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Assessment of dose uniformity and optimal CT number for virtual bolus in breast VMAT planning

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ABSTRACT

Background: ICRU Report No. 83 proposes using the Flash Region in the strategic design of breast cancer treatment. However, concerns persist regarding the delivery of the designated radiation dose to breast cancer patients undergoing Volumetric Modulated Arc Therapy (VMAT) with virtual bolus in the irradiation plan.

Objective: This study aimed to assess dose uniformity in breast VMAT treatment with a virtual bolus, validate the planning dose by comparing it with nanoDot™ measurements on a Rando phantom, and determine the optimal CT number for the virtual bolus in breast VMAT planning.

Materials and methods: To assess dose uniformity in the breast VMAT plan, nine nanoDot™ dosimeters were placed on the breast of Rando phantom, followed by CT simulation and VMAT treatment planning. The clinical target volume (CTV) and organs at risk were contoured, and the planning target volume (PTV) boundaries were expanded by 5 mm and 10 mm for virtual bolus thicknesses of 10 mm and 15 mm, respectively. The CT number of the virtual bolus varied from 0 to -700 HU. The planning doses at 9 points were determined, and the coefficient of variation (%CV) was calculated. Additionally, measurements at these 9 points were performed using nanoDot™ dosimeters. The calculated and measured doses were then compared. Finally, VMAT treatment plans with a virtual bolus were implemented in 10 breast cancer patients, using the virtual bolus with varying CT numbers as in the phantom study to evaluate the optimal CT number of the bolus.

Results: The doses among the 9 points for each plan were uniform, with a %CV of less than 4. For calculated dose validation, the percentage differences between the measured and calculated dose for all treatment plans, with variations in the CT number and the bolus thickness, were within ±5%. To determine the optimal CT number for the virtual bolus, the breast cancer treatment plan that met the dose criteria for tumors and organs at risk was the plan with a CT number of 0 HU for both virtual bolus thicknesses of 10 and 15 mm.

Conclusion: Virtual bolus provides uniform dose distribution for breast VMAT planning, which measurements from nanoDot™ can validate. The appropriate CT number for the virtual bolus is 0 HU for both bolus thicknesses. In future studies, measurements should be conducted on actual patients.

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Introduction

For breast cancer, treatment will vary depending on the stage and type of cancer. Several treatment techniques

are used for breast cancer, including Three-dimensional conformal radiation therapy (3D-CRT), Intensity-modulated radiation therapy (IMRT), and Volumetric modulated arc therapy (VMAT). The VMAT technique may increase the risk of second cancers and other complications due to the low dose of radiation that the patient receives.[1,2] This emphasizes the importance of carefully choosing VMAT irradiation. Therefore, in patients with breast cancer, this technique is primarily employed in highly complex cases, as planning treatment according to dose constraints using standard techniques is not possible.[1] VMAT was found to spare radiation doses to the heart, lungs, and breast on the opposite side better than the 3D field in the field.[3]

According to ICRU report No. 83, the Flash region is recommended for treatment planning[4] because the breast is in the area affected by breathing movement, leading to potential anatomical changes such as edema and uncertainty in patient positioning.[5] The study found that incorporating virtual bolus in VMAT did not affect radiation dose. Yet, it resulted in a more favorable distribution of radiation doses in anatomically changing visual data than calculations without virtual bolus. This led to the conclusion that the use of virtual bolus was both safe and helpful in compensating for breast changes that may occur during irradiation.[6]

When performing the treatment plan with IMRT, a tool known as Skin Flash (Eclipse treatment planning system, Varian Medical Systems, Palo Alto, CA) is employed. Skin flash refers to a method where an intentional margin of the treatment field is extended beyond the skin surface to ensure the skin receives the required dose. However, for VMAT, since Skin Flash is unavailable, virtual bolus is used as an alternative option. This technique electronically applies a virtual bolus to the skin surface within the treatment planning system to achieve the desired dose distribution.

The nanoDot™ (Landauer Inc., Glenwood, IL, USA) is an optically stimulated luminescent dosimeter (OSLD) generally used in point dosimetry for radiation therapy applications.[7-12] It is employed for dosimetry to determine organ doses during irradiation, such as skin[13-16] and eye lens.[17] The nanoDot™ offers several benefits, including its tiny size and repeatable readout, making it a preferred alternative for in vivo dosimetry. [17,18] This study selected nanoDot™ to measure the breast dose compared with treatment planning.

A previous study by Lizondo *et al*. optimized virtual bolus thickness and HU values in VMAT for breast radiotherapy.[1] They found that this could improve the efficacy of pseudo skin flash, thereby enhancing treatment precision. However, this study did not compare the results with actual measurements. To the best of our knowledge, limited research exists regarding the planning doses for breast cancer in the flash region compared to measurements. Therefore, this study aims to assess dose uniformity in breast VMAT treatment with a virtual bolus and validate it by comparing radiation doses between breast VMAT treatment planning (utilizing virtual bolus) and nanoDot™ measurements in breast treatments performed on the Rando phantom. Additionally, we seek to assess the appropriate CT number for the virtual bolus in the breast VMAT treatment plan and compare the radiation doses received by tumors and organs at risk during breast VMAT (virtual bolus) treatment planning for breast cancer patients.

