



Feasibility of Board Tilt Angle on Critical Organs during Hippocampus-Sparing whole-Brain Radiotherapy

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Abstract:

The objective of this study was to investigate the impact of altering the board angle on critical organ doses during whole-brain irradiation. Tomography images of the head region of the rando phantom were taken at angles of 0°, 10°, 20°, 30°, and 40°. Target volume (PTV) and organ at risk (OAR) contours were created on CT images using RTOG 0933 criteria. Tomography images of the head region of the rando phantom were taken at angles of 0°, 10°, 20°, 30°, and 40°. Target volume (PTV) and critical organ contours were created on CT images using RTOG 0933 criteria. During this comparative study, we aimed to achieve a standardized dose distribution in the PTV. We evaluated the doses received by D2 (minimum dose received by 2% of the target volume), D98 (minimum dose received by 98% of the target volume), D50 (dose received by 50% of the target volume), and organs at risk (OAR) in the PTV using CT scans taken at different angles. Additionally, we compared the homogeneity index (HI), conformity index (CI), and treatment time (MU) values. This method aimed to decrease the dose of the OAR region near the target volume, specifically the hippocampus. Our findings indicate that a board angle of 30° offers the greatest protection in terms of critical organ doses.

1. Introduction

In radiotherapy, the objective is to administer the full dose to the target organ while minimizing the dose to the surrounding critical structures. The key steps in treatment planning are accurately defining the target volume and organ at risk (OAR) [1]. Technological advancements in medical imaging techniques, dosimetric software, and treatment devices have made it possible to distribute the dose defined in the target volume as desired. Dose volume histograms (DVH) and isodose curves [2-4]. can be used to analyze plans created in different planning systems. While isodose evaluation and/or DVH evaluation may be sufficient for target volume evaluation, it is also useful to compare

plans in terms of conformity index (CI) and homogeneity index (HI) values [5]. These values take into account the target volume with OAR doses.

Treatment planning is performed using various treatment planning systems (TPS) and radiotherapy (RT) techniques. Several studies have demonstrated that Tomotherapy reduces critical organ doses [6-9].

Whole brain irradiation is a palliative treatment for patients with various malignancies that have brain metastases or prophylactic treatment for patients with small cell lung carcinoma [10-14]. As anticipated, the hippocampus plays a crucial role in learning, memory, and mood regulation [15]. Recent clinical studies have shown that there

is a risk of post-radiotherapy decline in delayed recall in learning that is related to the radiation dose received by the hippocampus [16-18]. To protect the hippocampus and other at-risk brain regions from radiation exposure, researchers have explored various strategies.

One such strategy is the use of advanced radiotherapy techniques, which has led to the proposal of hippocampus-sparing whole brain radiotherapy. Additionally, studies have shown a low incidence of metastasis development in the hippocampal region [19, 20]. To avoid high doses in this area, several studies have been conducted [10, 21-26].

The hypothesis of this study was to generate RT plans to deliver a dose of 30 Gy to the whole brain volume on computed tomography (CT) acquired at different board angles. The secondary objective was

to simultaneously minimize the dose delivered to the OAR while delivering an increased dose of up to 28.5 Gy Dmin to the whole brain and to identify the board angle that provides a significant difference in terms of dosimetric parameters.

2. Material and Methods

For use in the TPS, as shown in Figure 1, the entire head region of the supine Rando phantom with an angled head board and thermoplastic head mask was reconstructed and imaged using a soft tissue kernel on a Somatom Definition AS 20 (Siemens AG) CT unit with a slice thickness of 2 mm. The head plate was positioned in five different angular positions and then image acquisition was performed at 140 kV and 300 mAs tube values.



Figure 1. CT simulation with angled board at 5 different angles

Contouring was performed by a neuroradiologist in the Tomotherapy Planning System according to RTOG 0933 criteria [19, 27]. Body, whole brain, brainstem, eyes, optic nerve, chiasm, cochlea, parotid gland, hippocampus, and lens contours were drawn (Figure 2).

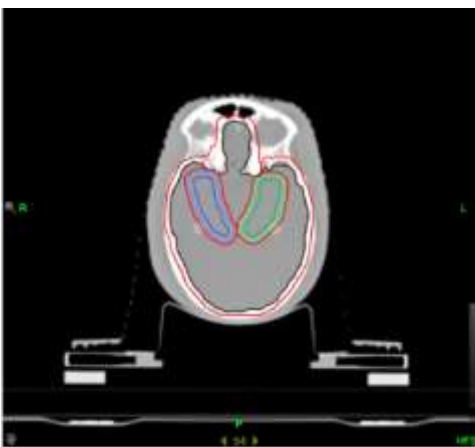


Figure 2. Transverse section view at 40° board angle

Mackie developed helical tomotherapy, which is now commercially available through TomoTherapy (TomoTherapy Inc, Madison, WI, USA) [28]. The first patient was treated with Helical Tomotherapy in 2002 [29].

