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Original article

Effect of body thickness on helical and direct treatment delivery modes: a phantom study

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Abstract

Objective: Chemoradiation therapy is among the standard treatments for cancer, which often causes a decrease in appetite and subsequent weight loss. When weight loss occurs during treatment, the external body contour changes from that indicated during initial planning, causing changes in dose distribution to the target tumor regions and organs at risk (OARs). This study aimed to examine the dose changes to both the target regions and OARs, based on the dose-volume histogram (DVH).

Methods: We established a 60 mm-diameter planning target volume (PTV) and a 30 mm-diameter rectum region of interest (OAR), using a phantom; this was followed by a 50 Gy/25 fraction irradiation to the target region that was measured using a two-dimensional-array ion chamber device. The measurement was conducted by varying the bolus thickness from 0 to −25 mm, in 5 mm decrements. In addition, the maximum dose for both PTV and OAR were evaluated based on the DVH, created using the Adaptive software.

Results: The gamma analysis showed that the pass rate was less than 95% when the bolus thickness was altered by −25 mm for the helical delivery mode and by −10 mm for the direct delivery mode, resulting in a dose error greater than 3%. Results of the DVH evaluation revealed that the maximum dose of PTV increased by 5.18% when the bolus thickness was −25 mm for helical delivery, whereas a 9.95% increase was noted for the direct delivery mode compared with the dose at the reference level of 0 mm bolus thickness.

Discussion: Our results suggest that it is necessary to formulate a new treatment plan owing to increased dose error, if the body thickness decreases by more than 20 mm and 10 mm for the helical and direct delivery modes, respectively. The results also demonstrate that helical delivery is less affected by changes in body thickness than direct delivery.

Key words: tomotherapy, dosimetry, body thickness, helical delivery, direct delivery

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Introduction

In recent years, intensity-modulated radiation therapy (IMRT) has been widely used as a radiotherapeutic modality. Several IMRT delivery techniques are known, such as multiple field delivery, arc delivery (e.g., volumetric modulated arc radiotherapy, VMAT), and helical and direct delivery of tomotherapy. As compared with conventional treatments, IMRT allows higher radiation doses to be delivered to the tumor regions, while minimizing the dose to the surrounding organs at risk (OARs)[1–3]. Moreover, radiotherapy is often combined with concurrent chemotherapy, which improves treatment outcomes[4]. However, chemotherapy alone may cause appetite loss and subsequent weight loss[5]. Previous studies have shown that when weight loss occurs during treatment, the external body contour changes from that indicated in the initial treatment plan, causing a change in the dose distribution to the target tumor regions and OARs[6–8]. In addition, weight loss in the course of chemotherapy may affect the grading of side effects[9]. During IMRT, as the dose is concentrated within the tumor region, a minor change in the external body contour can influence dose distribution, treatment outcome, and tumor development, resulting in increased risk of side effects. Previous studies have reported that even with identical changes in body thickness, there can be a difference in dose distribution between the multiple delivery and arc delivery modes[10, 11].

In this study, we examined the effects of body thickness on dose distribution to the target regions and OARs using the helical and direct delivery modes of tomotherapy, based

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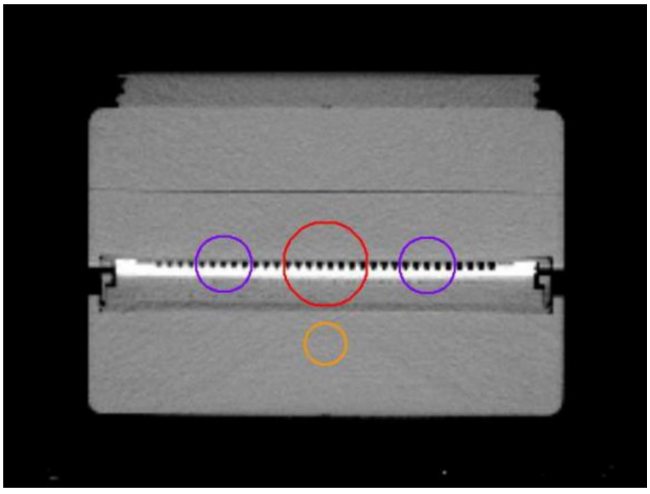

Figure 1 ROI settings. PTV ROI (red), Femoral heads ROI (purple), and OAR ROI (orange). PTV: planning target volume, OAR: organ at risk, ROI: region of interest.

