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Improvement of the robustness to set up error by a virtual bolus in total scalp irradiation with Helical TomoTherapy

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Abstract
Intensity-modulated radiation therapy has recently been used for total scalp irradiation. In inverse planning, the treatment planning system increases the fluence of tangential beam near the skin surface to counter the build-up region. Consequently, the dose to the skin surface increases even with small setup errors. Replacing the electron density of the surrounding air of some thickness with a virtual bolus during optimization could suppress the extremely high fluence near the skin. We confirmed the usefulness of a virtual bolus in total scalp irradiation. For each patient, two beams were planned, one with and the other without a virtual bolus. The dose distribution was calculated using computed tomography images that were shifted to simulate setup errors. The hot spot dose was suppressed in the plans using a virtual bolus. In conclusion, using a virtual bolus improved the robustness to setup errors.

Keywords Total skin irradiation · Helical TomoTherapy · Intensity-modulated radiation therapy

1 Introduction

Total scalp irradiation (TSI) for scalp angiosarcoma is a challenging technique because of the complex shape and superficial nature of the target. Although electron beams have been used frequently because of their relatively high surface-dose distribution, they have problems such as low-dose homogeneity, uncertainty of field junctions, and complexity of the treatment setup [1]. With the recent advancement of radiation techniques, intensity-modulated radiation therapy (IMRT) with Helical TomoTherapy (Accuray Inc., Sunnyvale, CA, USA) has been used for TSI [2]. However, the dose calculation and optimization of the IMRT tends to be inaccurate, which is an important problem, because the clinical target volume (CTV) in TSI is located in a thin build-up region near the skin surface [3]. Unexpected high-dose areas appear with small setup errors because the treatment planning system increases the fluence of tangential beams near the skin surface to counter the build-up region. The use of a virtual bolus (VB) in tomotherapy planning has been proposed for targets close to, or even outside, the skin surface [4]. The VB replaces the electron density of the surrounding air of some thickness with some value during the optimization, which is removed during the actual treatment, resulting in the suppression of the extremely high fluence near the skin surface. Moreover, the thickness of the target could be increased using a VB and the robustness to the setup errors could be improved. In this study, we aimed to confirm the usefulness of a VB by simulating how the dose distribution of TSI varied with the setup error depending on whether a VB was used.

2 Materials and methods

The simulation was performed in two patients treated with TSI. Planning computed tomography (CT) images were obtained with 2-mm-thick slices using a 16-slice CT

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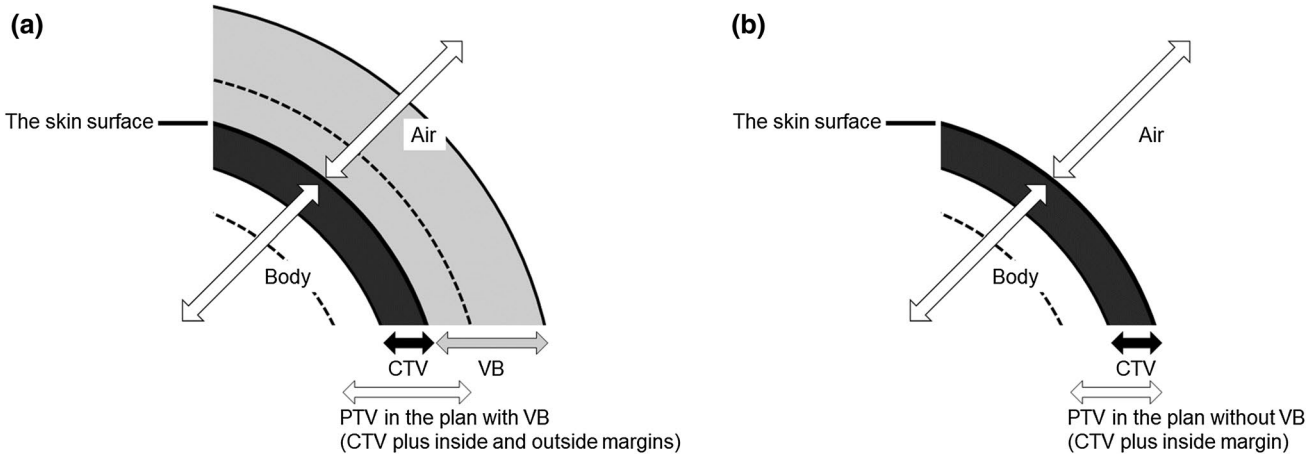

