6MV-FFF, 800 MU/min) using 6-partial co-planar arcs with different collimator angles and the same advanced Acuros-based dose engine for tissue heterogeneity corrections. All plans were evaluated using the single-dose arm of RTOG 0915 lung SBRT protocol, and we assessed compliances for target conformity index (CI), gradient indices (GI), and maximum dose to adjacent organs-at-risk (OAR). Various gradient indices that were used to evaluate these SBRT plans were gradient index (GI, ratio of V50% to V100%), gradient measure (GM, difference of equivalent sphere radii of the 50% and 100% prescription volumes), and D2cm (maximal dose 2 cm away from the target in any direction). Total monitor units (MU), beam on time (BOT), and beam modulation factor (MF) were analyzed to assess treatment efficiency. Additionally, patient-specific quality assurance (QA) results using a 2%/2mm clinical gamma criteria were reported and supplemented with independent in-house Monte Carlo (MC) physics second-check results.

Results:

All retrospective SBRT plans met RTOG 0915 protocol requirements for target coverage, CI, and GI. Halcyon's co-planar geometry resulted in a statistically improved dose fall-off from the target based on the computed GI values (4.39 vs 4.69, $p < 0.005$) and GM (0.93 cm vs 0.99 cm, $p < 0.005$), compared to clinical non-coplanar TrueBeam VMAT plans. Additionally, the Halcyon plans revealed statistical similarities when evaluating CI and D2cm. In terms of treatment efficiency, Halcyon required longer delivery times than clinical TrueBeam plans based on BOT, MF, and total MU. Halcyon plans required on average around 1.5 times higher MU (11,118 MU vs 7413 MU, $p < 0.005$), resulting in a much higher beam MF (3.71 vs 2.47, $p < 0.005$). Due to the Halcyon's much lower achievable maximum output (800 MU/min) compared to the 6MV-FFF beam on TrueBeam (1400 MU/min), the BOT was increase significantly by a factor of 2–3 (13.9 min vs 5.3 min, $p < 0.005$). However, all SBRT plans met RTOG-0915 requirements for maximum dose to OAR on both platforms. Moreover, coupled with its lower nominal mean energy of its 6MV-FFF beam, lower beam penumbra and smaller values of MLC leakage and transmission due to its stacked/staggered design, it is revealed that Halcyon was able to generate high-quality lung SBRT plans with reduce dose to OARs including lower dose to healthy lung (total lung-ITV) via V20Gy (0.52% vs 0.57%, $p < 0.005$) and V10Gy (2.46% vs 2.62%, $p < 0.005$), compared to clinical TrueBeam plans. In this cohort, Halcyon plans also demonstrated lower values of maximum dose to the esophagus (5.05 Gy vs 5.77 Gy, $p = 0.036$) and to the ribs (15.19 Gy vs 17.01 Gy, $p < 0.005$). With EPID-based dosimetry QA measurements and independent MC second check, the accuracy of all Halcyon plans proved to be clinically acceptable with passing rates greater than

95%. However, due to very high total MU required to deliver a single-dose of 30 Gy for lung SBRT, delivering pre-treatment patient-specific QA shows glaring issues for the deliverability of this treatment schemata on current Halcyon. Water cooling temperatures did heat up past the current machine heating tolerance limits (>35.5°C) for a number of SBRT validation plans that had greater than ~10,000 MU causing delivery interruptions.

Conclusion(s):

The current Halcyon RDS was proposed for the potential use of delivering a single-dose of 30 Gy via SBRT to solitary lung lesions. Although, we have demonstrated highly conformal lung SBRT plan quality and delivery accuracy via co-planar Halcyon, our detail study has identified many potential deliverability issues on the current Halcyon such as the relatively longer BOT which may affect treatment delivery accuracy due to patient intra-fraction motion errors. Moreover, due to excessive total MU, it may lead to machine interlock such as overheating and potentially interrupt the patient’s treatment. Based on this end-to-end testing and validation study, we offer the following recommendations to the vendor for potential future improvements of Halcyon LINAC in order to effectively deliver a single-high dose of lung SBRT: (1) provide rotational couch corrections, (2) incorporate intra-fraction motion management and online monitoring, (3) allow MLC aperture shape controller options to reduce the beam modulation factor to less than 3 to allow for faster treatments with reduced MU, and (4) tune up the Halcyon’s maximum dose rate up to 1400MU/min, similar to 6MV-FFF TrueBeam LINAC. With these potential upgrades, single-dose of 30 Gy lung SBRT treatment could be delivered more accurately and faster on Halcyon by a factor of 2.5 compared to current Halcyon in order to achieve clinically required beam on times as performed on TrueBeam. This may create an avenue for same-day lung SBRT treatment on Halcyon RDS for remote and underserved patient cohort in future.