DOSIMETRIC PLAN EVALUATION FOR CARNIOPSPINAL IRRADIATION USING 3D-CONFORMAL RADIOTHERAPY TECHNIQUE

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Abstract

Craniospinal irradiation (CSI) is indicated for medulloblastoma and some rare tumours of central nervous system. Traditionally, CSI is delivered with the patient in the prone position, using a combination of two lateral opposed photon beams for the brain, matched to one or more posterior photon fields to treat the spine. In this work are presented two treatment plans of CSI, geometrically different, using the conventional 3D conformal radiotherapy technique, by evaluating dose distributions over the target and organs at risk. Plans are realized using treatment plan system Eclipse, according to the department protocol.

Key words: radiotherapy, craniospinal, dose, treatment plan.

Introduction

The whole craniospinal volume is irradiated in some tumors of the central nervous system like medulloblastoma, which is the most common malignant primary nervous system tumor occurring in the pediatric ages. By definition, medulloblastomas arise in the posterior fossa and often have a spread in cerebrospinal fluid. Postoperative craniospinal irradiation is considered as a standard treatment with a greater dose (boost) given to the bed tumor. Adjuvant chemotherapy, as the risk of relapse, is substantial after radiation alone Perez & Brady (2007).

Many different treatment techniques exist for irradiation of whole neuroaxis such are Three Dimensional Conformal Radiotherapy (3D-CRT) and advanced techniques such are intensity modulated radiothetary IMRT, Volume Modulation Arc Therapy, Tomotherapy, etc., Seravelli *et al* (2018).Conventional technique 3D-CRT for CSI irradiation is still in wide use.

Traditionally symmetrical lateral opposed *cranial fields* coupled with one or two posterior *spinal field (s)* are planned to cover entire length of Planning Target Volume (PTV). This approach results in dose inhomogeneity, especially at the beam junction(s), and a significant dose anterior to the spinal target volume. Consideration should be taken to the non uniformity of dose distribution on neuroaxis on the overlapped areas caused from adjacent radiation beam divergence as well the doses to organs at risk.

In the following we will bring comparison of two treatment plans geometrically different, in three patients of 14 years old age, realized with 3D-CRT modality. For each patient were builted retrospectively the dosimetric plans based on two different geometrical setup fields. Dosimetric parameters as the PTV coverage, conformity index, dose homogeneity index as well doses at organs at risk will be compared. The dose prescribed for treatment of a medulloblastoma was 23.4 Gy with 1.8 Gy per fraction for cranio-spinal irradiation followed with a boost in the tumour bed in total dose of 54 Gy.

Overview on craniospinal field junction (s)

The craniospinal irradiation is accomplished by two lateral parallel opposed brain fields coupled with a posterior spine field (s), which are placed in orthogonal planes. To avoid the risk of dose overlap in junction of cranial fields with the orthogonal spinal field different techniques are in use. The most common are: the "gap- junction" method, the half beam blocked and couch - collimator rotation method, Khan (2014); Athiyaman *et al* (2014).

For "*Gap- junction"* method the spine field is separated from the cranium field by the distance S, which depends on the spine field size L, the depth d at which the orthogonal fields are allowed to join and the source-surface distance, SSD, according to the equation below:

$$S = \frac{1}{2} L \text{ x} \left(\frac{d}{SSD}\right) \quad (1)$$

Elimination of cranial field divergence by using a *half-beam block* method is achieved by using independent jaw to split the fields at the craniospinal junction line by positioning at the central axis, thereby eliminating divergence of the rays at the junction line.

In the collimator - couch rotation method a diverging symmetric cranium and spine fields are used for whole length of PTV. Alignment (matching) of inferior border of bilateral cranium fields with superior margin of spine field is achieved by rotating the collimator and couch till that the margin of fields geometrically come in parallel (Figure 1).

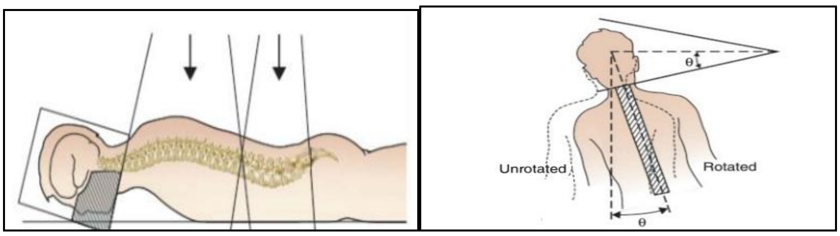

Figure 1. Schematic geometry of cranial-spine fields**.**In the left, lateral view of cranial fields aligns with the diverging border of the spinal field by collimator rotation. In the right, couch rotation between the spinal field and the diverging border of the cranial field in coronal plane, Khan (2014)

