A Dosimetric Analysis of the Overlapping and Gap Areas Produced by Simulated Set-Up Errors on a Treatment Planning System in a Case of the Cranio-Spinal Irradiation of an Adult Patient

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Abstract

The purpose of this study is to make a dosimetric analysis of the overlapping and gap areas in the case of a cranio-spinal irradiation. A simulation of the overlaps and gaps was performed on a treatment planning system. The overlaps and gaps were simulated for the 2, 4, 5, 6 and 8 mm overlaps or gaps. The data recorded: global and local maximum of doses, depth of the 95, 100 and 125% dose, the depth of spine location in the overlapping/gap areas. The local maximum values were increased up to 7.03 Gy in the case of the cranial-upper spinal field overlaps and up to 5.45 Gy in the case of the upper-lower spinal fields. The gaps cause the decreases of the local maximum values up to 6.65 Gy in the case of cranial-upper spinal field. An increase of the depth of 125% isodose line of 1.04 cm in the case of the 5 mm upper-lower spine fields overlapping was recorded. The total coverage of the target volume by 125% isodose line, in the case of the 5 mm + 5 mm overlapping between the cranial and the upper spinal field may be a source of a damage of spinal cord. The partially covered treatment volume by 95% isodose line in the case of 4 mm + 4 mm and 5 mm + 5 mm gap area between the cranial and the upper spinal field, may cause a relapse of the tumor.

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Keywords

Medulloblastoma • Cranio-spinal irradiation • The three dimensional conformal radiotherapy

1 Introduction

Medulloblastoma has a contribution of about 20% in the total number of the central nervous system cancers in pediatric patients [1]. This type of carcinoma is relatively rare in adults [2]. In the case of radiotherapy treatment, the cranio-spinal irradiation of brain and the whole spinal cord is used. Despite the fact that 3DCRT (the three dimensional conformal radiotherapy) is an advanced technique the cranio-spinal irradiation is a challenge, especially for an achievement of a required coverage of the target volume, otherwise a relapse of the tumor may be occurred [3, 4].

The other difficulties are related to the traditional prone position of a patient. The treatment delivery in children requires anaesthesia for immobilization. A supine position has advantages: a patient comfort and the access to the airway, a reproducibility of the treatment and simultaneous delivery a boost to posterior fossa. The immobilization in the supine position for the adult patients is released using a thermoplastic mask fixation for head and neck. From a dosimetric aspect, there is no the significant differences in a dose coverage of the target volume depending on prone and supine positions, as well as in a dose homogeneity and the doses to the organs at risk [2].

For the cranio-spinal irradiation a problem is an overlapping between cranial and upper spinal fields caused by the set-up errors. In the overlapping area, an overdose for a spine may happen. The overdose is the more possible if the cranial fields and spinal field are matched in a way that there is no gap between them. In an arrangement of the fields where a gap between the cranial and spinal field exists, a possibility of an under-dose for the target volume appears. In both cases, the problem is tried to overcome using weekly shifts between the junctions which may be a source of the additional errors.

The probability of the errors occurred in the treatment delivering may increase by the different reasons:

- treatment time duration,
- a couch movement and rotation,
- a visual check of the fields' borders and spine alignment is not possible in supine position,
- an inappropriate immobilization tools,
- a limited reposition accuracy of a thermoplastic mask in a fractionated radiotherapy,
- immobilization tools set-up errors produced by them self [5],
- a fact that the treatment planning systems underestimate out-of field doses and collimator scatter near the treatment fields [6].

All above sources of errors may produce hot or cold spots in the field junction areas or, on the other ways, may affect the dose distribution. As a result of an overdose in spine the toxicity, as myelitis, may increases, and as a result of an underdose in the target volume the probability of the tumor relapse increases.

In this study a dosimetric analysis of the overlapping and gap areas was made for different overlap and gap dimensions. The simulations of the overlapping and gap areas were performed using a commercial treatment planning system.

