Evaluation of Treatment Planning for Head Tilting in WBRT 3D-CRT by TomoDirect mode: a Phantom Study

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ABSTRACT

The purpose of this study was to evaluate a three-dimensional conformal radiotherapy (3D-CRT) treatment plan with regard to head tilting in whole-brain radiotherapy (WBRT) using TomoDirect (TD) mode in Tomotherapy. WBRT 3D-CRT by TD was compared for a total of five head tilt angles (-20°, -10°, 0°. +10° and +20°). The dose homogeneity index (HI) and prescription dose index (CI) were calculated to confirm the target coverage. The maximum and average doses for critical organs such as the lens, eyeball and parotid glands were calculated for different angles of head tilting. The HI and CI were closet to the result value of 1 at the head tilted angle +10° and +20°. At a head tilted angle of +10°, the dose to the lens and eyeballs decreased by about 74% and about 30%, when compared with the reference angle (0°), respectively. The results of this study suggest that a head angle of +10 with chin-up would save adequate target coverage and reduce exposure dose to the lens.

Keywords: Whole-brain, TomoDirect, 3D-CRT, Head tilting

I. INTRODUCTION

Metastatic brain tumor is a common malignant tumor in the cranial cavity, observed in approximately 50% and 80% of patients with small cell lung cancer and non-small cell cancer, respectively. Whole brain radiation therapy (WBRT) is used for radiation of metastatic brain tumor over the entire brain[1-3]. This is achieved using various treatment radiation technologies including simple parallel-opposed portal technique and three-dimensional conformal radiation therapy (3D-CRT) as well as the intensity modulated radation therapy (IMRT) and volumetric modulated arc therapy (VMAT) that enable precise treatment while minimizing complications of normal functioning organs. Important critical normal organs were the lens, parotid gland, and hippocampus in WBRT. Currently, the maximum threshold dose to the lens doses not exceed 5 Gy or 10 Gy depending on the radiation therapy[4,5]. In addition, the mean dose to unilateral and bilateral parotid glands must be lower than 20 Gy and 25 Gy, respectively[6].

In WBRT, the patient's position may affect quality of treatment. Siglin et al.[7] reported that the exposure doses to the hippocampus can be reduced by up to 14.7 Gy when the head is fixed at 30° in non-coplanar IMRT treatment plan. In particular, the maximum exposure dose to the brain-stem and lens were reduced. Similarly, Lin et al.[8] reported that the exposure dose to the hippocampus and lens can be reduced by increasing the head tilting angle from 0°

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to 35°, recommending that the head tilting angle should be maintained at a minimum of 15°. However, the head tilting angle only refers to the patient's position with the chin lowered for non-coplanar plan technique such as the IMRT and VMAT. In simple treatment techniques such as parallel opposed portal technique, chin-down may not be appropriate regardless with beam angle. Additionally, the IMRT is associated with long treatment time, unnecessary low-dose and reduced accuracy and reproducibility of treatment effects due to patient movement. In emergency situation for WBRT, simple treatment techniques may be more useful with respect to treatment plan and temporal considerations.

Tomotherapy (Accuray Inc., Sunnyvale, CA) is enables IMRT option by helical mode with a gantry rotating at 360°. On the other way, TomoDirect (TD) mode uses the gantry fixed beam on at specific angles to enable the 3D-CRT. However, the patient's position is important in WBRT 3D-CRT by TD mode in Tomotherapy.

The purpose of this study was to evaluate a three-dimensional conformal radiotherapy (3D-CRT) treatment plan with regard to head tilting in whole-brain radiotherapy (WBRT) using TomoDirect (TD) mode in Tomotherapy.

II. MATERIAL AND METHODS

1. Phantom and CT scan images

A RANDO® human head phantom (Alderson Laboratory, New York, USA) was used in this study. The Tilt-Pro Tilting Base (QFix, Avondale, PA, USA) was used to adjust the position and flexion of the head phantom. A CT simulator (SOMATOM Confidence, Siemens, Munich, Germany) was used to acquire CT images to treatment planning under scanning conditions (120 kVp, 92 mAs, FOV 500 mm, slice-thickness 1 mm).

The head phantom was placed that an angle of 0° with the phantom in supine position and perpendicular to the orbitomeatal line (OML) and plane of the CT simulator table was set as the reference angle. Treatment planning images were acquired with five different head tilted angles (-20˚, -10˚, 0˚, +10˚ and +20˚) as shown in Fig. 1. Head flexion with the chin-up was set at +10° and +20° in reference to the OML, and was set at –10° and –20° in chin-down.

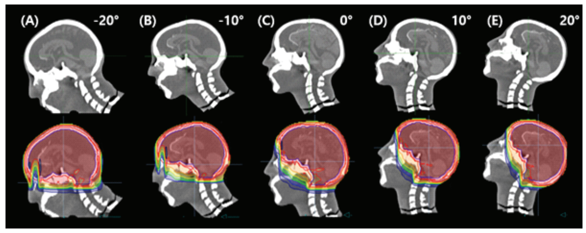

Fig. 1. Sagittal plane CT images (upper) and dose distribution (lower) of an anthropomorphic head phantom.

