Craniospinal Irradiation: Dosimetric Comparison Between Ring-Based vs. Gantry-Based Delivery System

Tracy Ngo, BS[1]; Daniel Pham, PhD, CMD[2]; Nataliya Kovalchuk, PhD[1,2]
[1]The University of Texas MD Anderson Cancer Center School of Health Professions, [2]Stanford Health Care

ABSTRACT

The complexity of craniospinal irradiation (CSI) planning can be attributed to the target length extending beyond the 40 x 40 cm Varian linac field size limitation. Implementation of a multi-isocenter technique provides a solution by dividing the target volume into smaller radiation fields such as the whole brain, the upper spine, and the lower spine. While the usage of multiple isocenters in CSI VMAT can allow for full PTV coverage, drawbacks include longer setup and imaging times, longer treatment times, and increased risks for setup errors. This study aims to determine whether the ring-based delivery system of RefleXion X1, which utilizes a moving couch in the cranial-caudal direction, can be dosimetrically and clinically beneficial to pediatric CSI by eliminating the need for multi-isocenter treatment.

CT datasets were obtained from five pediatric patients previously treated using CSI VMAT on Eclipse, with PTV lengths of ≤ 50 cm measured from the top of the skull to the sacrum to meet the RefleXion X1 field size limit. All patients were then planned on the RefleXion TPS using step-and-shoot IMRT technique. Plans created on Eclipse and RefleXion for each patient were evaluated for maximum global dose, homogeneity, dose received by critical structures, and treatment time. A paired sample t-test was then performed between the Eclipse plan and the RefleXion plan for each patient.

Preliminary data analysis showed that RefleXion plans provided comparable dosimetric results and treatment time to VMAT. The elimination of multiple isocenters with RefleXion will additionally decrease setup and imaging time associated with CSI VMAT, allowing for significant workflow improvement.

Keywords: Craniospinal irradiation, CSI VMAT, RefleXion X1, Pediatric CSI, Step-and-Shoot IMRT, Dosimetry, Treatment Planning

CONTACT

Tracy Ngo
MD Anderson Cancer Center, School of Health Professions
Stanford Health Care
ttngo2@mdanderson.org
281-716-0149

INTRODUCTION

The development of linear accelerators has allowed for versatility in radiation delivery, providing x-ray and electron beam production for various treatment techniques. The linac's maximum 40 cm x 40 cm field size limitation provides sufficient coverage to many tumor volumes, but craniospinal irradiation (CSI) is one treatment technique that typically extends beyond the 40x40 field. Usage of multiple isocenters provides a common solution to this limitation by dividing the target volume into three treatable fields—the whole brain, the upper spine, and the lower spine—while introducing two drawbacks: longer treatment times and risks for setup errors.

One technique that negates the need for multiple isocenters in CSI is Tomotherapy, which utilizes a ring-based system and a moving treatment couch. The elimination of multiple isocenters can reduce the associated risks for translational errors.

This study aims to compare dosimetric differences between ring-based gantry and multi-iso VMAT.

METHODS AND MATERIALS

Eligibility for this study included any pediatric patients diagnosed with medulloblastoma, treated with VMAT CSI, and had a maximum PTV length of 50 cm in the cranio-caudal direction. PTV length was measured for each patient from the top of the skull to the sacrum to meet the RefleXion X1 (RFX-X1) field requirement. This 50 cm restriction is due to hardware limitations of the RFX system.

All patients in this study were previously treated on a linac using multi-isocenter VMAT technique on Eclipse V15.6 with 6 MV energy beams. Two full arcs were used to treat the brain and a single arc was used to treat the spine, with an overlap of at least 2 cm between the brain and spine fields. Plans were then normalized for 95% PTV coverage by the prescription dose (36 Gy/20 fx).

All patients were then planned on the RFX-X1 TPS using step-and-shoot IMRT technique with 6 MV FFF energy. No normalization tool was available, and each plan was optimized to allow for 95% of the PTV to receive the prescription dose. No RFX treatments were actually delivered.

Plans created on Eclipse and RFX for each patient were evaluated for maximum global dose and dose to critical structures. For Eclipse plans, ARIA was used to collect the treatment time points at first pretreatment imaging, time of first arc delivery, and time of final arc delivery. The total time included any imaging required at each isocenter shift. For RFX, treatment time is estimated and reported by the TPS.

A paired sample t-test was performed between the Eclipse plan and the RFX plan for each patient, with statistical significance defined at $p<0.05$.

RESULTS

Out of a total of 73 pediatric patients treated using a CSI technique from Jan 2012 to October 2021, five patients met the planning criteria of a target volume <50 cm in length.

All plans allowed for PTV D95% = 100% of the prescription dose (36 Gy). Statistical significance was detected only for the difference in Dmean to the bowel bag, with RFX reporting a lower average Dmean compared to Eclipse VMAT of 1.36 Gy (p=0.04).

