Original Article

Dose Agreement Analysis of Treatment Planning System-Calculated Doses and Markus Chamber-Measured Doses in the Near-Surface Region for Breast Cancer Patients' Conformal Treatment Plans

Garima Gaur, Raja Paramjeet Singh Banipal[1], Pardeep Garg, Om Prakash Gurjar[2], Gurpreet Kaur, Sheetal Sachdeva[3], Romikant Grover, Manraj Singh Kang, Vinod Kumar Dangwal[1]

Department of Radiation Oncology, Guru Gobind Singh Medical College and Hospital, Faridkot, [1]Department of Radiation Oncology, Government Medical College, Patiala, [3]Advance Cancer Centre, Bhatinda, Punjab, [2]Department of Radiotherapy, Government Cancer Hospital, MGM Medical College, Indore, Madhya Pradesh, India

Abstract

Background: Surface/skin dose measurement is one of the most challenging tasks for clinical dosimetry in radiotherapy and comparison with almost all the commercially available treatment planning systems (TPSs) brings a significant variation with the measured dose. **Aims and Objectives:** In the current study, doses calculated from the TPS in the near-surface region for conformal plans (both three-dimensional conformal radiotherapy [3DCRT] and intensity-modulated radiotherapy [IMRT]) of 35 breast cancer patients were evaluated and compared with the doses measured with Markus chamber. **Materials and Methods:** The computed tomography (CT) images of a solid water slab phantom with a Markus chamber (at different depths ranging from 1 mm to 5 mm from the surface) were taken and imported into the TPS. All the conformal treatment plans made in TPS were executed on a linear accelerator and dose agreements between TPS calculated and chamber measured doses were analysed. **Results:** Results showed that this TPS underestimated the calculated doses in the superficial region by up to 26% and 21%, respectively, with respect to mean and maximum dose values obtained within the effective volume of the chamber used. **Conclusion:** The uncertainty of doses in the superficial region should be kept in mind when evaluating treatment plans for superficial tumours in TPS.

Keywords: Breast cancer, conformal planning techniques, Markus chamber, solid water phantom, skin dosimetry, treatment planning system

Received on: 19-12-2021 **Review completed on: 06-04-2022** **Accepted on: 12-04-2022** **Published on: 08-11-2022**

Introduction

The evaluation and determination of the skin doses are of major concern when it contains target volumes, especially in the near-surface regions, for example, chest wall irradiation in the breast carcinoma (Ca), Ca maxilla, Ca buccal mucosa, or other superficial tumors. Radiotherapy, apart from surgery and chemotherapy, plays a significant role in the treatment of breast cancer. Virtual dose simulations are carried out by the treatment planning systems (TPSs) using various dose calculation algorithms to acquire the best optimized conformal dose distribution.[1] Underdosage to the target can result in recurrence of tumor while overdosage can lead to severe skin reactions. While modern TPS is, in most cases, able to accurately predict doses for a patient, several studies have demonstrated inaccurate surface and near-surface dose estimation by TPSs.[2,3] Hence, surface dose measurement is one of the important dosimetric tasks for the proper dose delivery to cancer patients where the target structures are superficial.

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_153_21

Address for correspondence: Dr. Vinod Kumar Dangwal, Department of Radiation Oncology, Government Medical College, Patiala, Punjab, India.
E-mail: drvkdangwal@gmail.com

How to cite this article: Gaur G, Banipal RP, Garg P, Gurjar OP, Kaur G, Sachdeva S, *et al*. Dose agreement analysis of treatment planning system-calculated doses and markus chamber-measured doses in the near-surface region for breast cancer patients' conformal treatment plans. J Med Phys 2022;47:256-61.

In the literature, skin dose measurement has been done with various available dosimeters (extrapolation chambers, parallel-plate chambers, radiographic or radiochromic films, and thermoluminescent dosimeters [TLDs], and metal oxide semiconductor field-effect transistors [MOSFETs]) for different types of beam geometries.[4-15] Although the extrapolation chambers with variable sensitive volume mass are best suited for accurate measurement of absorbed doses in the near surface of the medium, their unavailability in the present institute has led to the Markus type parallel-plate chamber to be chosen for surface dose measurements.[16] Due to its thin entrance window, less perturbation toward primary photon beam and electron contamination, and fixed electrode separation, parallel-plate ionization chambers are also suited for surface and buildup region dose measurements instead of extrapolation chambers. However, secondary electrons scattered from its sidewall result in an overresponse by the parallel-plate chamber, which can be corrected using the correction factors proposed by Gerbi *et al*.[17]

The present study aimed to measure surface doses using a Markus-type parallel-plate chamber on a solid water phantom and compared to TPS (CMS XiO)-calculated doses for conformal radiotherapy plans of breast cancer patients. The literature has yet to address dose agreement analysis in the near-surface region in breast cancer for CMS XiO TPS with Markus chamber for conformal fields.

