Journal of Radiotherapy in Practice

Journal of Radiotherapy in Practice (2016)
15, 269–275
doi:10.1017/S1460396916000212

Original Article

Improvement of dose homogeneity with irregular surface compensator in whole brain radiotherapy

H. Fujita, N. Kuwahata, H. Hattori, H. Kinoshita, H. Fukuda

Department of Radiation Oncology, Osaka Saiseikai Nakatsu Hospital, Kita-ku, Osaka, Japan

(Received 24 December 2015; revised 29 March 2016; accepted 31 March 2016; first published online 2 May 2016)

Abstract

Purpose: The aim of this study was to evaluate the dosimetric aspects of whole brain radiotherapy (WBRT) using an irregular surface compensator (ISC) in contrast to conventional radiotherapy techniques.

Methods: Treatment plans were devised for 20 patients. The Eclipse treatment planning system (Varian Medical Systems) was used for dose calculation. For the ISC, a fluence editor application was used to extend the range of optimal fluence. The treatment plan with the ISC was compared with the conventional technique in terms of doses in the planning target volume (PTV), dose homogeneity index (DHI), three-dimensional (3D) maximum dose, eye and lens doses and monitor unit (MU) counts required for treatment.

Results: Compared with conventional WBRT, the ISC significantly reduced the DHI, 3D maximum dose and volumes receiving 105% of the prescription dose, in addition to reducing both eye and lens doses ($p < 0{\cdot}05$ for all comparisons). In contrast, MU counts were higher for the ISC technique than for conventional WBRT (828 versus 328, $p < 0{\cdot}01$).

Conclusion: The ISC technique for WBRT considerably improved the dose homogeneity in the PTV. As patients who receive WBRT have improved survival, the long-term side effects of radiotherapy are highly important.

Keywords: dose homogeneity index; fluence editor; irregular surface compensator; multileaf collimator; whole brain radiotherapy

INTRODUCTION

Whole brain radiation therapy (WBRT) is one of the main treatment methods for brain metastases. In addition, prophylactic cranial irradiation (PCI) is currently a recommended treatment method for patients with small-cell lung cancer (SCLC) because it has been shown to reduce the incidence of symptomatic brain metastases while promoting immune response and improving overall chances of survival.[1,2] As patients who receive cranial radiotherapy have improved survival rates, the long-term side effects of radiotherapy, which include dementia, neurocognitive impairment and radionecrosis, are highly important. These complications are a particularly important

Correspondence to: Hideki Fujita, Department of Radiation Oncology, Osaka Saiseikai Nakatsu Hospital, 2-10-39 Shibata, Kita-ku, Osaka 580-0012, Japan. Tel: 81(6)6372-0333. Fax: 81(6)6105-1360. E-mail: hima71f@zeus.eonet.ne.jp

consideration for patients with longer life expectancy. Therefore, treatment planning with better dose homogeneity is required.

Although WBRT uses a bilateral opposed field arrangement in general, the dose distribution is complicated because of contour irregularities of the skull and variations in the source-to-skin distance. Although the International Commission on Radiation Units and Measurements (ICRU) recommends that the planning target volume (PTV) should be within 95 to 107% of the isodose surface,[3] radiation-dose homogeneity is seldom achieved in conventional WBRT.

To date, several whole brain irradiation techniques have been reported to improve the dosimetry distribution. These include the use of physical compensators, electronic compensation and inverse-planning intensity-modulated radiation therapy (IMRT).[4–11] However, these are not practical methods because of the cost, planning time and skill required.

In the present study, we used an irregular surface compensator (ISC) technique to increase the homogeneity of the dose to the target volume while decreasing the dose absorbed in irradiated tissues outside the targeted tissue. Electronic compensation involves radiation beam modulation using dynamic multileaf collimators (dMLCs) instead of physical wedges, and it is one method of forward-planning IMRT. There are two types of electronic compensators available in the Eclipse treatment planning system (TPS). The first is a planar electronic compensator, which compensates to a plane perpendicular to the central axis of the beam. To generate an electronic compensator, a physical planar compensator must first be generated. The software then allows the planar compensator to be converted to an electronic compensator. Conversely, the ISC compensates to a curved surface. The use of a curved compensation surface provides better distributions in cases where the shape of the target volume is rounded, such as breast treatment. The ISC, in conjunction with the fluence editor, demonstrated improved dose homogeneity in whole breast radiotherapy.[12] However, to our knowledge, there have been no studies investigating the efficacy of the fluence editor alone in WBRT. Thus, the present study aimed to compare the dose distribution of WBRT between the ISC technique and the conventional technique.

