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Evaluation of Dose Calculation Accuracy of Isogray Treatment Planning System in Craniospinal Radiotherapy

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ABSTRACT

Introduction: Craniospinal radiotherapy is a therapeutic technique for central nervous system (CNS) tumors, which requires meticulous attention to technique and dosimetry. Treatment planning system (TPS) is one of the main equipment in radiotherapy; therefore, the evaluation of its accuracy is essential for dose calculation. The present study evaluates the validity of Isogray TPS in craniospinal irradiation techniques.

Material and Methods: The computed tomography (CT) images of the brain and spine of the Rando phantom were acquired. Two techniques were designed. In technique 1, the whole CNS was irradiated with 6 MV photon beam. In technique 2, the brain and spine were irradiated with 6 MV photon and 18 MeV electron beam, respectively. The tumor and organs at risk doses were measured by thermoluminescent dosimeter (TLD). In addition, photon and electron dose measurements inside and outside the treatment field were accomplished using TLD, and then compared to the corresponding values calculated by TPS.

Results: According to the results, in both electron and photon beams, the differences between the doses calculated by TLD and TPS for the points inside the treatment field were less than 4% for 90% of the measurement points. However, for the points outside the treatment field borders, the differences ranged within 10-40%. These differences were indicative of the sufficient dosimetric accuracy of Isogray TPS.

Conclusion: The comparison of dosimetry results with those of TPS results revealed the accuracy of Isogray TPS. In both techniques, the maximum difference between the TLD- and TPS-measured doses was observed in the mandible.

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Introduction

Radiotherapy is a well-established and effective treatment in patients with whole central nervous system (CNS) tumors. Craniospinal irradiation is used for the patients who are at risk or have a disseminated disease throughout CNS that is not sufficiently responsive to chemotherapy, such as medulloblastoma, ependymoma, and intracranial germ cell tumor with the evidence of distant CNS metastasis [1].

This technique includes the use of opposed lateral fields to irradiate the brain and one or more posterior spinal fields to cover the entire spinal cord [2]. In craniospinal radiotherapy, special attention is required to select the best technique for the treatment of tumors in order to decrease patient radiation doses [3-6]. Accurate treatment planning and proper dose delivery are of importance to achieve the best result in whole CNS tumor treatment [7-10]. The final goal of radiotherapy is to deliver a prescribed dose to the tumor with the highest accuracy and decrease the radiation doses to the critical organs.

In modern radiotherapy, treatment planning systems (TPSs) facilitate the determination of optimum treatment parameters to simulate an actual treatment using patient's images. These systems provide calculated doses for tumor and other organs. The accuracy of dose calculation is very important to make sure that the calculated dose is similar to the dose received by the organ [7]. The main goal of quality assurance of TPS is the confirmation of dose calculation. Accordingly, many studies have evaluated the results of dosimetric measurements and TPS calculations [8-10].

There are multiple studies evaluating the accuracy of different TPSs. The accuracy of TPS dose calculation is mainly evaluated through comparing the results with the thermoluminescent dosimeter (TLD)-measured data. However, some researchers apply Mont Carlo programs to evaluate the dosimetric accuracy of TPS. Mollazade et al. evaluated the validity and accuracy of RtDosePlan TPS by Monte Carlo and radiochromic film. Their results showed that the difference between the TPS and dosimetric

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measurements was 3%, which is within the acceptable range[11].

Furthermore, Howell et al. determined the accuracy of dose outside the field by Eclipse TPS (version 8.6) for a clinical treatment delivered through a Varian Clinac 2100 machine. They calculated the doses by TPS and TLD at 238 points. They concluded that the measured doses at the field border and outside the field were lower than the doses prescribed by TPS [12].

Weber et al. also evaluated TPS with volumetric modulated arc therapy and intensity-modulated radiotherapy in Hodgkin lymphoma. They concluded that the out-of-field doses were underestimated by TPS [13]. In addition, numerous studies have investigated the accuracy of the doses calculated by analytical anisotropic algorithm (in Eclipse) in the penumbra region and inside the field in a heterogeneous water phantom [14-18].

With this background in mind, the present study aimed to evaluate the validity of Isogray TPS using two different craniospinal radiotherapy techniques. To this end, we compared the radiation doses measured in an anthropomorphic Rando phantom with those calculated by the TPS since this method is regarded as the most effective technique to evaluate the TPSs.