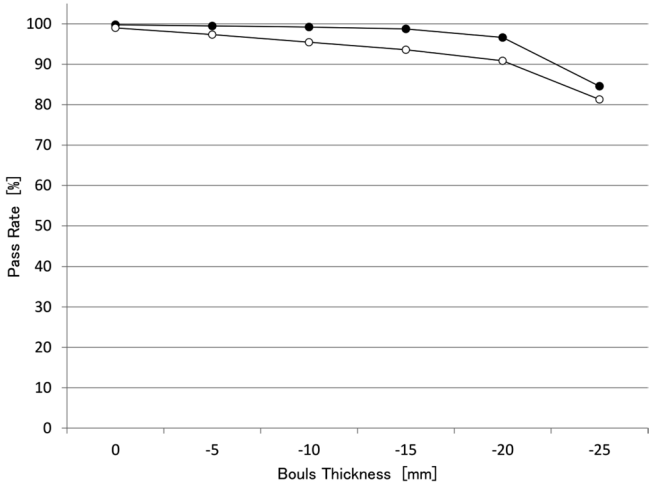

Figure 2 Gamma analysis results (● Helical, ○ Direct).

on a phantom experiment on a simulated bladder tumor. Our analysis was based on the dose-volume histograms (DVH) obtained from the experiment. The bolus size and a two-dimensional ionization chamber dosimeter were used to measure the target dose, and a subsequent gamma analysis was conducted.

Materials and Methods

Materials

A computed tomography (CT) scan (Aquilion 64 CX, Toshiba Ltd., Tokyo, Japan) was used for radiotherapy planning and tomotherapy (Accuray Oncology, Sunnyvale, CA). We used Pinnacle (Philips Healthcare, Andover, MA, Ver. 9.0) for contouring and the Tomotherapy Planned Adaptive software (Accuray, Ver. 5.1.0) for calculating dose distribution. Verification of dose delivery was conducted using the Tomotherapy DQA station software (Accuray, Ver. 5.1.0). The dose was measured using the MatriXX Evolution system (IBA Dosimetry, Schwarzenbruck, Germany); the MULTICube Lite Phantom (IBA) was attached to it. A gamma analysis was performed using the OmniPro-I'mRT software (IBA), also attached to the MatriXX measurement system. A 5 mm and a pair of a 10 mm thickness Bolx boluses (CIVCO Medical Solutions, Kalona, IA) were used. Additionally, the Tomotherapy Planned Adaptive software was used for drawing the DVHs.

Methods

First, we obtained images of the phantom for which the bolus was set with the radiotherapy planning CT scanner. The total bolus thickness was 25 mm (a 5 mm bolus and a pair of 10 mm boluses were set on the phantom). The exposure settings were as follows: slice thickness, 2 mm; tube voltage, 120 kVp; and tube current, 400 mA. The images obtained were transferred to the treatment planning system (Pinnacle), and then contouring was performed. As shown in Figure 1, a 60 mm diameter circular region of interest (ROI; planning target volume or PTV) was set as an imaginary bladder tumor in the middle of the detector, and a pair of 40 mm ROIs were set up as femoral heads placed on both sides. In addition, we also established a 30 mm diameter rectum ROI (OAR) underneath the PTV. In the longitudinal axis direction, the ROI was set at 60 mm for both the PTV and OAR, and 40 mm for the femoral head ROIs. The contouring data were transferred to the Tomotherapy Planning Station software for calculating the dose distribution; the dose was calculated as 50 Gy (in 25 fractions), with 2 Gy per fraction. The helical and four-beam direct delivery modes (45°, 135°, 225°, 315°) were used. The DQA plan was created to verify dose delivery, using the Tomotherapy software DQA station. Table 1 shows the factors that affected dose calculation. For obtaining the data, the measurement was conducted by altering the bolus thickness from 0 to −25 mm, with 5 mm decrements. A phantom was set at a total of 25 mm bolus thickness as reference, and then the changes in pass rate and dose were measured. The DVH was drawn based on the megavoltage CT (MVCT) images that were collected for the image-guided radiation therapy (IGRT) for every 5-mm decrement starting from 0 mm to −25 mm, and then the maximum doses for the PTV and OAR were calculated. We also calculated the dose fluctuation for each value, using 0 mm bolus thickness as reference.

Table 1 Factors affecting dose calculation

	Helical	Direct
Prescribed dose	D95 50 Gy	D95 50 Gy
Jaw size	2.51	2.51
Pitch	0.430	0.215
Modulation factor	2.000	2.000
Dynamic jaw	(–)	(–)

Table 2 Dose calculation results

	Helical delivery	Direct delivery
PTV maximum dose	51.69	51.96
OAR D50%	18.90	18.86
OAR D35%	20.19	20.19
OAR D25%	21.29	21.29
OAR D15%	22.61	22.61
Femoral head (Rt)D5%	23.51	23.54
Femoral head (Lt)D5%	23.18	23.21

PTV: planning target volume, OAR: organ at risk, Rt: right, Lt: left.

