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Dosimetric comparison of three different techniques for craniospinal irradiation

Soliman OY[1], Abdalgeleel SA[2], Elawady R[3], Hammad M[4], Ashour M[1]

[1] Radiation Oncology and Nuclear Medicine department, National Cancer Institute, Cairo University, Egypt.
[2] Biostatistics and epidemiology department, National Cancer Institute, Cairo University, Egypt.
[3] Physics unit,Radiation Oncology, and Nuclear Medicine department,National Cancer Institute, Cairo University, Egypt.
[4] Pediatric Oncology department, National Cancer Institute, Cairo University, Egypt.

Address of correspondence:
Osama Yousof Soliman, Radiation Oncology and Nuclear Medicine department, National Cancer Institute, Cairo University, Fom Elkhalig, Cairo, Cairo11796, Egypt, e-mail: osama.soliman@nci.cu.edu.eg

Abstract

Background: To evaluate the dosimetric gains of Intensity-Modulated Radiation Therapy (IMRT) versus 3D-Conformal Radiotherapy (3D-CRT) using either 6MV or 15MV for Craniospinal axis Irradiation (CSI) in pediatric patients.
Methods: A total of 30 treatment plans for ten patients receiving CSI were evaluated retrospectively using Monaco Software (Version Monaco Medical Systems Inc., Version 5.11.2.). Three different delivery plans (3D-CRTwith6MV, 15MV, and IMRT) were made for each case. The homogeneity index (HI) of the planning target volume (PTV) and organs at risk (OARs) doses were assessed.
Results: The coverage of PTV-spine V95was significantly better in the IMRT plan than in the other two conformal plans. The coverage of PTV-brain V95 was the least in the 3D-CRT plan using 15 MV and was better in the 6 MV plan.
The maximum dose was significantly higher in the 3D-CRT plan using 6 MV than IMRT and 15 MV plans. The homogeneity index of the PTV spinewas significantly better in the IMRT plan than in the two conformal plans. Regarding the integral dose, it was significantly higher for the IMRT plan as compared to the other two plans.
Conclusions: For craniospinal irradiation, IMRT offers better results regarding PTV homogeneity and critical OARs sparing when compared to 3D-CRT using 6MV& 15MV.IMRTresults in increased integral dose, which is of major concern in pediatric patients.

Keywords: Dosimetric comparison; 3D-conformal radiotherapy; intensity-modulated radiotherapy; craniospinal irradiation.

Background

Different techniques of craniospinal axis irradiation (CSI) can be used to treat several tumors including medulloblastoma, CNS lymphoma, and other CNS tumors. Medulloblastoma is one of the most common pediatric central nervous system tumors.

Combining two lateral opposed photon beams for the brain, matched to one or more posterior photon fields for the spine, has been the most widely used technique for treating the craniospinal axis.

The highly conformal techniques Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), and TomoTherapy will minimize the dose to the structures anterior to the vertebrae at the cost of a greater volume of low-dose irradiation to the whole body.

Several studies show that using modern radiotherapy techniques improves the conformity index (CI) and heterogeneity index (HI) for the planning target volume (PTV) and field-junctions as compared to 3D-conformal radiotherapy (3D-CRT) [1–3].

Highly conformal techniques include understanding the uncertainties associated with the target's potential motion and accurate target volume delineation.

Methods

Patient characteristics

A total of 10 pediatric patients who received CSI were recruited. Pretreatment assessments for all patients included a full physical examination, Karnofsky performance status (KPS) scoring, hematological and biochemical panels, chest imaging, and whole-abdomen ultrasonography. None of the patients had any distant metastases.

Treatment planning

The patients were positioned prone and immobilized with arms at both sides with head-neck-shoulder thermoplastic fixation masks. Fixation was also performed by the use of body marker lines.

A General Electric CT system was used to obtain CT images with a 3 mm slicing thickness from above the head to the sacral end for planning, then CT images were imported into Monaco Medical Systems Inc., Version 5.11.2.