Materials and Methods

In order to assess the TPS, the computed tomography (CT) images of Rando phantom (Phantom Laboratory, Salem, NY, USA) were acquired using Brilliance scanner, and then delivered to Isogray TPS. The TPS was run for two techniques with photon and electron beams, and the doses were calculated. Afterwards, Rando phantom was irradiated using the Elekta Precise Linear Accelerator.

Dose measurement was performed with a total of 69 TLD-100 chips (Bicron, Harshaw, Cleveland, OH, USA) and 55 TLD-700 chips (ProRad, Germany) inserted at various locations inside the phantom for photon and electron fields, respectively. Finally, the results of the doses measured with TLD and TPS were compared with each other.

Treatment Planning System

The phantom was scanned in the prone position with the CT slice thickness of 3 and 5 mm for the brain and spine, respectively. The CT images were delivered to a three-dimensional (3D) TPS (Isogray planning system). For each slice, the whole CNS tumor and other critical organs, such as mandible, thyroid, heart, lungs, and kidneys, were contoured by a radiotherapist. The clinical target volume (CTV) included the brain and spine, and the planning target volume (PTV) was the posterior cranial fossa.

The two treatment planning techniques are presented in Figure 1. Technique 1 included two opposed lateral cranial photon fields and two posterior spinal photon fields (Figure 1-a). Technique 2 consisted of two opposed lateral cranial photon fields, three posterior electron fields, and one anterior photon field for spinal irradiation (Figure 1-b). In both techniques, the craniospinal axis of phantom (CTV) received a dose of 36 Gy, and the PTV received a dose of 18 Gy as a boost dose. In technique 2, since the spinal cord in the lumbar area is located in a deeper depth, compared to other areas, electron beam did not provide sufficient dose for this region. Therefore, a photon field was applied anteriorly to compensate for dose deficiency.

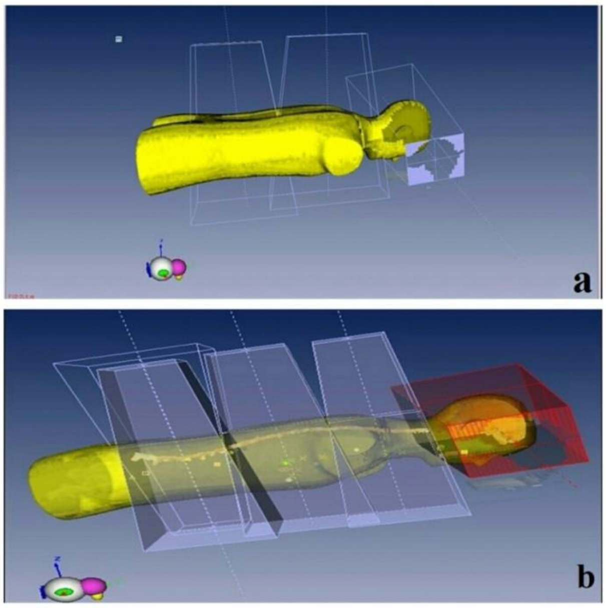

Figure 1. a) Treatment area and radiation fields in Rando phantom in technique 1 (the brain and spine were irradiated with 6 MV photon beams), b) treatment area and radiation fields in Rando phantom in technique 2

Calibration of Thermoluminescent Dosimeter

Lithium fluoride TLD chips with the dimensions of 3×3×0.9 mm were used to measure the organ doses. The TLDs-100 (Harshaw Chemical Company, Solon, OH, USA) and TLDs-700 (ProRad-Germany) chips were calibrated using 0.5 Gy of 6 MV X-rays and 0.5 Gy of 18 MeV electron beams emitted from a linear accelerator (Precise), respectively. To deliver an accurate dose, the TLDs were placed on a water phantom and covered by 1.5 and 3 cm of Perspex as a build-up material for the calibration of TLD-100 and TLD-700, respectively. The calibration was repeated three times. Annealing was performed by heating the chips at 400°C for 1 h, followed by 100°C for 2 h.