Table 3 Pass rate for helical and direct delivery with changes in bolus thickness

Thickness (mm)	0	−5	−10	−15	−20	−25
Helical delivery	99.78	99.47	99.22	98.75	96.61	84.55
Direct delivery	99.00	97.34	95.44	93.58	90.85	81.29

Table 4 Dose error for helical and direct delivery with changes in bolus thickness

Thickness (mm)	0	−5	−10	−15	−20	−25
Helical delivery	0.00	0.76	1.41	2.18	2.99	3.93
Direct delivery	0.00	1.18	2.50	3.87	5.17	6.64

Results

The dose calculation results of helical and direct delivery are show in Table 2. The changes in the pass rate are shown in Table 3 and Figure 2. These results were obtained from a gamma analysis based on the data measured as the bolus thickness varied from 0 to −25 mm. The dose error that resulted from the change in the bolus thickness is given in Table 4 and Figure 3. The pass rate for helical delivery shows a minor change; the pass rate was more than 95% when the bolus thickness was between 0 and −20 mm. A gradual decrease in dose error was noted for the direct delivery method as the bolus thickness decreased, and the pass rate was less than 95% when the bolus thickness was −15 mm. The dose error increased when the bolus thickness changed to −25 mm from 0 mm. Furthermore, an increase of 0.75% per −5 mm change in bolus thickness was noted in the helical delivery mode, as opposed to the direct delivery mode for which a change of more than 1% per −5 mm decrease was observed, and the value exceeded 3% at −15 mm. The results of the DVHs for PTV and OAR, as calculated using the Tomotherapy Planned Adaptive software, are shown in Figure 4 (a) and (b) for the helical delivery mode and in Figure 5 (a) and (b) for the direct delivery mode. In addition, the results of the maximum dose and dose error obtained from the DVH, for both PTV and OAR, are shown in Tables 5 and 6. The DVH values obtained from measuring the dose when the bolus thickness ranged 0 to −25 mm indicated that as the bolus thickness decreased for both the helical and direct delivery modes, the maximum dose of PTV increased. The same tendency was observed for the OAR maximum dose. In regard to the dose error for the helical delivery mode, an increase of 5.1% and 4.1% in maximum dose was noted at −25 mm for PTV and OAR, respectively, compared with the dose at the reference level of 0 mm bolus thickness. For the direct delivery mode, there was an increase of 9.95% and 3.01% in maximum dose at −25 mm for PTV and OAR, respectively, compared with the dose at the reference level.

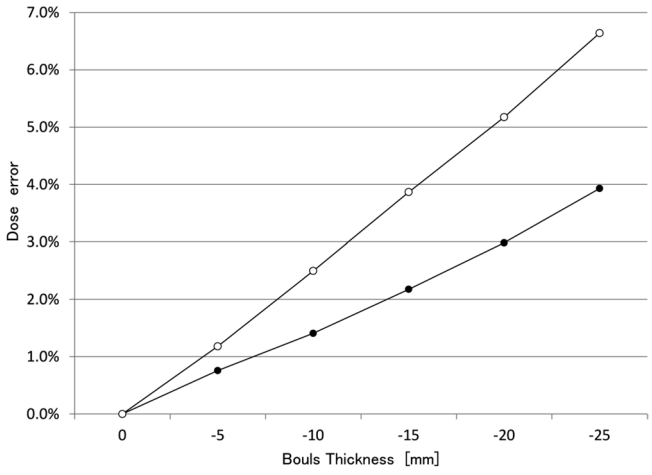

Figure 3 Dose error results (● Helical, ○ Direct).