The angles of couch and collimator rotation can be calculated as :

$$\theta_{coll} = \arc\tan\left(\frac{L_{spine}}{2\,SSD}\right)\ (2); \quad \theta_{couch} = \arc\tan\left(\frac{L_{cranial}}{2\,SAD}\right)\ (3)$$

Where L_{spine} is the length of the posterior spinal field, $L_{cranial}$ is the length of the lateral cranial field, SSD is the Source Skin Distance for the spinal field, and SAD is the Source to Axis Distance for the cranial fields, assuming that the SSD technique is used for the spinal field and the SAD technique for the cranial fields. The couch is rotated toward the side of the cranial field enters the head and the couch rotation angle depends on the length of cranial fields and the source-axis distance as in Equation (3). The collimator angle depends on length of spinal fields and the setup mode used.Literature has been reported that couch and collimator rotation angles vary from 7° to 11°, Barret (2009); Mayles, Nahum &, Rosenwald (2007).

Spinal field, despite the use of an extended source-skin distance (SSD) up to 140 cm , two *adjacent posterior fields* are commonly required to cover the spinal cord in adults and older children because of the spine length.By using more than one posertior spinal field it is still common to match beams by using a "gap" between beams in the skin surface so that the beam edges converge at a planned depth. The total separation S on the skin surface can be calculated as:

$$S = S1 + S2 = \frac{1}{2}L1x\left(\frac{d}{SSD1}\right) + \frac{1}{2}L2\,x\left(\frac{d}{SSD2}\right)\ (4)$$

L1 is length of spine field, SSD_1 dhe SSD_2 is “source skin distance and d is the “depth” at which both field are matched. Schematically are presented like in the Figure 2.

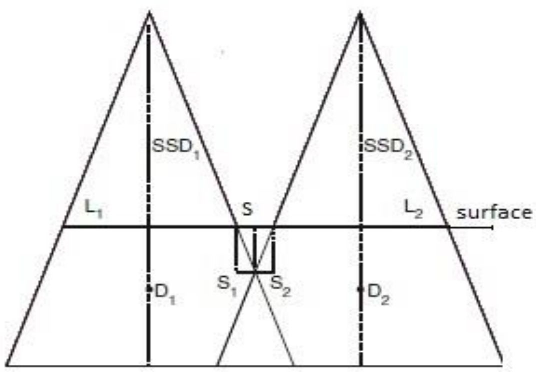

Figure 2. Schematic of the geometry of two adjacent beams, separate by S1+S2 on the surface and junctioning at the depth d.

Because homogeneous dose is required to potential tumour cells within the spinal cord the "junction point" is moved in a cranio-caudal direction at regular intervals to prevent any risk of overdose.

Materials and methods

Patient immobilization

Patients have traditionally received craniospinal irradiation (CSI) in the prone position, but treatment in the supine position, especially for pediatric ages are in general more comfortable when the anesthesia is required.

In each case, immobilization is important and involves the use of a head mask or full-body immobilization.

Patients in this study were immobilized in prone position with thermoplastic mask system. The neck must be extended to avoid the exit dose to the oral cavity.

A Computed Tomography (CT) scan was acquired with Somatom Siemens CT scan of 3 mm slice thickness, from the top of the skull to the interevertebral space S2-S3 of the spine. Six reference CT markers were placed during simulation on thermoplastic mask and the other three in thoracic region, which shall be used for shifting the patient position to treatment isocenter in the Treatment Planning System.

Target Volume and organ at risk contouring

For target volume definition is best accomplished using CT simulation with CT–MRI image coregistration. The Clinical Target Volume CTV for craniospinal radiotherapy has an irregular shape that consists of the whole brain and spinal cord and their overlying meninges. CT scanner images for each patient are acquired using Somaton Siemens with slices of 3 mm in thickness.

The Planning Target Volume (PTV) is delineated on CTV by adding a margin of 5 mm. As well the organ at risk is contouring such are lens, parotide glands, thyroid, lungs, heart, kidney, pancreas, etc.

Dose prescription

The conventional daily fraction size for the treatment of medulloblastoma for paediatric ages is 1.6-1.8 Gy and the total dose typically on the order of 54 Gy. It is also usual to use lower doses for children younger than age 3 years to reduce the risk of neurocognitive deficits.

The dose prescription for medulloblastoma was 23.4 Gy with 1.8 Gy per fraction for CSI phase, followed by the boost irradiation with a total dose of 54 Gy.