Materials and methods

This ethical research was approved by the Naresuan University IRB (IRB No. P1-0163/2565) and the ethical committee of Chanthaburi Province (COA No. 022/66). To achieve the objectives, we experimented with two steps. The first step involved evaluating dose uniformity and validating the doses from breast VMAT treatment planning with measurements from nanoDot™. For the second step, the optimal CT number of the virtual bolus was evaluated in clinical breast VMAT plans.

Assessment of dose uniformity for a virtual bolus in breast VMAT planning and validation with nanoDot™ measurement: Phantom study

Computed tomography simulation

Nine nanoDot™ dosimeters were positioned on the left breast of the female Alderson RANDO phantom (RSD Radiology Support Devices, CA, USA) with the 5 cm separation between two neighboring (Figure 1a), to determine the position of nanoDot™ in the treatment planning (not for dose measurement). Then, a bolus with a thickness of 1.5 cm was placed over the nanoDot™ detectors covering the left breast to maintain a charged particle equilibrium in the measurement, as shown in Figure 1 (b); this physical bolus represented the breast tissue of the phantom. Subsequently, a scan was conducted using the Brilliance Big Bore computed tomography (CT) simulator (Philips, Amsterdam, the Netherlands) with a slice thickness of 3 mm, 120 kVp, and 140 mAs. The set-up position is presented in Figure 2. Then, CT images were transferred to a computerized treatment planning system.

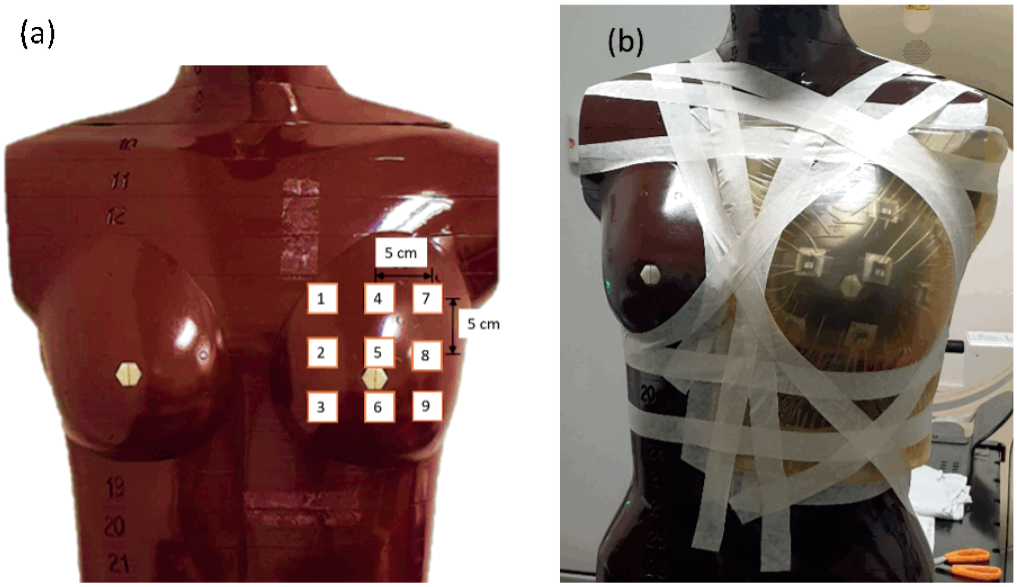


Figure 1. *The nanoDot™ dosimeter settings with the Rando phantom show the position of the nanoDot™ dosimeters (a) and 1.5 cm of bolus covering the left breast (b).*