MATERIALS AND METHODS

Twenty patients previously treated with conventional WBRT were selected for retrospective planning using the ISC technique. Before the CT scan, each patient was immobilised using a thermoplastic head shell in the supine position. Patients underwent a CT scan with a slice thickness of 1·0 mm. CT data were then transferred to the TPS, Eclipse (version 8.9; Varian Medical Systems, Palo Alto, CA, USA), in accordance with the common practice at our institute. The body contour was automatically generated by a built-in contouring feature of the TPS. Eyes and lenses were delineated as organs-at-risk (OARs) by a medical physicist according to the policy at our institute. In the present study, the PTV was defined as whole brain tissue for simplicity.

For each patient, treatment plans were designed using two parallel opposing fields (initially 90° and 270°) for conventional WBRT. The gantry was tilted until both the lenses were on a line parallel to the beam direction. The collimator angle was 0° for all treatment planning procedures. The isocentre was placed in the mid-plane of the PTV. The radiation fields were automatically created by adding 10-mm margins to the inferior direction and 20-mm margins to all other directions. However, the beam edge of the nearby lens traversed ~5 mm behind the lens. The anisotropic analytical algorithm (version 8.9.17)[13] was used for dose calculation. Tissue heterogeneity correction was used in all the treatment plans. The prescription dose was 30 Gy in 10 fractions at the isocentre. The dose rate was set to 400 monitor unit (MU) counts per minute. All treatments were performed with 10 MV photon energy from a Clinac iX with a 120-leaf MLC (Varian Medical Systems). For this study, we performed treatment planning with the ISC technique based on conventional WBRT fields.

An ISC, a type of electronic tissue compensation system, is a feature of the Eclipse device, which enables improved dose homogeneity for irregularly shaped surfaces. If the dose is not sufficiently homogenous, the fluence editor, which colours the fluence map, can modify the fluence distribution to achieve better dose homogeneity. The fluence editor, which visualises the fluence of a selected field from the beam's-eye-view (BEV), allows the user to extend the fluence outside a body surface graphically with a digital 'paintbrush'. The ISC technique is a manual forward-planning IMRT and is designed to shrink hot and cold regions. First, by viewing the dose distribution along the BEV, the fluence editor was used to shield the areas of the brain receiving >105% of the prescription dose. On the BEV windows, the value of the transmission factor of the hot-spot regions was measured. Subsequently, the transmission factor was replaced by a paintbrush. The transmission factor of the cold-spot regions was similarly replaced. The hot- and cold-spot regions could be modified by replacing the transmission factor. Fluence maps were converted to leaf sequences for dMLC delivery. On the BEV windows, the value of the transmission factor of the hot-spot regions, which is a parameter regarding leaf sequence, was measured. After the recalculation of dose distribution, if a dose >105% remained, the processes described above were repeated to achieve an optimal dose distribution. A standard initial fluence pattern is presented in Figure 1a, and the fluence pattern after modification using the fluence editor is presented in Figure 1b.

Two different treatment plans (conventional or ISC) were objectively compared using dose volume histograms (DVHs) dose to PTV, OAR and MU counts required for treatment. For PTV, the following values were compared: the dose homogeneity index (DHI) and the per cent volumes receiving at least 103 and 105% of the prescribed dose ($V_{103\%}$ and $V_{105\%}$, respectively).

DHI is defined as follows:

$$\mathrm{DHI} = (\mathrm{D}_{2\%} - \mathrm{D}_{98\%})/\mathrm{D}_{50\%} \times 100$$

where $D_{2\%}$ for PTV is the dose corresponding to 2% volume on the cumulative DVH, $D_{98\%}$ for PTV is the dose corresponding to 98% volume on cumulative DVH and $D_{50\%}$ is the dose corresponding to 50% volume on the cumulative DVH. For the OAR, the following parameters were compared: mean dose to eye, maximum dose to eye, mean dose to lens, maximum dose to lens and three-dimensional (3D) maximum dose.