Treatment Planning with Eclipse treatment planning system

Treatment plans are prepared by using Eclipse Treatment Planning System (TPS) by Varian and the modality was 3D-CRT. Photon dose calculation model was the Analytical Anisotropic Algorithm (AAA) implemented to the Eclipse for the X- ray photon beam of 6 MV energy with flatten filter.

In forward planning each field is placed manually for achieving the ICRU recommendations for 3D – CRT that states: 95 % of prescribed dose to cover the minimum 95 % of the volume of PTV.

Two treatments plans, different geometrically, are realized on CT-simulations for each patient in prone position, to cover entire length of (PTV) for CSI with the dose prescription of 23.4 Gy in 1.8 Gy per fraction.

The first geometry includes two lateral parallel opposed brain fields coupled with a posterior spine field at the extended SSD. *The second geometry*, two lateral parallel opposed brain fields are coupled with two posterior spine fields in isocentrically setup. In both cases alignment of inferior border of opposed cranial fields with the superior border of the posterior spine field is achieved by collimator/couch rotation.

An overview of treatment plans realized for the three patients by using 3D-CRT regarding; the spine length; couch, collimator rotation angles (in cervical junction"; the extended distance SSD; are shown in the Table 1.

Table 1. Summary data for cases for CSI technique

Patient	Spine length (cm)	Cranial fields, angle degree			Extended SSD (cm)
		Gantry	Coll.	Couch	
1	45.3	270.0	349.0	9.0	110.5
		90.0	11.0	351.0	
2	46.7	270.0	353.0	352.0	116.4
		90.0	7.0	8.0	
3	52.0	270.0	350.5	353.0	140.0
		90.0	9.5	7.0	

When two adjacent posterior spinal fields were used, their alignment has followed the "gap" on the skin surface and junctioning in a point at the depth at the level of anterior spinal cord calculated from the Equation 3.

The field junction over the cervical cord has been placed in such a way that avoids the inclusion of the teeth in the exit of the spinal field. Avoiding the over and underdosage over spinal cord, both junctions either Cervical or Spinal, has been shifted by moving caudally every 5-7 fractions. This shifting is called as "*feathering technique"* by which the inferior margin of the cranial field is shortened and the superior and inferior portions of spine field edges is extended (Figure 3).

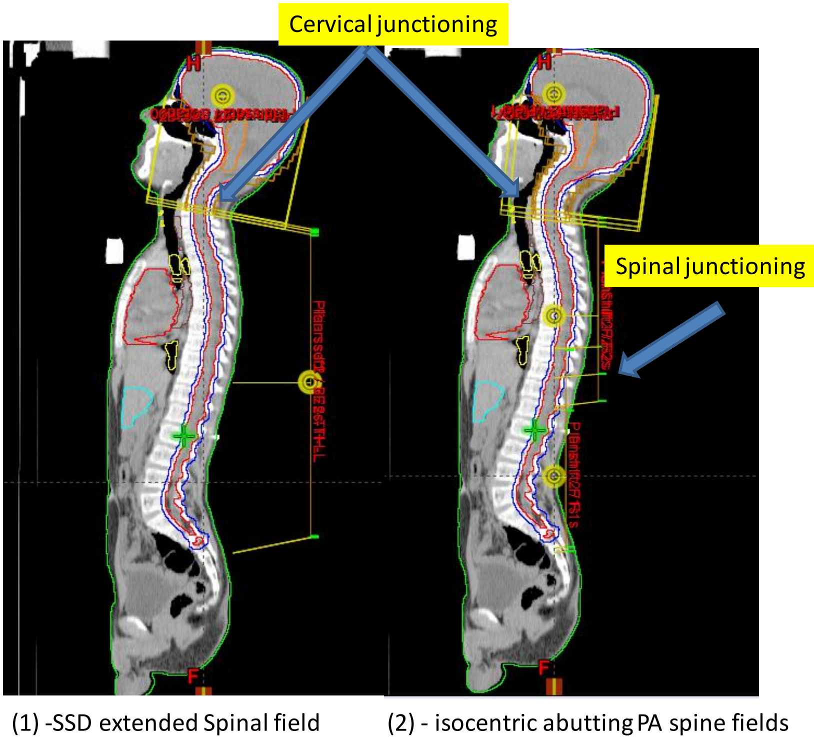

Figure 3. Lateral view of scan image of a patient with the geometry of field used for treatment; (1) SSD extended Spinal field geometry; (2) isocentric abutting Posterior spine fields

In the figure above there is the lateral view of field alignment for both treatment plan geometries on the CT scan images of the patient.