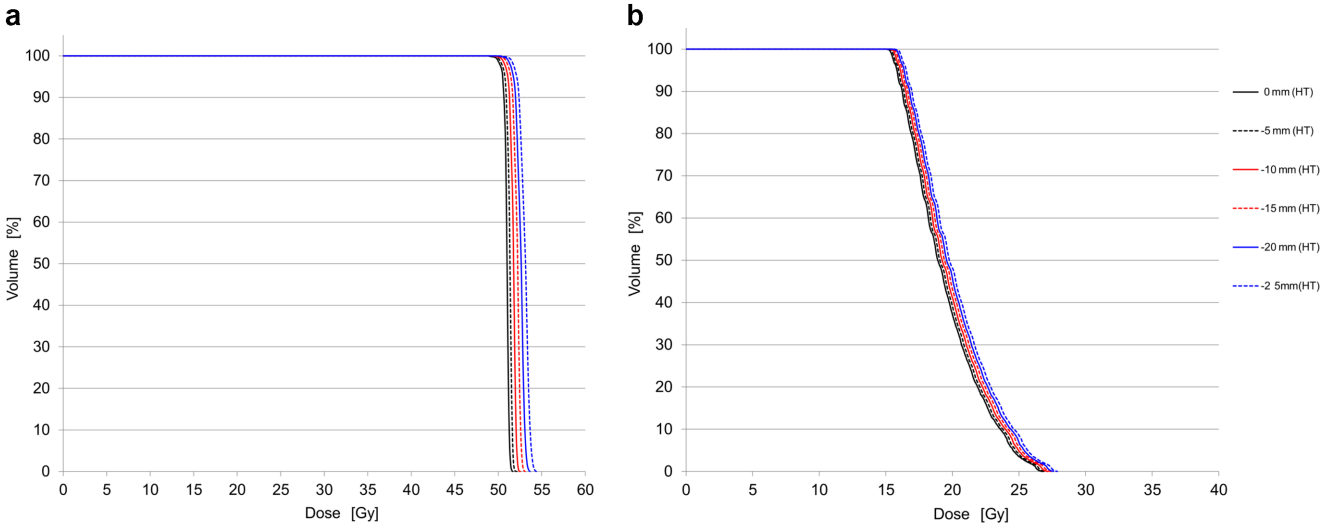

Figure 4 (a) DVH for PTV, when using helical delivery. (b) DVH for OAR, when using helical delivery. PTV: planning target volume, DVH: dose-volume histogram, OAR: organ at risk.

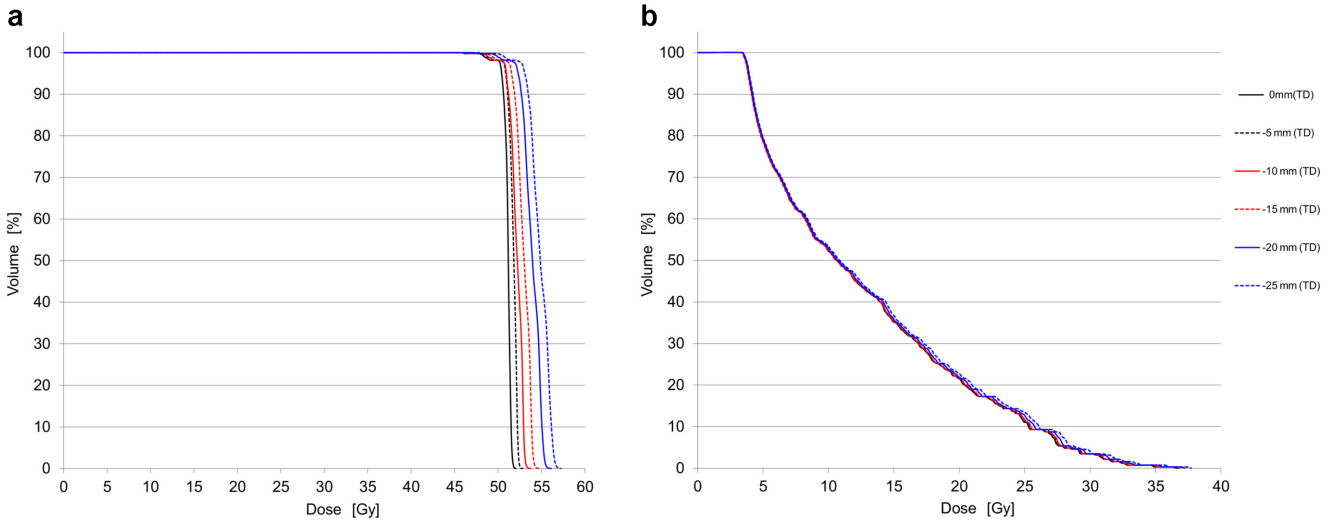

Figure 5 (a) DVH for PTV, when using direct delivery. (b) DVH for OAR, when using direct delivery. DVH: dose-volume histogram, PTV: planning target volume, OAR: organ at risk.

