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Whole CNS radiotherapy - a modification of the lower spinal field to reduce organ doses in the abdominal cavity

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Summary

Introduction: A modification of the lower spinal field in the whole CNS irradiation technique was introduced at the Radiotherapy Department, University Children's Hospital of Kraków. We developed a modification of the standard technique since we were not able to use high-energy electron beams wanted to obtain maximum protection of healthy tissues in the irradiated children.
Materials and methods: 7 patients (2 girls and 5 boys) have been subjected to radiation treatment by a modified technique since 2002. The changes involved rotation of the gantry and the table column in the lower spinal field.
Results: A more homogenous dose distribution in the spinal canal volume (in the area of the spinal field junction) was achieved. The maximum liver dose was reduced by 5 Gy. The total maximum and mean ovarian doses however increased by 0.6 Gy and 0.4 Gy, respectively. The mean dose to the intestines increased by 2 Gy, which was due to the larger volume of the organ covered by the radiation field in the modified technique. The doses to other organs were similar in both techniques.
Conclusions: The modified technique made it possible to decrease the dose delivered to the liver and to achieve homogenous dose distribution in the spinal canal volume. This modification, however led to an increase in the mean dose to the intestines by 2 Gy and the total maximum and mean ovarian doses by 0.6 Gy and 0.4 Gy, respectively. Therefore the modified technique is recommended for boys rather than girls.
Key words: children cancer, CNS radiotherapy, modification.

Napromienianie układu nerwowego - modyfikacja pola rdzeniowego dolnego w celu obniżenia dawki na narządy jamy brzusznej

Streszczenie

Wprowadzenie: W Pracowni Radioterapii Uniwersyteckiego Szpitala Dziecięcego w Krakowie została opracowana modyfikacja techniki napromieniania całego OUN. Modyfikacja dotyczy dolnego pola rdzeniowego. Powodem opracowania modyfikacji techniki standardowej była maksymalna ochrona tkanek zdrowych oraz brak możliwości napromieniania rdzenia kręgowego przy użyciu wiązki elektronowej o odpowiednio wysokiej energii.
Materiał i metoda: Od 2002 roku leczeniu według zmodyfikowanej metody napromieniania całego OUN poddano 7 pacjentów (2 dziewczynki i 5 chłopców). Zmiany dotyczą kąta głowicy przyspieszacza oraz kąta ustawienia stołu terapeutycznego w dolnym polu rdzeniowym.
Wyniki: Uzyskano bardziej jednorodny rozkład dawki w obrębie kanału kręgowego (w obszarze odpowiadającym łączeniu pól rdzeniowych). Uzyskano także obniżenie maksymalnej dawki w obrębie wątroby o 5 Gy. Całkowita maksymalna i średnia dawka otrzymana przez jajniki wzrosła odpowiednio o 0.6 Gy i 0.4 Gy. Średnia dawka w obrębie jelit wzrosła o 2 Gy. Przyczyną wzrostu dawki jest fakt, że w zmodyfikowanej metodzie większa objętość tych organów poddana jest działaniu promieniowania. Dawki otrzymywane przez pozostałe organy były porównywalne w obu technikach napromieniania.
Wnioski: Metoda zmodyfikowana w Pracowni Radioterapii USD w Krakowie umożliwia obniżenie dawki otrzymanej przez wątrobę oraz uzyskanie bardziej jednorodnego rozkładu dawki w obrębie kanału kręgowego. Wadą metody zmodyfikowanej jest zwiększenie średniej dawki w obrębie jelit oraz maksymalnej i średniej dawki otrzymanej przez jajniki (odpowiednio 0.6 Gy i 0.4 Gy). Dlatego też zaleca się stosowanie tej modyfikacji u chłopców.
Słowa kluczowe: nowotwory dziecięce, radioterapia OUN, modyfikacja.

Introduction

The whole CNS irradiation is prescribed in about 25% of paediatric cancer cases. It is applied in various diagnoses such as: PNET/ medulloblastoma brain cancer, brain tumours with dissemination to the spinal canal, and relapse of bone marrow leukaemia with CNS involvement [1,2,3,4]. Megavoltage photon or electron beams from a linear accelerator are usually used in neuro-axis radiotherapy. This method is specially recommended for children, when any radiation exposure to healthy, developing tissues is not desirable [2].