Treatment plans for helical tomotherapy were developed using the Precision 1.1.1.0.0 treatment planning workstation (Accuray, Sunnyvale, CA, USA) with a 6 MV photon beam algorithm. The isocenter has 64 leaf MLCs, each measuring 0.625 cm. As the gantry revolves at a steady speed, the MLC opens 51 times every rotation before closing entirely between different 'projections'[30].

Helical tomotherapy plans for CT images with five different board angles were calculated, optimized, and validated by an experienced medical physicist on the TomoTherapy Planning Station. The prescription dose was planned according to the following characteristics.

Whole brain PTV will receive 30 Gy in 10 fractions.

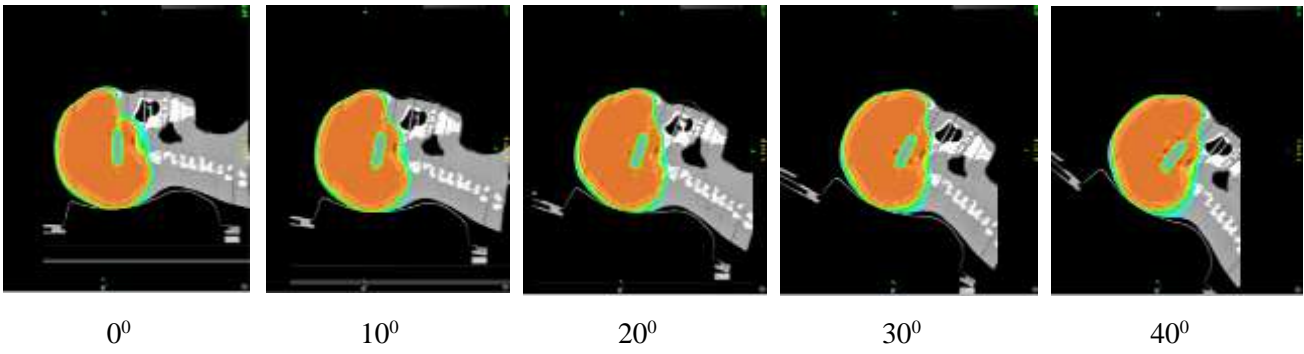


Figure 3. Representation of dose distribution in sagittal view with slopes of 0° , 10° , 20° , 30° and 40°

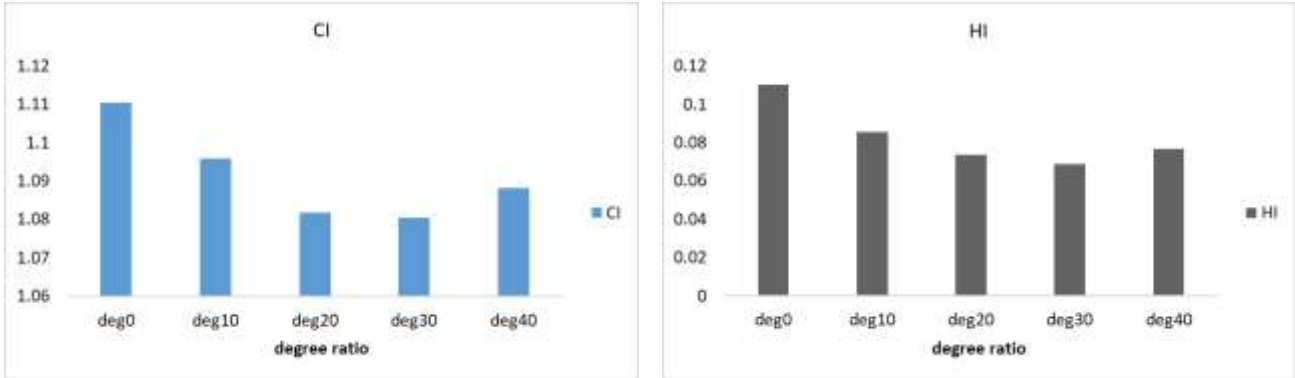


Figure 4. CI and HI values for 5 different board angles.