2. Treatment planning

The planning target volume (PTV) as treatment target and organ at risks (OARs) for WBRT were contoured in MIM Maestro (MIM Software, Cleveland, USA) which a program for contouring sites of interest. The PTV was set to sufficiently include the forebrain by adding a 5 mm blank isotopically in consideration of the asymmetric beam field and positioning errors of the clinical target volume (CTV). An OARs included the bilateral lens, bilateral eyeballs, and bilateral parotid glands. The 3D-CRT treatment plans by TD mode was performed in Accuray Precision (ver. 2.0.1.0). The angles were adjusted to the horizontal line of the lens in consideration of the beam spreading in the gantry angles of 270° and 90° under field width, pitch, and delivery mode conditions in TD mode. To reduce exposed dose to the bilateral lens, a beam blocking function was applied to prevent the binary multi-leaf collimator from opening. The prescription dose for the PTV was 30 Gy in 10 fractions with 95% of the PTV volume.

3. Evaluation

The mean of homogeneity index (HI) and conformal index (CI) for the target were calculated in treatment planning system. The homogeneity index (HI) and conformal index (CI) are obtained through Eq. (1) and Eq. (2).

$$HI = \frac{D_{95}}{D_5} \quad (1)$$

$$CI = \frac{PTV_{95\%PD}}{V_{PTV}} \quad (2)$$

A value of close to 1 for CI and HI index manes better regardless to the target coverage. In addition, the minimum, maximum, and mean doses for the OARs were also calculated.

III. RESULT

1. Target coverage

In treatment plan of the target for a total of five head tilted angles, the mead dose of PTV was 31.15 Gy in shown Table 1. The maximum dose was 3.59 Gy at –10° head tilting with chin-down, which was 119.7% higher compared with the prescription dose. In contrast, the minimum dose was 32.20 Gy at +20° head tilting with chin-up, which was 107.3% higher than the prescription dose.

Table 1. Target coverage and plan evaluation index (CI and HI) of the planning target volume (PTV).

Parameter		Head tilting angle -20°	-10°	0°	+10°	+20°
Volume (cm^3)		2035.53	2031.56	2042.08	2037.02	2038.58
Dose (Gy)	Minimum	3.48	3.66	10.09	8.44	26.84
	Maximum	35.51	35.90	34.53	32.93	32.20
	Mean	31.40	31.05	31.04	30.92	31.34
Index	CI	1.23	1.17	1.17	1.14	1.14
	HI	1.18	1.20	1.15	1.10	1.07

CI, conformity index; HI, homogeneity index

In overall, the mean HI and CI for PTV were 1.17 and 1.14, respectively. The HI and CI values for target closed to 1 as the head tilted angle increased in this study.

2. OARs

Table 2 shows the exposure dose to the bilateral lens, eyeball, and parotid gland for the five treatment plans. The mean volume of both left and right lens were 0.56 cm^3. In reference angle (0°), the maximum dose to the left and right lens were 9.18 Gy and 10.20 Gy, respectively. The dose was approximately decreased by 74% compared with the prescription dose.

The mean volume of the left and right eyeball were 14.16 cm^3 and 14.2 cm^3, respectively. The maximum dose to the eyeball decreased, while for the head tilted angle increasing, that shows an inverse relationship. In reference angle (0°), the maximum mean dose to the left and right eyeballs were 23.64 Gy and 24.71 Gy, respectively. In contrast, the minimum dose to the left and right eyeballs were 16.57 Gy and 17.92 Gy at a head tilted angle of +10°, respectively. The dose decreased by 30% for the left eyeball and 27% for the right eyeball compared with the prescription dose.

Table 2. The organ at risk (OARs) dose for WBRT 3D-CRT with five different head tilting angles.

Para-meter	OARs		Head tilting angle -20°	-10°	0°	+10°	+20°
Maxi-mum (Gy)	Lens	Rt.	6.63	6.96	10.20	2.64	4.22
		Lt.	4.80	8.34	9.18	2.40	5.48
	Eyeball	Rt.	33.42	33.39	32.23	32.23	30.63
		Lt.	33.73	33.57	32.28	32.36	30.72
	Parotid	Rt.	31.52	31.67	31.12	31.47	31.43
		Lt.	31.45	31.73	30.79	31.42	31.04
Mean (Gy)	Lens	Rt.	3.37	3.45	4.06	2.04	2.39
		Lt.	3.20	3.75	3.39	1.93	2.55
	Eyeball	Rt.	21.06	20.87	24.71	17.92	20.63
		Lt.	20.79	20.93	23.64	16.56	20.81
	Parotid	Rt.	29.39	28.86	28.10	28.00	27.63
		Lt.	29.36	28.33	27.81	28.71	26.09

OARs, organ at risks; Rt, right; Lt, left

The mean volume of the left and right parotid were 7.85 cm^3 and 8.18 cm^3, respectively. In –10° head tilted angle, the maximum dose to the left and right parotid glands were 31.73 Gy and 31.67 Gy, respectively. The minimum dose to the left and right parotid glands were 30.79 Gy and 31.12 Gy at a head tilted angle of 0°.