The Wilcoxon signed rank test was used for comparing each dosimetric parameter. The significance was set at $p < 0{\cdot}05$. The statistical analyses were performed using IBM SPSS Statistics 21 for Windows (IBM Japan, Chuo-ku, Tokyo, Japan).

RESULTS

The dose distributions obtained for a standard plan using ISC and the conventional technique are shown in Figure 2. The isodose regions greater than 105% of the prescribed dose were eliminated in the ISC technique. The comparison of DVHs between the two techniques is shown in Figure 3. It can be observed that the maximum and mean dose to the eyes and lens are much higher in the conventional technique than in the ISC technique.

The patient characteristics are listed in Table 1. The mean brain volume outlined in the 20 patients was 1292 cm^3. The results of dose variation analysis of the 20 patients are compared with the DVH values in Table 2. It can be seen that DHI was 8·3 for the conventional technique and 3·6 for the ISC technique. The $V_{105\%}$ for PTV was 22·2% for the conventional technique and 0% for the ISC technique.

The ISC technique was superior to the conventional technique in the following aspects. The ISC technique had a significantly reduced DHI for volumes receiving 103 and 105% of the prescription dose, the 3D maximum dose, and the lens and eye mean doses for dose evaluation ($p < 0{\cdot}05$ for all comparisons).

The total MU for the conventional and ISC techniques were 328·2 and 828·0, respectively. The beam-on time of the two-field arrangement for conventional and ISC techniques were approximately 49·2 s and 124·7 s, respectively. The mean values of the treatment MUs were significantly increased for the ISC when compared with those for the conventional technique ($p < 0{\cdot}01$).

