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Comparing the results of 3D treatment planning and practical dosimetry in craniospinal radiotherapy using Rando phantom

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Background: Craniospinal radiotherapy faces technical challenges which are due to the sensitivity of the location in which the gross tumor is, and to organs at risk around planning target volume. Using modern treatment planning systems causes a reduction in the complexities of the treatment techniques. The most effective method to assess the dosimetric accuracy and the validity of the software used for treatment planning is to investigate the radiotherapy and treatment planning by means of a anthropomorphic Rando phantom which was used here for treatment planning and practical dosimetry for craniospinal radiotherapy. Studying the absorbed dose by the organs at risk was the secondary objective discussed in this paper. ***Materials and Methods:*** Treatment planning in craniospinal radiotherapy was done using CorePlan 3D treatment planning software. Radiotherapy was administered on a anthropomorphic Rando phantom and practical dosimetry was done using GR-200 TLDs. Varian Clinac 2100C/D was used for radiotherapy. ***Results:*** The absorbed dose by regions of interest was separately calculated for treatment planning and radiotherapy. Except the conjunction areas of the cranial and spinal radiation fields, the difference among the results was not more than 5%. Full comparison of the results for each part has been presented. ***Conclusion:*** The comparison the results of practical dosimetry and treatment planning software supports the validity of CorePlan treatment planning system. Also analysis of the absorbed dose through organs at risk showed that the absorbed dose by organs at risk have an acceptable value with respect to tolerance dose of these organs. The only unacceptable result was related to thyroid. **Iran. J. Radiat. Res., 2011; 9(3): 151-158**

Keywords: *Craniospinal radiotherapy, rando phantom, thermoluminescence dosimetry, treatment planning.*

INTRODUCTION

Medulloblastoma is one of the most common diseases of central nervous system tumors for which craniospinal radiotherapy is used for treatment purposes [1, 2]. Treatment planning and radiotherapy of the central nervous system tumors are facing technical challenges which are imposed by the sensitivity of gross tumor location and the normal tissues and organs at risk around the planning target volume (PTV). The treatment targets in craniospinal radiotherapy consists the entire brain and the spine, and the organs at risk are the eye lens, heart, cribriform plate, thyroid and testis [2]. Craniospinal radiotherapy causes detrimental changes in the white matter of children's brain. Consequently this change leads to a reduction in the patient's learning and mental skills at the learning age [3]. It is common among these patients to suffer from disorder in the function of the endocrine glands (like thyroid) and as a consequence of unwanted received doses by these glands. So, it might be the testis (or ovary) that is exposed to scattered radiation from spinal cord of the patient [4]. New techniques like radiotherapy coupled with moving the conjunction of radiation fields [5], or conformity

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of cerebral and spinal radiation fields using geometric calculations [1] may reduce the harmful results of radiotherapy. At present, to administer craniospinal radiotherapy, photon beam is used for cerebral PTV, and electron and/or photon beam for spinal PTV. Some of treatment centers, however, have presented the results drawn from using proton beam [6]. Using modern instruments to treatment planning and radiotherapy reduces the complexities of this treatment technique and ensures uniformity of dosage in treatment PTV [7]. The most effective way to evaluate the accuracy of dosimetry and validity of the treatment planning software is to investigate the radiotherapy in anthropomorphic Rando Phantom that has been used in this research, to compare the results of treatment planning system (TPS) and practical dosimetry. Evaluation of the absorbed dose by organs at risk has been discussed as a secondary objective.

MATERIALS AND METHODS

Dosimetric phantom

RANDO Phantom provides the detailed mapping of dose distribution that is essential for evaluating radiotherapy treatment plans. A Rando phantom produced by the phantom laboratory (USA) was used for radiotherapy. This phantom was a skeleton of a man with 173.5 cm of height and 73.5 Kg of weight in which isosionat plastic was used for the soft tissues, having the normal human skeletal system [8]. The Phantom was divided longitudinally into 33 slices each 2.5 cm and all of them used for radiotherapy. Each slice had holes in it to sit the dosimeter for measuring the absorbed dose in radiotherapy and radiography research. Each slice had two pins at its edges; the different slices of Phantom were bound up together by those pins, in order to have a full phantom. To prevent the slices from being torn out and avoiding air gap production among them, the Phantom was surrounded by an assembly composed of two wooden plates placed at the head of the first slice and the end of the last one [9].