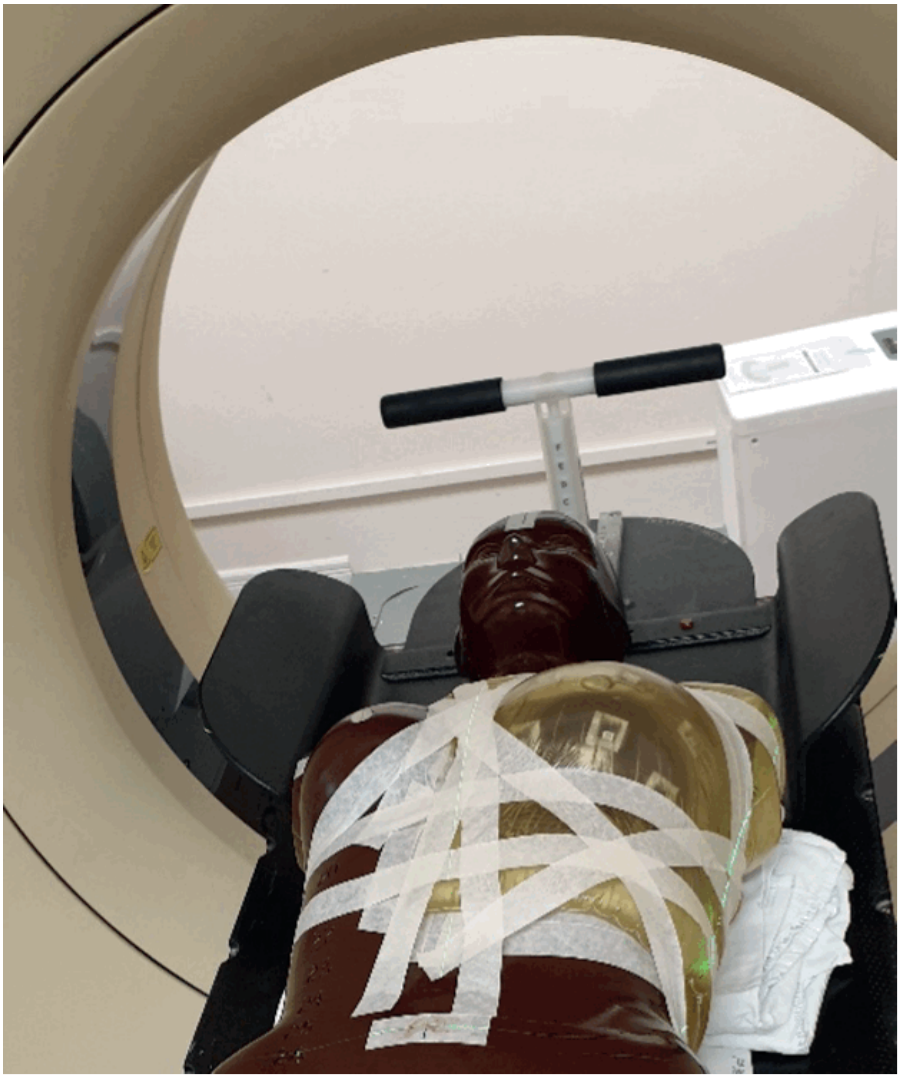


Figure 2. *Phantom setup during CT simulation.*

Treatment planning

The left breast (planning target volume; PTV) was delineated with the boundary covering the skin of the physical bolus, as observed in the CT image (Image Set 1, representing no virtual bolus). Subsequently, two additional sets of image data were generated by extending the tumor boundaries beyond the front torso by 5 mm and 10 mm, respectively, as illustrated in Figure 3. According to the Eclipse™ treatment planning system version 16.01.10 (Varian Medical Systems, CA, USA) instruction, creating a bolus that covers the extended target volume with at least a 3 mm margin is recommended. This was done to develop virtual boluses with thicknesses of 10 mm (PTV +5 mm) and 15 mm (PTV+10 mm). Consequently, there are three datasets: no virtual bolus, 10-mm virtual bolus, and 15-mm virtual bolus. The CT number of the bolus was adjusted from 0 to -700 HU in 100 HU decrements for each CT image dataset.

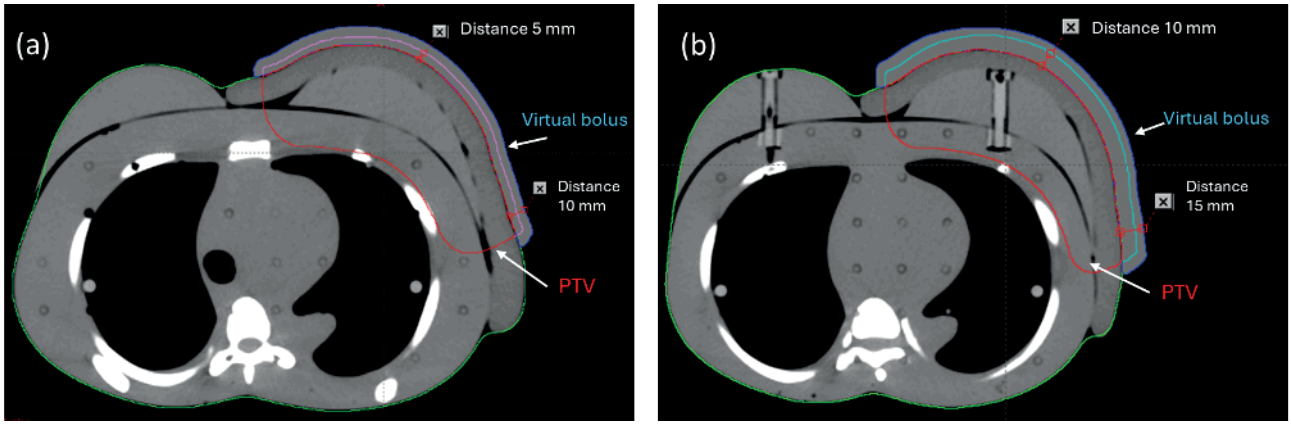


Figure 3. *Delineation of the PTV (red line) and virtual bolus (blue line) creation. a: CT image of 10-mm virtual bolus (PTV +5mm) (a), b: CT image of 15-mm virtual bolus PTV+10 mm.*

After establishing the treatment plan, the virtual tissue equivalent material was removed, and the radiation dose was recalculated. The number of fractions was changed to 1. Subsequently, the doses at all 9 locations from the treatment plan, corresponding to the positions of the nanoDot™, were recorded for comparison with the measurement data.

The treatment plans with VMAT technique were generated for these 3 image sets using the Eclipse™ treatment planning system version 16.01.10, employing 6 MV energy and assigning a total dose of 50 Gy in 2 Gy per fraction for 25 sessions. For planning criteria, the maximum dose (D_{max}) received did not exceed 115% of the prescribed dose or 57.5 Gy, and the dose to 95% of the volume ($D_{95\%}$) received was not less than 95% of the prescribed dose or not less than 47.5 Gy. The example of dose distribution is illustrated in Figure 4.