Beams arrangement

1-3D-CRT (6MV- 15MV)

Two parallel-opposed lateral cranial fields with angles 90 and 270 were used for conformal radiotherapy. The posterior spinal field was positioned with a gantry angle of 0. Both cranial and upper spine fields were arranged with a mono-isocenter to avoid the hot spot. If the spine length is more than 20cm, another lower spine was used with a new iso-center. To avoid beam divergence into the spine fields, the couch angle for the lower spine field was rotated 90 degrees, and the gantry rotated until matched with the divergence of the upper-spine field

2-IMRT

Designed on Monaco with 6 MV photon beams, IMRT plans contained six distributed coplanar fields for the cranial field positioned with gantry angles of 90, 260, 40, 315, 110, and 210. The gantry angles for the spinal fields were 0, 30, and 330.The collimator's position, size, and angle were adjusted. Inverse planning software was used to iteratively refine the plans for optimum PTV coverage and OARs sparing.

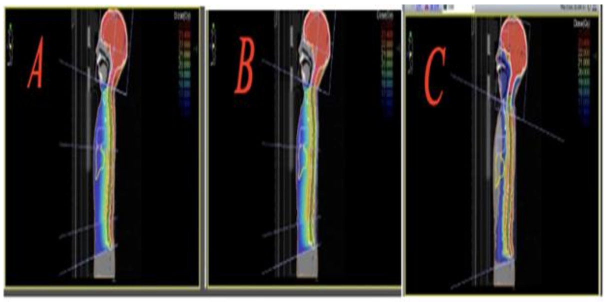

Fig. 1. Sagittal view of CSI dose distribution A. 3D-CRT 6MV, B. 3D-CRT 15MV, C. IMRT

Dose prescription

The brain's clinical target volume (CTV) included the whole brain. The CTV spine covers the spinal canal and neural exits down to S2 or S3.The CTV to PTV margin was 3 mm for the brain, and it was 5 mm for the spine. Figure 2

The prescribed dose for irradiation of the craniospinal axis is 2340cGy/13 fraction (180cGy/Fx). Both lenses, eye, optic chiasm, optic nerves, cochleas, heart, lung, liver, kidneys, thyroid, and parotids were contoured as organs at risk (OARs).

Plan evaluations

Dosimetric outcomes of 3D-CRT using 6MV, 15MV, and IMRT included was evaluating PTV and OARs coverage. ICRU83 was used to evaluate target volume coverage and dose homogeneity.

Homogeneity index (HI) was defined as follows: HI= $D_{2\%}$- $D_{98\%}$/ $D_{50\%}$

Where $D_{2\%}$, $D_{98\%}$ and $D_{50\%}$ is defined as dose to 2%, 98% and 50% of total volume.

(ICRU 83) [4].

The closer the value of HIis to zero, the better conformity of PTV.

Dmax to PTV and the percentage of PTV covered by ≥95% of the prescribed dose (V95%) were also used.

OARs: For each patient, Dmax, Dmean, and a series of RTOG-recommended OARs values were evaluated, including the lenses, optic chiasm, optic nerves, heart, lungs, liver, and kidneys, with a lower value indicating improved protection.

Statistical method

Data were analyzed using SPSS win statistical package version 22. Numerical data were summarized as mean ± standard deviation or medians and ranges. A comparison between more than two groups for numerical variables was made using the non-parametric Friedman test. Probability (p-value) equal to or less than 0.05 is considered significant.

Results and discussion

The dosimetric comparison was made between 3 plans: IMRT, 3D-CRT 6MV, and 15MV for ten patients receiving CSI.

PTV dose coverage and homogeneity index

Table 1: Target volumes dose coverage and homogeneity index.

	15 MV Mean±SD (%)	**6 MV Mean±SD (%)**	**IMRT Mean±SD (%)**	**P-value**
CTV brain V95	97.2±1.6	99.6±0.8	98.9±1.1	0.002
CTV spine V95	98.3±1.3	95.7±3.2	98.9±1.8	0.006
PTV brain V95	94.9±1.9	97.3±2.4	96.9±1.8	0.005
PTV spine V95	95.2±2.2	93.8±4.2	98.9±1.3	0.005
PTV spine Dmax	25.5 (24.5-27.8)	26.5 (25.8-29.2)	25.7 (24.3-27.6)	0.007
Hi index brain	.1±0.07	.21±0.1	0.1±0.06	0.007
Hi index spinal cord	0.2±0.04	0.2±0.08	0.08±0.03	0.002

{Data are presented as mean ± SD, or median (range)}

The mean volume that received 95% isodose line distribution of IMRT plan in PTV-brain was (96.9%) compared to 6MV 3D-CRT (97.3%) and 15 MV 3D-CRT (94.9%) (p=0.005) with the least coverage of PTV-brain V95 in the 3D-CRT plan using 15MV. Regarding the PTV-spine; its coverage was significantly better in the IMRT plan than in the two conformal (Table 2), with the mean volume that received 95% isodose line distribution in the IMRT plans equal 98.9% compared with 6MV conformal (93.8%) and 15 MV conformal (95.2%) (p=0.005); Figure 3.

