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Dosimetric Comparison of The Effects of Different Treatment Plan Techniques on Reduction in Critical Organs in Whole Brain Radiotherapy Application

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Abstract

Different radiotherapy treatment techniques can be used in whole-brain radiotherapy (WBRT). This study aims to investigate the dosimetric advantages of the anterior isocenteric (AI) technique which is produced as an alternative to the central isocentric (CI) technique. 25 whole brain patients were included in this retrospective study. Plans were made with two treatment techniques for each patient. One central isocenter (CI) was made using a conventional helmet field (HF) to center the whole brain, which is the isocenter of the target volume. An automatic margin of 5 mm was given to the planning target volume (PTV) with multileaf collimators (MLC) for both plans. For CI and AI techniques, a total dose of 30 Gy was given in 10 fractions with 6 MV photon energy. The two planning techniques were compared dosimetrically. The dose homogeneity index (DHI) had lower values in the AI plan according to CI plans significantly (p=0.049). There was a 6,57% difference between CI and AI planning techniques for the maximum dose of the right lens. For the minimum dose and mean dose AI plans significantly had lower values according to the CI plan (p=0.001 and p=0.028 respectively). In this dosimetric study, we found that the AI treatment technique for WBRT was superior to the CI technique for DHI and organs at risk. We recommended to use the AI technique, especially to better protect organs at risk in WBRT.

Keywords: Anterior isocenter, brain, radiotherapy, central isocenter

1. Introduction

Although developments in the field of radiotherapy used in the treatment of cancer patients are very rapid, conventional approaches are still frequently used in whole-brain (WB) irradiation. Brain metastases, one of the most common intracranial tumors in adults, are 10 times more common than brain tumors and are seen in 24% of autopsies of all cancer patients [1]. Palliative WB radiotherapy is one of the main treatment methods in the treatment of metastatic brain tumors [2]. WBRT is also the main treatment method for patients with intracranial metastases and the average life expectancy of these patients is between 4 and 6 months [3]. Long-term side effects such as dementia, neurocognitive disorders and radionecrosis are important in increasing the survival rates of patients receiving WBRT and these complications are more important for patients with longer life expectancy [2]. Therefore, better targeting and critical organ protection are important for WB patients. In addition, the International Commission on Radiation Units (ICRU) recommends that the PTV in WB irradiation should be between a minimum of 95% and a maximum of 107% dose distribution [4] and it is not always possible to reach this dose distribution [5,6].

On the other hand diagnostic devices such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and positron emission tomography (PET) can be used to delineate critical organs and tumor. For example, if PET/CT is available it can be used for determining the localization of the hidden disease in early detection, distant metastasis and synchronous cancer plays an important role in its definition [7].

Currently, several WB irradiation techniques are used to improve dosimetric dose distributions. These include therapy techniques such as physical compensators, electronic compensators, and intensity-modulated radiotherapy, Helical tomotherapy (HT) [8-17]. These techniques can be selected based on availability according to the number of devices, number of patients and planning systems [2].

In our study we aimed to make new WB treatment plan acroos the CI plan which named AI plan. The CI plan standart helmet field which two opposite lateral beam to the icocenter. The plan we offer is AI plan which isocenter point close to anterior of PTV to decrease divergency. In AI plan we expected that make plan dose distribution homogenusly and less dose to the critical structures.

2. Materials and Methods

2.1. Patients

25 WB patients with an average age of 53 years, who had previously been treated with a standard 3D-conformal plan were selected for the retrospective study. The simulation of these patients was performed using a thermoplastic head mask, in the supine position and with the arms at the side. We used CT (Siemens Somatom Duo, Germany) with a 5 mm section interval, covering the entire brain, up to the end of the cervical vertebra. The data obtained from CT transferred dia with Digital İmaging and Comminication in Medicine (DICOM) to Eclipse™ treatment planning system (TPS), (version 8.9.08, Eclipse, Varian Medical Systems, Palo Alto, CA, USA).

2.2. Planning target volumes and critical structure

The body contour was drawn automatically by the planning system and the critical organs, the eyes, lenses and optic nerves were drawn by radiation oncologists according to the Radiation Therapy Oncology Group (RTOG) guidelines. When defining the planning target volume a 3 mm margin was given to WB tissue determined as the target tissue but arrangements were made in the organ at risk (OAR) regions formed by lenses, eyes and optic nerves.