It is recommended to apply high-energy electrons from 18 to 21 MeV, in order to be certain that the entire spinal cord receives the total prescribed dose. The depth of the spinal cord should not exceed 7 cm in any part [2]. Unfortunately, application of this method is not possible in our department, since the highest available with our accelerator is 15 MeV electron beam energy. Therefore, we had to use high-energy photon beams (6 or 10 MV) when irradiating the spinal cord.

The necessity to apply two spinal fields forced modification of the standard method of whole CNS irradiation so as to minimise its side effects in the abdominal cavity volume. This was especially important in the irradiation of older children, when covering the spinal cord with a single beam was not possible and resulted in an overdose to the abdominal cavity.

Materials and methods

The method of whole CNS irradiation, described below, is based on the neuro-axis irradiation technique presented in "Principles and Practice of Radiation Oncology" edited by CA Perez and LW Brady [4]. It concerns patients, for which covering of the spinal cord with a single beam is not possible. According to this method, two parallel photon beams are used to irradiate the spinal cord. The gap between the adjacent fields, measured on the patient's skin, is calculated according to the equation:

$$S = 1/2L_1 \frac{D_1}{SSD_1} + 1/2L_2 \frac{D_2}{SSD_2} \qquad (1.1.)$$

where:
S - is the gap between upper and lower spinal fields in cm,
L_1 - is the length of the upper spinal field in cm,
L_2 - is the length of the lower spinal field in cm,
D_1 - is the depth of the dose calculation point for the upper spinal field in cm,
D_2 - is the depth of the dose calculation point for the lower spinal field in cm,
SSD_1 - is the source - to - skin distance for the upper spinal field in cm, and
SSD_2 - is the source - to - skin distance for the lower spinal field in cm.

Then, the dimensions of two opposing cranial fields are defined. Given the length of the upper spinal field, the collimator angle of the cranial fields is calculated according to the equation:

$$tg^{-1} = \left(\frac{1/2L_1}{SSD} \right) \qquad (1.2.)$$

where:
- - is the angle of the cranial field collimator in degrees,
L_1 - is the length of the upper spinal field in cm, and
SSD - is the source - to - skin distance for the cranial field in cm.

In order to avoid a systematic overdose or underdose to the spinal cord volume the field junction is moved after half of the total dose. The main drawback of this method involves an overdose to the abdominal cavity volume, where the spinal fields overlap.

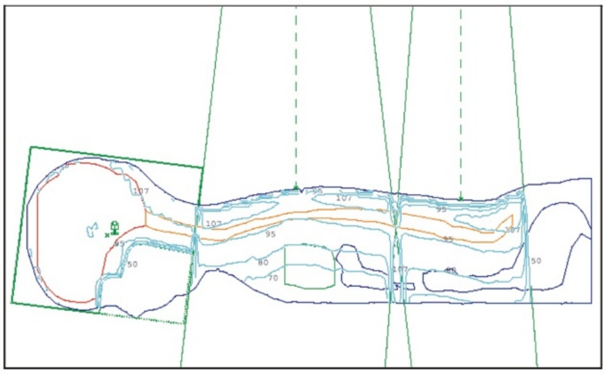

Figure 1. The geometry of radiation fields in the axial cross-section.

The above method of whole CNS irradiation was modified at the Radiotherapy Department, University Children's Hospital of Kraków. We started to apply this modification in 2002. Since then 7 patients (2 girls and 5 boys) have undergone that kind of treatment. The changes involved table and gantry rotation while irradiating the lower spinal field. The information about preparation for the therapy, the irradiation method and quality control is given below.

Patients were immobilised with a Pedi-board system. They were laid prone with their head resting on the system cradle, which enabled them to breathe freely during the therapy and allowed levelling their spinal cord in the neck area. A thermoplastic mask was used to immobilise the patient's head.

Each patient had a CT examination for the treatment planning purposes. The distances between slices were: 6 mm for the head area to C5 vertebra and from 12 to 18 mm for the spinal cord area. In the orbital cavity, slices were enlarged to 3 mm to draw a precise shape of the shielding blocks in cranial fields.

