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Dosimetry Verification of Chest Wall Radiotherapy Planning Using Virtual Bolus Compared to Plasticine Bolus for 3DCRT and IMRT

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Abstract. Aim: Plasticine bolus has been used widely in Indonesia to achieve dose coverage in breast cancer radiotherapy based on treatment planning using virtual bolus. The purpose of this study was to evaluate dosimetry differences between virtual bolus and plasticine bolus on both of 3DCRT and IMRT planning. Methods: Ten original chest CT simulation files were modified as a pair file with virtual bolus and plasticine bolus. 3DCRT and IMRT planning was made for each file using "ECLIPSE" software. We compared the dosimetry result for Conformity Index (CI), Homogeneity Index (HI), and $D_{2\%}$. Findings: We found that for 3DCRT breast cancer planning, HI and CI were lower for plasticine bolus compared to virtual bolus. There is no significant difference for $D_{2\%}$ between plasticine and virtual bolus. IMRT breast cancer planning parameters for HI, CI, and $D_{2\%}$ were lower for plasticine bolus than a virtual bolus. Conclusions: Virtual bolus causes an overestimation of breast cancer radiation dosimetry. Several considerations are needed for using plasticine bolus to overcome the dosimetry decrement.

INTRODUCTION

Breast cancer is a worldwide health burden and the first leading cancer for women in Indonesia [1,2]. Breast cancer treatment involves surgery, radiotherapy, and systemic treatment such as chemotherapy, hormonal therapy, and targeted therapy. After a mastectomy, radiotherapy is highly recommended for the tumor more than 5 cm in size and one to three positive nodes to decrease locoregional recurrence and mortality [3,4]. In some cases, due to delayed treatment or progressive disease, causing local recurrence after mastectomy, we give radiotherapy to locoregional is with booster doses.

Achieving proper radiotherapy planning to the chest wall can be challenging due to the curvature of the thorax and irregularity of the surface [5], and in most of the situations for radiotherapy after mastectomy, the planning target volume is superficial or adjacent to the skin surface [6]. As ionizing radiation interacts with the skin surface, the energy increases to the maximum in a deeper position, making a dose build-up region near the skin surface [7]. In this situation, bolus with tissue equivalence density can be used to increase the dose at the skin surface, as well to improve dose homogeneity

A wide range of different bolus types made from various materials, from homemade water or plasticine bolus, 3D printed bolus to commercial mold, is available to current practice in radiotherapy [8,9]. Modelling clay toy such as plasticine, paraffin wax, and playdoh is used in most radiotherapy centers in Indonesia because of its cheap, availability, easy to mold, and tissue-like density [10]. Plasticine composition consists mainly of bulking agents, petroleum jelly, lime, lanolin, and stearic acid.

After the patient decides to take radiotherapy as treatment, the process begins with CT simulation, and CT image data were sent to the treatment planning system. The common practice for planning chest wall radiotherapy with bolus in Indonesia was creating a treatment plan using a virtual bolus generated by the software. When the treatment

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planning is accepted, a plasticine bolus was made according to the virtual bolus size and thickness. No data proves that using plasticine bolus will have the same dose result as the virtual bolus planning. It is vital to analyze this method of chest wall radiotherapy to ensure its safety. This study compares the homogeneity index, conformity index, and near max dose differences between radiotherapy planning using virtual bolus and planning with plasticine bolus.

MATERIALS AND METHODS

Ten patients were consecutively selected in our institution for this study. The patients are within the inclusive criteria for stage IIA to IIIB breast cancer, after modified radical mastectomy, without reconstruction, and on schedule to adjuvant locoregional radiotherapy. These patients were receiving radiotherapy treatment according to our institution's standard practice. We only used the patient's CT image data and made a replanning to accommodate this study.

CT images were acquired using a Toshiba Alexion multislice CT scanner, with 5 mm image thickness. During CT scanning, the patients lay in a supine position using CIVCO breast board fixation. Small radiopaque markers were put as superior, medial, lateral, and inferior borders to aid identified chest wall clinical targets. Plasticine bolus with 5 mm thickness was made into rectangle shapes covering all clinically targeted chest wall and molded following the patient's thorax curvature.