Calibration of applied dosimeters and dosimetric method

GR-200 Thermoluminescence crystals produced by PTW Company (Germany) which included LiF (Mg, Cu, P) in the form of tablets with the diameter of 4.5 mm and thickness of 0.8 mm were used in this research [10]. 40 dosimeters were used for the different areas inside the phantom and 4 dosimeters for controlling the background radiation. To use these dosimeters, at first the efficiency correction coefficient (ECC) of each TLD's was calculated and then the calibration curve of the applied TLDs was produced. To produce the calibration curve, 38 dosimeters were divided into several groups, and each group was ex-posed to a certain amount of gamma rays produced by ^{60}Co machine. The calibration curve of applied dosimeters was as follow in figure 1.

The Fimel TLD reader produced by PTW Company was used to read the TLDs. The liquid nitrogen pressure was1.1 bars inside it. Every TLD was exposed to temperature at two stages. At the first stage, the exposition lasted for 6 seconds in 155^{cG}. This was done to stabilize the TLD responses. At the second stage, which was the dosimeter reading stage, every TLD was exposed to heat for 35 seconds at 260^{cG} of temperature.

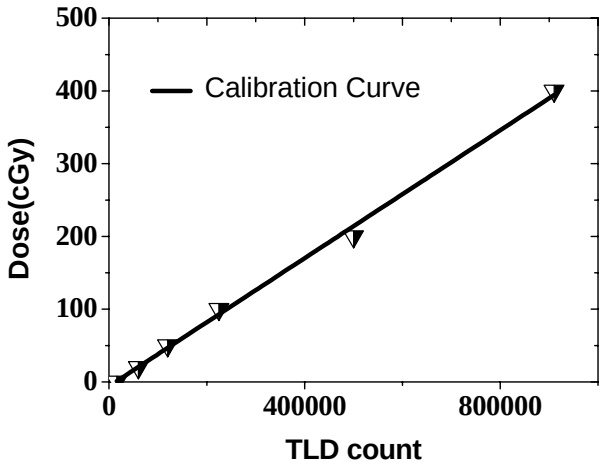

Figure1. The calibration curve of used TLDs.

Treatment planning

The Phantom was scanned by Somatom CT Scan machine Produced by Siemens Company (Germany) in prone position. The applied CT system was spiral, and it was able to scan with Smart mA feature.

For treatment planning, the CT images of the phantom were input to the CorePlan 3D treatment Planning software in Dicom format. This software has been produced in Seoul C&J Inc, (Korea) and was able to show the isodose curves in all CT plans. In this software, photon dose is performed by Collapsed Cone Convolution algorithm (in adaptive and non-adaptive way) and Equivalent TAR (ETAR) algorithm, and electron dose calculations by Hogstrom Pencil Beam algorithm. These methods could count tissue inhomogeneity in a reasonable manner [11, 12], and the absorbed dose in different areas, therefore, can be precisely calculated. In treatment planning, 6 MV X-ray photons were used for irradiation of the brain and upper spine (extending from the first cervical vertebrae down to the first lumbar vertebrae), and 18 MV X-ray photons were used for the lower spine (extending from the second lumbar vertebra down to second sacral vertebrae). In order to avoid overlap between cranial and upper spine fields, the couch was given an angle of 4 degree and 9 for the collimators of cranial fields (figure 2). The treatment targets in the treatment planning included the brain, upper and lower spines, Organs at risk like the lens, thyroid, the heart and testis. The reference points were set at PTV centers of brain, upper and lower spine. The radiation fields were configured in a way that the absorbed dose in these points would be 50 cGy.

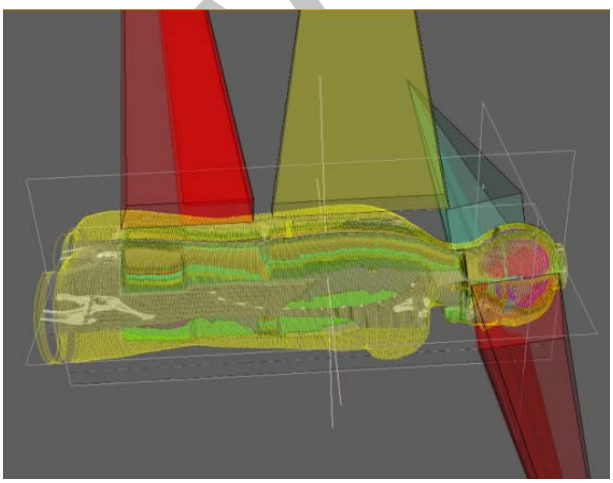

Figure 2. Adjustment of the radiation fields in treatment planning.