The treatment plan consisted of three stages, and was prepared in the 3D treatment planning system, TMS Helax.

In order to compare dose distributions and DVHs for each organ two plans for each patient were generated: the first one using the standard method and the other one using the modified technique. Patients were irradiated according to the modified method with 6 or 10 MV photon beams from the linear accelerator.

In the first and the second stage, the whole brain and the spinal cord to C4/C5 level was covered with two isocentric lateral collimated cranial portals. The spinal cord was covered with two posterior photon fields. The therapeutic table column was rotated through 90 degrees in the lower spinal field, which covered the lumbar and sacral part of the spinal canal. The gantry angle was set to compensate divergences of the upper and lower spinal fields. The gantry angle value for the lower spinal field depended on the length of both spinal portals.

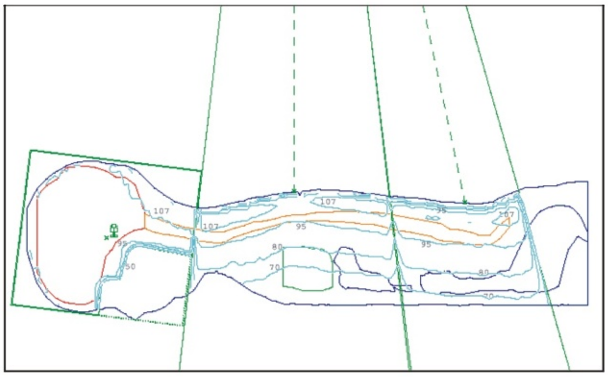

Figure 2. The geometry of the radiation fields in the axial cross-section in the modified technique.

The field junction was moved at half of the total dose. Two cranial portals were extended asymmetrically. The upper spinal field was shifted and the lower one was shortened and shifted. The gantry angle in the lower spinal field was corrected. The aim of such a change was to avoid either an overdose or underdose to the spinal cord volume. The gaps between the cranial and upper spinal fields and between both spinal fields were calculated individually. In the third stage, two photon beams covered the tumour or tumour primary bed with a 1.5 to 2 cm margin (isocentric technique).

Quality assurance

Checks verifying blocks' position were taken every first fraction in each stage of the therapy. In vivo measurements, using MOSFET detectors, were performed to control the dose delivered to the patient. The dose was measured on the eyelid, in the eye corners and in the axis of each beam. The patient positioning was controlled carefully and the gaps between the fields were checked precisely.

Results

The application of the modified technique made it possible to achieve a homogenous dose distribution to the spinal canal volume and eliminated an overdose, which resulted from overlapping of the spinal fields in the liver volume. A comparison of doses delivered to various organs after a single fraction and the whole treatment is presented below. Doses were evaluated in the 3D treatment planning system. Our results were similar in all patients that calculations presented below concern only one chosen patient (*Table 1*).

DVHs to different organs are presented below. The doses were evaluated for the first stage of the plan (*Figure 3 and 4, Table 2 and 3*).

The most significant differences in doses evaluated in both methods were observed for the liver. This is due to the fact that the spinal field's junction is usually positioned at the liver level. The comparison of the calculated doses for the liver volume for three chosen patients is presented below (*Table 4*).

Discussion

Achieving homogenous dose distribution in the spinal cord volume in the standard method leads to an overdose to the liver volume, pancreas, ovaries and the spinal cord it-

Table 1. Percentage fraction doses (100% = 1.67 Gy) to various organs in the first stage of the plan (11 fractions).

Organ	Standard technique			Modified technique		
	Min. [%]	Max. [%]	Mean [%]	Min. [%]	Max. [%]	Mean [%]
Spinal canal	70	114	101	70	110	101
Intestines	2	94	16.5	2.8	95	20
Liver	3.5	**114**	18	3.5	**87**	17
Heart	4	83	38	4	83	38
Ovaries	2.5	5.2	3.5	3	7	4

Table 2. Percentage fraction doses (100% = 1.67 Gy) to various organs in the second stage of the plan (10 fractions).