The treatment plans were replanned by adjusting the CT number of the tissue equivalent material to all HU settings for 2 bolus thicknesses and re-optimization with the new CT number.

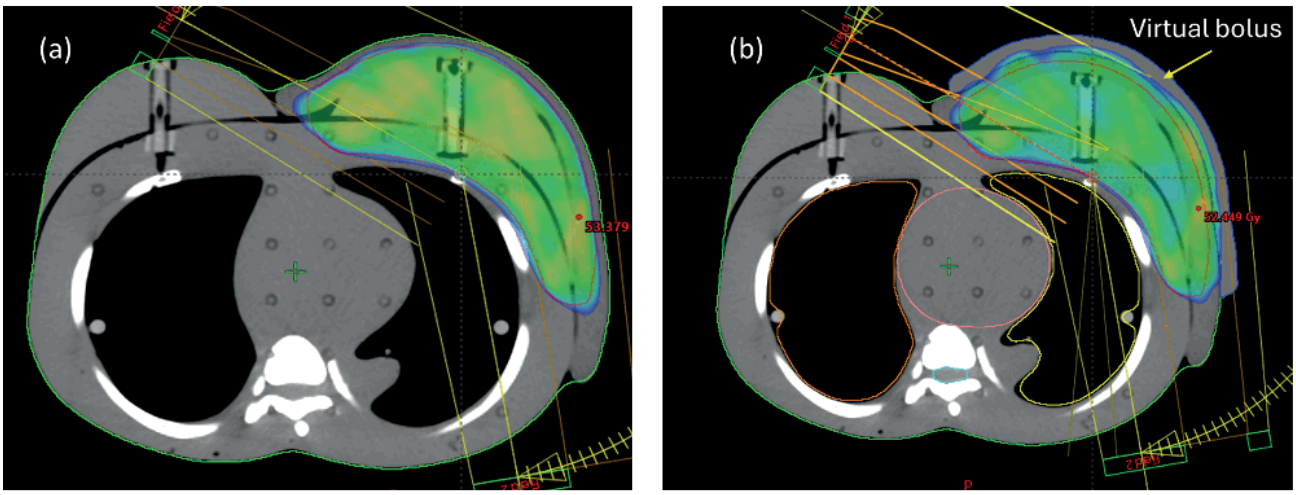


Figure 4. *Treatment plan in Rando Phantom. a: no virtual bolus, b: with virtual bolus.*

The nanoDot™ dose measurement

Determination of sensitivity correction factor of nanoDot™

The nanoDot™ sensitivity correction factor addresses the adjustments required for error readings among detectors within a given batch. While it is ideal for all detectors to provide identical dose measurements, individual detectors might display variations in sensitivity. To address these differences, a correction factor called the "sensitivity correction factor" (k_{sen}) was applied.

The correction factor for each nanoDot™ was computed by establishing the ratio between the average reading obtained from all detectors in the same batch (M_{avg} in cGy) and its specific reading (M in cGy), as demonstrated in Equation 1.

$$k_{sen} = \frac{M_{avg}}{M} \quad (1)$$

For the determination of the sensitivity correction factor, a total of 100 nanoDot™ detectors underwent irradiation with a 100 cGy dose of a 6MV X-ray beam, where the irradiation setup included a source-to-axis distance (SAD) of 100 cm, a depth of 10 cm, and a field size (FS) of 20x20 cm^2. The Clinac 2100 linear accelerator (Varian Medical Systems in Palo Alto, CA, USA) was employed for this study. Subsequently, Equation 1 was utilized to calculate the sensitivity correction factor for each nanoDot™. The nanoDot™ detectors exhibiting a sensitivity correction factor beyond ±5% were excluded, and only those with sensitivities close to 1 were included in the subsequent experiment.

Calibration of nanoDot™

For the calibration of nanoDot™ dosimeters, 3 out of the 100 detectors in the batch were selected, ensuring their sensitivity did not vary by more than ±5%. These 3 nanoDot™ dosimeters were calibrated by comparing it with an ionization chamber (IC) of 0.65 cm^3 volume (Wellhofer FC65-G IBA Dosimetry, Schwarzenbruck, Germany), irradiating with 6 MV X-rays at a dose of 100 cGy, a dose rate of 400 MU/min, a field size of 10 x 10 cm^2, source-to-axis distance (SAD) of 100 cm, and a depth of 1.5 cm. The VitalBeam linear accelerator (Varian Medical Systems, CA, USA) was employed for this study. The sensitivity of each dosimeter was corrected, and the nanoDot™ calibration factor was determined using Equation 2.

$$Calibration\ factor\ (CF) = \frac{D_{IC}}{M_{OSLD}} \quad (2)$$

where, D_{IC} is radiation dose measured by IC (cGy) according to the recommendation of TRS 398 [19] and M_{OSLD} is the nonoDot reading with the correction of sensitivity (cGy).

Measurement

All planned treatment sessions measured the radiation dose in the nanoDot™. The radiation doses in the treatment plan were evaluated by comparing the measurements using nanoDot™ dosimeters. The background nanoDot™ readings were removed from the reading, and the readings were corrected for sensitivity. The calibration factor was then applied according to equation 3. The nanoDot™ measurements were repeated three times, and the results were averaged for each measurement point. Then, the percentage difference between calculated and measured doses was assessed to confirm the planning dose with the measurement.

$$D_{OSLD} = M_{OSLD} \times CF \quad (3)$$

where,M_{OSLD} is the nanoDot™ reading corrected for k_{sen} and CF is the calibration factor of nanoDot™.