Dose Measurement

For each technique and measurement, the TLDs were placed in small holes considered in the phantom slices that corresponded to the location of the organs of interest. For technique 1, based on the plan designed with TPS, 6 MV photon beams were used for the irradiation of cranial and spinal fields.

For technique 2, the lateral cranial and spinal fields were irradiated with 6 MV photon beam and 18 MeV electron beam, respectively. For the lumbar area, in addition to a posterior electron field, an anterior 15 MV photon field was also utilized. The total prescribed doses of PTV and CTV for the two techniques were 54 and 36 Gy, respectively. The techniques were performed in 20 fractions with a daily dose of 1.8 Gy.

In case of irradiation by photon, the TLD-100 chips were used to measure the dose, while for the irradiation by electron beam; TLD-700 chips were employed. The doses of the points, which were irradiated with both photon and electron beams, were obtained based on the sum of the two measurements. The number of the dosimeters placed in each organ and the applied technique are presented in Table 1. The two techniques were repeated three times to increase the accuracy. The TLD-100 and TLD-700 were read with an TLD reader. The differences were determined as follows:

$$\%\text{diff} = \left(\frac{D\,cal - Dmeas}{Dmeas}\right) \times 100 \quad (1)$$

Where D_{cal} is the dose calculated by Isogray system, D_{meas} is the dose measured by TLD, and Diff is the percentage difference.

Table 1. Number of thermoluminescent dosimeters in the two techniques

Organs	Number of TLD		
	Technique 2		Technique 1
	TLD-700	TLD-100	TLD-100
CTV	23	18	25
PTV	4	4	4
Optic chiasma	0	2	2
Mandible	5	3	5
Thyroid	5	5	5
Heart	8	0	8
Right lung	5	0	5
Left lung	5	0	5
Right kidney	5	5	5
Left kidney	5	5	5

TLD: thermoluminescent dosimeter, CTV: clinical target volume, PTV: planning target volume

Results

Tables 2-4 illustrate the results of photon and electron beam irradiation based on the location of the points (i.e., inside or outside the irradiation fields). The positive and negative values indicated that the TPS dose was higher and lower than the TLD dose, respectively. Figures 2-a¸ 2-b¸ 2-c, and 2-d depict the percentage difference in the points of inside and outside the photon and electron fields.

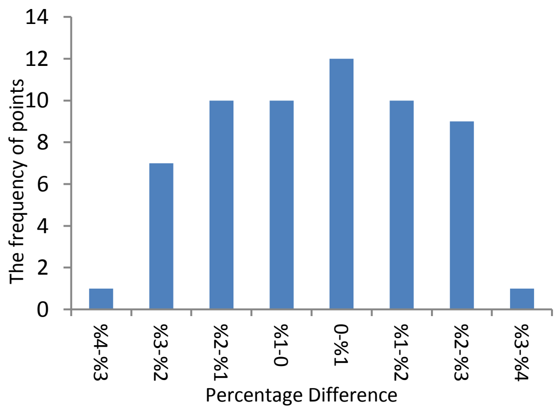

Figure 2-a. Percentage difference in the measurement points inside the photon field

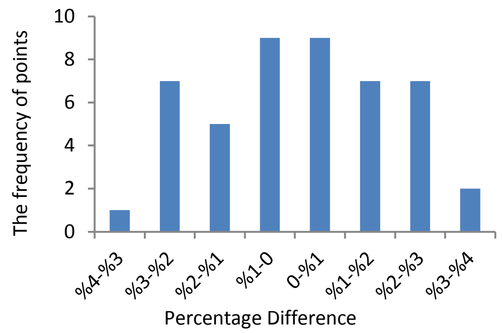

Figure 2-b. Percentage difference in the measurement points inside the electron field

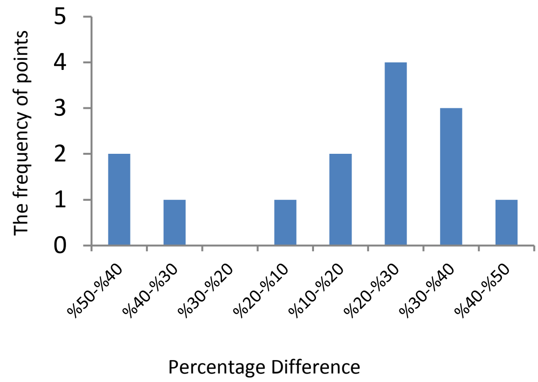

Figure 2-c. Percentage difference in the measurement points outside the photon field