Materials and Methods

This retrospective study involved 35 conformal radiotherapy treatment plans (25 plans with intensity-modulated radiotherapy (IMRT) and 10 plans with three-dimensional conformal radiotherapy (3DCRT) techniques) used for postmastectomy breast cancer patients. All the patients were planned using CMS XiO (version 5.1, Computerized Medical Systems, USA) TPS for 6 MV photon beams generated by Elekta Synergy Platform linear accelerator (Elekta Medical Systems, Crawley, UK). A superposition algorithm was used for dose calculation during planning with a grid size calculation of 2 mm. A prescribed dose of 50 Gy in 25 fractions over 5 weeks was given to all the patients. All patients in the current study had a target volume extending up to the skin (including the chest wall along with regional axillary and supraclavicular lymph nodes).

To carry out the dose agreement analysis to 5 mm depth into the superficial region, computed tomography (CT) images (slice thickness 2.5 mm) of an RW3 solid water slab phantom (PTW Freiburg, Germany, dimension 30 cm × 30 cm and thickness ranging 1 mm to 10 mm), with a Markus chamber (Markus 23343, PTW Freiburg, Germany) placed in the slotted slab, were acquired using a 16-slice Optima CT 580W (Wipro GE Hangwei Medical systems Co. Limited, China) CT Simulator. A total of five CT scans per patient were acquired such that a varying thickness of solid water phantom slab, ranging from 1 mm to 5 mm, was in place above the Markus chamber contained in the slotted slab. A total of five slabs (each with thickness of 1 cm) beneath this slotted slab were used for all scans to ensure full backscattered condition for the current experiment.

These CT images were then transferred to a Monaco (Elekta Medical Systems Pvt. Ltd.) contouring station through Digital Imaging and Communication in Medicine. The body of the solid water phantom and the effective volume of the Markus chamber were contoured in all the five scans; these images were then sent to the CMS XiO TPS. The reference point and isocenter were marked at the center and top surface of the Markus chamber, respectively, in the TPS with a constant source-to-chamber distance of 100 cm in all the scans. The conformal treatment plans of breast cancer patients were made and delivered on all the phantom scans using the same procedure as generally employed for routine patient-specific quality assurance (QA) plans. From dose-volume histogram statistics, maximum and mean doses were recorded for the contoured effective volume structure of the Markus chamber (approximately 0.05 cm^3 volume) for all the conformal plans at depths up to 5 mm (ranging from 1 mm to 5 mm, at intervals of 1 mm).

The experimental setup used for dose measurement using the Markus chamber at different depths is shown in Figure 1.

The Markus chamber used for the surface dose measurement has a fixed plate separation of 2 mm with a sidewall-to-collector distance of 0.35 mm. Each patient's conformal plan was delivered on the proposed five different experimental phantom setups as shown in Figure 1. The meter readings were obtained from an electrometer, PTW UNIDOS E (SN: T10008-080915, PTW Freiburg, Germany) for all conformal plans for the experimental setup described. The value of the dose at a given depth was calculated from a meter reading using the formula (1).[18]

$$\text{Dose} = (M \times k_{T,} p \times N_{D,\,w} \times k_p \times k_s \times k_{Q,\,Q0})/PDD \quad (1)$$

where "M" is the meter reading, "$k_{T,P}$" is the temperature-pressure correction factor, "$N_{D,\,w}$" is the absorbed dose to water calibration factor, "k_p" is the polarity correction factor, "k_s" is the ion recombination correction factor, "$k_{Q,\,Q0}$" is the correction factor that corrects for the difference between the reference beam quality, Q_0, and the actual beam quality, Q, being used, and "PDD" is the percentage depth dose at a given depth in a 20 cm × 20 cm field size. The PDD values for all five depths, ranging from 1 mm to 5 mm at an interval of 1 mm, were taken from the PDD profile of a 6 MV photon beam in a 20 cm × 20 cm field size. All other factors were calculated as per the formalism given in the International Atomic Energy Agency (IAEA) Technical Report Series No. 398.[18]

Since the Markus chamber is being used to measure the absorbed dose in a photon beam, k_Q^{PP} was calculated using the formula as mentioned in equation (2).[19]