Set-up for irradiation (treatment)

Varian linear accelerator 2100C/D model (USA), was used for craniospinal radiotherapy. This accelerator is able to produce X rays with energies equal to 6 MV and 18 MV and electron beams with energies equal to 6 MeV, 9 MeV, 12 MeV, 15 MeV and 18 MeV. For radiotherapy, the phantom was in prone position. (Another position in which the phantom can be laid is supine [13]) In order to avoid overlap between cranial and upper spine fields, the conjunction of orthogonal fields was adjusted by changing the position of the couch and the collimators of the cranial fields. The couch was given 4 degrees of angle (clockwise) for the left lateral cranial field and 4 degrees (anticlockwise) for the right lateral cranial one. The cranial field collimators were also rotated 9 degrees (clockwise). Because of the long length of the spinal cord, two spinal fields were used to entirety cover the spinal PTV and achieve dose unifor-mity across the spinal cord [14]. The upper spine was considered to be extending from the first cervical vertebrae down to the first lumbar vertebrae, and the lower spine from the second lumbar vertebra down to the second sacral vertebrae. Like the treatment planning stage, for the upper spine 6 MV and for the lower spine 18 MV X-ray was used. Monitor unit of the machine was adjusted to deliver 50 cGy to ICRU reference point. For irradiation of the brain and spinal cord, source to axis distance (SAD), and source to surface distance (SSD) technique were used, respectively.

40 Thermoluminescence dosimeters were used in practical dosimetry. These dosimeters were planted inside the brain, at

the conjunction of cranial radiation fields and upper spine radiation field, thyroid, heart and testis.

RESULTS

The results of treatment planning

The results of treatment planning system were divided into quantitative and qualitative groups. In the qualitative group, isodose curves in the axial slices, where treatment targets and organs at risk have been located, were presented. Treatment targets and organs at risk have been separately margined in those slices. Isodose curves are differentiated by different colors. Doses associated with each color have been presented at the right top of each image. Figures 3, 4, 5, 6 and 7 are related to brain PTV and eye lens, thyroid, heart, conjunction site of cranial and upper spine fields and testis, respectively.

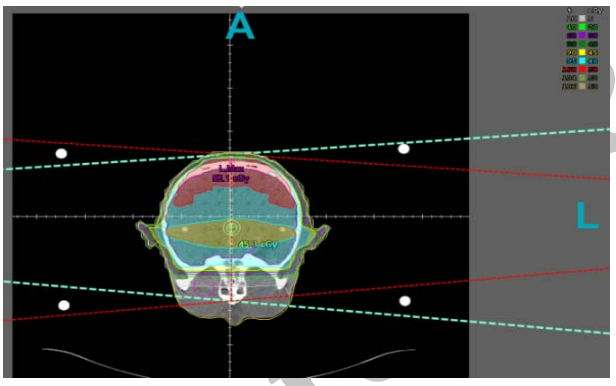

Figure 3. Treatment plan and isodose curves for brain and eye lenses.

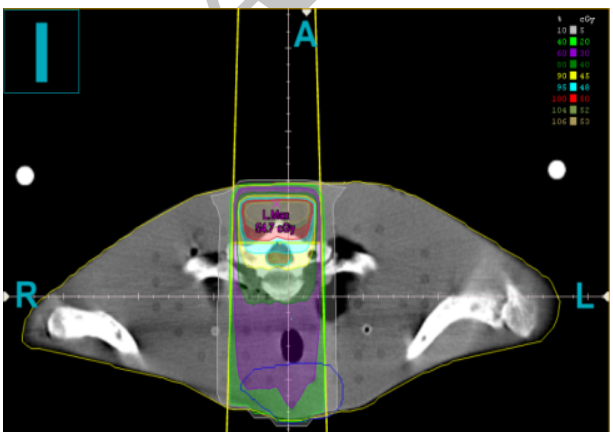

Figure 4. Treatment plan and isodose curves for thyroid.