2 Materials and Methods

For the purpose of the analysis an adult patient with the diagnosis medulloblastoma was chosen. A treatment simulation of the patient in supine position was performed on a CT simulator with a slice thickens of 3 mm. The delineation of brain and spinal treatment volumes and the organs at risk was performed on FOCAL planning system. The 3DCRT treatment plan was prepared on XiO treatment planning system. The prescribed dose for cranial and spinal target volume was 36 Gy with the boost of 18 Gy to posterior fossa.

2.1 Preparation of 3DCRT Treatment Plan

The preparation of the treatment plan was done using the technique introduced by William and Carolyn [7] with a small modification. This technique includes: two half beam blocked opposite lateral cranial fields with the isocenter at the level of the C2 vertebral body, an upper posterior spine field with the isocenter located at a point 20 cm distal to the cranial fields and the one lower posterior spine field with the isocenter located at a point 30 cm distal to the upper spinal field. A small modification of this approach was made in a case of the lower spinal field. A couch was rotated by 90° and with a gantry angle tilt, it was ensured that the divergent inferior border of the upper spine field matches the divergent superior border of the lower spine field.

A margin of 0.5 cm to the cranial target volume and 1 cm to the spinal target volume was added. The photon beam energy of 6 MV and the superposition calculation algorithm were chosen. The shifts of 1 cm per week, was used in the junction area. Figure 1 shows the normal treatment plan with all fields included and week shifts.

2.2 A Simulation of the Overlapping and Gap Areas

The overlaps or gaps may appear in the field junction areas due to the set-up errors. An occurrence of the errors was supposed to be in the last week of the treatment where the divergence of the cranial and upper spinal field is the largest during. These situations were simulated on XiO treatment planning system so that the isocenters of the treatment fields were moved causing overlapping or producing the gaps of 2, 3, 4, 5, 6, 8 and 10 mm in the adjacent fields.

2.3 Data Collection and Analysis

The data of all simulated situations were collected from the treatment planning system. It was analyzed the changes in the local maximum doses in the overlapping and gap areas, the appearances and depths of 125% isodose lines (45 Gy) and the depths of 95 and 100% isodose lines. This value of 45 Gy was chosen as a dose limit for spine. The obtained values were taken from the middle positioned slice of the overlapping and gap areas.

3 Results and Discussion

The obtained results were presented in Tables 1 and 2.

From Tables 1 and 2 is evident that, in the spinal-spinal field junction areas, the 125% (45 Gy) isodose lines are at the lower depths than at the locations of spinal cord, and the local maximum values are higher in the spinal field junction areas than in the cranial-upper spinal field junction areas, but still lower than the global maximum values.

The data from Table 3 show an increasing in local maximum values with an increasing of an overlapping area. The 125% isodose lines are partially appear for 4 and 5 mm overlaps.

The data from Table 4 show a decreasing in local maximum values with an increasing of a gap area. The 125% isodose line does not appear and, in the case of the 5 mm gap, the target volume is partially covered by 100% isodose line.