2.3. Treatment planning

All plans for all the WB patients that we selected were re-made with the Eclipse TPS. First, the plan named central isocenter (CI) was made using a conventional helmet-field (HF) to center of the WB which is the isocenter of target volume. Plans were calculated by giving 5 mm automatic margins to the PTV with multi-leaf collimators (Figure 1a and Figure 1b.). While making the second plan, the isocenter was placed close to the eye level and named the AI plan was calculated by automatically giving 5 mm margin to the PTV in all directions by MLC. Figure of beams eye view (BEV) showed in Figure 2a and Figure 2b. The maximum dose of the AI plan was normalized to the same value as the CI plan for the sake of same comparison conditions. In both techniques, three-dimensional conformal treatment plans were made using 6 MV photon energy. To ensure the same plan conditions no manual shaping was done in MLC in the two planning techniques.

2.4. Dosimetric Evaluation

In the study, the treatment dose was administered as 30 Gy in 10 fractions at the isocenter. A linear accelerator with 82 leaf (Siemens Primus Plus, Germany) treatment device was used for the planning. To help compare the dosimetric parameters of the CI plan and AI plans under the same conditions, the AI plan, which always has a lower maximum dose but less PTV coverage, was normalized to obtain plans with the same maximum dose. Additionally, dose volume histograms (DVH) were created for both plan groups. Dose homogeneity index for PTV were compared for both plans. Dose homogeneity Index (DHI) was calculated for all plans as D5/D95 (minimum dose at five percent of PTV/ minimum dose at ninety-five percent of PTV) [16]. The value of DHI close to 1 means the better homogeneous dose distribution in the plan. Minimum, maximum, and mean doses for lenses, eyes and optic nerves in each plane were compared.

2.5. Statistical Analysis

The Statistical Package for Social Sciences (SPSS) v.25.0 was used for statistics (SPSS Inc. Chicago, II., USA). A paired samples t-test was used for comparison. The minimum, maximum and average doses to the OAR; lens, eye and optic nerves were compared for both plans. It was considered significant because the p value was less than 0.05.

3. Results and Discussion

DVH for a patient is shown in Fig.3. On the other side *p* values for both plans are listed in Table 1. There was a 6,57% difference betwen CI and AI planning technique for maximum dose of the right lens. But also there was a significant difference between two techniques for the minimum and mean dose of right lens. AI planning technique had less minimum right lens dose acording to CI technique (p=0.001) and also AI technique had less mean right lens dose according to CI technique (p=0.028). On the other hand we have significant difference for the minimum, maximum and mean dose of the left lens. For these doses AI planning technique had less doses due to CI planning technique. Mean doses for both right and left eyes had differences 0.27% and 0.039 respectively for two techniques.

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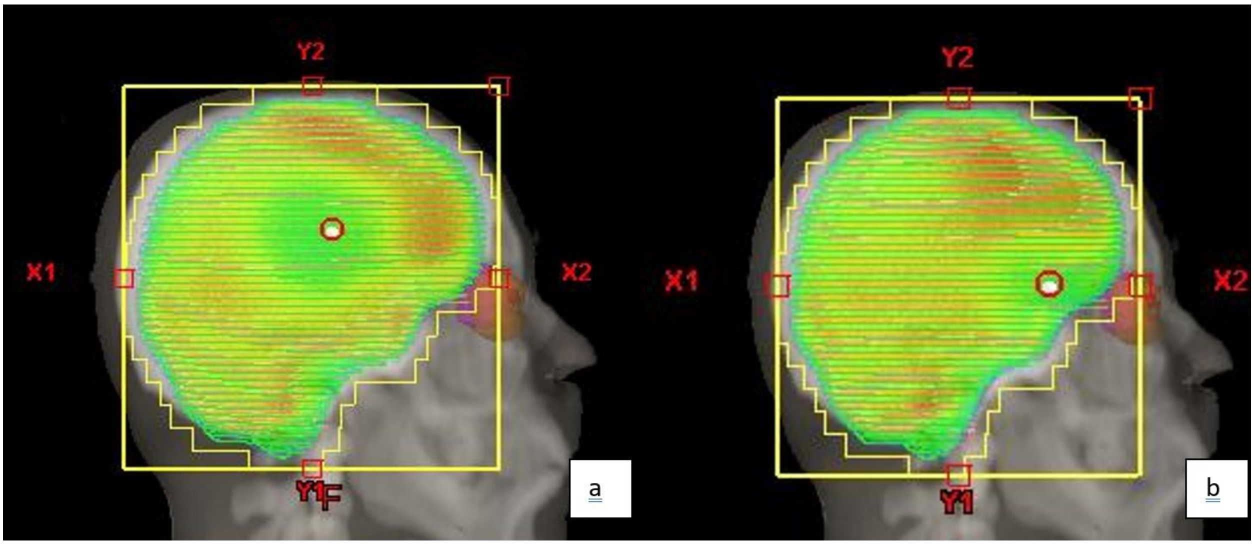