Organ	Standard technique			Modified technique		
	Min. [%]	Max. [%]	Mean [%]	Min. [%]	Max. [%]	Mean [%]
Spinal canal	71	116	101	72	110	100
Intestines	2	94	17.4	2.5	103.7	25
Liver	4	**126**	19	**4**	**87**	18
Heart	5	82	38	5	82	38
Ovaries	2.5	6	4	4	8	6

Table 3. Total dose (Gy) to various organs.

Organ	Standard technique			Modified technique		
	Min. [Gy]	Max. [Gy]	Mean [Gy]	Min. [Gy]	Max. [Gy]	Mean [Gy]
Spinal canal	30	**40**	35.4	30	**38.6**	35.3
Intestines	1	33	6	1	33	8
Liver	1.5	**35**	6.5	1.5	**30**	6
Heart	1.5	29	13.4	1.5	29	13.4
Ovaries	1	2	1.3	1.2	2.6	1.7

Table 4. Percentage fraction doses delivered to the liver volume for three chosen patients (100% = 1.67 Gy).

		Standard technique			Modified technique		
		Min. [%]	Max. [%]	Mean [%]	Min. [%]	Max. [%]	Mean [%]
Patient 1	stage I	3.5	114.0	18.0	3.5	86.6	17.1
	stage II	4.0	126.0	19.3	3.9	86.8	17.8
Patient 2	stage I	3.6	125.4	18.2	3.5	83.0	16.5
	stage II	3.3	87.5	15.7	3.4	82.7	15.0
Patient 3	stage I	3.7	124.2	26.4	3.6	82.8	20.3
	stage II	3.9	108.7	24.3	3.8	81.9	21.3

self [4,5,6]. This is due to spinal field overlapping in the abdomen cavity volume. Usually, the overlap involves the pancreas volume or liver, which is more sensitive to radiation. The fraction doses delivered to each organ during the first and the second stage of both methods are compared in *Tables 1* and *2*. The dose to the pancreas is not taken into account because this organ is less sensitive to radiation than other organs. The maximum fraction dose delivered to the liver in the standard method is 1.5 to 2.1 Gy and depends on the position of the spinal field junction, whereas the maximum fraction dose to that organ in the modified technique is 1.4 Gy. The maximum dose delivered to the spinal canal, using 6 or 10 MV photon beams, was lower in the modified technique than in the standard method by 4 - 5%. It was calculated for the chest or lumbar part of the spinal cord and depended on the position of the field junction. The total doses to various organs and both methods are presented in table 3. Delivering 35 Gy to the spinal cord in the standard method causes an increase in the maximum dose to the liver by 5 Gy as compared with the modif