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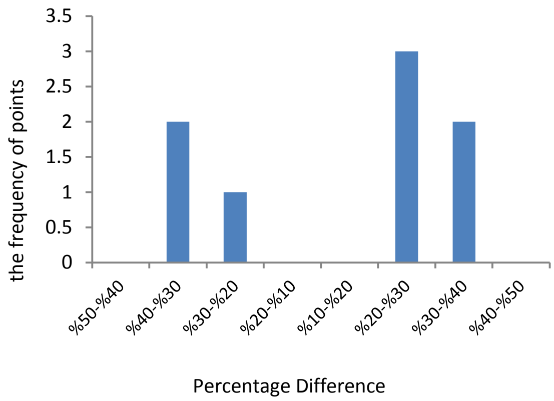

Figure 2-d. Percentage difference in the measurement points outside the electron field

Table 2. Percentage difference between the results of thermoluminescent dosimeter and treatment planning system for measurement points inside the photon and electron treatment fields

Organs	Electron field		Photon field	
Thyroid	2.65	0.81	-3.43	-1.57
	2.02	3.26	-1.54	-0.45
Heart	1.05	0.64	-0.51	1.10
	-0.87	-0.53	-2.59	1.05
	1.32	-1.35	-2.25	-3.46
Spinal cord	-1.81	-0.54	-1.22	2.52
	0.64	1.23	2.02	-5.12
	-2.59	-3.45	-1.58	-1.25
	4.25	-0.76	-0.76	0.66
	1.64	-2.25	0.34	-2.79
	-2.78	-1.33	0.56	0.90
	-0.25	0.95	2.89	-2.69
	2.47	-2.72	1.23	-1.84
	1.71	-0.25	-0.43	-2.15
	-2.90	2.02	-2.35	0.26
Right lung	3	2.42	-2.43	0.22
	0.59	1.44	0.54	1.36
Left lung	1.26	0.32	0.27	-0.88
	-1.23	1.51	-2.07	2.34
	-0.47	0.54	0.84	1.3
Right kidney	-2.17	-0.65	3.84	1.11
	0.34	1.97	2.65	-1.07
Left kidney	2.36	1.48	-0.28	1.31
	-0.27	-1.23	-0.23	1.2

Table 3. Percentage difference between the results of thermoluminescent dosimeter and treatment planning system for measurement points inside the photon treatment fields

Mandible	Chiasma	CTV
0.22	-1.85	-1.48
2.26	1.33	-0.48
-1.26	-0.25	0.61
0.71		-2.27
2.77	-0.33	2.33
1.32		-0.74
1.63		-0.88

CTV: clinical target volume

Table 4. Percentage difference between the results of thermoluminescent dosimeter and treatment planning system for measurement points outside the photon and electron treatment fields

Organs	Electron field	Photon field	
Mandible	-23.17	10.57	24.77
	33		-30.33
Right lung	29	26.31	34.80
	-31		-44.41
Left lung	29.32	25.1	-29.2
	39.4		15.37
Right kidney	-37	36.78	23.45
Left kidney	31.25	40	-15.37
			52.24

Discussion

In this study, the practical dosimetry of whole CNS radiotherapy was applied to evaluate the accuracy of dose calculation performed by Isogray TPS. To this end, the photon and electron doses were measured inside and outside the treatment field using the TLD-700 and TLD-100 to compare the results with those of the Isogray TPS.

According to the results, there were no significant differences between the results of TLD and TPS in terms of the electron beam inside the field. However, the calculated doses by Isogray TPS were overestimated for some points and underestimated for other points, compared to the doses measured by TLD outside the field. This difference was higher at the junction location.

Among the points outside the irradiated area, the maximum difference was observed in the mandible points. The reason is that mandible is located at the junction area of the two fields. This finding is in line with that obtained by Baghani et al. observing the maximum difference at junction between the two fields. The reason for the difference between the TPS data and TLD measurement may be the fact that the TPS calculated the mean dose of all points in the organ, whereas the TLD chips measured the dose at only a few points in the mandible of the phantom [19].