Treatment was to be administered once daily, 5 fractions per week. For whole brain PTV, the dose was prescribed to cover 95% of the prescribed dose [31, 32]. For PTV, normalization to 95% of the prescribed dose was performed. In the tomotherapy planning workflow, normalization is performed during the optimization process. The same dose criteria for the target volume and critical organs were used for all plans. The maximum dose to 2% of PTV (D2%) is 37.5 Gy and the minimum dose to 98% of PTV (D98%) is 29.4 Gy. The hippocampal contours were expanded 5 mm in three dimensions while hippocampal avoidance zones were created. According to the RTOG 0933 protocol, the dose to 100% of the hippocampal dose was not more than 9 Gy and the maximum hippocampal dose was not more than 16 Gy. Care was taken to ensure that the dose delivered to any point in the optic nerves or chiasm did not exceed 37.5 Gy.

HI is an objective measure of the homogeneity of dose distribution in the target volume. Different formulations are used in the literature to define the homogeneity index. When comparing different treatment plans or irradiation techniques, it is necessary to use the same formulation because it depends on the target volume. [33] According to RTOG [34];

D2: the minimum dose received by 2% of the target volume (maximum dose), D98: the minimum dose received by 98% of the target volume (minimum

dose), and D50: the dose received by 50% of the target volume are given in equation 1.

$$HI = \left(\frac{D2 - D98}{D50} \right) \quad (1)$$

If the HI is less than or equal to 2, the treatment will follow the protocol. If the index is between 2 and 2.5, there is a minor deviation from the protocol. If the HI exceeds 2.5, a significant deviation from the protocol has occurred, but it may still be acceptable [35]. According to ICRU Report 62, the closer the HI is to zero, the more homogeneous the plan [36].

The RTOG criterion defines an ideal dose distribution as having a CI of 1. A CI greater than 1 indicates that the irradiated volume exceeds the target volume, while a CI less than 1 indicates partial irradiation of the target volume. A CI value between 1-2 indicates compatibility with the treatment plan, while values between 2-2.5 or 0.9-1 indicate a small deviation. Values outside of these ranges indicate a large deviation. Knöös et al. first applied the conformity index (CI) to 57 patients treated in 3D [37]. The CI can be used as part of the optimization process, but it is not informative on its own. It becomes meaningful when used in combination with tomography sections and dose-volume histogram (DVH) evaluation [5, 36].

Equation 2 provides the VRI (reference isodose volume) and TV (target volume in cc) according to RTOG criteria [34].

$$CI = \left(\frac{VRI}{TV} \right) \quad (2)$$

All DVH analyses were performed with TPS. DVH data were extracted into a TXT file and then DVH data for target volume (D2, D50, D98), CI in critical organs (min, mean, max), HI, and treatment time (BoT) parameters were calculated and compared between 5 different board angles.

3. Results and Discussions

All plans were reviewed for area volume ($V_{30} \geq 90\%$ and $D_2 \leq 40$ Gy at or above 30 Gy in the PTV. Treatment plans were redesigned if 100% of the hippocampus exceeded 10 Gy and the maximum hippocampal dose exceeded 17 Gy [27, 38]. Table 1 shows the HI, CI, treatment times and PTV parameters for 5 different board angles. Table 2 shows the min, mean and max values in Gy for organs at risk.

Table 1. HI, CI, BoT and D2, D50, D98 values

	0°	10°	20°	30°	40°
D2	31.55	31.36	31.25	31.2	31.3
D98	28.162	28.74	29	29.1	28.95
D50	30.79	30.64	30.58	30.55	30.57
CI	1.11031	1.09590	1.08169	1.08033	1.08803
HI	0.11004	0.08551	0.07358	0.06874	0.07688
BoT (sn)	1260	1236	1194	1152	1242

Figures 4 and 5 show the changes in HI, CI and treatment times and depending on the board angle, respectively.

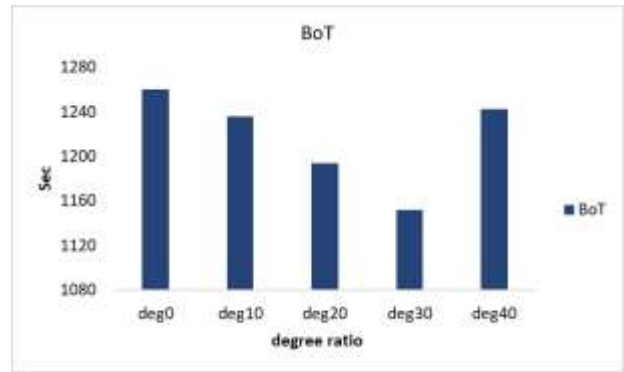


Figure 5. Treatment times for 5 different board angles

As shown in Figure 4, in hippocampus-protected whole brain RT, the CI value decreases linearly from 0° to 30° and approaches 1, but in the plan made with a 40° board angle, the value moves away from 1. Likewise, it is seen that HI takes the closest value to zero in the plan made with a 30° board angle, and moves away from the ideal plan at a 40° angle. In addition, in Figure 5, we see a similar trend for BoT, with the 30° board angle offering the shortest treatment time. In the dosimetric comparison, it was seen that the board angle of PTV, D2 and D98 was closer to 30 Gy as the board angle increased from 0° to 30° and gave results compatible with the literature. At 40° board angle, we see that D2 and D50 are at high dose values, and D98 value moves away from the reference dose. Figure 6 shows the change of dosimetric parameters of PTV with board angle.