Fig. 1 The schema of contour in plans using blous (VB). The VB was placed as an external ring all around the body, from the skin surface to a depth of 8 mm thickness (the gray area). The CTV was delineated from the surface of the scalp skin to a depth of 3 mm (the black area) PTV was CTV with a 3-mm margin on both sides of CTV (area surrounded by broken lines). The Schema of contour in plans not using a VB. The CTV is the same as that used a VB. PTV was CTV with a 3-mm margin only on the inside of CTV and excluding the area outside CTV

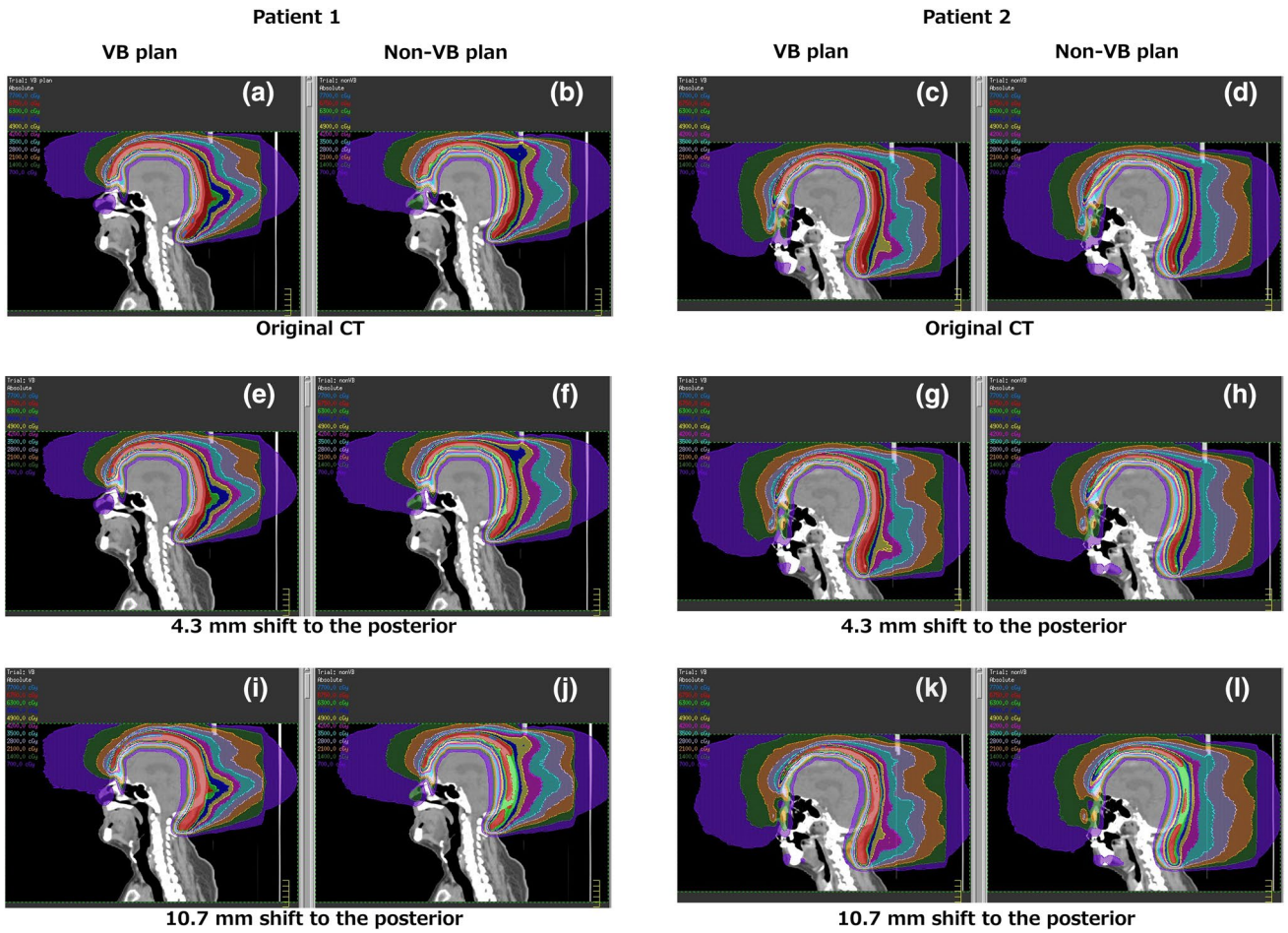

Fig. 2 The dose distribution of the original plans (**a**–**d**) and the simulation on compound tomography images shifted in the posterior direction by 4.3 mm (**e**–**h**) and 10.7 mm (**i**–**j**). The red area was irradiated by 95% of the prescribed dose. In the plans not using a virtual bolus with 10.7-mm shift (**j**–**l**), a low dose area was visible in the occipital region