Similar results were obtained for photon beam. In this technique, there was no significant difference between the results of TLD and TPS inside the field. However, for photon beam, the differences between the dose calculated by TLD and TPS for points outside the fields were more than the corresponding values for electron beam. For both electron and photon beams, the difference between the doses measured by TLD and TPS was less than 4% for 90% of the points in the irradiated area. However, for the points outside the irradiated area, the difference was 10-40%.

According to the NCS protocol that provides information on the quality assurance of TPSs, the results revealed a good consistency between the TPS calculation and TLD measurement. These differences indicated the sufficient dosimetric accuracy of Isogray system. In a similar study, Hood et al. confirmed the accuracy of TPS (ADAC Pinnacle 3D radiation treatment planning) in craniospinal radiotherapy using photon and electron beam irradiation [20]

Another study investigated the accuracy of electron dose calculation using different TPSs/algorithms. Toossi et al. also assessed the accuracy of electron dose calculations in the internal mammary field for Prowess Panther TPS (version 5.2) with TLD-700. They concluded that for outside the field and under shield regions, Prowess Panther TPS underestimated the dose, compared to the TLD-700.

Nonetheless, for the in-field regions, the calculated doses by Prowess Panther TPS were overestimated for some points and underestimated for the other points, compared to the doses measured by TLD-700. They concluded that the accuracy of electron dose calculations of Prowess Panther TPS was not enough in the internal mammary field [21].

The accuracy of TPS is mainly evaluated using dose measurement; however, in some studies, Mont Carlo programs have been used for this purpose. In this regard, Pemler et al. investigated a commercial electron beam TPS by Monte Carlo treatment planning algorithm using various tests. In the mentioned study, the algorithm showed satisfactory results for all of the basic tests and in the presence of inhomogeneities. Deviations were observed at the high dose and off-axis regions for high (18 and 22 MeV) and very low (6 MeV) energies [22].

Remoto and Corpuz carried out the quality assurance of Pinnacle TPS for external beam radiation therapy. In the mentioned study, the assessment of the electron dose calculation accuracy was accomplished by comparing the manual and Pinnacle calculations. Furthermore, for the assessment of the accuracy of photon dose calculation, the doses calculated by the TPS was verified with the doses measured through a Farmer chamber. They concluded that the dose calculation accuracy of the TPS for electrons and photons in most of the calculation points was acceptable although significant differences were observed between the Pinnacle TPS and manual dose measurements in some points [23].

Mollazade et al. (2010) evaluated the validity and accuracy of RtDosePlan TPS with Monte Carlo and radiochromic film[11]. In the mentioned study, the difference between the TPS and dosimetric measurements was 3%, and their results were within the acceptable range. Howell et al. determined the accuracy of outside the field dose by Eclipse TPS (version 8.6) for a clinical treatment delivered through Varian Clinac 2100 machine. The doses were calculated by TPS and measured at 238 points by TLD as well. They concluded that the doses measured by TLD were lower at the field border and outside the field than the prescribed doses by TPS [12]. Weber et al. evaluated TPS with volumetric modulated arc therapy and intensity-modulated radiotherapy in Hodgkin lymphoma. They concluded that TPS underestimated the dose at points outside the field [13].

In the current study, we arranged two lateral and a posterior fields with specific field size. Underestimated dose by TPS for points outside the field may be changed by field size, delivery technique, and beam angle. Therefore, further studies are recommended to investigate different field sizes, delivery techniques, and beam orientations. In addition, to assess the accuracy of different TPSs, the inside and outside field doses should be evaluated by different reconstruction methods, such as Monte Carlo calculations.

Conclusion

In this study, the accuracy of dose calculations in craniospinal radiotherapy for Isogray TPS was assessed using electron and photon beams. The results were indicative of no significant difference between the results of TLD and TPS in the two techniques. Therefore, the accuracy of Isogray in dose calculation for the inside and outside the field was confirmed.

The comparison between the results of practical dosimetry and TPS supported the validity of Isogray TPS. In both electron and photon beams, the difference between the doses measured by TLD and TPS was less than 4% for %90 of the points in the irradiated area. However, for the points outside the irradiated area, the difference was 10-40%. Since these differences are acceptable, Isogray TPS can be concluded to have sufficient dosimetric accuracy.

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