CT images data were sent to Varian ECLIPSE for the delineation and planning process (Fig. 1). A team of radiation oncologists delineates clinical target volume (CTV), planning target volume (PTV), and organ at risk (OAR) using RTOG guidelines [11]. A 50 Gy dose prescribed to the PTV of the chest wall. Dose constraints were set according to our institution standard. For ipsilateral lung mean dose $\leq$ 20 Gy and V20 $\leq$30%. The heart's dose constraint was V25<20% [11].

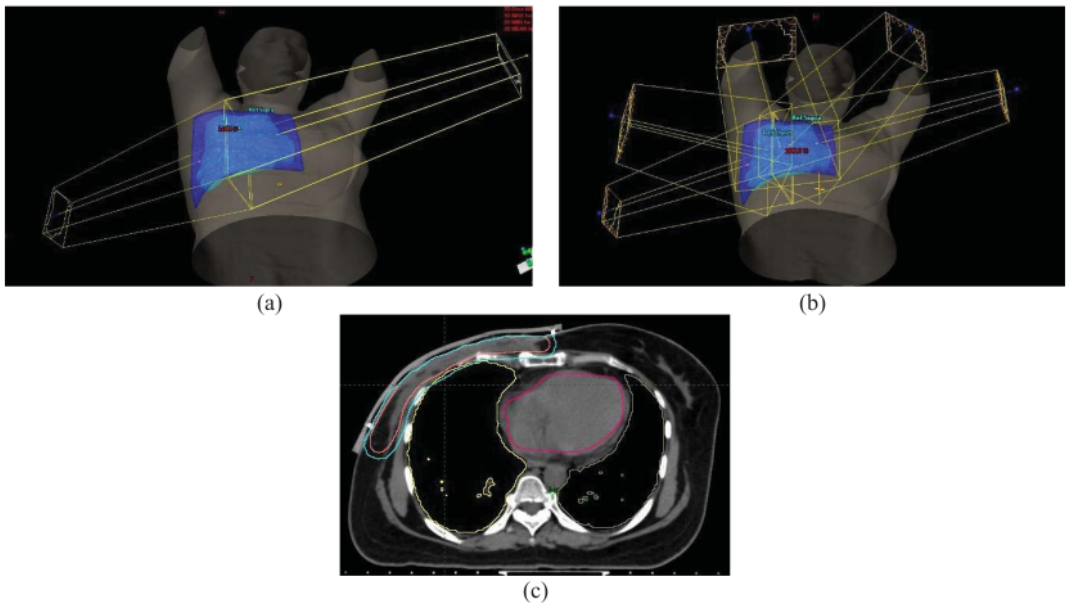


FIGURE 1. Chest wall radiotherapy planning (a) Tangential beam arrangement for 3DCRT, (b) Multibeam arrangement for IMRT. (c) CT image slice with delineation of chest wall's CTV (pink), PTV (blue), and organ at risk (lungs and heart)

The delineated CT file (Figure 1) was made into four copies, each for different sets of bolus types and radiotherapy techniques, as stated in Table 1. CT files for virtual bolus planning were prepared by erasing plasticine bolus density and replaced with a virtual bolus generated by the Varian ECLIPSE software. The virtual bolus was made of the same size and thickness as the plasticine bolus.

TABLE 1. CT copies for four types of planning with 3DCRT or IMRT techniques and plasticine or virtual bolus

CT files set	Techniques	Bolus	n
1	3DCRT	Plasticine	10
2	3DCRT	Virtual	10
3	IMRT	Plasticine	10
4	IMRT	Virtual	10

Radiotherapy planning with 3-dimensional radiotherapy (3DCRT) and Intensity Modulated Radiotherapy (IMRT) technique was made from the CT files pair. For 3DCRT planning, each pair was given an identic tangential 6MV photon beam. For IMRT planning, each pair was also given an identic photon beam parameter and fluence map optimization. Dose Volume Histogram (DHV) was analyzed to calculate the Homogeneity Index (HI), Conformity Index (CI) based on the ICRU 83 report formula, and dose at 2% ($D_{2\%}$) [12]. HI defines as dose uniformity on PTV, and CI was the ratio of volume covered by 95% of prescription dose divided by PTV volume. Each parameter was compared using Wilcoxon nonparametric analysis.