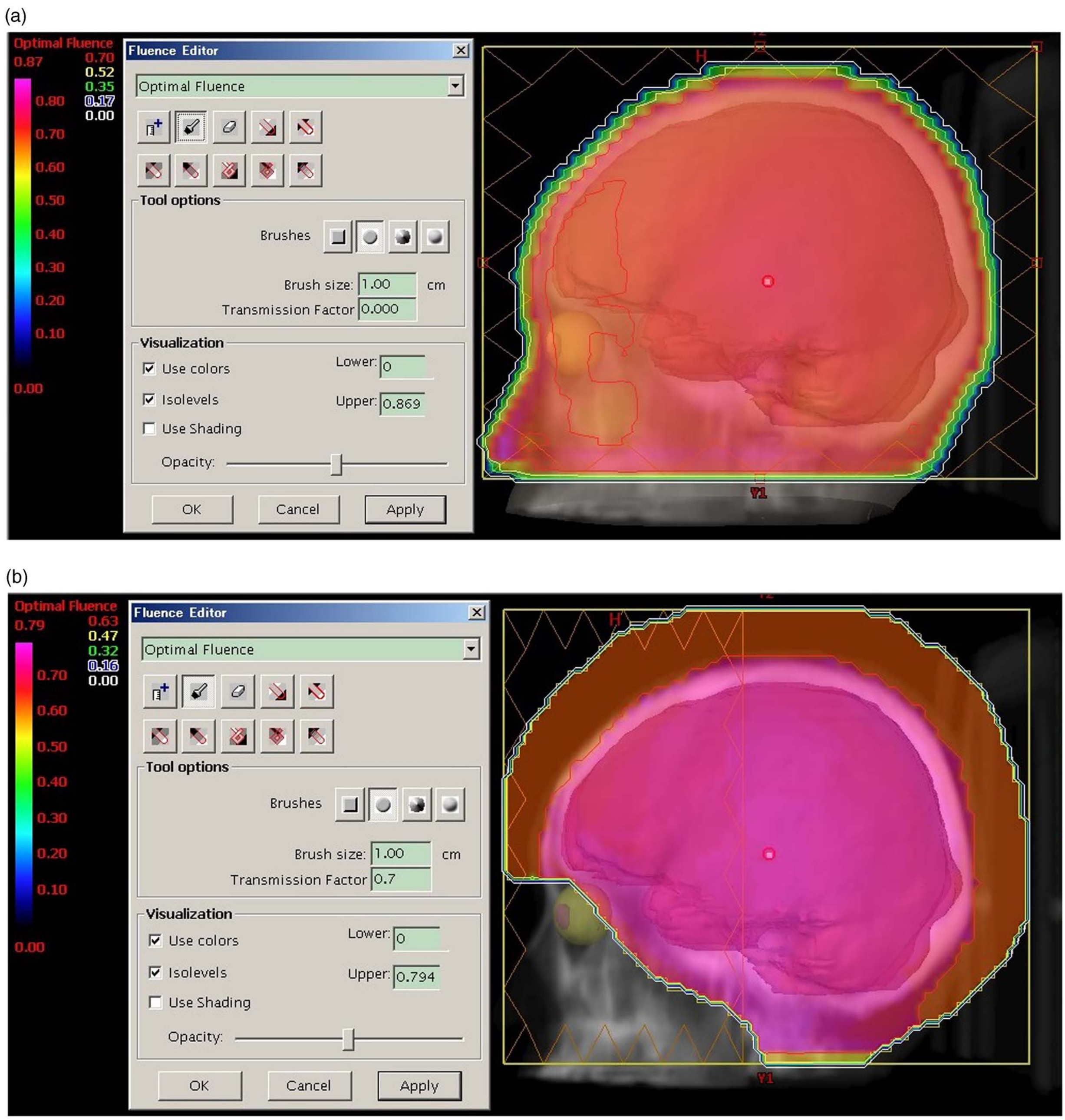

Figure 1. (a) Standard initial fluence pattern. (b) Fluence pattern after modification using the fluence editor tool.

DISCUSSION

This study aimed to compare two WBRT techniques in terms of the homogeneity of dose distribution and the hot-spot regions. Various techniques have been developed to provide a homogeneous dose distribution in the PTV, such as the field-in-field (FIF) technique, the use of customised compensators and inverse-planning intensity-modulated radiotherapy (IP-IMRT).[4–11] The FIF technique is a practical method that is less operator-dependent. However, the procedures to optimise the plans for WBRT have not been well used at our institution. The use of customised compensators is not a practical method in terms of the preparation and cost performance. Moreover, IP-IMRT requires a relatively higher planning time and advanced planning skills. Therefore, to

https://doi.org/10.1017/S1460396916000212 Published online by Cambridge University Press