Figure 1. BEV for an example patient (a) CI technique, (b) AI technique.

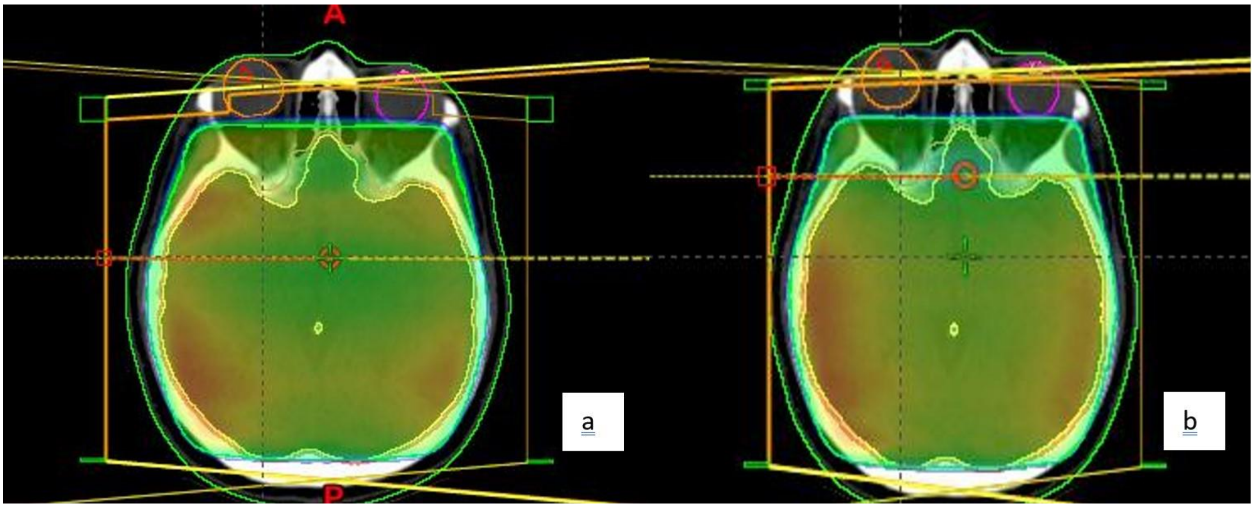

Figure 2. The dose distribution of saggital view for a patient (a) CI technique (b) AI technique.

