To Reduce Hot Dose Spots in Craniospinal Irradiation: An IMRT Approach with Matching Beam Divergence

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Purpose: In craniospinal irradiation (CSI), hot/cold dose spots are commonly seen with two overlapped fields to cover the spinal cord due to different beam divergences. The purpose of this study is to develop new techniques to reduce/eliminate the hot/cold spots and achieve more uniform dose coverage in the spinal cord and brain.

Materials and Methods: A new approach to reduce the effect of beam divergence was investigated. In the new method, two IMRT fields with beam-divergence match were employed to compensate the dose inhomogeneity due to different SSD. Based on a phantom torso, plans were created for the new IMRT method and compared with the conventional technique.

Results: Both new techniques can improve the dose homogeneity of spinal cord. When normalizing the mean dose to 180 cGy, the minimum dose is approximately 168 cGy for all three plans; however, the maximal cord doses are quite different: 237, 204 and 201 cGy for the conventional, 4-field and IMRT plans respectively. The maximal body dose is 269, 214 and 216 cGy and the volume received a dose >200 cGy is 128, 78 and 42 cm3, respectively.

Conclusion: The new IMRT technique with matching beam-divergence has been developed for CSI to effectively reduce hot/cold spots and improve the dose uniformity in the spinal cord. The two-field IMRT technique has the greatest potential and is feasible to be implemented clinically. The remarkable improvement in dose coverage with the beam-divergence matching techniques warrants further studies with more patient data.

Introduction

Craniospinal irradiation (CSI) is a significant technique known for being the best treatment for central nervous system (CNS) malignant cancers. As a particularly challenging technique, CSI requires the junction of multiple fields, The CSI technique is most often used in pediatric patients in whom long-term radiation toxicity is of concern. Typically two lateral cranial fields are rotated to match the divergence of the posterior spinal field [5]. Techniques include the use of half beam cranial fields or table kicks both with collimator rotation to make the cranial field divergence parallel with the spinal field edge. Often two spinal fields are required. By allowing the beam divergence to cross just anterior to the cord leaves an area of under dose over the cord which is compensated by shifting the junction after a certain number of treatments. The divergence will overlap in the body; eventually resulting in dose inhomogeneity in the cord and high dose regions in the adjacent

Field Type	Gantry Angle		Coll Rtn		Iso Rtn		Field X (cm)		Field Y (cm)		SSD (cm)	
Rt Lat Brain	95	95	9	9	354	354	22.9	20.2	24.1	22.0	91.4	91.4
2 Lt Lat Brain	265	265	351	351	6	6	23.0	20.4	24.1	22.0	91.4	91.4
Upper Spine	0	0	0	90	0	270	6.6	6.1	35.0	36.2	100.0	96.5
Lower Spine	0	342.5	0	90	0	270	12.7	6.4	21.0	20.8	100.0	100.0

Conventional Plan
IMRT Plan

Table 1 Treatment and Field Parameters for Conventional and IMRT Plan

critical structure. The regions of overdose will put nearby organs at risk and will damage normal tissue. This report describes a new technique to deliver uniform dose through utilizing IMRT and by creating a divergence match of the cranial and spinal fields.

Studies were conducted to improve the dose homogeneity of radiation throughout the body through an intensity-modulated radiation therapy (IMRT), use of dynamic wedges, and various patient position adjustments [6-8]. Other studies propose methods to administer supine position treatment, use intrafractional junction shifts, a moving junction versus stationary junction, and junction feathering, leaving no gaps inbetween junctions, and proton treatment [10, 3, 11]. However, the sole use of IMRT and other proposed methods do not significantly improve the dose coverage for a patient unless the matching of the beam divergence is considered.

The inherent property of an x-ray beam is to diverge. The beam divergence of the spinal fields introduces beam overlay resulting in hot and cold spots in the radiation field. A method using not only the divergence match of cranial fields, but also spinal fields would eliminate the beam overlap region, therefore removing the hot dose spots in nearby organs at risk (OAR). Because tilted beams are required for the divergence match, the skin-to-source distance (SSD) and depths will vary through different parts of the spinal cord, resulting in different dose rate. Therefore, intensity modulation is necessary to improve dose homogeneity in target (brain and spinal cord), and the IMRT technique is adopted. The purpose of this study is to develop a new technique of CSI to reduce or eliminate the hot spots in critical structure and cold spots in target, and achieve more uniform dose coverage in the spinal cord.