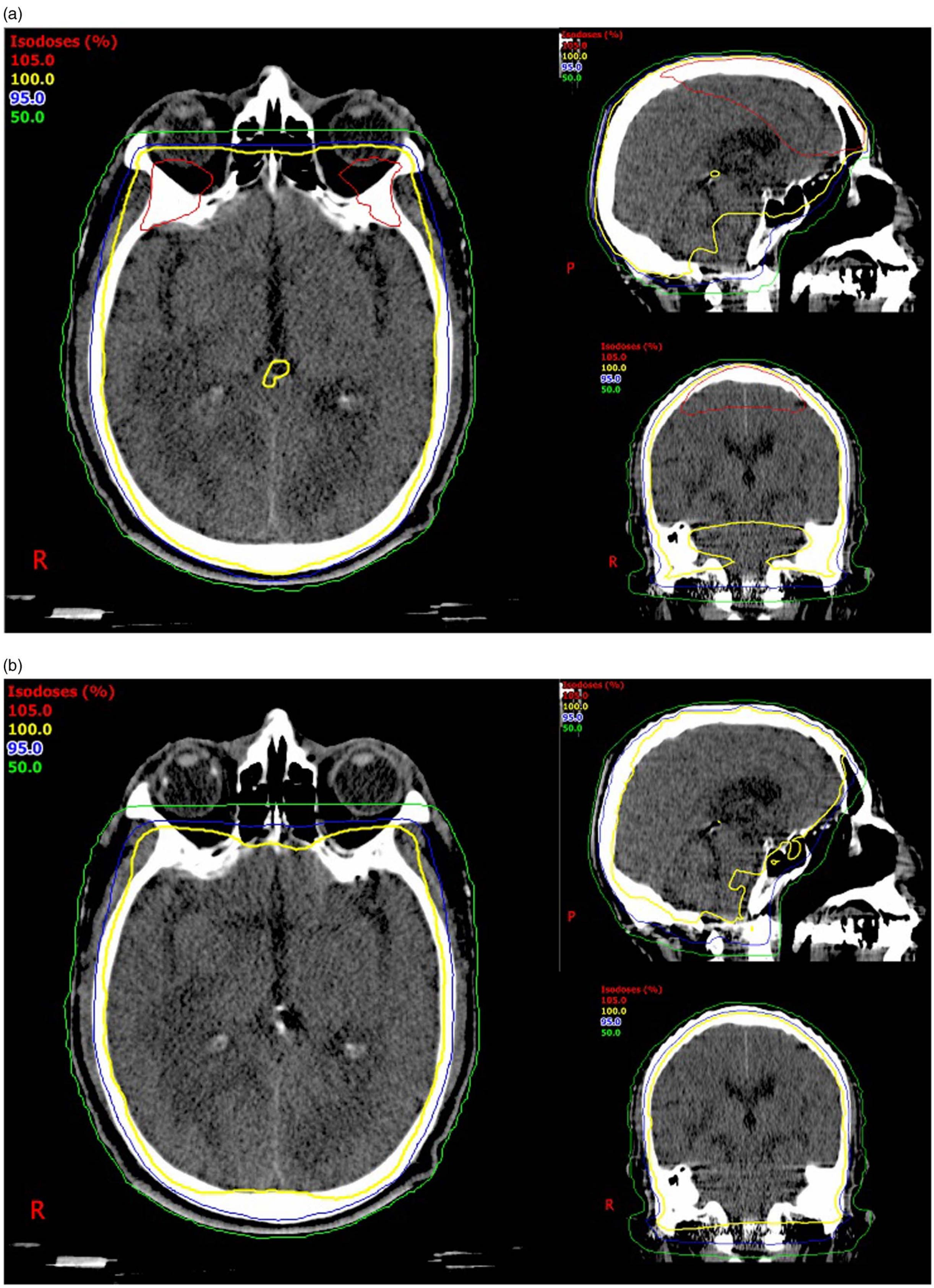

Figure 2. Dose distributions obtained in a standard treatment plan with (a) the conventional technique and (b) the irregular surface compensator technique. Isodose lines are normalised to the prescribed dose.

https://doi.org/10.1017/S1460396916000212 Published online by Cambridge University Press

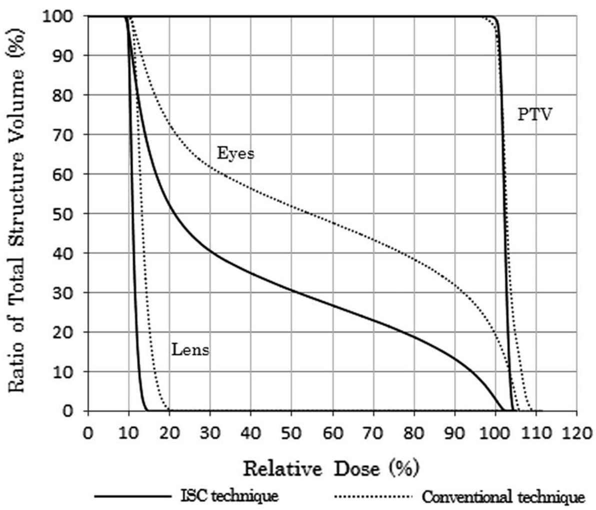

Figure 3. Dose volume histogram comparing the dose distributions for whole brain treatment using the conventional and the irregular surface compensator techniques.

Table 2. *Dosimetric results of 20 patients with the conventional and irregular surface compensator (ISC) techniques*

	Conventional technique	ISC technique	*P*-value
PTV			
$D_{2\%}$ (Gy)	32·6 (0·3)	31·2 (0·1)	<0·01
$D_{98\%}$ (Gy)	30·1 (0·2)	30·1 (0·2)	0·82
$D_{50\%}$ (Gy)	31·0 (0·2)	30·7 (0·1)	<0·01
DHI	8·0 (1·1)	3·5 (0·4)	<0·01
$V_{103\%}$ (%)	55·3 (11·2)	25·0 (11·2)	<0·01
$V_{105\%}$ (%)	22·2 (6·2)	0·0 (0·0)	<0·01
OAR			
Eye mean dose (Gy)	8·7 (3·0)	7·3 (2·2)	0·02
Eye maximum dose (Gy)	30·6 (1·2)	27·0 (5·1)	<0·01
Lens mean dose (Gy)	3·5 (0·5)	3·3 (0·3)	0·01
Lens maximum dose (Gy)	5·0 (1·0)	4·5 (0·7)	0·04
3D maximum dose (Gy)	33·6 (0·7)	31·5 (0·0)	<0·01
Total MU (counts)	328·2 (6·1)	828 (35·4)	<0·01

