Application value of 3D-printed Bolus in radiotherapy after radical mastectomy

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Abstract

Purpose: This study aimed to investigate the effects of 3D-printed Bolus or conventional Bolus on the dosimetric distribution of target area, dose of organs at risk (OARs) and body surface dose in patients with radiotherapy after radical breast cancer surgery.

Methods: 1. A 3D-printed Bolus was made on the basis of the 3D scan data of the body surface contour of the human body model used for radiation simulation. Conventional Bolus and 3D-printed Bolus were used to cover the phantom; computed tomography (CT) simulation, target area and OARs were delineated and an intensity-modulated radiotherapy (IMRT) plan was created. The conformity, uniformity and dose of the OARs were evaluated for comparative analysis. 2. Two patients undergoing radiotherapy after radical mastectomy at the Liaoning Cancer Hospital were selected to produce 3D-printed Bolus on the basis of the 3D scan data of the patient's body surface. During radiotherapy, the conventional Bolus and 3D-printed Bolus were used for tissue compensation and a radiochromic film was used to measure the optical density (OD) values of the patient's body surface. The difference in body surface dose between the conventional Bolus and the 3D-printed Bolus was analysed.

Results: 1. The conformal index (CI) , heterogeneity index (HI) and dose of OARs of the 3D-printed Bolus intensity-modulated radiation therapy plan of the human body model used for radiation simulation were all superior to those of the conventional Bolus (CI = 0.941 vs. 0.979, HI = 0.134 vs. 0.288). 2. In the two patients undergoing radiotherapy after radical mastectomy for breast cancer, the OD values of the radiation chromogenic film using 3D-printed Bolus radiotherapy were higher than those using conventional Bolus (patient 1: $P = 0.047$; patient 2: $P = 0.016$).

Conclusions: Compared with conventional Bolus, 3D-printed Bolus has obvious advantages in the target dose distribution of radiotherapy after radical breast cancer surgery and protection of OARs. Thus, it could improve the body surface dose of patients and should be promoted and applied in clinical treatment.

1. Introduction

Radiotherapy mainly uses high-energy X-rays and high-energy electrons. High-energy X-rays have a built-up effect. When air (low density) is injected into the human body (high density), a low-dose area is formed on the skin surface[1, 2]. Therefore, in the treatment of superficial tumours (such as breast cancer and skin cancer), a 5–10 mm-thick tissue compensator (Bolus) is usually applied to the human body surface for the low-dose area to fall on the tissue. The compensation is used to increase the skin and subcutaneous dose and ensure the uniformity and accuracy of the superficial tissue-irradiated dose[3]. In patients who underwent radical mastectomy, 80%-90% of tumour recurrence occurs in the subcutaneous lymphatics[4, 5]. Therefore, Bolus plays an important role in adjusting the radiation dose distribution and increasing the skin and subcutaneous doses in radiotherapy after radical mastectomy.

Given that the body surface of the human body is an uneven curved surface and due to the formation of postoperative scars, the conventional Bolus with a flat surface could not be completely attached to the skin and an air gap must be present. Studies have shown that when the air gap is > 5 mm, the body surface dose drops to approximately 90%. When the air gap is > 50 mm, the body surface dose drops to approximately 80%[6, 7]. The air gap makes the actual radiation dose of superficial lesions more uncertain and the target dose distribution does not match the expected radiation treatment plan, thus affecting the efficacy of radiation therapy and patient prognosis. For irregular body surfaces, clinicians usually use paraffin, plasticine and other materials to create Bolus. They could partially solve the problem of air gaps but they have obvious disadvantages, such as rough craftsmanship, poor conformability and poor repeatability.