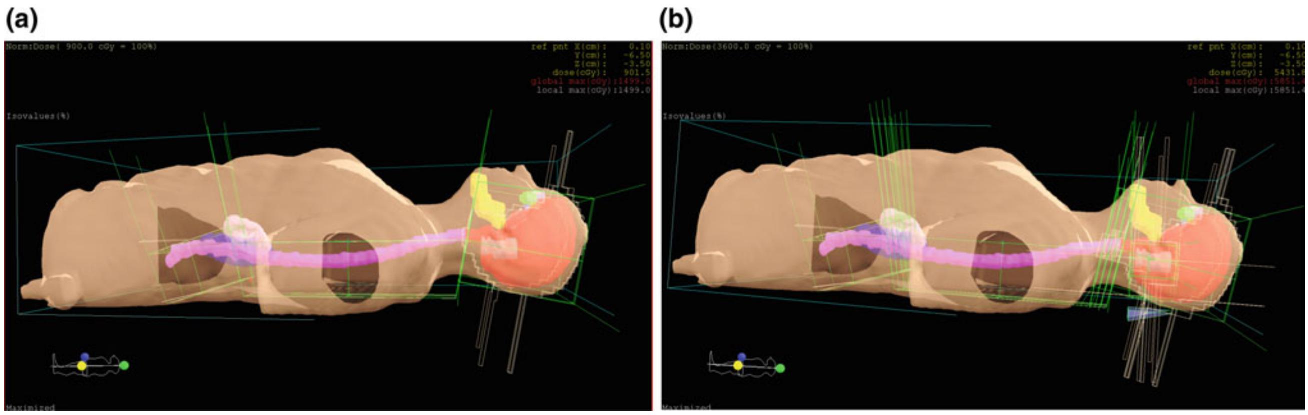

Fig. 1 **a** The fields matching and **b** the week shifts during the overall treatment

Table 1 The values of the parameters in a junction area of the cranial and the upper spine field for the normal treatment plan

D_{max} (Gy)	Local maximum (Gy)	Spinal cord depth (cm)	Treatment volume covered by 95% isodose line	Treatment volume covered by 100% isodose line	Treatment volume covered by 125% isodose line	Transversal coordinate
58.51	43.30	6.88	Yes	Yes	No	−16.00
58.51	43.38	6.80	Yes	Yes	No	−16.10
58.51	43.47	6.80	Yes	Yes	No	−16.20
58.51	43.53	6.76	Yes	Yes	No	−16.25
58.51	43.25	6.80	Yes	Yes	No	−15.90
58.51	43.19	6.84	Yes	Yes	No	−15.80
58.51	43.15	6.67	Yes	Yes	No	−15.75

Table 2 The values of the parameters in a junction area of the upper and lower spine field for the normal treatment plan

D_{max} (Gy)	Local maximum (Gy)	Spinal cord depth (cm)	Depth of the 95% isodose line (cm)	Depth of the 100% isodose line (cm)	Depth of the 125% isodose line (cm)	Transversal coordinate
58.51	55.16	6.38	9.32	8.12	4.93	−50.00
58.51	55.44	6.22	9.37	8.22	4.77	−49.90
58.51	55.71	6.42	9.50	8.50	4.68	−49.80
58.51	55.86	6.34	9.50	8.62	4.68	−49.75
58.51	54.92	6.34	9.28	8.08	4.93	−50.10
58.51	54.98	6.34	9.00	8.16	5.00	−50.20
58.51	55.11	6.60	9.24	8.25	5.06	−50.25

Table 3 The values of the parameters in the middle of the overlapping areas of cranial-upper spinal fields

Overlapping (mm)	D_{max} (Gy)	Local maximum (Gy)	Treatment volume covered by 95% isodose line	Treatment volume covered by 100% isodose line	Treatment volume covered by 125% isodose line	Transversal coordinate
2	58.48	44.80	Yes	Yes	No	−15.90
4	58.46	46.09	Yes	Yes	Partially	−15.80
5	58.46	47.12	Yes	Yes	Partially	−15.75

The data from Table 5 show an increasing in local maximum values with an increasing of an overlapping area. The same behavior is obtained for the depths of 95, 100 and 125% isodose lines.

The data from Table 6 show a decreasing of all parameters with an increasing of the gap areas. An exception makes the local maximum values which increases with the sizes of the gap areas.

From Table 7 it is evident an increase of local maximum values with an increasing of the overlapping areas. The treatment volume is covered by 125% isodose line in the case of 5 mm + 5 mm overlapping areas. It indicates that spine is also covered by 125% isodose line.

The data presented in Table 8 show a decreasing of local maximum values with an increasing of gap areas. In the cases of 4 mm + 4 mm and 5 mm + 5 mm gap areas, the treatment volume is only partially covered by 95% isodose line. Figure 2 shows the isodose distributions in the case of normal and the overlaps/gaps simulated treatment.