Methods and Materials

Simulation

Patients were placed in prone position on the treatment table. Mostly pediatric patients were used. The head of the patient was placed on a headrest. The head immobilized through the use of a thermoplastic mask. Anterior and lateral markers were set on the mask. Computed tomography (CT) images were acquired with a 2-mm slice thickness and separation. A clinical target volume (CTV) was created surrounding the brain and a planning target volume (PTV) around the spinal cord. The PTV received at least 95% of the prescription dose. The organs at risk (OARs) were the typhoid, esophagus, heart, lungs, liver, kidneys, bowel, ovaries, and eyes. All organs were outlined and contoured at a virtual simulation workstation and a CT image was created.

After the CT image was contoured, the isocenters were placed. Three isocenteres were used: one for the cranial fields and two for the upper and lower spinal fields. The upper spinal field isocenter was centered between the neck and mid-spine. For the patient study, the upper spine isocenter was placed deeper into the patient at a 96.5 cm SSD. The lower spinal field isocenter was centered between

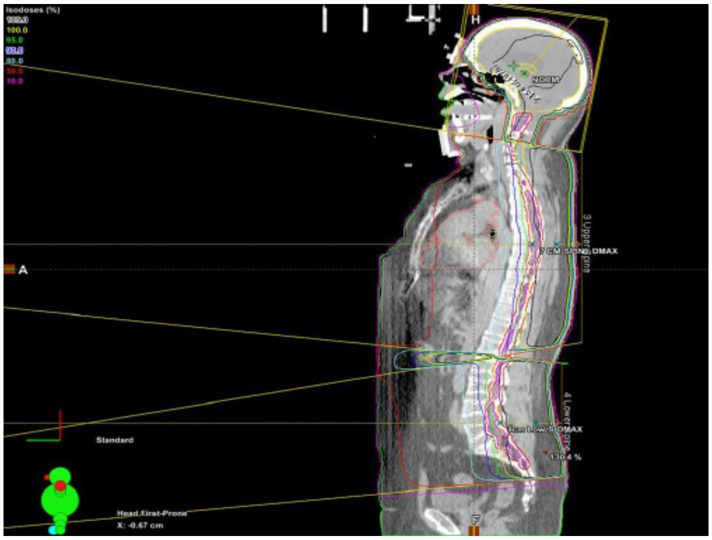

Fig 1 The contoured area of tumor (Conventional Plan Model View)