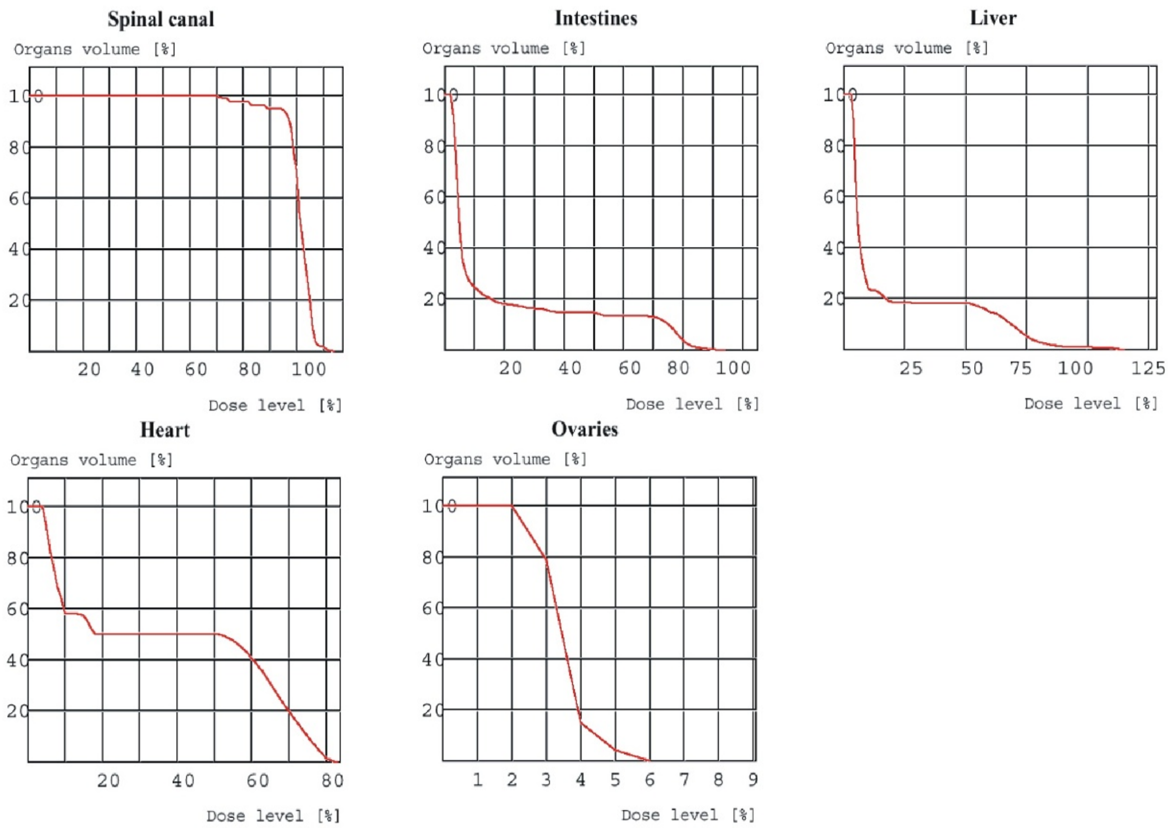

Figure 3. DVHs for the modified technique.