Table 4 The values of the parameters in the middle of the gap areas of cranial-upper spinal fields

Gap (mm)	D_{max} (Gy)	Local maximum (Gy)	Treatment volume covered by 95% isodose line	Treatment volume covered by 100% isodose line	Treatment volume covered by 125% isodose line	Transversal coordinate
2	58.55	40.72	Yes	Yes	No	−16.10
4	59.25	39.47	Yes	Yes	No	−16.20
5	61.31	39.28	Yes	Partially	No	−16.25

Table 5 The values of the parameters in the middle of the overlapping areas of upper-lower spinal fields

Overlapping (mm)	D_{max} (Gy)	Local maximum (Gy)	Depth of the 95% isodose line (cm)	Depth of the 100% isodose line (cm)	Depth of the 125% isodose line (cm)	Transversal coordinate
2	58.55	55.20	9.90	8.74	5.26	−50.10
4	59.25	55.68	9.90	9.40	5.70	−50.20
5	61.31	55.96	10.10	9.50	6.10	−50.25

Table 6 The values of the parameters in the middle of the gap areas of upper-lower spinal fields

Gap (mm)	D_{max} (Gy)	Local maximum (Gy)	Depth of the 95% isodose line (cm)	Depth of the 100% isodose line (cm)	Depth of the 125% isodose line (cm)	Transversal coordinate
2	58.48	55.32	8.60	7.50	4.60	−49.90
4	58.46	55.42	7.34	6.76	4.50	−49.80
5	58.46	55.47	7.00	6.50	4.40	−49.75

Table 7 The values of the parameters in the middle of the overlapping areas produced by moving the cranial fields and upper spinal field, the one towards to the other

Overlapping (mm + mm)	D_{max} (Gy)	Local maximum (Gy)	Treatment volume covered by 95% isodose line	Treatment volume covered by 100% isodose line	Treatment volume covered by 125% isodose line	Transversal coordinate
2 + 2	58.49	46.86	Yes	Yes	Partially	−16.00
3 + 3	58.48	48.36	Yes	Yes	Partially	−16.00
4 + 4	58.46	49.56	Yes	Yes	Partially	−16.00
5 + 5	58.46	50.56	Yes	Yes	Yes	−16.00

Table 8 The values of the parameters in the middle of the gap areas produced by moving the cranial fields and upper spinal field, the one away from the other

Gap (mm + mm)	D_{max} (Gy)	Local maximum (Gy)	Treatment volume covered by 95% isodose line	Treatment volume covered by 100% isodose line	Treatment volume covered by 125% isodose line	Transversal coordinate
2 + 2	58.55	39.25	Yes	Partially	No	−16.00
3 + 3	58.79	37.93	Yes	Partially	No	−16.00
4 + 4	59.25	37.17	Partially	No	No	−16.00
5 + 5	61.31	36.88	Partially	No	No	−16.00