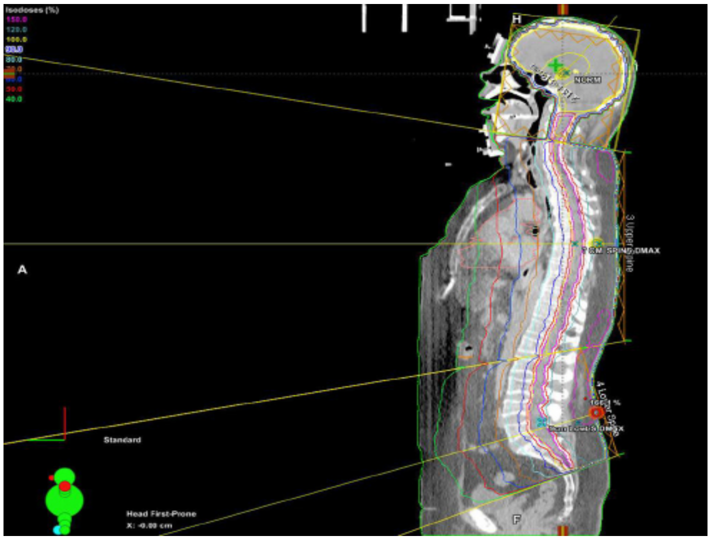

Fig 2 IMRT Model View

DVH Line	Structure	Plan	Course	Volume [cm³]	Dose Cover.[%]	Sampling Cover.[%]	Min Dose [%]	Max Dose [%]	Mean Dose [%]
	BODY	All F1	Research	91706.4	100.0	100.1	0.0	130.5	20.1
	BOWEL	All F1	Research	276.4	100.0	100.0	0.5	103.8	7.4
	BRAIN	All F1	Research	1759.6	100.0	100.0	99.5	111.9	105.4
	BRAIN STEM	All F1	Research						
	Cord +0.5cm	All F1	Research						
	EYE LEFT	All F1	Research						
	EYE RIGHT	All F1	Research						
	HEART	All F1	Research	1023.0	100.0	100.0	2.6	80.9	47.1
	LENS LEFT	All F1	Research						
	LENS RIGHT	All F1	Research						
	LUNGS	All F1	Research	4251.2	100.0	100.0	0.8	98.3	13.1
	NORMAL BRAIN	All F1	Research						
	OPTIC CHIASM	All F1	Research						
	OPTIC NERVE LT	All F1	Research						
	OPTIC NERVE RT	All F1	Research						
	SPINAL CORD	All F1	Research	185.0	100.0	100.1	37.6	119.3	99.6
	TOTAL LUNG	All F1	Research						

Fig 3 Dose Description Values (Conventional Plan)

DVH Line	Structure	Plan	Course	Volume [cm³]	Dose Cover [%]	Sampling Cover.[%]	Min Dose [%]	Max Dose [%]	Mean Dose [%]
	BODY	imrt plan-mo1	Research	91706.4	100.0	100.1	0.0	173.5	13.9
	BOWEL	imrt plan-mo1	Research	276.4	100.0	100.0	0.6	56.2	3.5
	BRAIN	imrt plan-mo1	Research	1759.6	100.0	100.0	96.0	107.9	102.1
	BRAIN STEM	imrt plan-mo1	Research						
	Cord +0.5cm	imrt plan-mo1	Research						
	EYE LEFT	imrt plan-mo1	Research						
	EYE RIGHT	imrt plan-mo1	Research						
	HEART	imrt plan-mo1	Research	1023.0	100.0	100.0	2.2	77.5	29.2
	LENS LEFT	imrt plan-mo1	Research						
	LENS RIGHT	imrt plan-mo1	Research						
	LUNGS	imrt plan-mo1	Research	4251.2	100.0	100.0	0.9	89.5	6.8
	NORMAL BRAIN	imrt plan-mo1	Research						
	OPTIC CHIASM	imrt plan-mo1	Research						
	OPTIC NERVE LT	imrt plan-mo1	Research						
	OPTIC NERVE RT	imrt plan-mo1	Research						
	SPINAL CORD	imrt plan-mo1	Research	185.0	100.0	100.1	87.5	116.0	103.9
	TOTAL LUNG	imrt plan-mo1	Research						

Fig 4 Dose Description Values (IMRT Plan)

the mid-spine and thecal sac. A SSD of 100 cm was used to compensate the dose inhomogeniety. The table and collimator was rotated 90˚ or 270˚.

Treatment

Treatment planning is conducted through the radiation therapy planning software, *Eclipse*. All of the OARs, spinal cord, and brain are contoured. Conventionally, the brain and spinal cord regions are each divided into two fields: upper and lower spine and right and left lateral brain. The spinal fields couch and collimator are not rotated. For the left lateral brain field, the collimator is rotated 351°, the couch is not rotated; for the right lateral brain field, the couch is rotated 354°, the collimator is not rotated. The cranial fields are arranged with the collimator to match divergence of the upper spinal field (9).The SSD was set to 100 cm for all spinal fields, and was set to 91.4 cm for cranial fields. The cranial fields were created first, followed by the spinal fields. The setup of a phantom is different as only two fields are used: one for the brain and one for the spinal cord. For the spinal fields, the collimator and couch would be rotated 90° and for brain fields, the collimator and couch would also be rotated by 90°. This conventional setup is a challenge due to the beam divergence of the spinal cord fields.

For the new technique, the gantry is adjusted by 342.5° to achieve divergence match with the upper spine field. For the spinal fields, the couch is rotated 270˚, and the collimator is rotated by 90°. Optimization with IMRT is then implemented using set doses. Similar to the phantom setup of the conventional method of treatment, there are two spinal fields, of which, the lower field is rotated to match the divergence of the upper spinal field. For the phantom studies, only spinal cord fields were experimented.

The distance between isocenters can be calculated on the treatment planning software (TPS). The cranial fields are set on the patient through isocenter marks on the mastk of the patient. The spinal fields are set through marks on the patient's trunk. The positions of the isocenters are transferred to *Eclipse*.