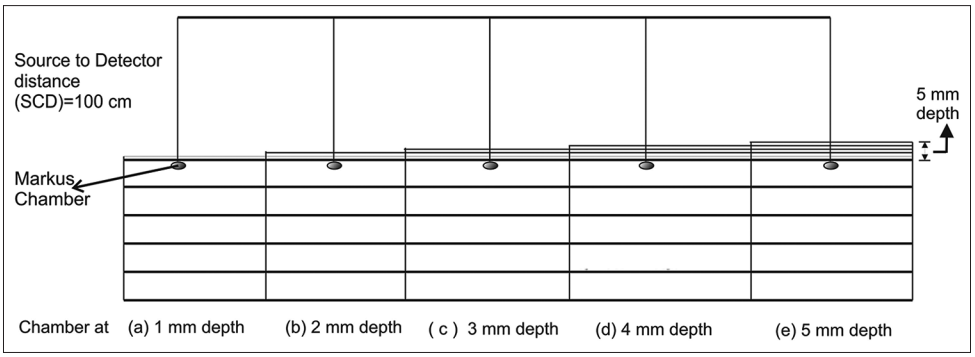

Figure 1: Schematic diagram for five different setups of a solid water phantom having a Markus chamber inserted at a constant SCD of 100 cm at the time of measurement. SCD: Source-to-chamber distance

$$k_Q^{PP} = \frac{N_{D,w}^{ref}}{N_{D,w}^{PP}} \frac{M_Q^{ref}}{M_Q^{PP}} k_Q^{ref} \quad (2)$$

The superscripts "PP" and "ref" denote the parallel-plate chamber under test and the reference chamber, respectively. A cylindrical chamber (0.6-cc Farmer-type ion chamber) was used as a reference chamber for calculating k_Q^{PP}. The procedure for calculating this factor is mentioned in a study conducted by Kapsch and Gomola (IAEA).[19]

Overestimation correction

The doses measured with the above Equations 1 and 2 were further corrected for the overresponse of parallel-plate chambers for measurement in the buildup region for megavoltage beams.[17,20] Gerbi *et al*. suggested formulas for all types of fixed parallel-plate chambers to estimate the total overresponse correction needed as shown in Equations 3 and 4. These factors are chamber specific and depend on their physical geometry, for example, volume, plate separation, and guard size

$$\xi\,(d, Q) = \xi(0, Q)\, e^{-\alpha(d/d_{max})} \quad (3)$$

$$\text{and } \xi\,(0, Q) = a + b\,(IR) \quad (4)$$

where *IR* is the ionization ratio, *Q* is the quality of radiation, α is the constant of proportionality (α = 5.5) equal to the fractional change in the overresponse, in percent, of the chamber per unit change in d/d_{max}, and a and b are the chamber dependent variables with units of percent and percent per ionization ratio, respectively. The overestimation factors calculated for two-photon beam energies (6 MV and 15 MV) for 5 depths is shown in Table 1.

Dose agreement analysis

Percentage variations between the TPS-calculated doses and Markus chamber-measured doses (corrected for overestimation) for each conformal plan at five depths were calculated for dose agreement analysis purposes.

Results

The surface doses measured by the Markus chamber and those calculated by TPS for breast cancer patients were analyzed. The values of mean percentage variation, standard deviation (SD), and range were calculated for the measured doses with that of the maximum and mean doses obtained from the TPS for the volume of the chamber for all conformal plans. The mean values of percentage variation along with the range and SD between measured dose and TPS calculated (max and mean dose) at all five depths (1 to 5 mm) for IMRT fields are tabulated in Table 2.

Table 1: The values of overresponse correction factors calculated at different depths (mm) for the user's 6 MV and 15 MV photon beam

Depth (mm)	Energy (6 MV) (%)	Energy (15 MV) (%)
0	11.16	5.52
1	7.71	4.6
2	5.37	3.83
3	3.72	3.19
4	2.57	2.65
5	1.8	2.2

As shown in Table 2, the largest mean percentage variation of the measured dose with respect to the TPS-calculated maximum and mean dose (in an effective chamber volume of 0.05 cm^3) is 20% and 26%, respectively. It is also observed that the measurements at 2 mm depth show a significantly largest percentage variation as compared to all other depths.

The percentage variations between measured dose and TPS-calculated dose (maximum and mean doses) for IMRT plans are shown in Figures 2 and 3.

The mean values of the percentage variation, the range, and the SD between measured dose and TPS-calculated (maximum and mean) dose at all five depths (1 mm to 5 mm) for 3DCRT fields are given in Table 3.