3D-printing Bolus is the application of 3D-printing technology on the basis of the curvature data of each patient's body surface by using a uniform texture, electron density close to water, short production time, and an easy-to-mould silicone material made of Bolus[8]. Given that 3D-printing Bolus is 'tailor-made', it has a high degree of individualisation and obvious advantages in the degree of fit with the patient's body surface[9, 10]. It also has the uniformity, conformability, bioequivalence and repeatability of silica gel material, which could improve the accuracy and stability of radiotherapy dose[11, 12]. In this study, by comparing the human body model used for radiation simulation and the target dose distribution of conventional Bolus or 3D-printed Bolus after radical breast cancer surgery, the difference in dose to organs at risk (OARs) and body surface dose was discussed to explore the effect of 3D-printed Bolus in radiotherapy after radical mastectomy.

2. Materials And Methods

2.1 Comparison of target area and OARs dose for radiation simulation of human body phantom

2.1.1 Phantom 3D-printing Bolus production

EinScan Pro 2X Plus handheld 3D scanner was used to scan the chest wall of the phantom, from the top to the lower edge of the clavicle head, from the lower boundary to 2 cm below the contralateral breast fold, from the inside to the midline of the body and from the outside to the midaxillary line and avoiding the axilla. The 3D body surface data of the phantom were obtained and outputted to a 3D-printer to produce 3D-printed Bolus. The 3D-printed Bolus material is the same type of silica gel in conventional commercially available Bolus.

2.1.2 CT simulation

The phantom was placed in supine position by using the Guangzhou Klarity ALL-IN-ONE System (R612) with the Head and Shoulder Accucushion (RG560-SH1) and the Head and Thorax Mask with Open at Treating Site (R322-S424C-L/R322-S424C-R) fixed phantom. The conventional Bolus and 3D-printed

Bolus were used to cover the affected chest wall of the phantom. Siemens SOMATOM large-aperture CT simulation positioning machine was used for positioning scanning. The scanning range was up to the mastoid and down to the diaphragm (including the whole lung), with a thickness of 5 cm. The positioning images were transmitted to Philips Pinnacle radiotherapy planning system.

2.1.3 Delineation of target areas and OARs

The target area was delineated separately for the positioning images by using the conventional Bolus and 3D-printed Bolus. The delineation of the target area was discussed and completed by two senior doctors.

The clinical target volume ranged up to the lower edge of the clavicle head, down to the disappearance level of the contralateral breast fold, inside to the lateral edge of the affected side of the breastbone, outside to the outer contour of the contralateral breast and not exceeding the mid-axillary line, anterior to the skin, posterior boundary to the front edge of the ribs and including the pectoralis muscles. The surgical scar must be included and the margin to the surgical scar was ≥ 1 cm. In the plan tumour volume (PTV) range, 0.5 cm was spread out from each side and shrank to the subcutaneous. The delineated OARs were heart, lung (lung-l/r/all) and spinal cord.

2.1.4 IMRT plan design

IMRT plans were designed for the target areas by using conventional Bolus and 3D-printed Bolus, using 6MV-X ray, 95% chest wall/PTVcw dose: 50 Gy/2 Gy/25 f. The volumes of PTV receiving 55 and 53.5 Gy prescription doses were limited to less than 5% and less than 10%, respectively, and no high dose was given outside the PTV area (> 55 Gy). The volumes of the affected lung to be exposed were limited to doses of 5 Gy or more to not exceed 50%, above 10 Gy to not exceed 40%, above 20 Gy to not exceed 25% and above 30 Gy to not exceed 20%. The average dose of the heart did not exceed 15 Gy (both patients had right breast cancer; thus, the lung-r on the affected side is lung-r), and the volume of the heart with a dose of 30 Gy or more did not exceed 40%.

2.1.5 Evaluation of target area's CI, HI and dose of OARs

The target CI was calculated as CI = (VTref/VT)/(VTref/Vref), where VT is the PTV volume, VTref is the PTV volume surrounded by the 45 Gy isodose line and Vref is the 45 Gy isodose. The volume of all areas was surrounded by the line. The value of CI ranged from 0 to 1. The closer the value is to 1, the better the conformability of the target area. The dose HI was calculated as HI = [(D2 − D98)/D50]. The farther the HI value is from 1, the worse the uniformity of the planned dose distribution. The dose-volume histogram (DVH) was used to view the dose values of Dmean heart, Dmax heart, Dmean lung-r, Dmax lung-r, V5 lung-r, V20 lung-r and V30 lung-r.