Once the lower spinal field is configured, the lateral collimator was opened. Once the upper and lower spinal fields was set, the lateral borders changed to the width of the spinal field before treatment began.

Patients are given 6 MV photons on a linear accelerator and 120 leaf MLCs. The spinal isocenter is 20 cm from the brain isocenter. Both the brain and spinal isocenters share the same source-axis distance (SAD). Because the patients were in prone position, the posterior fields were not difficult to see.

Divergence Match and IMRT

For the two-field IMRT method, the lateral cranial fields of the conventional technique were adopted with an SSD of 91.4 cm. The PA lower spinal field was rotated 342.5˚ at an SSD of 100 cm to create a divergence match with the upper spinal field. The couch was rotated 90˚ for the spinal fields and the table was rotated 270˚.

Real patients have a similar setup, while the length of the field is varied proportionately in correspondence with the patient's spinal cord length. Phantom patients have a set parameters, however after placing the isocenters on a patient, the parameters will be reset and recalculated.

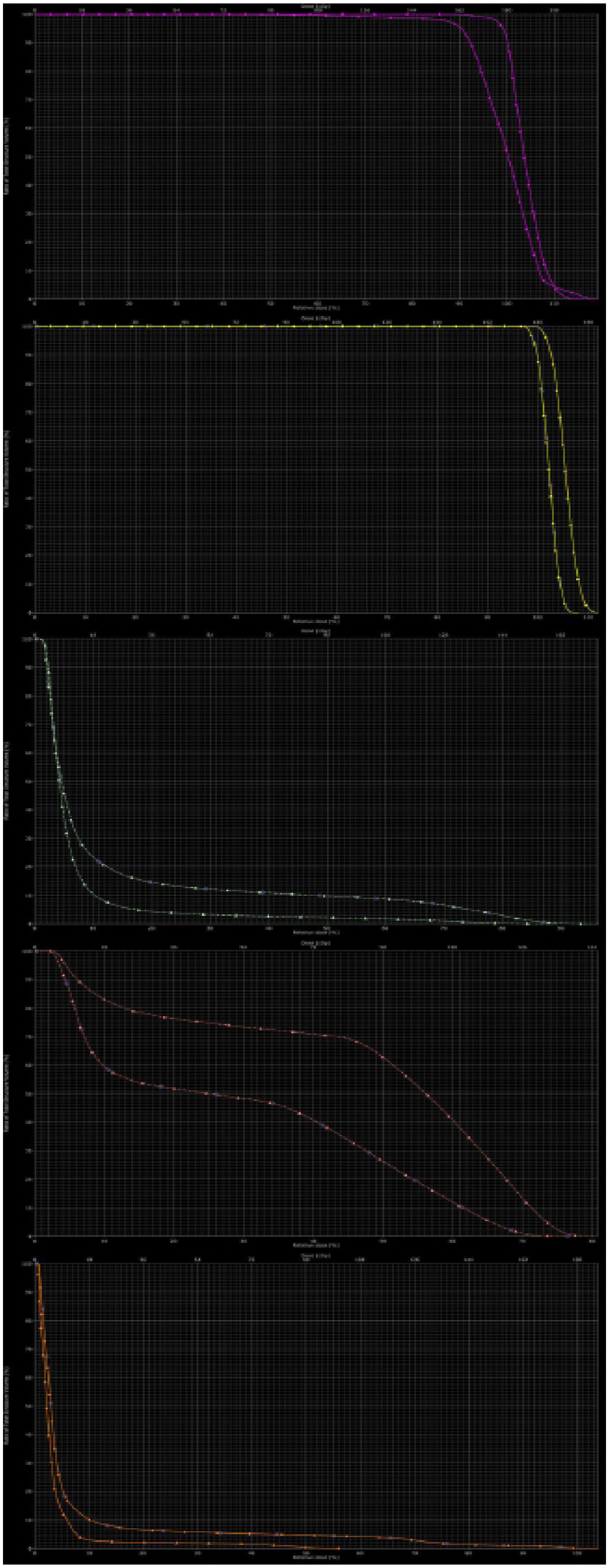

Fig 5 Comparison of IMRT to conventional DVH. From top graph to bottom: spinal cord, brain, lungs, heart, and bowel

Results

Our technique was applied on both a phantom and a CT-simulated phantom. Both case studies yielded results that show that matching beam divergence with IMRT improves dose distribution. In the phantom study, application of the technique caused the maximal dose to effectively reduce. The bowel, where much dose inhomogeneity can occur, was not contoured in the phantom plan, and can therefore not be presented with results.

