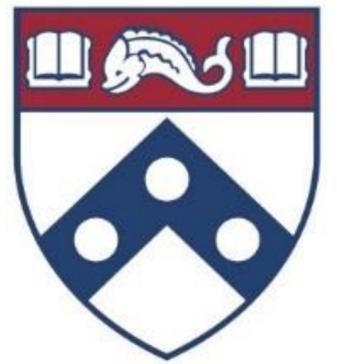


Single-Segment Spine SBRT on a Ring-Gantry Halcyon Linear Accelerator: Evaluation of Planning Techniques and Rotational Setup Errors



Lee Xu¹, Hui Lin¹, Steven Philbrook¹, Anthony Kassaei¹, Christopher Kennedy¹, Dimitris Mihailidis¹, Taoran Li¹, David J. Carlson¹

¹Department of Radiation Oncology, University of Pennsylvania, Philadelphia, PA 19104

Introduction

Stereotactic body radiotherapy (SBRT) has been shown to be safe and highly effective for the treatment of spinal metastases [1,2]. Currently, patients receiving spine SBRT at our institution are treated on a Varian True beam (TB) equipped with a high-definition multi-leaf collimator (HD-MLC). Recently, there has been a growing interest within the community to implement spine SBRT on the Varian Halcyon, which uses a dual-layer staggered MLC system with an effective modulation width of 0.5cm. A previous study by Petroccia et. al indicated that 3-arc spine SBRT plans on the Halcyon exhibited poorer dose conformity and fall-off than 3-arc plans on the TB HD-MLC [3]. This current study demonstrates the benefit of using 4 or 6 arcs over 3 on the Halcyon, resulting in plans closely resembling—and at times improving on—those generated on the TB HD-MLC.

From a treatment delivery perspective, one of the limitations of the Halcyon is the lack of a 6 degree-of-freedom couch, which hinders the precise alignment of the target and patient during treatment setup. Because spine SBRT typically involves high doses per fraction, tight treatment margins, and nearby organs-at-risk (OARs), we wanted to investigate the impact of rotational setup errors and quantify the magnitude of dose deviations they caused if left uncorrected.

Methods

15 patients from our institution were retrospectively planned on the Halcyon to a dose of 3,000cGy using 4 and 6 full arcs. For each case, the optimization objectives were adjusted manually by an experienced planner and the final plans were renormalized such that the PTV D90% = 100% to allow for the comparison of relevant dose metrics. Spinal cord max, thecal sac max, conformity Index (CI), gradient measure (GM), PTV D95%, and total MUs were tabulated for the 4 and 6-arc plans as well as the 3-arc Halcyon and TB-HDMLC plans from a previous study with the same cohort [3]. Dose metrics were also compared on a patient-by-patient basis between the 4 and 6-arc plans.

For the rotational analysis, a workflow was developed in 3DSlicer using the transforms and radiotherapy modules to evaluate the dosimetric impact of rotational setup errors. In this workflow, the CT, structure set, and dose files for each of the 4-arc plans were imported into 3DSlicer from Eclipse. The dose was then rotated by ± 1 -degree about the isocenter in the pitch, yaw, and roll directions and the dose metrics for the PTV and relevant OARs were re-calculated individually.

Results

The max doses to the spinal cord and thecal sac were lowest in the 6-arc Halcyon plans at 14.1 ± 2.5 Gy and 24.1 ± 3.2 Gy, respectively, improving even on the TB HD-MLC plans. The CI and GM were similar among the 4/6-arc Halcyon and TB HD-MLC plans, but were noticeably higher for the 3-arc Halcyon plans. When comparing the 4 and 6-arc halcyon plans directly, the 6-arc plans offered—in most cases—slightly improved spinal cord and thecal sac sparing at the expense of increased MUs.

	TB HD-MLC ³	HAL 3-ARC ³	HAL 4-ARC	HAL 6-ARC
Spinal Cord max (Gy)	14.6 \pm 1.94	16.2 \pm 2.28	15.1 \pm 2.59	14.1 \pm 2.53
Thecal Sac max (Gy)	27.6 \pm 2.14	27.4 \pm 3.17	24.9 \pm 2.93	24.1 \pm 3.22
Conformity Index	0.96 \pm 0.03	1.02 \pm 0.07	0.95 \pm 0.03	0.95 \pm 0.03
Gradient Measure	1.26 \pm 0.27	1.39 \pm 0.29	1.21 \pm 0.29	1.19 \pm 0.25
PTV D95% (%)	97.2 \pm 1.46	95.1 \pm 1.39	94.9 \pm 2.17	94.8 \pm 2.19
Total MU	4427 \pm 1134	3390 \pm 411	4520 \pm 623	4887 \pm 644

Table 1: Overview of relevant dose metrics for the 4 and 6-arc Halcyon plans compared to the 3-arc TB HD-MLC and Halcyon plans from a previous study with the same cohort [3]. Data are tabulated for 15 patients.