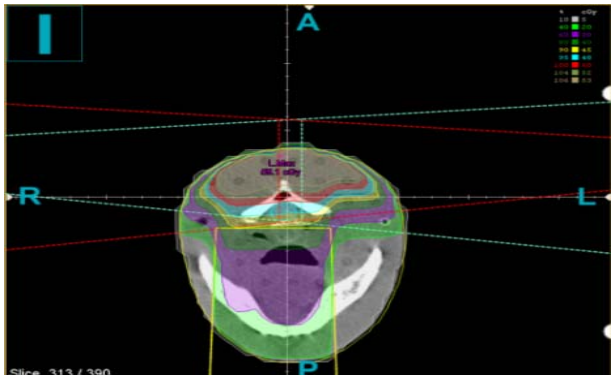

Figure 5. Overlap of fields in treatment planning and isodose curves in this region.

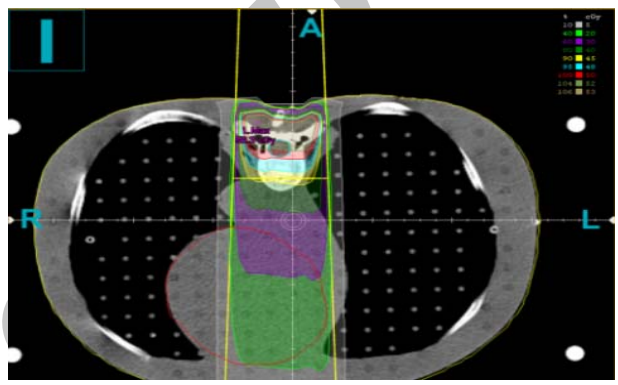

Figure 6. Treatment plan and isodose curves for heart.

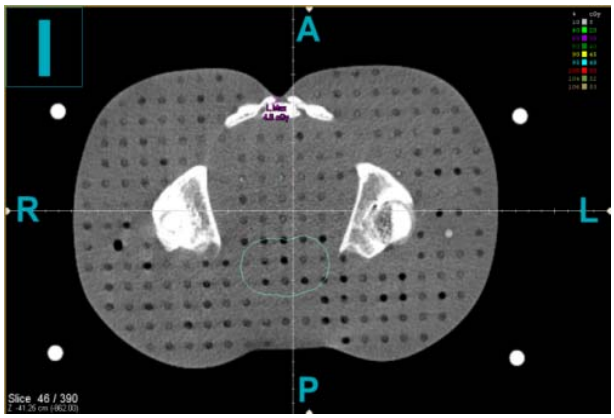

Figure 7. position of testis in treatment planning.

In the quantitative group, dose volume histograms (DVH) associated with the treatment targets and the organs at risk have been displayed in figure 8. The large amount of dosimetric data that must have been analyzed, while evaluating the treatment plan had prompted the development of new methods of condensing and presenting

the data in more easily understandable formats. One of such data reduction tools has been the DVH. The diagram was very useful for calculation of average absorbed dose and dose uniformity in target volume [2]. Each color in every diagram indicated a target or an organ at risk. Each organ associated with each color has been presented at the right top of the image. It could be seen that brain PTV, upper and lower spine had received uniform dose, hence the absorbed dose by volume of organs at risk was nonuniform.

Using isodose and DVH curves related to each organ, one can calculate the average absorbed dose in the treatment targets and organs at risk. The following table (table 1) shows the absorbed dose in these areas.