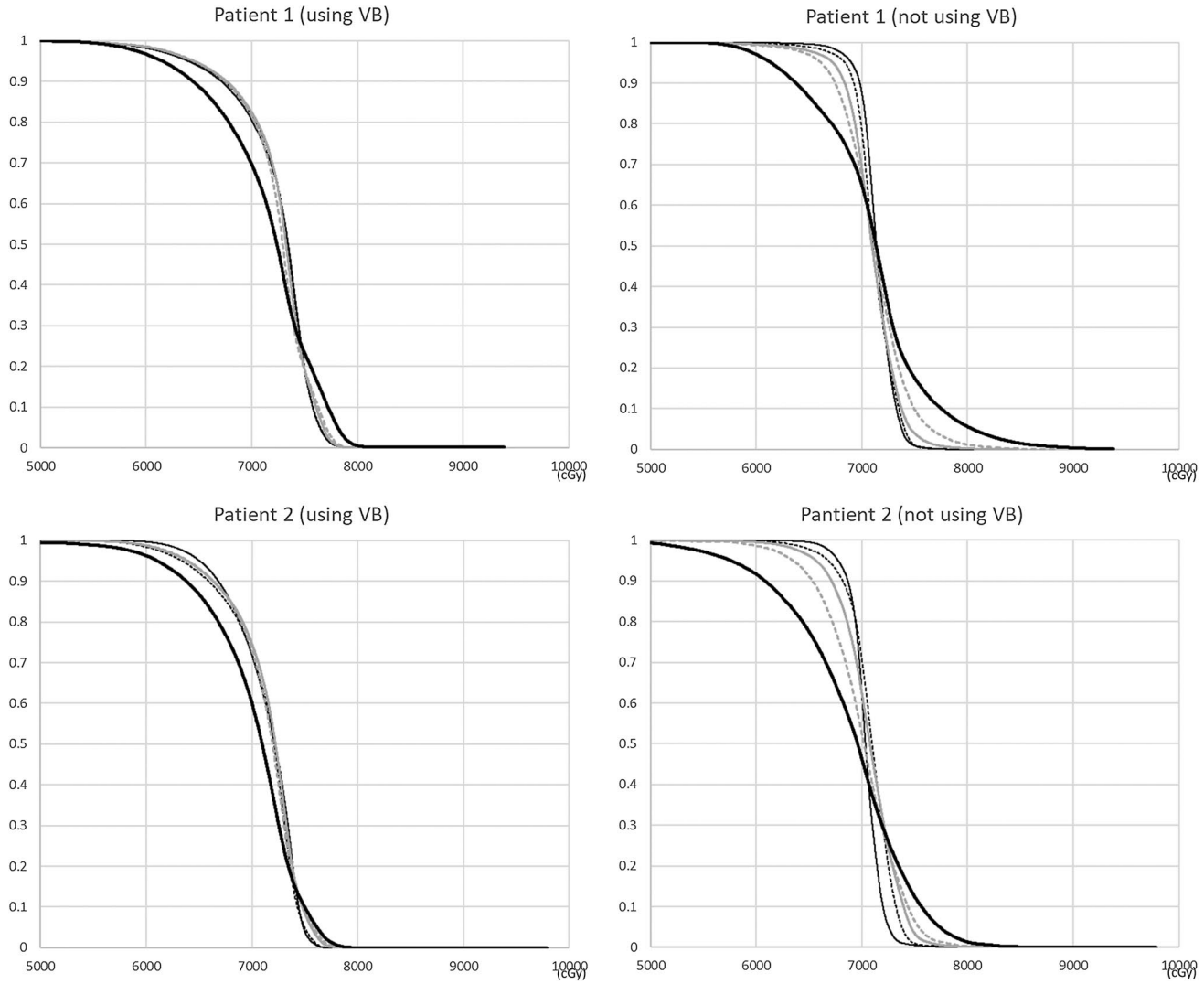

Fig. 3 Dose–volume histograms. DVH of the original plan is indicated by the thin solid black line is one pixel (2.1 mm), the solid gray line is two pixels (4.3 mm), the dashed gray line is three pixels (6.4 mm), and the thick black line is five pixels (10.7 mm)