The comparison of mean calculated and measured doses in terms of percentage dose difference could confirm the reliability of the doses calculated with the virtual bolus, ensuring that the dose distribution covered the entire breast by calculating the coefficient of variance (%CV). The following experiment aimed to determine the optimal CT number for the virtual bolus in VMAT plan applications for various breast cancer cases.

Determination of optimal CT number of virtual bolus: Clinical study

Ten sets of CT images from breast cancer patients were included in this study. The inclusion criteria were the VMAT plans of breast cancer patients with left breast. The left breast patient was chosen because we would like to evaluate the dose for the heart. For each patient, three CT images were studied, representing no virtual bolus, a 10-mm virtual bolus, and a 15-mm virtual bolus. The CT numbers were varied from 0 to -700 HU in 100 HU decrements. A treatment plan was then executed on a series of CT images of left breast cancer patients, with the treatment plan and adjustment parameters being identical to those used in the phantom study. The maximum dose (D_{max}) received was at most 115% of the specified dose or 57.5 Gy, and the dose to 95% of the volume ($D_{95\%}$) received was not less than 95% of the prescribed dose or not less than 47.5 Gy.

Equations 4 and 5 were used to determine the conformity number (CN) [20] and homogeneity index (HI)[4], respectively.

$$CN = \frac{TV_{RI}}{TV} \times \frac{TV_{RI}}{V_{RI}} \quad (4)$$

where, TV_{RI} is the target volume covered by the reference isodose, TV is the target volume, and V_{RI} is the volume of the reference isodose.

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \quad (5)$$

where *D2%*, *D50%*, and *D98 %* are the doses to 2%, 50%, and 98% of the target volume, respectively. The range of CN is 0 to 1, with the ideal value equal to 1. The HI should be close to 0 to indicate homogeneity.

The radiation doses in high-risk organs were compared, considering D_{mean} and $V_{35\%}$ for the heart and $V_{55\%}$ for the lungs, regarding specific limits outlined in RTOG 1005.[21] This comparison aided in determining the CT number of

the virtual tissue equivalent material suitable for planning treatment with this technique.

Results

Sensitivity correction factor of nanoDot™

The sensitivity correction factor of nanoDot™ was in the range of 0.952-1.072. The nanoDot™ with a sensitivity correction factor higher than ±5% was excluded from the further experiment.

Calibration factor of nanoDot™

Upon calibrating the nanoDot™ dosimeter with an ionization chamber, the nanoDot™ dosimeter's average radiation dose was 84.18 cGy, while the ionization chamber's average radiation dose was 103.00 cGy. Therefore, the calibration factor was 1.22.

Dose uniformity of virtual bolus in breast VMAT planning and validation with nanoDot™ measurement

The distribution of breast dose was uniform, with the coefficient of variation (%CV) among 9 points being less than 3% for both calculation and measurement, except for the measured dose at 15 mm and -600 HU, as shown in Table 1.

Table 1. The difference in measured radiation dose versus calculated radiation dose from an average of 9 locations.

Thickness of virtual bolus (mm)	CT number of bolus (HU)	Measured dose (cGy)		Calculated dose (cGy)		%Dose difference
		Mean±SD	%CV	Mean±SD	%CV	
No virtual bolus	-	211.69±5.60	2.65	208.16±1.96	0.94	-1.67
10	0	211.83±3.14	1.48	207.86±1.85	0.89	-1.87
	-100	210.84±2.94	1.39	206.02±2.52	1.22	-2.29
	-200	212.04±3.19	1.50	205.48±2.07	1.01	-3.09
	-300	211.07±5.07	2.40	204.80±4.26	2.08	-2.97
	-400	210.14±5.54	2.64	204.56±4.52	2.21	-2.66
	-500	209.76±5.61	2.67	204.17±3.96	1.94	-2.66
	-600	205.39±5.21	2.54	199.57±3.81	1.91	-2.83
	-700	208.96±3.19	1.53	201.78±2.45	1.21	-3.44
15	0	217.06±2.92	1.35	212.02±2.27	1.07	-2.32
	-100	216.06±5.59	2.59	211.50±3.23	1.53	-2.11
	-200	213.68±4.65	2.18	207.33±4.88	2.35	-2.97
	-300	211.19±4.34	2.06	205.89±4.71	2.29	-2.51
	-400	209.71±4.40	2.10	205.34±4.43	2.16	-2.08
	-500	210.20±4.57	2.17	205.43±3.34	1.63	-2.27
	-600	207.68±7.23	3.48	203.08±5.26	2.59	-2.21
	-700	206.20±5.42	2.63	202.49±4.93	2.43	-1.80

Note: *%CV: (SD/Mean) x 100, %dose difference:* $\frac{(\text{Calculated dose} - \text{Measured dose})}{\text{Measured dose}} \times 100$

By measuring the dose in the Rando phantom using the nanoDot™ dosimeter, which underwent corrections for sensitivity and calibration factors, it was determined that the discrepancy between the measured dose and the dose calculated from the treatment plan system averaged across nine locations in a treatment plan that excluded virtual bolus.