Notes: Data are presented with mean ± standard deviation.
PTV, planning target volume; $D_{2\%}$, dose corresponding to 2% volume on cumulative dose volume histogram; $D_{98\%}$, dose corresponding to 98% volume on cumulative dose volume histogram; DHI, dose homogeneity index; $V_{103\%}$, $V_{105\%}$, percentage volumes receiving at least 103% and 105% of the prescribed dose, respectively; OAR, organ-at-risk; 3D, three-dimensional; MU, monitor unit.

Table 1. *Patient characteristics*

Gender	
Male	11
Female	9
Age (years)	
Range	52–87
Mean	71
Median	72
Brain volume (cm^3)	1292
SD	132

improve the dosimetry of the irradiated brain further, we focussed on the ISC technique, a method with which we have sufficient experience.

Goyal et al. compared the dosimetry among the ISC technique, the conventional technique and IP-IMRT for WBRT, and they reported increased dose homogeneity with the ISC technique.[6] Although the maximum dose to the intracranial volume with ISC and IP-IMRT was reduced compared to that with the conventional technique, the minimum dose to the intracranial volume was also reduced. In the present study, the ISC technique resulted in not only a significant decrease of the high-dose region for PTV ($D_{2\%}$) but also $V_{103\%}$ and $V_{105\%}$ values that were comparable to those of the conventional technique as well as a similar low-dose region for PTV ($D_{98\%}$).

With the DHI evaluation, the ISC technique was determined to improve the dose homogeneity of PTV significantly when compared with that of the conventional technique. Figure 1 presents the difference in dose distributions between the ISC and the conventional technique. The prescription or 100% isodose line (30 Gy in this case) covers brain tissue sufficiently well, and no hot spot (105% isodose line) is shown for the ISC technique.

With regard to the OAR, our results indicated that with the ISC technique, the mean doses to the lens and eye significantly decreased. In addition, the ISC technique reduced the 3D maximum dose by 7% (2·1 Gy). It is expected that with this technique, the risk of early and late radiotherapy-associated complications will be reduced.

The ISC technique significantly increased the MU counts compared with those of the conventional technique (p <0·01). The beam-on time for the ISC method was 2·5 times (124·2 s) that for the conventional technique (49·2 s). The ISC technique required a greater number of MU counts than the conventional technique because the ISC technique used dMLCs. This is a disadvantage for the patients and the institution.

With both techniques, the treatment plans were generated by an expert medical physicist, and the standard planning time for the ISC technique was 10–15 min longer than for the conventional technique. The optimisation process was repeated 30–50 times using the fluence editor. Although the treatment-delivery and planning time for the ISC technique were longer than those for the conventional technique, the use of the ISC technique shows an improvement in dose distribution that is critical to patient outcomes. The patients selected for this study were treated with the ISC techniques. In fact, the ISC technique has been applied to all patients except those using a bed or stretcher for movement and 70% of patients at our institution are treated with this technique. One limitation of the ISC technique is that a high level of planning skill is required. However, our institution has two expert planners; hence, this technique can be performed with little additional workload, achieving superior levels of dose homogeneity compared with those of conventional techniques.

Several studies investigated hippocampal-sparing WBRT using IMRT.[7–10] Hippocampus sparing during WBRT is useful to reduce neurocognitive deficits caused by radiation. In the future, we intend to evaluate the feasibility of hippocampal-sparing WBRT using the ISC technique.

CONCLUSION

The ISC technique for WBRT results in a significantly improved dose distribution in the PTV, in addition to causing a significant reduction in the radiation dose received by the lenses, eyes and surrounding tissues. It is expected that with this technique, the risk of late radiotherapy-associated complications will be reduced.

Acknowledgements

None.

Financial support

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Conflicts of Interest

None.

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