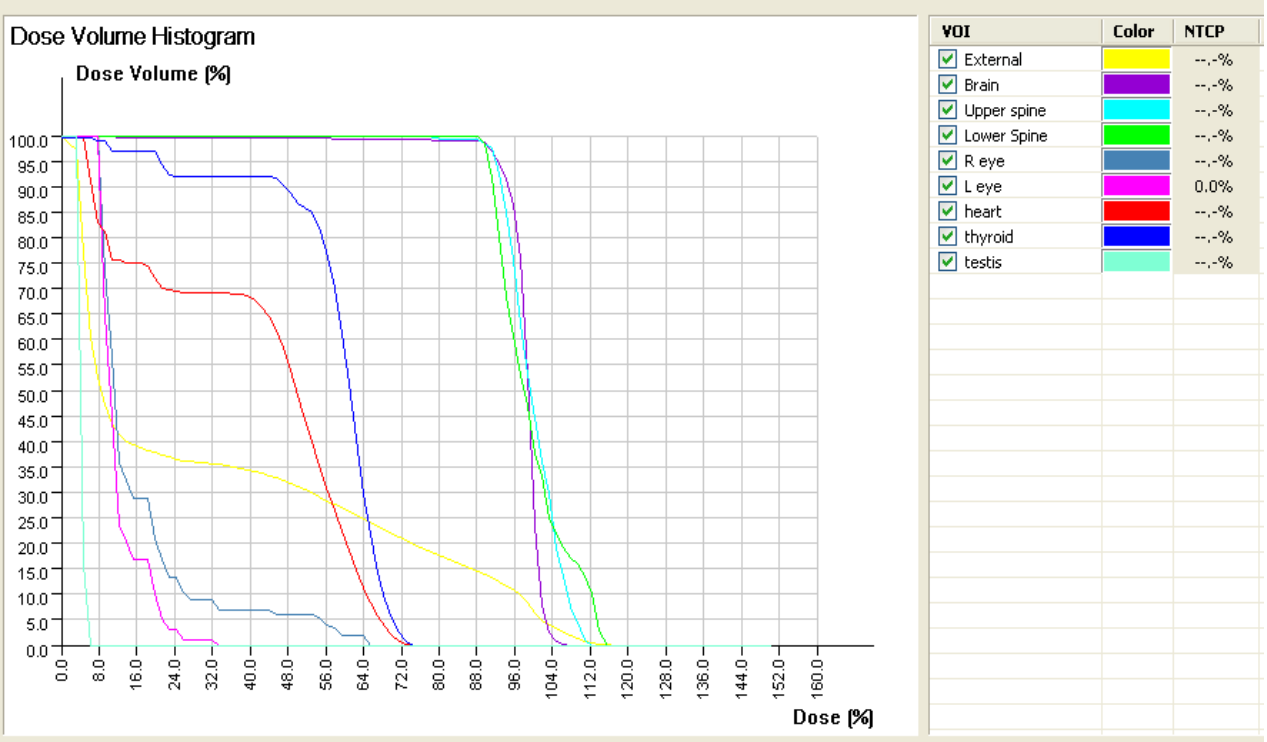

Figure 8. DVH curves of treatment targets and the organs at risk in treatment planning.

Table 1. Relative absorbed dose in different regions resulted from tratment planning system (to delivery of 50 cGy to the refrence point).

Interested area	Relative absorbed dose (%)
Brain	102
Overlap area of cranial and upper spine fields	90
Left eye	28
Right eye	34
Thyroid	48
Heart	46
Overlap area of upper and lower spine fields	150
Testis	**Very small**

The results of Practical Dosimetery

In order to determine the absorbed dose, at the practical stage, the dosimeters were located inside the organs of interest (figure 9), and the average dose coming out of all these dosimeters in the organ were calculated. For elimination of background effects, 4 TLDs were used during radiotherapy.

The results of the practical dosimetry in the Phantom have been presented in the following table (table 2). It must be mentioned that the reported absorbed doses in different regions, both treatment planning and radiotherapy, were normalized to reference dose (50 cGy), to provide better comparison between the results.

Comparing the quantitative results (figure 10), it was concluded that, except the conjunction areas of the cranial and spinal radiation fields, there is no difference higher than 5%, and the results of practical dosimetry were consistent with those by the treatment planning system and the consequent with the validity of CorePlan TPS.

Figure 9. Location TLDs in heart region for practical dosimetry

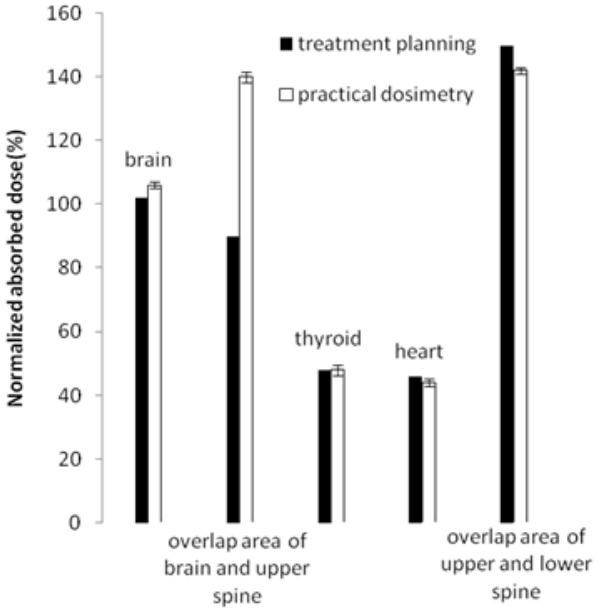

Figure 10. Comparision between the practical dosimetry and treatment planning results.