In treatment plans where a 10-mm virtual bolus at 0 HU to -700 HU was applied, the discrepancy ranged from 1.87% to -3.44%. Similarly, in treatment plans employing a 15-mm virtual bolus within the same HU range, the variation ranged from -1.80% to -2.97%, as shown in Table 1. Importantly, all treatment plans demonstrated dose differences of less than ±5%, under the recommendations outlined in the IAEA Human Health Report No. 8. [22]

Application of virtual bolus in breast cancer patient plans

In the treatment plans involving adjustments of the thickness of the virtual bolus and modifications of the CT number of the virtual bolus, $D_{95\%}$ for all treatment plans were consistently found to be at least 95% of the prescribed dose or 47.5 Gy. Similarly, the D_{max} value for all treatment plans was maintained at not higher than 115% of the prescribed dose or 57.5 Gy. Notably, a reduction trend was observed with lower CT values in treatment plans featuring identical thicknesses of the virtual bolus, as illustrated in Table 2. The CN for all plans ranged between 0.78-0.85, and HI ranged between 0.08-0.15. The averages and the standard deviations among 10 breast cancer patients for all plans are shown in Table 2.

Table 2 The average dose of PTV in the treatment plan of 10 breast cancer patients.

Virtual bolus		Dose parameters		CN	HI
Thickness (mm)	CT number (HU)	D_{max} (Gy)	$D_{95\%}$ (Gy)		
No virtual bolus	-	55.61±0.82	50.01±0.01	0.83±0.04	0.08±0.01
10	0	56.18±0.51	50.08±0.09	0.80±0.06	0.10±0.01
	-100	57.23±1.22	49.10±0.98	0.82±0.06	0.13±0.04
	-200	56.89±0.99	48.85±0.95	0.83±0.05	0.13±0.04
	-300	56.60±1.24	48.74±0.97	0.83±0.05	0.12±0.04
	-400	56.49±1.25	48.51±1.09	0.83±0.05	0.13±0.04
	-500	56.17±0.99	48.41±1.04	0.84±0.06	0.13±0.04
	-600	56.27±0.95	48.21±0.92	0.85±0.05	0.13±0.04
	-700	56.32±1.22	47.99±1.40	0.84±0.07	0.13±0.05
15	0	56.36±0.63	50.23±0.25	0.78±0.06	0.11±0.01
	-100	57.31±1.31	48.97±1.06	0.79±0.05	0.15±0.05
	-200	56.93±1.40	48.80±0.98	0.80±0.05	0.15±0.05
	-300	56.52±1.21	48.63±0.99	0.81±0.05	0.14±0.05
	-400	56.22±1.46	48.36±0.97	0.82±0.05	0.14±0.04
	-500	56.12±1.65	48.00±1.01	0.83±0.05	0.14±0.05
	-600	55.49±1.39	47.84±1.05	0.84±0.04	0.14±0.05
	-700	55.55±1.69	47.73±0.96	0.84±0.04	0.14±0.04

Note: *CN: conformity number, HI: homogeneity index, D_{max}: maximum dose, $D_{95\%}$: dose received by 95% of the target volume.*

As illustrated in Table 3, the treatment plan without a virtual bolus received the lowest dose to organs at risk compared to the plans with a virtual bolus. In the virtual bolus plans, considering the absorbed dose to organs, the V_{5Gy} of the lung on the lesion side did not exceed the specified dose range of 55% of the lung volume in all treatment plans utilizing a virtual bolus with a thickness of 10 mm, except for those with a CT number of -600 HU.[21] For the virtual bolus with a thickness of 15 mm, only the treatment plans with a CT number of 0 HU met the criteria.

Regarding the D_{mean} of the heart, limited to a radiation dose not exceeding 5 Gy, it was observed that only treatment plans utilizing virtual bolus with CT number of 0 HU for thicknesses of 10 and 15 mm met the specified criteria. For V_{10Gy}, restricted to not exceeding 35% of the heart volume, this criterion was met within the defined threshold across all treatment plans, as indicated in Table 3.

Considering the dose parameter for tumors and organs at risk, the optimal CT number for the virtual bolus was 0 HU for both 10 mm and 15 mm thicknesses.

Table 3. The average dose of the lungs and heart in the treatment plan of 10 breast cancer patients.

Virtual bolus	Lung		Heart	
Thickness (mm)	CT number (HU)	V_{5Gy} (%)	D_{mean} (Gy)	V_{10Gy} (%)
No virtual bolus	-	43.43±4.33	4.10±0.62	7.80±1.88
10	0	44.31±4.43	4.24±0.65	8.81±1.76
	-100	53.21±8.67	5.35±1.47	12.30±6.43
	-200	54.64±9.17	5.51±1.51	12.85±6.76
	-300	53.32±8.80	5.49±1.39	12.72±6.54
	-400	53.57±9.85	5.35±1.38	12.25±6.05
	-500	54.10±10.03	5.40±1.42	12.22±6.06
	-600	55.20±9.48	5.45±1.44	12.37±5.91
	-700	54.63±11.19	5.39±1.50	12.28±6.55
15	0	45.41±5.38	4.39±0.43	9.23±1.40
	-100	59.49±10.16	6.06±1.09	14.09±4.70
	-200	59.99±9.46	5.93±1.06	13.55±4.51
	-300	59.27±8.46	5.93±1.19	13.69±5.29
	-400	59.42±10.74	5.77±1.16	12.99±4.79
	-500	61.19±10.39	5.88±1.24	13.42±5.25
	-600	60.11±8.80	5.77±1.11	13.21±5.10
	-700	59.40±9.51	5.78±1.19	13.05±4.89