Results

Craniospinal irradiation is accomplished by two lateral parallel opposed brain fields coupled with a posterior spine field, in the case when the extended SSD spinal field is used, or two adjacent fields aligned with a gap on the skin surface along PTV, junctioning in anterior of spinal cord. Both junctions are moved caudally for 7.2 Gy.

As the treatment plans are geometrically different we will compare dosimetric parameters regarding the dose conformity and homogeneity within the PTV and mean doses to organs at risk, for each geometry, in the same patient as well for all of three patients.

PTV dose coverage and Conformity Index (CI) were evaluated using direct the Dose Volume Histogram (DVH) for each plan in Eclipse TPS. The definition of CI is the volume closed by the prescription isodose surface divided by the target volume.

Dose homogeneity index (DHI) were defined as a ratio between the dose reached in 95% of the PTV volume ($D \geq 95\%$) and the dose reached in 5% ($D\geq 5\%$) of the PTV volume. The ideal value is 1 and it increases as the plan become less homogeneous. The DHI was calculated for all three patients (for the six plans created in total) and evaluated. Ideal value is 1 and it increases with dose inhomogenity within PTV. All dosimetric data are summarized at the table below.

Table 2. Dosimetric parameters of treatment plans; extended SSD and isocentrically matched fields

Type of plan	Patients	Coverage on PTV (%)	Conformity index	DHI
SSD ex(1)	1	98.0	1.5	1.3
	2	98.6	1.6	1.2
	3	98.2	2.1	1.2
Isocentric (2)	1	98.0	1.7	1.3
	2	97.2	1.5	1.2
	3	99.5	2.2	1.2

(1) treatment plan realized with two cranial fields + one spine field at extended SSD on PTV; (2)treatment plan realized two cranial fields + two spinal fields isocentrically junctioning on PTV

For all six planes the dosimetric parameters are within the recommendations.

In both cases is obtained good results in dose coverage which shows that 95.0 % of prescription dose (22.23 Gy in absolute value) covers with an average of 98.2 % of PTV on both treatment plans for the three patients.

The conformity index is varying in the region from 1.5 to 2.2 for the two type of treatment plans but it seems that increasing the PTV coverage it increase in value (eg patient 3 for the type of plan isocentrically it has a value of CI= 2.2, however it stays within the recommendation of RTOG.

Regarding dose homogeneity by comparing the two plans on the same patient it seems that there is no difference in the dose distribution within the PTV.

For visualization of the dose distribution along the PTV in craniospinal irradiation has been showed for a patient, by using as the the threshold the dose 22.23 Gy.

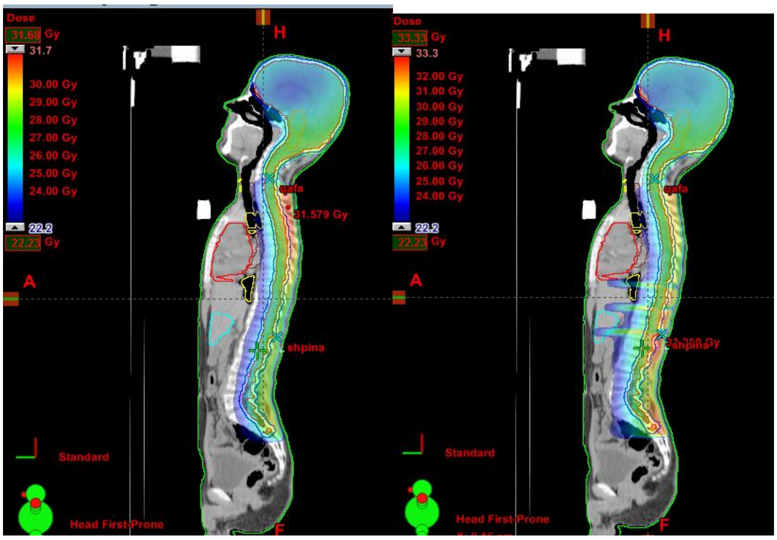

Figure 4. Dose distributions within Craniospinal axis on the first patien. In the left, SSD extended set up; in the right Isocentric abut Postrerior spine fields

Matching the upper border of the spine field to the lower border of the cranial field (cervical junction), requires strict attention to achieve the accuracy, overlapping of the spinal field to cranium (i.e. overdosing) may lead to catastrophic outcomes for the patient. Is evident that by the couch-collimator rotations has been achieved a good junction on the level of cervical PTV area. As well the dose distribution along the PTV, in saggital planes, Figure 4, presents visual the dose distribution greater than the threshold (the three spikes on the Lumbar region) which corresponds to the junctions of spinal fields and cold spots near to skin area ("Gap-junction" of spinal fields.