Discussion

For the helical delivery mode, with a minimum pass rate of 95% and maximum dose error of ±3%, the pass rate from gamma analysis for a bolus thickness of −25 mm was less than 95%, which is below the minimum level. For bolus thickness changes of more than −25 mm, the dose error was more than 3% and exceeded the allowance level. DVH evaluation for the helical delivery mode showed that if the bolus thickness is −25 mm, the maximum doses for PTV and OAR increase by 5.18% and 4.07%, respectively, compared with the reference levels. In contrast, for the direct delivery mode, the pass rate from the gamma analysis for a bolus thickness of −15 mm was less than 95%, which is less than the minimum level. For bolus thickness changes of more than −15 mm, the dose error was more than 3%, and exceeded the allowance level. DVH evaluation for this delivery mode showed that with a bolus thickness of −25 mm, the maximum doses for PTV and OAR increase by 9.95% and 3.01%, respectively, compared with the reference levels. The

Table 5 Maximum dose and dose error for both PTV and OAR as bolus thickness changes for the helical delivery mode

Thickness (mm)	0	−5	−10	−15	−20	−25
PTV Max Dose [Gy]	51.69	52.13	52.54	53.08	53.66	54.37
Dose error [%]	0.00	0.85	1.64	2.69	3.81	5.18
OAR Max Dose [Gy]	26.78	26.96	27.17	27.39	27.58	27.87
Dose error [%]	0.00	0.67	1.46	2.28	2.99	4.07

PTV: planning target volume, OAR: organ at risk.

Table 6 Maximum dose and dose error for both PTV and OAR as bolus thickness changes for the direct delivery mode

Thickness (mm)	0	−5	−10	−15	−20	−25
PTV Max Dose [Gy]	52.07	52.85	53.78	54.81	56.12	57.25
Dose error [%]	0.00	1.51	3.29	5.27	7.78	9.95
OAR Max Dose[Gy]	36.62	36.75	36.84	36.90	37.20	37.72
Dose error [%]	0.00	0.36	0.60	0.78	1.59	3.01

PTV: planning target volume, OAR: organ at risk.

present results suggest that for the helical delivery mode, the dose and dose distribution will be above the allowance level if body thickness changes by more than −25 mm. Therefore, our results indicate that a 20 mm decrease in body thickness would necessitate protocol re-planning. Similarly, a 10 mm decrease in body thickness would necessitate re-planning of the initial protocol, when using the direct delivery mode.

It would be relatively easy to detect changes in the external contour using the MVCT or Kilovoltage CT (KVCT) functions for IGRT, such as those used in the tomotherapy machine. However, if these functions are not available, identification of such changes may be difficult. While the use of radiotherapy shells in radiotherapy for the head and neck allows visualization of the changes in the external contour through the gap between the shell and the skin surface, it would be relatively difficult to notice such changes in radiotherapy for the trunk of the body, except in treatments where shells are used. Thus, if changes in body contours could be assessed by changes in body weight, it would be feasible to determine the timing for re-planning. Ogawa developed an equation to determine body thickness from height and weight[12]. Based on his equation, we could calculate the body weight loss corresponding to a 20 mm change in body thickness. In an individual weighing 65 kg with a height of 165 cm, this would be equivalent to a weight loss of approximately 10 kg (approximately 15% loss). Similarly, we calculated changes in body weight for 10 mm and 15 mm changes in body thickness; for the same individual, these were found to correspond to a loss of approximately 5 kg (8%) and 8 kg (12%), respectively.

In IGRT, it is important to determine the timing for re-planning based on weight changes in the patients even if the radiotherapy machine does not include CT functions. Chow *et al.* reported that they simulated the effect of changes in body thickness on dose error in the abdomen area, when using VMAT and fixed seven beams in IMRT, and found that a 20 mm change in body thickness resulted in a dose error of 6% for VMAT and 8% for the fixed IMRT.

In this study, the results showed that the helical delivery mode was less affected by changes in body thickness compared with the direct delivery mode. This implies that arc-type techniques such as VMAT and helical delivery could be less affected by changes in body thickness than IMRT techniques using fixed beams. Here, we only considered the abdomen area for assessing changes in body thickness. However, in clinical settings, determining changes in the body contour would be more complicated. Moreover, the movement of the target tumor region due to breathing[13, 14] needs to be considered to determine changes in dose distribution. Although, the timing of re-planning cannot be determined solely by changes in body thickness, it should be included in the criteria for re-planning.

Conclusion

In clinical settings, changes in body thickness may also occur due to a patient's breathing movement during irradiation. Additionally, changes in the size of the tumor and movement of the tumor due to intestinal gas during the radiation exposure would affect dose distribution. All these factors should be considered during treatment planning and execution. Our phantom experiment suggests that dose er-

rors will be above the allowance level if the changes in body thickness are greater than 20 mm and 10 mm for the helical delivery mode and direct delivery mode, respectively. In such cases, it is necessary to consider re-planning of the treatment.

Conflict of Interest: The author declares no conflict of interest in preparing this article.

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