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \quad (1)$$

$$CI = \frac{V_{95\%}}{Volume\ of\ PTV} \quad (2)$$

RESULTS AND DISCUSSION

In this study, the patient's age average was 50 years, ranging from 32 to 65, with most of them at stage IIIB. The PTV volume has a wide range from 376 – 953 cc because of different clinical targets and chest wall thickness variances after mastectomy. The patient's characteristics were shown in table 2.

TABLE 2. Characteristic of patient

Characteristic	n%	mean	median	Min-max	SD
Age (year)	-	50.2	50	32-65	9.519
Breast cancer					
Right breast	4(40%)	-	-	-	-
Left breast	6(60%)	-	-	-	-
Stage					
IIB	2(20%)	-	-	-	-
IIIA	1(10%)	-	-	-	-
IIIB	7(70%)	-	-	-	-
PTV Volume (cc)		651.3	563.5	376-953	212.2

We analyzed the DHV of 3DCRT planning for plasticine bolus and virtual bolus, as shown in table 3. Mean HI for 3DCRT planning with virtual bolus was 0.2±0.03 (better uniformity), and for plasticine bolus was 0.5±0.04 (worse uniformity). A lower HI is a better uniformity, where zero value is considered as a perfect homogeneity. Mean CI for 3DCRT chest wall radiotherapy was better in planning using virtual bolus (0.97±0.03), and lower mean CI for plasticine bolus (0.85±0.06). As stated in ICRU 83, a CI value equal to 1 was considered as the perfect conformity [12]. In this study, for 3DCRT planning, we found that HI and CI were both statistically different between compared planning (p=0.005).

TABLE 3. Comparative analysis of $D_{2\%}$, HI and CI for 3DCRT planning

3DCRT parameter	variable	Descriptive Statistic				p-value
		mean	median	SD	Min-Max	
$D_{2\%}$	Plasticine bolus	5726	5703	221	5453-6206	0.093
	Virtual bolus	5800	5735	223	5580-6295	
HI	Plasticine bolus	0.500	0.489	0.039	0.453-0.559	0.005
	Virtual bolus	0.202	0.202	0.033	0.148-0.249	
CI	Plasticine bolus	0.852	0.845	0.057	0.743-0.9379	0.005
	Virtual bolus	0.967	0.971	0.030	0.890 -0.999	

IMRT planning's DVH analysis for plasticine bolus and virtual bolus was shown in table 4. Mean $D_{2\%}$ was higher for plasticine bolus (54±0.6Gy) compared to the virtual bolus (51.8±0,4Gy). We found that HI was worse in plasticine bolus planning (0.4±0.04) than the virtual bolus (0.07±0.01). Following the same trend, CI was also worse in the plasticine bolus (0.9±0.02) than the virtual bolus (0.995±0.003). All of the parameters were statistically significant (p=0.005). The decrement of the dosimetry parameter when replacing the virtual bolus with a plasticine bolus was shown in table 5.

TABLE 4. Comparative analysis of $D_{2\%}$, HI and CI for IMRT planning

IMRT parameter	variable	Descriptive Statistic				p-value
		mean	median	SD	Min Max	
$D_{2\%}$	Plasticine bolus	5412	5404	69.2	5306-5530	0.005
	Virtual bolus	5178	5167	39.2	5135-5251	
HI	Plasticine bolus	0.408	0.402	0.039	0.364-0.491	0.005
	Virtual bolus	0.066	0.063	0.012	0.050-0.091	
CI	Plasticine bolus	0.907	0.907	0.019	0.862-0.934	0.005
	Virtual bolus	0.995	0.996	0.003	0.989-0.999	