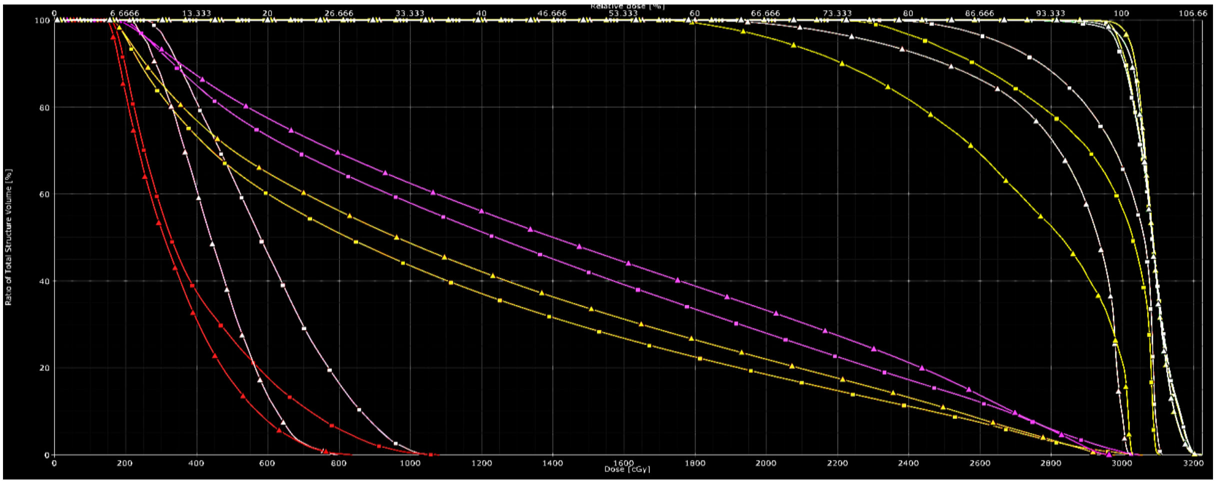

Figure 3. Dose-volume histogram comparison of a patient for two techniques; red: right lens, pink: left lens, yellow: right eye, purple: left eye, open green: right optic nerve, open pink: left optic nerve and white: PTV

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Table 1. Comparison of dosimetric parameters between CI and AI plans.

Parameters		**CI Plan (cGy) (Mean±SD)**	**AI Plan (cGy) (Mean±SD)**	**ΔMean±SD (CI-AI)**	**P**
RT Lens	D_{max}	809.67±283.54	756.46±319.13	53.21±99.08	0.056
	D_{min}	238.33±111.55	221.27±108.63	17.07±16.61	**0.001**
	D_{mean}	448.07±192.19	422.07±198.39	25.99±41.21	**0.028**
LT Lens	D_{max}	780.21±330.63	715.39±329.54	64.82±102.88	**0.029**
	D_{min}	253.69±127.41	225.47±101.30	28.22±46.36	**0.033**
	D_{mean}	456.93±188.39	409.99±172.55	46.95±71.32	**0.023**
RT Eye	D_{max}	3087.15±109.42	3031.58±94.99	55.57±39.22	**<0.001**
	D_{min}	139.23±45.57	130.83±42.50	8.40±5.78	**<0.001**
	D_{mean}	1338.19±388.19	1334.48±392.22	3.70±46.25	0.761
LT Eye	D_{max}	3076.77±59.32	3034.90±59.12	41.87±39.83	**0.001**
	D_{min}	144.09±54.13	133.39±60.73	10.69±14.91	**0.015**
	D_{mean}	1420.45±349.58	1419.90±358.92	0.55±59.83	0.972
RT Optic Nerve	D_{max}	3110.98±40.30	3032.21±39.35	78.76±21.84	**<0.001**
	D_{min}	2022.56±774.08	1972.73±764.26	49.83±160.29	0.249
	D_{mean}	2843.35±263.97	2775.16±253.31	68.19±58.48	**<0.001**
LT Optic Nerve	D_{max}	3091.62±38.88	3028.83±34.85	62.79±23.61	**<0.001**
	D_{min}	2289.71±492.94	2253.08±476.74	36.63±184.68	**0.455**
	D_{mean}	2899.07±158.23	2842.06±136.48	57.01±50.79	**0.001**
HI		1.0724±0.0107	1.0701±0.0092	0.0022±0.004	**0.049**
MU		317.67±4.53	316.00±6.11	1.67±3.98	0.127

CI: Central isosentric, AI: anterior isosentric

The minimum and maximum doses for two techniques were significant and AI technique had lower doses then CI technique. For the optic nerves, maximum and mean doses significantly had lower dose in the AI plan technique then CI technique. The homogenity index of the AI plan significantly had a lower value due to CI plan (p=0,049).