system (Aquilion LB, Canon Medical Systems, Tokyo, Japan) in the supine position, with the patient wearing a thermoplastic head mask. For each patient, two beams were planned, one using a VB and the other not using it. The schema of the contours in the plans are shown in Fig. 1. The CTV consisted of the total scalp skin, from the surface of the scalp skin to a depth of 3 mm, and gross tumors. In the plans using a VB, the planning target volume (PTV) was the CTV with a 3-mm margin in all directions. The VB with a density of 1.0 g/cm^3 was placed as an external ring all around the body, from the skin surface and with an 8-mm thickness. In the plans not using a VB, the PTV was CTV with a 3-mm margin only toward the inside. The planning was performed using the TomoTherapy Planning Station (TomoHDA System ver. 2.0.2, Hi-Art ver. 4; Accuray Inc., Sunnyvale, CA, USA). The prescribed dose was 70 Gy in 35 fractions to $D_{95\%}$ (exceeding 95% of the volume) of the PTV in the plans with a VB and to $D_{80\%}$ of the PTV in the plans not using a VB. The size and type of jaw were 2.512 cm and dynamic, respectively. The pitch was 0.303. The planning modulation factor was 3.0. To assess the influence of the setup errors, the dose distributions of both plans were calculated on CT images that were uniformly shifted to the posterior direction. We rewrote the tag information of digital imaging and communications in medicine (DICOM) using an in-house program and shifted the CT images. In the TomoTherapy Planning Station, a dose grid of CT was reconstructed into $256 \times 256 \times N$ pixels (where N is the number of planning CT slices). As the field of view of planning CT is 55×55 cm, 1 pixel equals 0.2148 cm (= 55/256 cm) in an axial slice. The simulation was performed on CT images shifted to the posterior with

Table 1 DVH parameters

DVH Parameters	Shift (mm)	Patient 1		Patient 2	
		VB	Non-VB	VB	Non-VB
CTV D2cc (Gy)	0	78.0	75.7	76.1	74.7
	2.1	77.9	75.3	76.3	75.7
	4.3	78.2	78.3	77.0	77.4
	6.4	78.4	82.1	77.4	79.0
	10.7	79.8	88.2	78.1	82.1
CTV D98% (Gy)	0	60.4	67.7	63.1	66.6
	2.1	60.7	66.5	60.6	64.8
	4.3	61.1	64.9	61.1	63.5
	6.4	61.2	63.9	61.8	61.1
	10.7	58.2	59.1	57.6	53.5
CTV D98% (Gy)	0	91.3	99.1	91.1	98.2
	2.1	91.8	98.0	88.4	95.7
	4.3	92.1	96.5	89.6	92.7
	6.4	92.2	94.0	89.6	84.4
	10.7	84.6	82.0	81.4	70.4

CTV clinical target volume, *DVH* dose-volume histogram, *VB* virtual bolus

1 pixel (2.1 mm), 2 pixels (4.3 mm), 3 pixels (6.4 mm), and 5 pixels (10.7 mm). In addition, the simulations on CT images shifted to other directions were also performed. The simulations of the shift on the axial cross section were examined with a shift of 3 pixels (6.4 mm). The simulations of the shift to cranio-caudal directions were examined with a shift of 3 slices (6 mm).

3 Results

3.1 The simulation performed on CT images shifted to the posterior direction

The dose distributions of both the plans in two patients calculated on CT images, which were shifted by 4.3 and 10.7 mm, are shown in Fig. 2. The dose-volume histograms (DVH) are shown in Fig. 3. DVH parameters are summarized as Table 1. In the plans not using a VB, the dose homogeneity decreased as the shift amount increased. On the other hand, the shift within 6.4 mm did not significantly affect DVH in the plans using a VB.

The high point dose was suppressed with a VB. In patients 1 and 2, the dose to the most exposed 2 cm^3 (D_{2cc}) of CTV on CT images shifted by 10.7 mm increased to 88.2 and 82.1 Gy, respectively, in the plans not using a VB and to 79.8 Gy and 78.1 Gy, respectively, in the plans using a VB. The dose coverage of CTV was inferior in the original plans using VB because of build-up effect. However, the dose coverage of CTV in plans using VB was superior when the shift amount exceeded 4.3 mm.