2.2 Measurement of OD values of patient's body surface

2.2.1 Radiotherapy and measurement of OD values of patient's body surface

Two patients admitted to Liaoning Cancer Hospital in January 2021 after radical mastectomy were selected and provided with postoperative adjuvant radiotherapy in accordance with to the NCCN Guidelines for Breast Cancer (2021.V1). Both patients signed an informed consent. The 3D-printing Bolus production, simulation, target area and OARs and IMRT plan design were the same as those in the phantom experimental method.

The patient's position is the same as that during radiotherapy and the Varian IX5600 linear accelerator was used to implement the radiotherapy plan. During the first and second radiotherapy, conventional Bolus and 3D-printed Bolus were used to cover the patient's chest wall on the affected side and five 3 cm × 3 cm radiation colour films were placed on the chest wall under the Bolus. The OD values of the outer top, outer bottom, inner top, inner bottom and centre were measured and a marker was used to mark the film outline and ensure that the two film placement positions were the same.

2.3 Statistical analysis

IBM SPSS 26.0 was used for the non-parametric test on the OD value of the patient's body surface with two independent samples. $P < 0.05$ indicates that the difference is statistically significant.

3. Results

3.1 The CI, HI and OARs dose of 3D-printed Bolus were better than those of conventional Bolus

Conventional Bolus and 3D-printed Bolus radiation simulation human body model were used for positioning, target area delineation and intensity modulation plan design. The conformability, uniformity index and OARs dose of the target area were evaluated. The conventional Bolus target area VT was 673.606 cm^3, VTref was 598.881 cm^3, Vref was 635.731 cm^3, D2 was 5181.71 cGy, D98 was 3736.28 cGy and D50 was 5018.07 cGy. The 3D-printed Bolus target area VT was 699.692 cm^3, VTref was 642.709 cm^3, Vref was 679.907 cm^3, D2 was 5173.92 cGy, D98 was 4503.72 cGy and D50 was 5013.07 cGy. The CI, HI and OARs dose of the 3D-printed Bolus were better than those of the conventional Bolus (Table 1, CI = 0.941 vs. 0.979, HI = 0.134 vs. 0.288).

Table 1

Comparison of the target area and OARs dosimetry distribution of different types of Bolus in the radiation simulation human body phantom

		Conventional Bolus	3D-printing Bolus
CI	VT (cm^3)	673.606	699.692
	VTref (cm^3)	598.881	642.709
	Vref (cm^3)	635.731	679.907
	CI	0.941	0.979
HI	D98 (cGy)	3736.28	4503.72
	D50 (cGy)	5018.07	5013.07
	D2 (cGy)	5181.71	5173.92
	HI	0.288	0.134
OARs	Dmean heart (cGy)	301.1	338.6
	Dmax heart (cGy)	2811.6	3688.5
	Dmean lung-r (cGy)	990.5	1022.6
	Dmax lung-r (cGy)	5248.2	5187.5
	V5 lung-r (%)	46	46
	V20 lung-r (%)	25	26
	V30 lung-r (%)	21	22

CI = (VTref/VT)/(VTref/Vref), where VT is the PTV volume, VTref is the PTV volume surrounded by the 45 Gy isodose line and Vref is the volume of all areas surrounded by the 45 Gy isodose line. The CI value ranges from 0 to 1 and the closer to 1, the better the conformability of the target area; HI = [(D2 − D98)/D50] and the farther the HI value is from 1, the worse the uniformity of the planned dose distribution.