Table 2. The results of practical dosimetry in regions of interest (to delivery of 50 cGy to the refrence point)

Interested area	Minimum relative dose (%)	Maximum relative dose (%)	Average relative dose (%)	standard deviation
Brain	102	114	106	±0/13
Overlap area of cranial and upper spine fields	88	147	140	±0/22
Thyroid	10	86	48	±0/22
Heart	36	64	44	±0/17
Overlap area of upper and lower spine fields	136	150	142	±0/14
Testis	**Very small**	-	-	-

DISCUSSION

The only difference in the results was observed in the conjunction areas of the cranial and spinal radiation fields which has been left a matter of further discussion. This might have been caused by errors made in the practical stage, including those caused by radiation field adjustments, inaccuracy in positioning dosimeters in the conjunction of cerebral and upper spinal fields, inherent errors of the used TLDs, the errors of TLD reader machine, or a defect in the software while calculating the dose at the conjunction of cerebral and upper spinal fields. Due to the intense dose gradient in these regions, the occurred errors in positioning of TLDs could have an important role in incoherence of results.

Due to the lack of any holes in spinal cord, eye lens and cribriform plate, it was not possible to measure the dose in these regions using TLD. Moreover, since the holes were way distant from the skin, measuring the absorbed dose by the latter was impossible too.

In spite of the fact that using two spinal radiation fields would lead to better dose distribution across the spinal cord, it caused an overlap area in the conjunction of these fields; thus, the absorbed dose at the con-junction increases. To reduce this effect, the conjunction of these radiation fields was being changed during the treat-ment [5, 15]. Moreover, for spinal radiotherapy, electron beam could be used instead of the photon beam. This made a better separation of the normal tissues from spinal PTV [2, 16]. The inhomogeneity of the tissue, however, can have much more effects on the isodose curves of the electron beam and may caused nonuniform distribution of dose across the spinal cord, and leave this area underdosed [2] In craniospinal radiotherapy for Medullobalstoma, the total dose adminis-tered to the cerebral PTV (excluding the boost dose administered to posterior fossa) was between 3500 to 4000 cGy and the total administered dose to the spinal PTV is between 3000 and 3500 cGy [17]. Considering the total administered dose to the brain was 3600 cGy and that which is administered to the spinal cord is 3200 cGy, the total absorbed dose by the thyroid gland was 1664 cGy at the end of the radiotherapy. As it is shown in the reference [2], the thyroid disorders caused by the direct radiation of ray may vary, which tends to be considered in terms of thyroid stimulation hormone (TSH). Regardless of thyroxin being increasing or decreasing, the cases of disorder tend to be occur when the absorbed dose by the whole gland is between 1500 and 5000 cGy. Although the absorbed dose by this organ does not exceed 5000 cGy, it fell in the variation range of the thyroid performance. Generally, this is a matter of debate, because the literature on radiotherapy has not elaborated on the tolerance dose of thyroid. The total dose absorbed by the heart was 1872 cGy which is quite acceptable in comparison with the tolerance dose of this organ that is 4000 cGy [2]. The testis receives a lesser dose. So, these glands received a lower dose of scattered rays due to the scattering of X-ray photons across spinal cord, although they are located outside the lower spine radiation field. This result was deduced from testis DVH in figure 10, too. The results of this research have a good accordance with the research by Hood and his colleagues [13]. One of the aims of the mentioned research was the validation of ADAC Pinnacle treatment planning in craniospinal radiotherapy. For evaluation of TPS performance, a Rando phantom had been used and dosimetric measurements during treatment had been performed using thermoluminescent dosimeters (TLDs). Other research in this field is related to Mollazade and colleagues [18]. In this research the validity and accuracy of RtDoseplan treatment planning software has been evaluated. The results of their research showed that the difference between TPS and dosimetric measurements has been 3% which is similar to the result yielded by the present research.

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