3.1.1 The simulation performed on CT images shifted to the other directions

DVH parameters calculated on the CT images that shifted to directions other than posteriorly are shown in Table 2. In general, the appearance of high-dose areas was suppressed using a VB and the posterior shift. Without using VB, D_{2cc} of CTV on CT images shifted by 6.4 mm to the anterior reached 99.4 Gy in the patient 1. The characteristic point is that dose coverage of CTV in the shift of caudal direction was worse than in the other directions with or without VB.

4 Discussion

We examined the usefulness of VB by calculating the dose distributions of the plans with and without VB in the shifted CT images simulating a setup error. The dose homogeneity was maintained even with a setup error of 6 mm in the plan using a VB. To the best of our knowledge, this is the first report of a simulation using a VB in TSI. A VB has two characteristics. One is that VB prevents unnecessary high dose by penalizing the optimization for areas with low electron density. The other is that it increases the thickness of the target and secures the dose coverage when a setup error occurs. A VB improves the robustness to setup errors in TSI by Helical TomoTherapy. A thick and dense VB is effective to compensate for the setup errors and suppress high fluence near the skin. However, the thicker the VB, the greater the deviation of the dose distribution between the plan and the actual treatment. The evaluation of the optimal thickness and density of the VB is beyond the scope of this study; however, this challenging research should be conducted in future studies. We adopted the dose prescription of D95% in the plans using VB whereas D80% in the plans not using VB. In a plan not using VB, PTV reaches the skin surface, so it was impossible to plan with a prescription of *95%D*. Moreover, in a plan using VB, even if we adopted the prescription of D95% for optimization, the PTV dose in the real treatment was decreased by the build-up effect. We decided the prescription to make the coverages of the CTV of 70 Gy as equal as possible in the plan with and without VB. The characteristic point is that the dose coverage of the CTV in the shift to the caudal direction was worse than that to other directions with or without VB. This is because the CTV does not protrude from the body surface on the planning CT by the shift to the caudal direction and is not exposed to the high fluence beam. In the setup of the actual treatment,

Table 2 DVH parameters in other direction

DVH parameters	Direction	Shift (mm)	Patient 1		Patient 2	
			VB	Non-VB	VB	Non-VB
CTV D2cc (Gy)	Original	0	78.0	787	76.1	74.7
	Posterior	6.4	78.4	82.1	77.4	79.0
	Anterior	6.4	80.0	99.4	78.7	86.3
	Left	6.4	80.6	93.6	77.9	88.1
	Right	6.4	80.5	96.8	79.2	88.1
	Cranial	6	78.1	79.0	75.9	86.1
	Caudal	6	78.3	74.7	75.0	76.3
CTV D98% (Gy)	Original	0	60.4	67.7	63.1	76.7
	Posterior	6.4	61.2	63.9	61.8	66.6
	Anterior	6.4	60.0	67.4	66.5	61.1
	Left	6.4	69.6	70.3	67.0	68.1
	Right	6.4	60.0	65.4	67.7	66.7
	Cranial	6	63.1	68.0	67.4	69.8
	Caudial	6	48.1	53.4	46.5	50.0
CTV V95% (%)	Original	0	91.3	99.1	91.1	98.2
	Posterior	6.4	92.1	94.0	89.6	84.4
	Anterior	6.4	90.7	98.9	88.4	95.0
	Left	6.4	91.0	95.9	90.2	89.1
	Right	6.4	91.7	97.1	92.1	89.2
	Cranial	6	95.4	99.3	91.1	97.5
	Caudal	6	74.2	78.6	65.0	73.8

the craniocaudal position should be preferentially adjusted. After that, it should be confirmed that the setup error in the axial section is within 6 mm. Some previous reports used a real bolus for TSI [5]. Although the real bolus is useful for stabilizing the dose to the skin surface, the reproducibility of its positioning is difficult to maintain. In the inverse planning using Helical TomoTherapy, the dose to the skin surface tends to increase by the tangential beams; thus, we considered that a bolus was unnecessary.

5 Conclusion

A VB improves the robustness to set-up errors in TSI by Helical TomoTherapy.

Compliance with ethical standards

Conflicts of interest The authors have no conflicts of interest. This is a simulation study using previously acquired information. This study was ethically approved by the institutional review board of the University of Tokyo Hospital, with reference No. 3372.

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