In this study, when the CI and AI plans were compared, which were brought to the same maximum dose plan value, the beam deviation that would occur by moving the treatment isocenter, the source of the plan difference, upwards from the target volume center was reduced in order to ensure that the lens and eye doses were lower with lower dose limits and the target volume received a better dose. In addition, the planner can make some changes to the MLCs and change a small isocenter, then a better plan can be obtained, but to try to provide equivalent conditions, the icocenter puts randomly and also the MLC coverage is done automatically. The average life expectancy of metastatic WB patients is around one year [17]. Studies show that in the long term, WB irradiation causes symptoms such as memory loss, motor control impairment and urinary incontinence [18-21]. In these cases, the better dose coverage of plans and less critical organ doses have an important role for the remaining quality of life. The dose distribution and critical organ doses changes with anatomy of patients. But statistically we saw that standard AI gave less critical organ doses and had better dose homogenity in PTV.

Fujita and his colleagues compare two WBRT techniques to compare dosimetric parameters of plans [3]. They chose twenty patients that had already been treated to made retrospective planning using irregular surface compensator (ISC) and compare it with conventional radiotherapy techniques. They found ISC technique had lower DHI and mean and maximum lenses and eyes doses (p<0.05) were also reduced. In this study AI plan had lower values of maximum, minimum and mean doses according to CI plan technique. It was also observed that the AI technique had more dose homogeneity.

Yavas and his colleagues aimed in their study that compared two standard HT plan and classical technique with collimator changed plans (CT) according to OAR such as lenses, eye-balls and optic nerves [22]. And also differences in DHI and monitor units (MU). They found that there were no differences for DHI (p:0.182) and MU (p:0.167) with two techniques. But for maximum and mean doses of the right lens, left lens and right eye-ball were significantly lower in CT technique (p values for maximum doses 0.007, 0.012 and 0.010 respectively; for mean doses 0.027, 0.046 and 0.002 respectively). However, significant differences in DHI were found in this study. Better DHI results were achieved with the AI planning technique than with the CI planning technique. Doses to critical organs (both lenses and eyes) in the AI technique were lower than in the CI technique. Another study on metastatic WBRT was conducted by Andic and colleagues. Compared dosimetric data of 30 patients for conventional two-dimensional (2D) helmet-field with three-dimensional conformal radiotherapy (3D-CRT) techniques to compare dose coverage to the brain and Retro-orbital area (RO) [23]. On the other side they looked for the ocular lens protection. They found the minimum doses mean for RO areas statistically higher in 3D-CRT plans than 2D plans (p=0.008). On the other hand the mean values of maximum doses in clinic target volume (CTV), RO areas and lenses had no differences for two plan techniques. They concluded that 3D-CRT planning improved dose coverage of RO areas and the dose homogenity in WB and protected ocular lenses when compared with 2D conventional radiotherapy planning technique. In this study, DHI was lower on the AI plan than on the CI plan, and lower doses were used for all critical organs.

James B. Yu and his colleague compared conventional helmet-field planning technique with two field intensity modulated radiation therapy(IMRT) techniques for 10 patients in WBRT [1]. They found that IMRT improved dose uniformity across External Beam Radiation Therapy (EBRT) for WBRT. The conventional technique increases the dose into superior frontal region of the brain. These hot points didn't occur in IMRT technique. But they also reported that IMRT technique increased the number of MU to deliver necessary doses. The more dose homogeneity and this increases the more total body dose including scattering and leakage. This may increase second malignancies probability [24]. There were also studies conducted by Hall et al., which stated that the likelihood of second malignancy was significantly increased in children who received long curative treatment and survived [25]. The AI technique used in this study had better treatment results in terms of homogeneous dose distribution but was not as good as the IMRT technique. On the other hand, less MU and less treatment time were obtained compared to the two-field IMRT technique. It can be stated that sometimes the treatment period of a WBRT patient may be very limited.

4. Conclusion

AI treatment technique had more advantages according to CI technique for WBRT treatment with respect to lower DHI and critical organ doses such as lenses, eyes and optical nerves. That is what we expect from this study. Thus in WBRT treatments changing isocenter close to the optical zone had less organ doses and more homogenity. If a clinic is going to perform 3D-CRT for WBRT, we recommend that they consider the AI technique.

Author's Contributions

Hikmettin Demir:

Gül Kanyılmaz:

Ethics

There are no ethical issues after the publication of this manuscript.

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