Figure 4 shows an example comparison of isodose line distributions for 3D conformal 15MV, 3D conformal 6MV, and IMRT plans for the same patient. The figure shows the color wash covered by 95%of 23.4 Gy dose distributions for each technique.

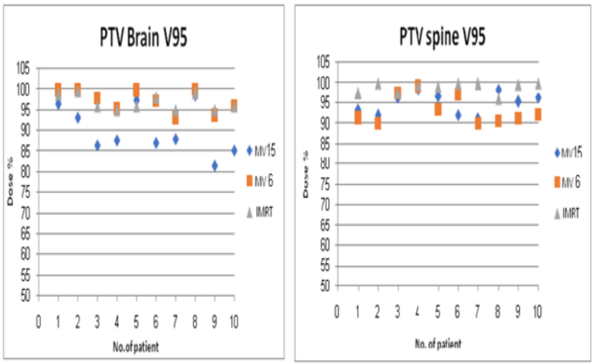

Fig. 2. V95% isodose line coverage of the ten patients. Left: for PTV-Brain. Right: PTV-Spine

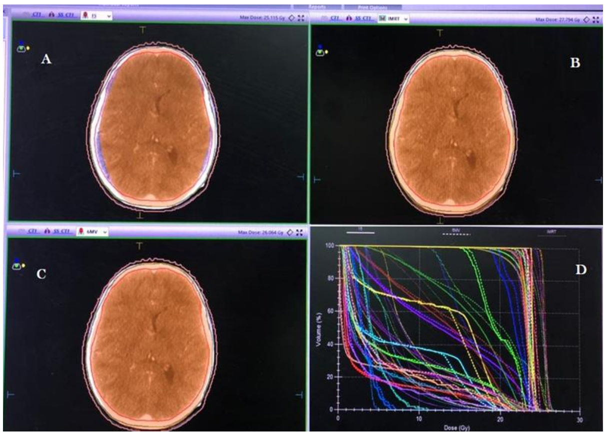

Fig. 3. Axial view of craniospinal dose distribution with a 95% isodose line. A- 3D conformal 15MV. B- IMRT. C- 3D conformal 6MV. D- Organs' DVH for the three plans

The maximum point dose in the PTV-Spine was significantly higher in conformal radiotherapy 6MV plan than in IMRT and 15 MV plans.

The homogeneity index of the spinal cord was significantly better in the IMRT plan than in the two conformal plans. However, the homogeneity index of the brain was significantly better in the IMRT and 15 MV plans than in the 6 MV conformal plan.

Organs at risk doses

The doses to heart, eyes, cochleas, thyroid, and parotids were the least in the IMRT plan than the two conformal plans shown in table 2.

No significant difference was noted between the three plans regarding dose to lenses, both kidneys, and both lungs.

Regarding the integral dose, it was significantly higher for the IMRT plan as compared to the other two plans.

Table 2: Organs at risk doses

	(3D-CRT) 15 MV Mean ± STD (Gy)	(3D-CRT) 6 MV Mean ± STD (Gy)	IMRT Mean ± STD (Gy)	P-value
Heart mean dose	11.9±2.5	11.3±2.5	7.5±1.8	<0.001
Left eye maximum	23.5±0.9	24.2±0.77	19.8±3.5	0.002
Left lens maximum	6,8±3.0	6.8±2.6	6.0±0.8	0.521
Right eye maximum	22.7±2.7	23.5±2.5	18.4±5.1	0.016
Right lens maximum	6.3±2.7	6.1±3.1	5.8±1.3	0.905
Left cochlea mean	23.5±0.6	24.0±0.5	22.9±0.9	0.010
Right cochlea mean	23.5±0.6	24.0±0.5	22.9±0.9	0.003
Thyroid mean	15.9±5.6	15.3±5.3	6.4±1.3	0.003
Left optic nerve maximum	23.9±.6	24±0.6	23.7±1.0	0.020
Right optic nerve maximum	23.9±0.6	24.0±0.7	24.5±2.1	0.202
Left parotid mean	15.3±3.9	17.1±4.4	14.5±3.5	0.001
Right parotid mean	15.3±5.5	16.3±5.9	14.5477±3 .4	0.331
Liver mean	5.3±1.8	5.5±2.2	5.4±1.9	0.927
Both kidneys mean	3.9±2.8	4.2±2.9	4.8±2.4	0.273
Both lungs V20	5.7±5.4	5.9±5.4	3.6±3.5	0.285
Integral Dose	5.1±1.1	5.2±1.2	5.4±1.4	0.117