For the phantom study, the mean dose was normalized to 180 cGy, while the minimum dose for all three plans was approximately 168 cGy. The new approaches gave overall maximum body doses of 214 and 216 cGy, less radiation absorption than the maximum dose of 269 cGy from the conventional method. Also, the IMRT and four-field technique had delivered dose over 200 cGy for body mass volumes of 42 cm3 and 78 cm3 respectively, which is less mass volume radiation absorption compared to the conventional method, which had dose over 200 cGy delivered to a volume of 128 cm3.

The maximal dose maximal dose lowered from 230 cGy of the conventional method to 201 cGy with application of IMRT. This indicates that the radiation had effective dose coverage. The IMRT plan effectively eliminated the hot spots, while sparing normal tissues and nearby organs at risk, improving overall patient care.

The IMRT plan fields used approximately 240.5 MU, while the conventional plan used about 169.075 MU. There was a difference of 1-3 MUs between the cranial fields for the IMRT as they used about 100 MU on average. However, the upper and lower spinal fields in the IMRT used 278 and 327 MU respectively opposed to the 204 and 221.8 MU used by the conventional method.

The IMRT plan can be adjusted for any spinal cord length or any patient size. However, most of the patients are pediatric and therefore we have a standard spinal length. The collimator and couch can easily adjust to the settings of IMRT. The cost to administer the IMRT modulation is no longer an issue at most clinics today. Treatment is still continuously delivered over monthly intervals. Depending on a patient, *Eclipse* can effectively make adjustments to the planning for treatment.

Discussion

Craniospinal irradiation is a challenging technique requiring the junction match of lateral cranial fields with spinal fields. The inherent property of a beam is to diverge; therefore the challenge was to create a divergence match with no overlap between the junction of the fields. Our aim was to improve the dose homogeneity for a junction from the ineffective and inhomogeneous conventional method. Our study has shown that the beam divergence and IMRT technique in the prone position is feasible.

Ongoing studies have been performed by numerous CSI investigators in order to eliminate hot and cold spots from forming. Studies have only been able to reduce over-radiation through techniques such as IMRT and junction shifts but not completely rid of it. The two-field IMRT technique has been a successful technique eliminating all hot and cold spots and significantly improving dose coverage.

The beam divergence match, used with IMRT to evenly distribute dose along the craniospinal region eliminates hot and cold spot formation. The SSD of the posterior-anterior lower spinal field had been the ultimate factor in delivering homogenous radiation. The depth of the isocenter for the lower spinal field had to be lowered. We found an SSD of 100 cm to be ideal to compensate dose inhomogeniety.

Most investigations for improving craniospinal irradiation are through clinical methods, however, this technique was performed only through dosimetry. This technique can be performed in either prone or supine position, however prone positioning was advantageous for the conjunction of the spinal cord.

Typical 18 MV photon energy beams have been used, however they have been found to cause neutron contamination from a betatron and linear accelerator [2]. It has been found that the linear accelerator produces more neutrons than the beatron [2]. Studies show that only energy beams of 10 MV and above produce neutrons, therefore 10 MV x-ray beams are common as their neutron contamination is negligible [9].

For this study, energy beams of 6 MV were used for the IMRT technique. They proved to be sufficient for treatment and avoided any neutron contamination.

A study using intrafractional junction shifts and field-in-field shaping was performed by South et al [10]. Their procedures have similarities with this study however there are some key differences. Their technique contained use of field-in-field shaping with MLCs, while this study makes use of an IMRT. The lateral spinal fields in the South et al. study contained two isocenters opposed to one central isocenter for our technique. MLC leaves were used to create divergence or gaps, which would result in more hot and cold spot formation.

Conclusion

A new IMRT method with matching beam divergence has been developed for CSI. It effectively reduces hot spots in the critical structure and improves the dose uniformity in the spinal cord and brain. The two-field IMRT technique has the greatest potential and is feasible to be implemented clinically. This marked improvement in dose coverage of the beam-divergence matching methods warrants further studies with patient planning data.

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