IV. DISCUSSION

The angle of head tilting is important In WBRT 3D-CRT by using TD mode in Tomotherapy. The patient's condition and treatment positioning are closely related with the accuracy and reproducibility of radiation therapy. In particular, the reproducibility of raising or lowering the chin is a fundamental factor in treatment planning. In IMRT, the head tilting angle doses not have as great effect on treatment planning, unless the head is tilted at large angles. For the non-coplanar treatment techniques, Ha et al.[9] reported that the exposure dose to the left eyeball, optic nerve crossover, brain-stem, and normal brain were decreased by 23.8%, 30.9%, 27.5%, and 8%, respectively, while the chin was raised to 45° in supine position using a flexed immobilization devices.

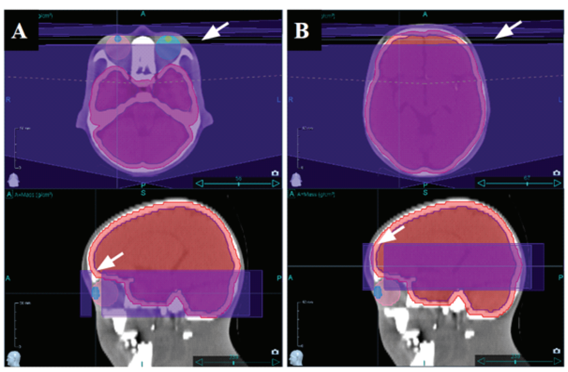

Fig. 2. View of two-opposite beam angles (purple color) in chin-down.

In 3D-CRT by TD mode, there may be difficulties in securing both sufficient target coverage and reduction of exposure dose the lens. Fig. 2 shows that how binary-MLC closes in the vicinity of the lens when the chin was not raised at a sufficient angle. Here Arrow indicate that open binary-MLC to protect exposure delivery dose to both lenses.

If the binary-MLC is interrupted in the middle to deliver the desired dose to the PTV, errors for patient positioning and movement as well as position mismatch may lead to inaccuracy and lack of reproducibility of treatment. In fact, the desired plan and treatment during clinical practice are often interrupted, while the patient's head is lowered.

Cheon et al. [10] evaluated the dose characteristics of 3D-CRT, IMRT, and Tomotherapy treatment plans by changing the angle of the head tilting base plate to 0°, 15°, 30°, and 40°. In the case of both lenses and eyes, the absorbed dose decreased when the head was elevated compared to 0°, and the best results were obtained at 30°.

In this study, There was definite differences in OARs dose by head tilted angles. At a head tilted angle of +10°, the dose to the lens and eyeballs decreased by about 74% and about 30%, when compared with the reference angle (0°), respectively. In particular, the maximum dose to the lens was 9.69 Gy at the reference angle, which exceeded the threshold dose of 5 Gy for the cataract. Merriam et al.[11] reported that an exposure dose of 2.5-6.5 Gy and 6.51-11.5 Gy for the lens increased the risk of the cataract by 33% and 66%, respectively, and suggesting the urgent need to reduce exposure dose to OARs.

V. CONCLUSION

In this study, WBRT 3D-CRT treatment plan was evaluated using TomoDriect mode and our findings showed differences in target coverage for PTV and OARs dose by head angles. The results of this study suggest that a head angle of +10 with chin-up would save adequate target coverage and reduce exposure dose to the lens.

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토모다이렉트를 이용한 3차원 전뇌 방사선치료에서 두상 각도에 따른 치료계획평가: 팬톰 실험

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요 약

본 연구의 목적은 토모다이렉트를 이용한 토모테라피 방사선치료에서 두상 각도(head tilting)에 따라 3차원 입체조형 전뇌 방사선치료 계획을 평가하고 자 하였다. 총 다섯 가지 두상 각도(-20°, -10°, 0°, +10°, +20°)를 비교 평가하였다. 두상 각도에 따라 표적에 대한 선량균질지수(homogeneity index, HI)와 처방선량지수(conformity index, CI)를 계산하였고, 정상 장기인 수정체, 안구, 귀밑샘에 대한 최대선량과 평균 선량을 구하였다. 선량균질지수와 처방선량지수는 두상 각도가 +10°와 +20°에서 수치 1에 가까웠다. 두상 각도 +10°에서 수정체와 안구의 선량은 기준 두상각도(0°)에 비해 각각 약 74%와 30% 감소하였다. 턱을 올린 상태의 +10°의 두상 각도는 표적에 대한 선량균일지수와 처방선량지수가 적합하며 렌즈와 안구의 선량을 줄일 수 있는 각도로써 권장한다.

중심단어: 전뇌, 토모다이렉트 3차원 입체조형 방사선치료, 두상 각도

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