Note: *V_{5Gy}: volume of an organ receiving a radiation dose of at least 5Gy, V_{10Gy}: volume of an organ receiving a radiation dose of at least 10Gy, D_{mean}: mean dose received by an organ at risk.*

Discussion

From the dose measurement of the VMAT technique, nanoDot™ with corrected sensitivity and calibration factors was utilized. The results indicated that the difference between the measured dose and the dose calculated from the treatment planning system at an average of nine locations did not exceed ±5%, as recommended by the IAEA Human Health Report No. 8.[22] However, the discrepancy between the measured dose and doses calculated from the treatment planning system might have been attributed to the volumetric intensity-modulated irradiation techniques with high dose gradients at the edge of the field. At specific points, there could have been a small field or radiation-measuring device at the edge of the beam. Moreover, the breast anatomy has a sloped surface, resulting in the placement of the device not being planar at the same level. In the event of measurement, it should have been studied in conjunction with other small dosimeters, such as metal oxide semiconductor field-effect transistor (MOSFET) dosimeter, radiophotoluminescence glass dosimeter (RPLGD). Additionally, locations where the difference exceeded 5% could have been attributed to the angular independence of this device. A previous study by Kern JR *et al*. reported the nanoDot™ exhibited a significant angular sensitivity when exposed to photon beams.[23] The angular dependence was 4% lower at 6 MV and 3% lower at 18 MV compared to the response observed when exposed to nominal incident beams.

Considering breast movement, a study by Frazier RC *et al*. found that inhalation moved the breasts forward, with an average movement of 6 mm (range: 3-11 mm) and 4 mm (range: 1-7 mm) at the inner and lateral edges, respectively.[24] The virtual bolus thickness in this study, 10 and 15 mm, covered the range of breast movement.

Based on the study of the application of virtual bolus in treatment plans, adjustments were made to the thickness of the virtual bolus, and changes were made to the CT number of bolus. This study reduced CT numbers of bolus to evaluate radiation doses from treatment plans. The treatment plan met all criteria utilizing virtual bolus with 10- and 15-mm thicknesses, with CT number values set to 0 HU. Furthermore, virtual bolus materials did not change the radiation dose in sensitive organs. This finding differs from a study by Lizondo M *et al*. which found that the most suitable CT numbers were approximately -400 HU and -550 HU for tissue equivalence materials with 10 mm and 15 mm thicknesses, respectively.[1] Therefore, the negative CT value was chosen in the current investigation. Discrepancies in the optimal CT number between this research and that conducted by Lizondo M *et al*. could be attributed to the influence of intra- and inter-fractional motion on position uncertainty, which was simulated through the utilization of the plan uncertainty feature integrated into Eclipse. Nevertheless, the actual motion of the breast during breathing cycles was not explored in this study. Future investigations could involve the evaluation of clinical cases to analyze virtual bolus VMAT plans or the utilization of a moving breast phantom to examine virtual bolus in the Flash region.

Conclusion

The difference between the measured dose and the dose calculated from the 9-position in breast falls within ±5%, aligning with the recommendation from the IAEA Human Health Report No. 8. The most significant difference, 6.36% (observed at the third position with a 10 mm thickness and a CT number of -700 HU in the bolus plan), is noted. For clinical plans, it is concluded that treatment plans utilizing virtual bolus are effective in meeting all dose criteria. Specifically, the plans employing 10- and 15-mm thicknesses with CT numbers equal to 0 HU demonstrate favorable outcomes. Only treatment plans with a CT number of 0 HU for organs at risk meet the criteria.

Further investigations are warranted to evaluate the measurement of radiation dose in actual patients. This includes assessing the broader population subjected to treatment plans involving virtual bolus. A larger sample size would facilitate more comprehensive evaluations.

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References

[1] Lizondo M, Latorre-Musoll A, Ribas M, Carrasco P, Espinosa N, Coral A et al. Pseudo skin flash on VMAT in breast radiotherapy: Optimization of virtual bolus thickness and HU values. Physica Medica 2019; 63: 56-62. doi: 10.1016/j.ejmp.2019.05.010.

[2] Monajemi TT, Oliver PAK, Day A, Yewondwossen M. In search of a one plan solution for VMAT post-mastectomy chest wall irradiation. J Appl Clin Med Phys 2020; 21(8): 216-23. doi:10.1002/acm2.12948.

[3] Bogue J, Wan J, Lavey RS, Parsai EI. Dosimetric comparison of VMAT with integrated skin flash to 3D field-in-field tangents for left breast irradiation. J Appl Clin Med Phys 2019; 20(2): 24-9. doi:10.1002/acm2.12527.

[4] ICRU. Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT), ICRU Report 83. 2010. doi:10.1093/jicru/ndq010.

[5] Rossi M, Boman E, Skyttä T, Haltamo M, Laaksomaa M, Kapanen M. Dosimetric effects of anatomical deformations and positioning errors in VMAT breast radiotherapy. J Appl Clin Med Phys 2018; 19(5): 506-16. doi:10.1002/acm2.12409.