3.2 The OD value of patients was higher upon receiving 3D-printed Bolus than receiving conventional Bolus

The OD values of five radiochromic films located on the outer top, outer bottom, inner top, inner bottom and centre when conventional Bolus was used in patient 1 were 204, 163, 140, 134 and 154, respectively (Fig. 1), and 256, 205, 207, 186 and 214, respectively (Fig. 2), when 3D-printing Bolus was used. When conventional Bolus was used in patient 2, the OD values of five radiochromic films located on the outer top, outer bottom, inner top, inner bottom and centre were 166, 219, 104, 147, and 163, respectively, and 268, 252, 192, 192 and 172, respectively, when 3D-printing Bolus was used. The OD value of the radiation

colour film of the two selected patients who received 3D-printed Bolus radiotherapy was higher than that when conventional Bolus was provided (Table 2, patient 1: *P = 0.047*; patient 2: *P = 0.016*).

Table 2
Comparison of body surface OD values of different types of Bolus in patients

	Quadrant	OD values(1/trans)		P values
		Conventional Bolus	3D-printing Bolus	
Patients 1	outer top	204	256	0.047
	outer bottom	163	205	
	inner top	140	207	
	inner bottom	134	186	
	centre	154	214	
Patients 2	outer top	166	268	0.016
	outer bottom	219	252	
	inner top	104	192	
	inner bottom	147	192	
	centre	163	172	

4. Discussion

In recent years, some experts and scholars have conducted verification studies on the clinical application value of 3D-printing Bolus. Some Chinese experts and scholars have applied 3D-printed Bolus to the radiotherapy of patients with nasopharyngeal cancer and perineal cancer. The results showed that the patient's 3D-printed Bolus has a high degree of individualisation and good dose uniformity[13]. A study on the effects of 3D-printed Bolus and conventional Bolus on the dose distribution of the target area in breast cancer and skin cancer compared by radiotherapists at Seoul National University Hospital in South Korea showed that the conformability of 3D-printed Bolus has obvious advantages. The use of 3D-printing Bolus could achieve the target dose distribution of the treatment plan, whilst the target area when using silica gel Bolus has defects, such as lack of dose[14]. Similarly, in head and neck malignancies and non-melanoma skin cancer, the application of 3D-printing Bolus in radiotherapy has also produced gratifying results[15, 16]. The above simulation verification or clinical research trials have proven that the conformability of 3D-printed Bolus is better than that of conventional Bolus. It could better adjust the radiation dose distribution, increase the skin dose and meet the needs of clinical treatment. However, the relevant clinical research data remain scarce and further exploration is needed to evaluate the clinical application value of 3D-printing Bolus.

In this study, human body model for radiation simulation was used to clarify the effect of 3D-printing Bolus on the target area and OARs dose and confirm its safety and dose distribution advantages. This Bolus was applied to postoperative breast cancer radical mastectomy. The patient and the application of radiochromic film further confirmed the difference in body surface dose between the 3D-printed Bolus and the conventional one. The results clarified that 3D-printing Bolus could optimise the dose distribution in the target area, increase the skin dose and reduce the amount of OARs. The application of 3D-printing Bolus could better meet the dosage requirements of clinical treatment, improve the quality of radiotherapy and possibly improve the prognosis of patients than that of conventional Bolus. This advantage is more obvious in patients with uneven surgical scars. Therefore, using 3D-printing Bolus for tissue compensation as much as possible is recommended in patients undergoing radiotherapy after radical mastectomy.

Declarations

Ethical Approval and Consent to participate

This study was approved by the Ethics Committee of Liaoning Cancer Hospital & Institute. Both patients signed an informed consent.

Consent for publication

Manuscript is approved by all authors for publication.

Availability of supporting data

All data included in this study are available upon request by contacting the corresponding author.

Competing interests

The authors declare no competing interests.

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Authors' contributions

N. Z. designed the study. Y. Z. and X. M. completed the statistical analysis and drafted the manuscript. Y. C., H. G., L. W., X. Z., C. S., N. H., S. S., Z. Q. and Z. L. conducted data collection. All authors read and approved the final manuscript.