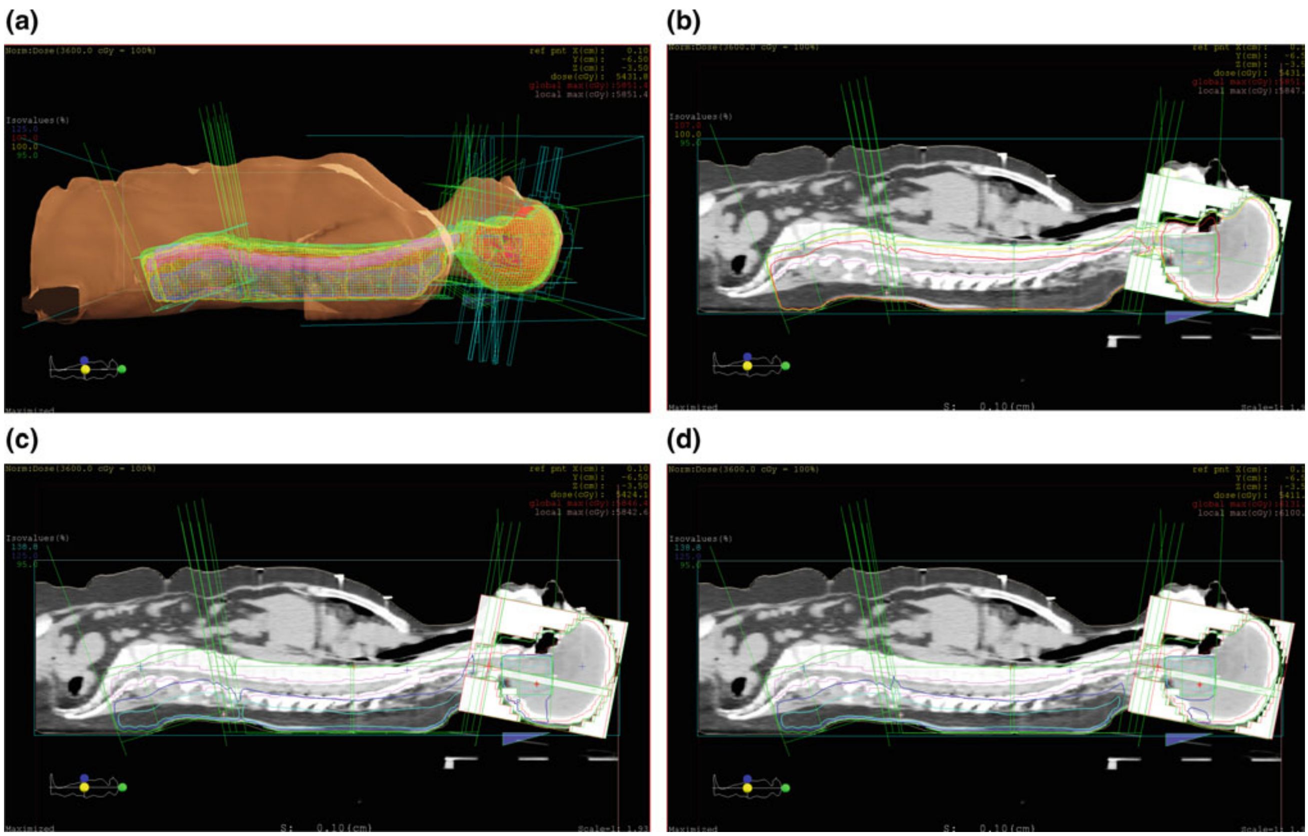

Fig. 2 **a**, **b** The dose distribution in the case of the normal treatment plan; **c** the isodose distribution in the case of the 5 mm + 5 mm cranial and upper spinal fields overlapping; **d** the isodose distribution in the case of the 5 mm + 5 mm cranial and upper spinal field gaps

4 Conclusions

The overlaps of a treatment fields simulated by the treatment planning system cause an increase in the local maximum dose values obtained in the middle slice of the overlapping areas. Comparing these values with the local maximum values obtained in the case of the normal treatment plan, the increases of 1.65–3.67 Gy and 3.71–7.03 Gy in the case of the cranial-upper spinal field overlaps and the increases of 3.63–5.45 Gy in the case of the upper-lower spinal fields were recorded. The appearance of the 125% isodose line at the depth of 6.10 cm, in the case of the 5 mm upper-lower spine fields overlapping (Fig. 2c), makes an increase of 1.04 cm compared to the normal situation. This is especially important due to the fact that spine is positioned at the depth of 6.60 cm at the same location.

On the other side, the gap areas simulated by the treatment planning system cause a decrease in the local maximum dose values. Comparing these values with the local maximum values obtained in the case of normal treatment plan, the decreases of 2.43–4.25 Gy and 3.90–6.65 Gy in the case of cranial-upper spinal field overlaps. There is no the differences in the local maximum values in the case of gap areas produced between upper spine and lower spine fields.

According to the obtained results, in the case of the 5 mm + 5 mm overlapping between the cranial and the upper spinal field, the total coverage of the target volume by 125% may be a source of damage of spinal cord. On the other side, the partially covered treatment volume by 95% isodose line in the case of the 4 mm + 4 mm and 5 mm + 5 mm gap area between the cranial and the upper spinal field, may cause a relapse of the tumor (Fig. 2d). The all other sources of the uncertainty and errors in these areas may also affect the overdose and underdose problems.

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