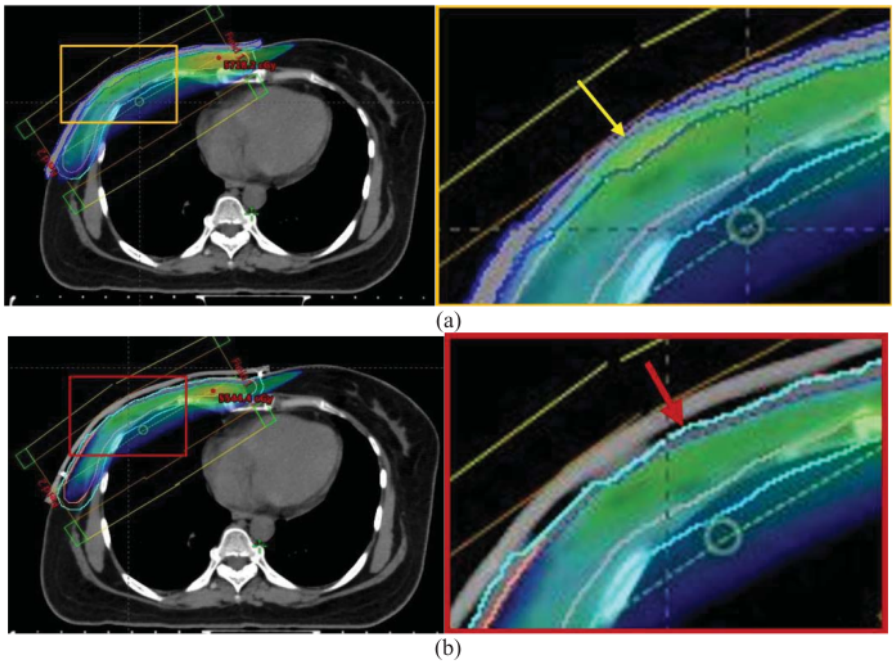
TABLE 5. Dosimetry decrement in radiotherapy planning when replacing the virtual bolus with a plasticine bolus.

Parameter Decrement	Mean	Median	Min-Max	SD
3DCRT planning				
$D_{2\%}$	-75	-92	(-195) - 196	113
HI	0.29	0.3	0.23 - 0.4	0.05
CI	0.12	0.13	0.06 - 0.16	0.04
IMRT planning				
$D_{2\%}$	234	242	117 - 334	67
HI	0.34	0.33	0.3 - 0.43	0.04
CI	0.09	0.09	0.06 - 0.13	0.02

Plasticine bolus has fat tissue like density [10]. As a homemade bolus, there is always room for human error, causing ununiform bolus density even with meticulous preparation. Sometimes shaping plasticine bolus following body contour and accidental force during handling can cause ununiform bolus thickness and density. Limitation on the malleability of plasticine bolus can cause the bolus does not fully adhere to the skin. Upon the CT scan, it is shown that the plasticine bolus may have airgaps above the skin surface (Fig. 2 and 3). Unlike plasticine bolus, the virtual bolus generated by planning system software seems to have a uniform density and adhered correctly to the skin.

Very few studies report plasticine or other homemade bolus usages because in a developed country where most of the breast cancer patients were treated early, and the need for skin surface dose coverage on chest wall radiotherapy was rarely found. The traditional homemade bolus is mostly replaced by 3D printed bolus in the developed countries because of 3D printed bolus dosimetrically replicate reference planning compare to traditional bolus [13].

A pursue to achieve perfect conformity index and homogeneity index has always been an objective in modern radiotherapy. When the photon beam passes through the plasticine bolus, the electron will scatter to the lateral and interact with the airgap and subsequently decrease particle fluence and disrupt dose distribution. Airgaps between bolus and skin will cause a wider photon penumbra. Changes in photon's penumbra were significantly visible when the airgaps more than five mm, causing underdose area on the skin surface and subsequently lower the conformity index [14,15].



(a)

(b)

FIGURE 2. Pair of CT image slice for 3DCRT planning, (a) virtual bolus without airgap and 95% isodose line reach skin surface (yellow arrow), (b) Plasticine bolus with airgap and underdose area at the surface (red arrow).