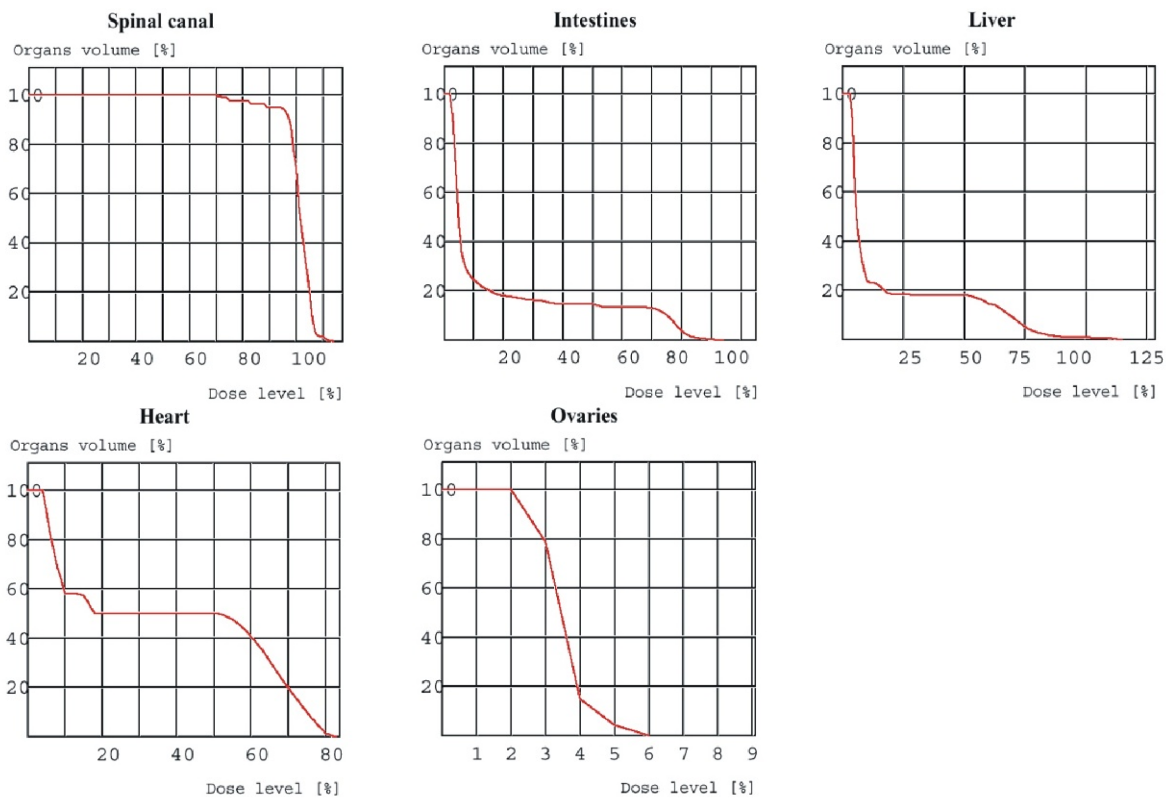

Figure 4. DVHs for the standard method.

ied technique. The difference in the maximum dose to the spinal canal, while using the whole spinal canal volume in a DVH calculations, 1.4 Gy, i.e. is smaller than that in the standard method. There are also some disadvantages of the modification. The mean percentage fraction dose to the intestines increases by 3.5 and 7.6 for the first and second stages of the treatment plan, respectively. The total mean dose to the intestines increases by 2 Gy. This is due to the fact that the volume of this organ covered with radiation is larger as a result of the gantry angle in the lower spinal field in the modified technique compared with the traditional method. The larger value of the gantry angle the larger the volume of the intestines covered by the radiation field. The total minimum and maximum doses are identical in both techniques. Unfortunately, there is a risk of delivering a higher mean ovarian dose in the modified technique. Thus, carrying out therapy using this modification should rather be recommended for boys. SV Harden described a modification of the CNS irradiation with MRI in order to localise the exact position of the ovaries in girls. The aim of his work was to protect the ovaries as much as possible, it allowed decreasing the dose delivered to the ovaries by 2.45 Gy [6]. However, Harden's results drew our attention to the fact that in the standard method of irradiation the mean ovarian dose (from 3 to 29.2 Gy for some patients) differed significantly. In our material, the maximum doses delivered to the ovaries in girls' were 2 Gy in the standard method and 2.6 Gy in the modified technique. The mean dose increased by 0.4 Gy and was 1.3 Gy in the standard method whereas in the modified treatment plan it was 1.7 Gy.

The technique modified at our department requires the same precision in such elements as the accuracy of patients' positioning and maintaining exactly the same a few-millimetre wide gap between the spinal fields. What was most important was to reduce the differences in the fraction dose (overdose) to the chest, lumbar part of the spinal cord (depending on the position of the field junction) and to the liver.

There is no doubt that the possibility of irradiating the whole CNS with high electron beams is more proper, which has been proved by several authors eg. A. Skowrońska-Gardas or L. Gaspar. Not only can lower doses to the abdominal cavity organs be achieved but also the doses to organs such as heart and thyroid, be reduced by half compared with the doses delivered with photon beams [2,7]. Unfortunately, this technique could not be implemented at our department and we had to look for other solutions in order to decrease side effects and complications after radiation therapy.

The whole CNS irradiation is one of the most difficult techniques in radiation therapy. According to the literature the quality of therapy is of great importance when considering young age patients and the high risk of late complications in that group of patients [2,3,8,9,10,11,12]. Precision in the therapy, attention paid to the field junction, proper irradiation volume and the value of the prescribed total dose are important elements contributing to the high long-term survival rate and the percentage of failure [13,14,15,16,17].

Conclusions

The necessity of using 6 or 10 MV photon beams in irradiating the spinal cord leads to a significantly bigger risk of delivering a higher mean dose to some parts of the spinal cord and to a part of the liver. This is a situation at radiotherapy centres that not equipped with an accelerator delivering high-energy electrons or with patients whose spinal cord is located deeper than at seven centimetres below the skin surface.

The method modified at our department may be an alternative to that used for the lower spinal field in the CNS irradiation, as it allows us to decrease the dose delivered to the liver volume and obtain a better dose distribution in the chest and the lumbar part of the spinal cord.

We recommend the modified technique, described in this work, especially for boys. As for girls MRI should be applied in order to localise the ovaries when planning the lower spinal field with a photon beam or perhaps to the lower part of the spinal cord should be irradiated with high-energy electrons.

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