The average beam-on time for Eclipse VMAT and RFX were 8.7 min and 16.7 min, respectively. The average total treatment time was also calculated for Eclipse VMAT as 27.75 min, which included pretreatment imaging time for setup verification. No average total treatment time was acquired for RFX because no treatment was delivered using RFX-X1.

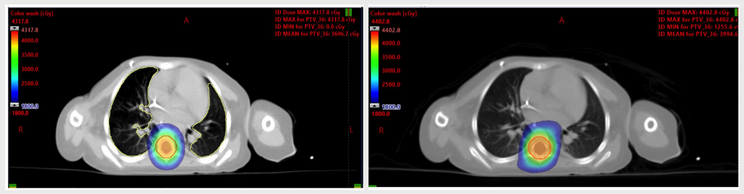

Figure 1. Axial comparison of dose distributions from RFX-X1 plan (left) and VMAT plan (right). Minimum colorwash indicates the 50% isodose line.

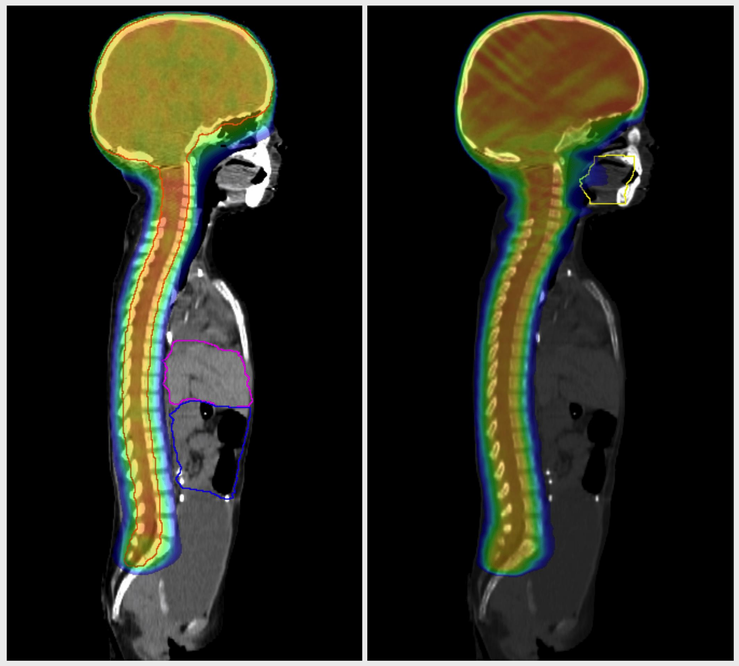

Figure 2. Sagittal comparison of dose distributions from RFX-X1 plan (left) and VMAT plan (right). Minimum colorwash indicates the 50% isodose line.

	Eclipse VMAT	RefleXion	p-value (2-tailed test)
Global Max (D2% to PTV)	39.2 Gy	41.28 Gy	0.0764
Bowel Bag (Dmean)	11.74 Gy	10.38 Gy	0.03798 *
Heart (Dmean)	12.38 Gy	12.32 Gy	0.97295
Right Kidney (Dmean)	20.16 Gy	19.66 Gy	0.87306
Left Kidney (Dmean)	17.68 Gy	18.22 Gy	0.87031
Combined Lung (Dmean)	13.33 Gy	14.66 Gy	0.21925
Oral Cavity (Dmean)	14.66 Gy	15.41 Gy	0.71836
Beam-On Time	8 min 42 sec	16 min 42 sec	-
Total Treatment Time	27 min 45 sec	-	-

Table 1. Average dosimetric indices and parameters achieved for Eclipse VMAT and RefleXion plans (n=5). Significant difference is defined by $p<0.05$.

DISCUSSION

Significant differences in dosimetric parameters between Eclipse VMAT and RFX-X1 were detected only for bowel bag Dmean, with RFX plans generating a lower average bowel bag mean dose than Eclipse VMAT plans.

Average beam-on time was the primary difference between these two treatment techniques.

While the average beam-on time for RFX was approximately twice the length as the average beam-on time for VMAT, RFX-X1 delivery utilizes a moving couch in the cranio-caudal direction, allowing for single-isocenter treatment instead of multiple-isocenter treatment.

Unlike VMAT CSI which requires imaging verification at every isocenter position prior to delivery, RFX-X1 requires imaging once for its single isocenter and can encompass the entire volume in one scan. This reduces any translational errors which may arise from multi-isocenter setups.

LIMITATIONS

One limitation of this study is the small sample size (n=5) due to the planning criteria for RFX-X1. This criteria includes a maximum PTV length of <50 cm to meet the computing power restriction of the current software release.

Another limitation is the limited commercial availability of RFX-X1 compared to linear accelerators.

CONCLUSIONS

Because no statistical differences were detected in the global maximum dose or average Dmean to critical structures except the bowel bag, RFX-X1 plans and Eclipse-planned linac-treated VMAT plans can be described as dosimetrically comparable.

Despite having longer average beam-on time than VMAT plans, RFX-X1 utilizes a moving couch to allow for single-isocenter technique by encompassing the entire volume in one scan, potentially reducing translational errors associated with multi-isocenter setups.