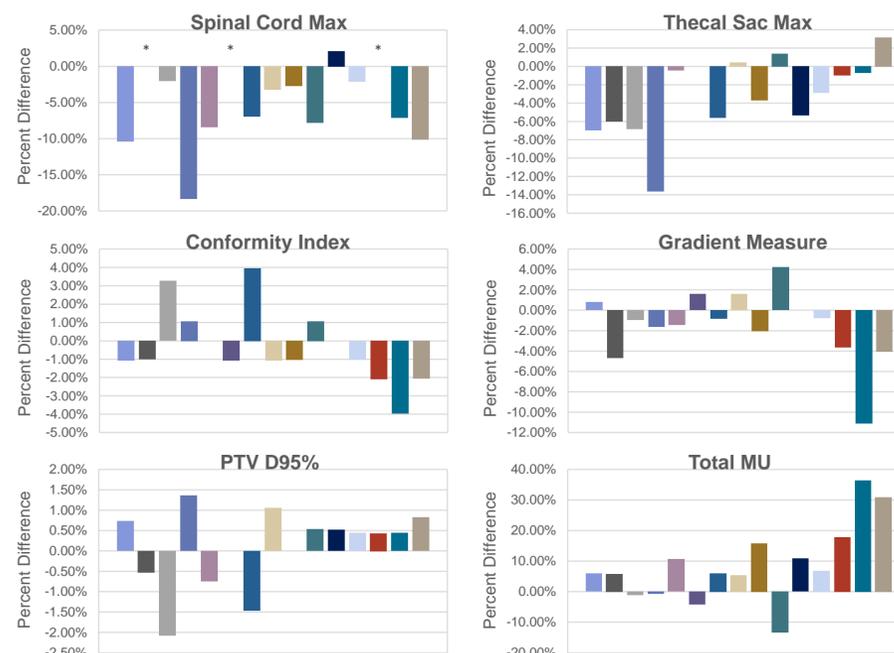


Figure 1: 6 vs 4 arc patient-by-patient comparison of dose metrics. Each colored bar represents one patient and shows the percent difference for the 6-arc plan compared to the 4-arc plan. Data for 15 patients are shown. *Spinal cord data are not available for patients 2, 6, and 13 due to the location of L-Spine treatment.

After applying a 1° rotation, the spinal cord max dose deviated from -1.26% to 6.95%, corresponding to an absolute change of -0.16Gy to 1.07Gy. The magnitude of deviation depended on patient anatomy, target geometry, and planning technique. PTV D95% coverage was minimally affected overall with an absolute deviation of well under 1% on average.

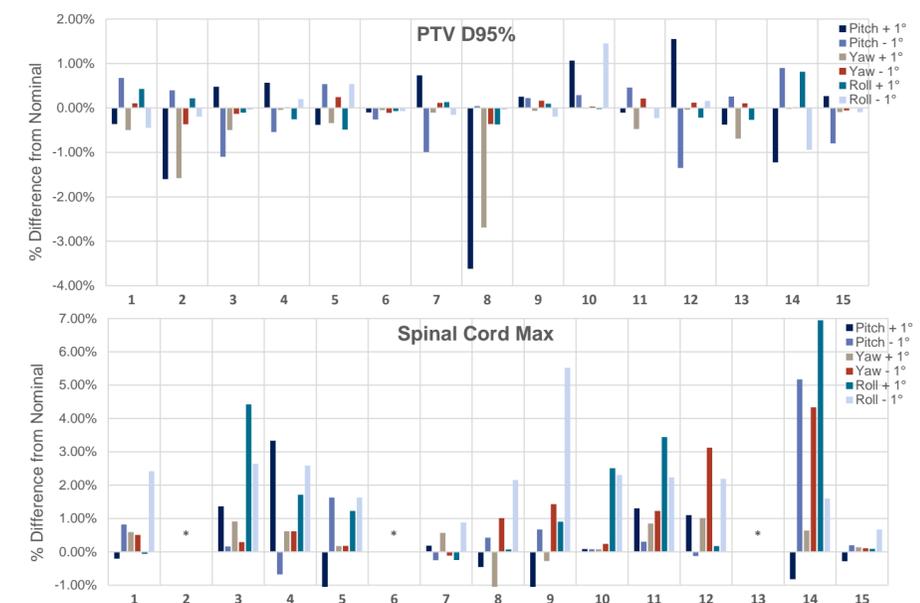


Figure 2: % difference after applying a $\pm 1^\circ$ rotation in the pitch, yaw, and roll directions. Analysis was done patient-by-patient using the 4-arc plans. Spinal cord max was taken as D0.03cc. *Spinal cord data are not available for patients 2, 6, and 13 due to the location of L-Spine treatment.

Conclusion

4 or 6-arc Halcyon plans deliver superior dose distributions for spine SBRT than 3-arc plans and closely resemble TB HD-MLC plans. Dose deviations due to rotational setup errors ranged in magnitude but were reasonably acceptable for most patients when limited to ≤ 1 degree.

References

- [1] Sahgal, A. et al. CCTG SC.24/TROG 17.06: A Randomized Phase II/III study Comparing 24Gy in 2 Stereotactic body Radiotherapy (SBRT) Fractions Versus 20Gy in 5 Conventional Palliative radiotherapy (CRT) fractions for patients with painful Spinal Metastases. *Int J Rad Onc Biol Phys*, 108(5), 1397-1398. 2020.
- [2] Huo, M. et al. Stereotactic spine radiosurgery: Review of safety and efficacy with respect to dose and fractionation. *Surgical Neurology International*, 8(1), 30. 2017.
- [3] Petroccia, H. et al. (2019). Spine SBRT WITH Halcyon™: Plan Quality, Modulation complexity, Delivery accuracy, and speed. *Frontiers in Oncology*, 9. 2019.