Considering the values given in Table 2; It was observed that the doses received by critical organs decreased significantly at the 30° board angle. We see that the max dose in the hippocampus and lens decreases with increasing slope.

4. Conclusions

We investigated the distribution of this information

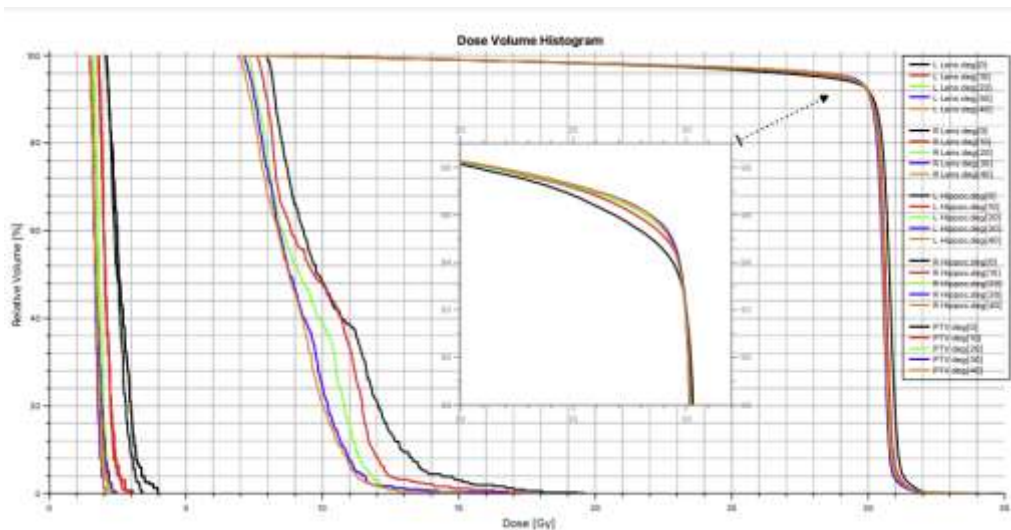


Figure 6. Comparison of target volume and DVH of organs at risk

Table 2. Max doses received by critical organs

OAR	[Gy]	0°	10°	20°	30°	40°
Brain stem	max	32.64	32.6	32.83	33.12	34.57
L_cochlea	max	31.71	30.93	31.22	31.52	32.14
R_cochlea	max	32.1	31.35	32.43	32.69	32.92
chiazma	max	29.49	32.42	32.44	33.12	34.29
L_eye	max	9.74	8.51	8.28	9.13	8.73
R_eye	max	10.17	10.15	10.39	11.45	9.98
L_lens	max	3.41	3.06	2.29	2.07	2.05
	mean	2.53	2.04	1.83	1.69	1.73
R_lens	max	3.98	3.06	2.35	2.44	2.32
	mean	2.54	1.78	1.85	1.46	1.73
L_optic nerve	max	32.23	32.16	31.42	31.75	31.62
R_optic nerve	max	32.22	32.46	31.91	31.44	31.34
L_parotid	max	16.11	15.24	15.19	15.17	15.7
R_parotid	max	16.06	15.63	15.43	15.54	15.74
L_hippocampus	max	16.95	16.46	16.83	14.96	14.6
	min	8.03	7.84	7.57	7.36	7.02
	mean	9.77	9.98	9.33	9.17	8.87
R_hicpocampus	max	19.63	17.38	16.17	16.78	15.32
	min	7.97	7.58	7.31	7.15	6.89
	mean	9.83	9.91	9.38	9.07	8.92

on the treatment plan and the organs at risk of the in the established angle of whole brain irradiation. Thus, we aimed to find the panel angle that gives the best results in terms of D2, D50, D98, CI, HI and OAR doses. The results obtained for 30° board angle;

- Treatment time by 8.5%
- Significant reduction of maximum dose for organ doses below risk, especially for the hippocampus (%14) and lens (%38)
- Optimum results are offered in terms of HI and CI policies
- Prescription dose of D98 and D2 in PTV gave the closest results
- The D50 slot, which is significant in terms of the possibility of normal tissue compatibility, is the lowest

For this reason, our study has expanded the usefulness of tomotherapy and hippocampal-preserving whole brain radiotherapy with a 30° board angle in terms of both target volume and organ doses at risk.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.

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- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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