As shown in Table 3, the largest mean percentage variation of the measured dose with respect to the TPS-calculated maximum and mean dose is 19% and 25%, respectively. A similar observation with IMRT plans was also seen in 3DCRT plans showing a largest percentage variation at 2 mm depth as compared to all other depths.

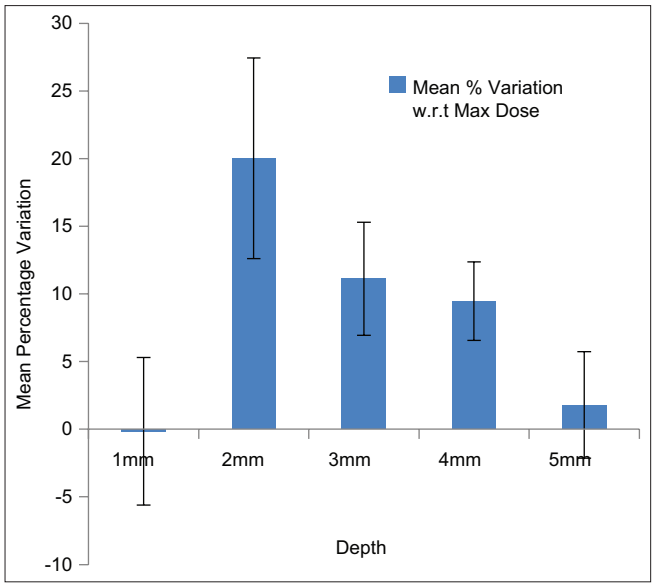

Figure 2: Mean percentage variation between Markus chamber-measured dose and TPS-calculated dose (D_{max} of contoured effective volume structure) at five depths in IMRT fields. TPS: Treatment planning system, IMRT: Intensity-modulated radiotherapy

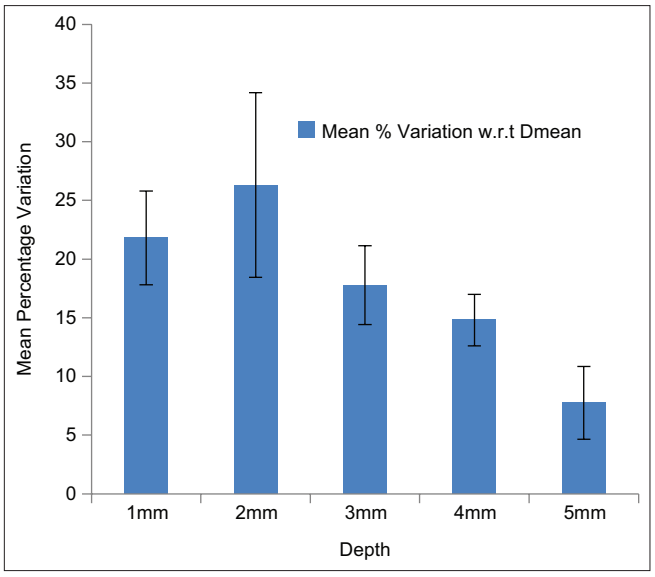

Figure 3: Mean percentage variation between Markus chamber-measured dose and TPS-calculated dose (D_{mean} of contoured effective volume structure) at five depths in IMRT fields. TPS: Treatment planning system, IMRT: Intensity-modulated radiotherapy

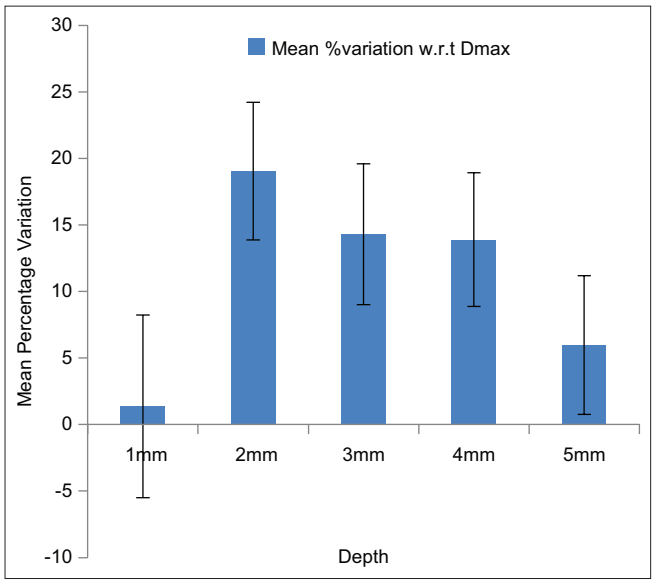

Figure 4: Mean percentage variation between Markus chamber-measured dose and TPS-calculated dose (D_{max} of contoured effective volume structure) at five depths in 3DCRT fields. TPS: Treatment planning system, 3DCRT: Three-dimensional conformal radiotherapy