Regarding the mean dose at the organs at risk it is not present a big difference in their values, in both setups (SSD extended posterior field or ISOcentric abut posterior fields). Exception is noticed only in the organs that are located nearby the cervical - junction and spinal junction, (bolded numbers in Table 3). Thyroid glands have a low variability for the second and third patient in cervical junction, but in the first patient there is a higher value of 6 Gy as a result that the matching line of cranial –spine fields has been placed lower than in SSD setup. Pancreas which is located nearby in the junction of spinal fields shows an increasing on mean dose 2.0- 3.0 Gy more than in extended SSD geometry; 14.1 ± 5.3 vs. 17.3 ± 6.6; 12.5 ± 4.2 vs.14.7 ± 5.2; 6.8 ± 4.7 vs.7.5 ± 4.8

Table 3. Mean dose values for the organ at risk in the brain region and spine region for three patients with two plans of different geometry

	D_{mean} SSD (P.1	Dmean ISO (P.1)	Dmean SSD (P.2)	Dmean ISO (P.2)	D_{mean} SSD (P.3)	D_{mean} ISO (P.3)
Lens L	3.4 ± 0.3	2.8 ± 0.2	4.4 ± 0.9	5.4 ± 3.8	2.8 ± 0.1	2.8 ± 0.1
Lens R	5.1 ± 1.4	3.9 ± 0.8	3.7 ± 0.6	4.7 ± 3.5	3.9 ± 0.7	3.9 ± 0.7
Parotid gl L	2.9 ± 0.9	2.9 ± 1.5	3.0 ± 0.9	2.8 ± 0.9	3.8 ± 2.6	3.7 ± 2.5
Parotid gl R	3.1 ± 2.4	3.6 ±3.1	2.5 ± 0.5	2.4 ± 0.6	5.9 ± 5.4	4.3 ± 4.0
Thyroid	**19.6 ± 1.8**	**12.4 ± 6.1**	**18.8 ±1.4**	**18.7 ± 1.6**	**18.6 ± 1.1**	**17.5 ± 1.2**
Heart	13.2 ± 7.2	13.3 ± 7.1	9.8 ± 7.3	9.2 ± 7.2	8.9 ± 6.8	8.0 ± 6.3
Lung_L	3.4 ± 4.6	3.6 ± 4.9	2.4 ± 2.9	2.2 ± 2.2	2.5 ± 2.4	2.2 ± 2.0
Lung_R	4.4 ± 5.8	4.6 ± 6.0	2.9 ± 4.2	2.8 ± 4.1	3.0 ± 3.8	2.7 ± 3.4
Oesophagus	22.3 ± 0.5	22.0 ± 1.0	21.3 ± 1.0	21.0 ± 1.0	21.4 ± 0.9	20.3 ±0.8
Pancreas	**14.1 ± 5.3**	**17.3 ± 6.6**	**12.5 ± 4.2**	**14.7 ± 5.2**	**6.8 ± 4.7**	**7.5 ± 4.8**
Kidney L	3.4 ± 4.2	4.2 ± 5.0	2.3 ± 2.1	2.3 ± 1.7	1.9 ± 0.8	2.1± 0.9
Kidney R	2.2 ± 2.5	2.8 ± 3.5	2.1± 2.2	2.2 ± 2.0	2.8 ± 0.9	2.1± 0.8

SSD extended Spine field geometry; ISO - isocentric abutting Posterior spine fields; P.1, P.2, P.3, patient 1, patient 2, patient 3, correspondently

Conclusions

Cranio spinal irradiation is the technique which irradiates the wholebrain and spine of patient with medulloblastoma. The goal of such treatments is the dose homogeneity and minimizing the dose to the organ at risk.

Comparison of dosimetric parameters, for the two treatment plans with different geometries, in dose coverage, conformity index and the homogeneity within the target volume has shown that are within recommendations and there is not a significant difference on them.

Regarding normal tissue (organs) sparing, by comparing the mean dose at the organs at risk on both treatment plans, there was not present a great difference in their values, in both setups (SSD or ISO). Exception is noticed only for the organ of Pancreas that is located nearby to the region where is the junction of spinal fields for the ISO geometry. In the case of SSD extended is used for spine PTV, the pancreas which is located nearby in the junction of spinal fields shows an decrease on mean dose to the range of 2.0- 3.0 Gy.

Based on results both planning geometries could be used in treatment of patients in the age of 14 years old with a spine length relatively greater than 40 cm. All dosimetric results were within the recommendations.

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