Abbreviations

OARs	organs at risk
CT	computed tomography
IMRT	Intensity modulated radiation therapy
OD	optical density
CI	conformal index
HI	heterogeneity index
PTV	plan tumour volume
DVH	dose-volume histogram

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Figures

Figure 1

Patient uses 3D-printed Bolus for radiotherapy and the OD value is measured
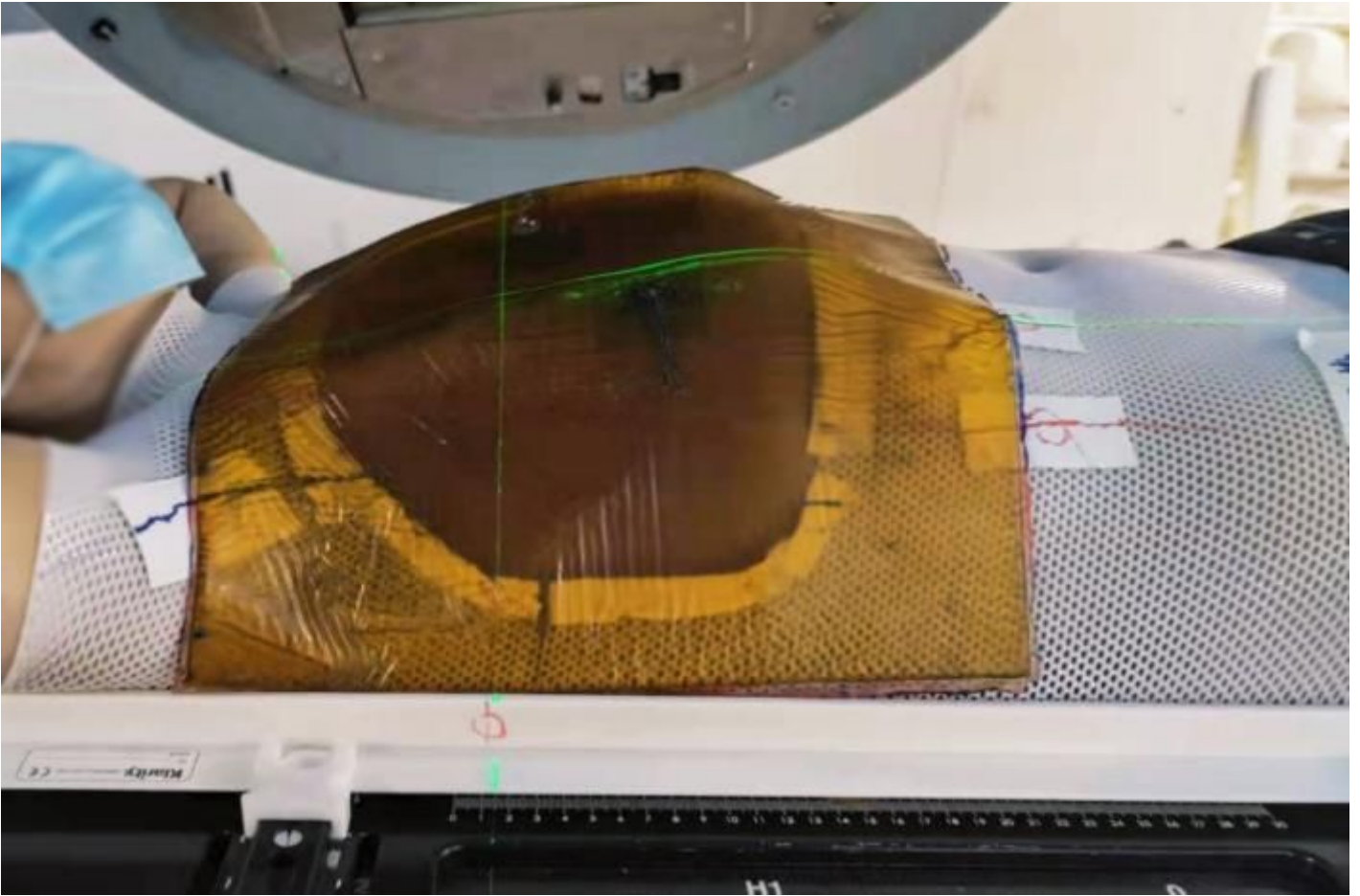
Figure 2

Patient uses conventional Bolus radiotherapy and the OD value is measured