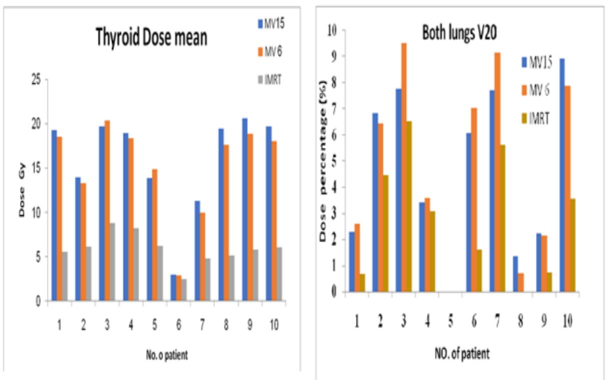

Fig. 4. Left. Mean dose to the thyroid in the three plans. Right. V20 to both lungs in the three plans

Discussion

Cancers with a risk of leptomeningeal spread are treated with CSI, including medulloblastoma, CNS lymphoma, and other CNS tumors that have the potential to metastasize. [5]

CSI is a technique that requires accuracy in design and implementation. Multiple matched fields with the possibility of under-dosing and over-dosing at the junction of each field remain a major concern in the delivery of treatment.

This study aimed to compare three different planning techniques to achieve good PTV coverage by reducing the dose to OARs and reducing the hot spot within the spinal field produced by the 3D-conformal radiotherapy using 6 and 15 MV.

Overlapping the fields and allowing inverse planning to monitor the homogeneity in the target in IMRT plans are alternative approaches for reducing uncertainties at the junction areas in the conformal plans.

The coverage of PTVspine was significantly better in the IMRT plan than the other two conformal plans, and the coverage of PTVbrain was the least in the conformal plan using 15MV and was better in the 6 MV and IMRT plans. The 6MV plan was the highest in terms of target maximum dose, and it was better in the IMRT and 15 MV plans; this was similar to the results published by Parker et al. [1]

The doses to both eyes in all plans were within the tolerance limit and better spared in the IMRT plan. Moreover, the doses to both lenses were small compared to their tolerance (<7Gy), as previously mentioned.

The heart mean dose was the highest with the 3D conformal radiotherapy plan using 15 MV due to its penetration power and was the least with IMRT with a statistically significant difference but all within its dose constraint. [6]

The liver is a lateral structure away from the field of radiation. We found no statistically significant difference between the three plans and remained less than its dose constraint as this was the same as Gurgaret al. [7]

Also, both kidneys' mean dose in all plans is minimal as they are lateral structures with no statistically significant difference; however, it is a bit higher in the IMRT plan but still low compared to its dose constraint.

Although IMRT plans have better target volume coverage, dose homogeneity, and avoidance of organs at risk, concerns regarding implementing IMRT for CSI remain because it results in increased integral dose with multiple beams and needs more monitor units for treatment; both of these factors are concerning for pediatric patients.

Conclusions

Target coverage was similar for CSI, IMRT, 6MV, and 15MVconformal radiotherapy. The use of IMRT, on the other hand, resulted in improved spine HI and OARs sparing. However, the higher integral dose achieved with IMRT should be further evaluated in larger prospective studies with long-duration follow-ups to ensure its safety, especially for pediatric patients.

List of abbreviations

IMRT	Intensity-Modulated Radiation Therapy
3D-CRT	3D-Conformal Radiotherapy
CSI	Craniospinal axis Irradiation
HI	homogeneity index
PTV	planning target volume
OARs	organs at risk
CNS	central nervous system
VMAT	Volumetric Modulated Arc Therapy
CI	conformity index
KPS	Karnofsky performance status
CTV	clinical target volume
SV2	2nd sacral vertebra

Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' contributions

All authors actively contributed to the research and read and approved the final manuscript.

Acknowledgments

None.

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