[6] Tyran M, Tallet A, Resbeut M, Ferre M, Favrel V, Fau P et al. Safety and benefit of using a virtual bolus during treatment planning for breast cancer treated with arc therapy. J Appl Clin Med Phys 2018; 19(5): 463-72. doi:10.1002/acm2.12398.

[7] Yukihara EG, Yoshimura EM, Lindstrom TD, Ahmad S, Taylor KK, Mardirossian G. High-precision dosimetry for radiotherapy using the optically stimulated luminescence technique and thin Al2O3:C dosimeters. Phys Med Biol 2005; 50(23): 5619-28. doi:10.1088/0031-9155/50/23/014.

[8] Jursinic PA. Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements. Med Phys 2007; 34(12): 4594-604. doi:10.1118/1.2804555.

[9] Dunn L, Lye J, Kenny J, Lehmann J, Williams I, Kron T. Commissioning of optically stimulated luminescence dosimeters for use in radiotherapy. Radiat Meas 2013; 51-2: 31–39. doi:10.1016/j.radmeas.2013.01.012.

[10] Viamonte A, Da Rosa LAR, Buckley LA, Cherpak A, Cygler JE. Radiotherapy dosimetry using a commercial OSL system. Med Phys 2008; 35(4): 1261-6. doi:10.1118/1.2841940.

[11] Alvarez P, Kry SF, Stingo F, Followill D. TLD and OSLD dosimetry systems for remote audits of radiotherapy external beam calibration. Radiat Meas 2017; 106: 412-5. doi:10.1016/j.radmeas.2017.01.005.

[12] Mrčela I, Bokulić T, Izewska J, Budanec M, Fröbe A, Kusić Z. Optically stimulated luminescence in vivo dosimetry for radiotherapy: Physical characterization and clinical measurements in 60Co beams. Phys Med Biol 2011; 56(18): 6065-82. doi:10.1088/0031-9155/56/18/018.

[13] Yusof FH, Ung NM, Wong JHD, Jong WL, Ath V, Phua VCE *et al*. On the use of optically stimulated luminescent dosimeter for surface dose measurement during radiotherapy. PLoS One 2015; 10(6): 1-15. doi: 10.1371/journal.pone.0128544.

[14] Zhuang AH, Olch AJ. Validation of OSLD and a treatment planning system for surface dose determination in IMRT treatments. Med Phys 2014; 41(8): 081720doi:10.1118/1.4890795.

[15] Wake JR, Chen FQ, Ashworth S, Byth K, Wang W, Stuart KE. Verification using in vivo optically stimulated luminescent dosimetry of the predicted skin surface dose in patients receiving postmastectomy radiotherapy. Medical Dosimetry 2021; 46(2): e1-e6. doi:10.1016/j.meddos.2020.10.001.

[16] Butson M, Chen T, Alzaidi S, Pope D, Butson E, Gorjiara T et al. Extrapolated skin dose assessment with optically stimulated luminescent dosimeters. Biomed Phys Eng Express 2016; 2(4): 47001. doi:10.1088/2057-1976/2/4/047001.

[17] Raj LJS, Pearlin B, Peace BST, Isiah R, Singh IRR. Characterisation and use of OSLD for in vivo dosimetry in head and neck intensity-modulated radiation therapy. J Radiother Pract 2021; 20(4): 448-54. doi:10.1017/S146039692000062X.

[18] Ponmalar R, Manickam R, Ganesh KM, Saminathan S, Raman A, Godson HF. Dosimetric characterization of optically stimulated luminescence dosimeter with therapeutic photon beams for use in clinical radiotherapy measurements. J Cancer Res Ther 2017; 13(2): 304-12. doi:10.4103/0973-1482.199432.

[19] IAEA. Absorbed Dose Determination in External Beam Radiotherapy, Technical Reports Series No. 398 (Rev. 1). INTERNATIONAL ATOMIC ENERGY AGENCY:

Vienna, 2024; doi:10.61092/iaea.ve7q-y94k.

[20] Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: A review. Int J Radiat Oncol Biol Phys 2006; 64(2): 333-42. doi:10.1016/j.ijrobp.2005.09.028.

[21] Freedman GM, White JR, Rosenstein B, Bentzen SM, Li A, Co-Chair S et al. Radiation therapy oncology group RTOG 1005 a phase III trial of accelerated whole breast irradiation with hypofractionation plus concurrent boost versus standard whole breast irradiation plus sequential boost for early-stage breast cancer, Study Chairs Document History. 2011 [cited 2024 May 14]. Available from: https://www.ctsu.org.

[22] IAEA. Development of Procedures for In Vivo Dosimetry in Radiotherapy, IAEA HUMAN HEALTH REPORTS No. 8. 2013 [cited 2024 May 14]. Available from: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1606_web.pdf.

[23] Kerns JR, Kry SF, Sahoo N, Followill DS, Ibbott GS. Angular dependence of the nanoDot OSL dosimeter. Med Phys 2011; 38(7): 3955-62. doi:10.1118/1.3596533.

[24] Frazier RC, Vicini FA, Sharpe MB, Yan D, Fayad J, Baglan KL *et al*. Impact of breathing motion on whole breast radiotherapy: A dosimetric analysis using active breathing control. Int J Radiat Oncol Biol Phys 2004; 58(4): 1041-7. doi:10.1016/j.ijrobp.2003.07.005.