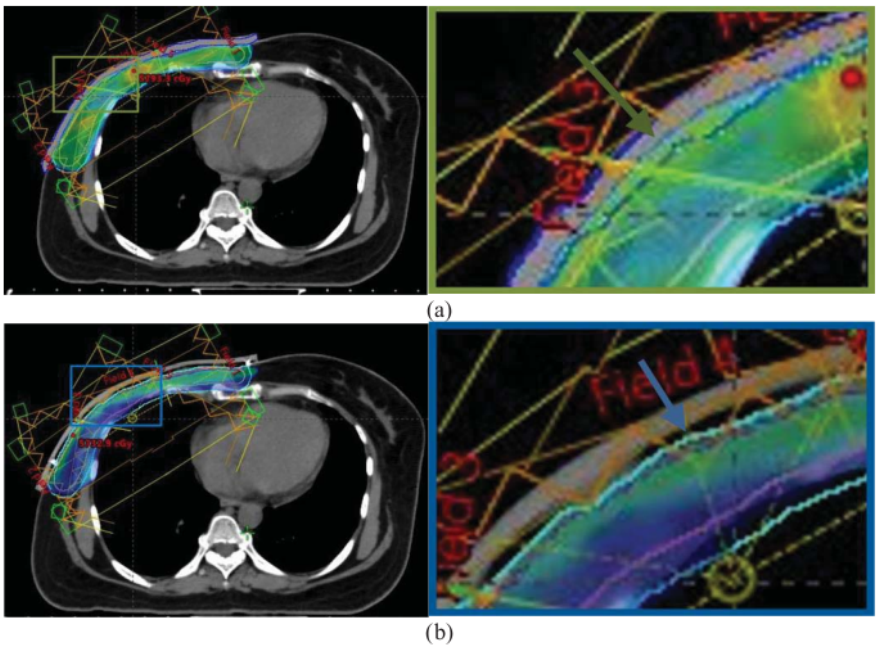


FIGURE 3. Pair of CT image slice for IMRT planning, notice, although not very visible, skin with underdose still present in IMRT with plasticine bolus (blue arrow).

In this study, IMRT planning showing a slightly better dose at the skin surface compared to 3DCRT. In 3DCRT planning, both using identic beam parameters, including tangential beam angle, photon energy, isocenter point, and dose normalization point. A virtual bolus without airgap will cause a higher near-maximum dose ($D_{2\%}$). While in IMRT planning with plasticine bolus, by setting PTV fluence map optimization, the software will provide additional beam fluence to increase skin dose and increase $D_{2\%}$ in IMRT planning with plasticine bolus [6,16]. A study about 3D-printed bolus impact for IMRT and VMAT by Xianfeng Liu et al. show that IMRT and VMAT have a tiny change in dose coverage compared to plan references, but they stated that uncertainty remains in airgaps because of bolus preparation and utilization [17].

DVH was a useful tool to evaluate radiotherapy planning. In practice, we choose the best radiotherapy planning with a prescribed dose covering all the target volume and as low as possible dose to the organ at risk. DVH does not provide information on the dose of clinical target volume at a specific location. When clinical target volume includes skin surface, it is crucial to ensure the dose at the skin surface is adequate to achieve tumor control [18]. Radiotherapy plan with plasticine bolus may decrease dose at the skin surface mostly when airgaps occur between bolus and skin. It is wise to evaluate the dose at CT slice and to consider is skin dose is acceptable.

CONCLUSION

Our study shows that virtual bolus has better dosimetry parameters than plasticine bolus in both 3DCRT and IMRT planning. However, homemade bolus usage in radiotherapy may still have a place in a developed country due to its cost-effectiveness. We need to evaluate the practice of making homemade bolus based on virtual bolus planning. Each radiotherapy center should evaluate its homemade bolus quality, including its density, malleability, unwanted air gaps, also the protocol for making and applying bolus. When the dosimetry parameter and clinical assessment of radiotherapy planning shown that the current practice may cause an underdose in the target volume, it may be better to acquire a CT scan slice for planning with a homemade bolus instead of using a virtual bolus in order to obtain better dose prediction accuracy.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8