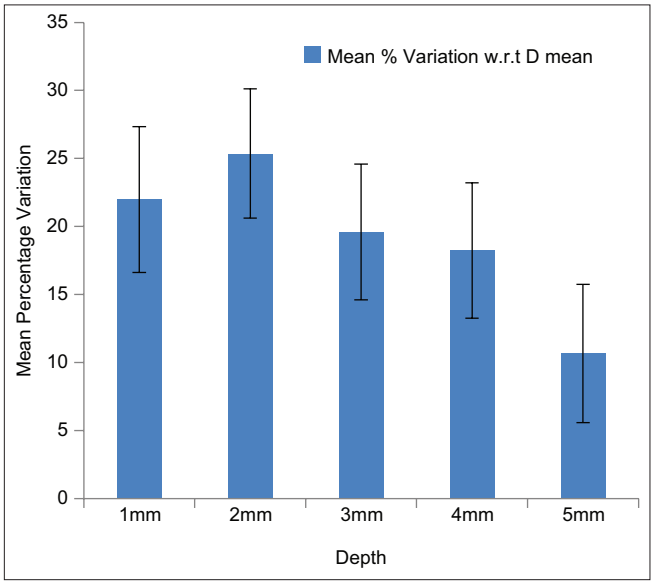

Figure 5: Mean percentage variation between Markus chamber measured dose and TPS calculated dose (D_{mean} of contoured effective volume structure) at five depths in 3DCRT fields. TPS: Treatment planning system, IMRT: Intensity modulated radiotherapy

The percentage variation between the measured dose and the TPS-calculated dose (maximum and mean) at different depths for 3DCRT plans is shown in Figures 4 and 5.

Discussion

It has been observed by several groups that the dose calculated by different commercially available TPSs brings significant uncertainty for different regions, for example, surfaces, areas of inhomogeneity, interfaces, and dose gradient regions.[2,3] The skin is the major organ at risk in the radiotherapy treatment after breast conservative surgery, while the same skin is the target volume for postmastectomy breast cancer patients requiring radiotherapy treatment and its measurement with different available dosimeters is a challenging task.

The agreement of dose calculation between TPS-calculated doses and Markus chamber-measured doses in solid water phantom was found to be within 26% in the near-surface region. Most of the calculated variations in dose show

Table 2: The values of percentage variation in surface doses measured to a depth of 5 mm by a Markus chamber and those of the treatment planning system for intensity-modulated radiotherapy plans

Depth (mm)	Percentage variation with respect to D_{max}		Percentage variation with respect to D_{mean}	
	Mean±SD	Range	Mean±SD	Range
1	−0.15±5.46	−11.27-9.05	21.78±3.99	15.84-28.14
2	20.02±7.42	8.62-33.83	26.31±7.86	14.75-41.2
3	11.12±4.18	2.10-18.69	17.79±3.35	11.54-23.31
4	9.47±2.91	3.24-14.82	14.81±2.20	9.37-19.08
5	1.80±3.93	−4.61-10.30	7.75±3.10	1.40-13.32

SD: Standard deviation

Table 3: The values of percentage variation in surface doses measured to a depth of 5 mm by a Markus chamber and those of the treatment planning system for three-dimensional conformal radiotherapy plans

Depth (mm)	Percentage variation with respect to D_{max}		Percentage variation with respect to D_{mean}	
	Mean±SD	Range	Mean±SD	Range
1	1.36±6.86	−6.85-13.19	21.98±5.35	15.36-31.57
2	19.05±5.17	13.41-26.80	25.36±4.75	19.28-31.75
3	14.30±5.28	8.90-21.97	19.59±4.98	14.41-27.14
4	13.89±5.02	8.45-22.27	18.22±4.98	12.78-26.76
5	5.98±5.21	0.98-15.84	10.66±5.08	5.76-20.02

SD: Standard deviation

an underestimation by TPS. The difference between the TPS-calculated doses and measured doses was found to decrease with an increase in depth except at 2 mm. The measurements at 2 mm depth showed the largest percentage variation among both IMRT and 3DCRT plans. One of the reasons is due to the electron contamination as a resulting from interactions of incident photons with different accessories, for example, collimators (jaws and multileaf collimators), wedges, flattening filters, and other shielding materials.[21,22] The different dosimetric chambers have different contributions toward doses from the electron contamination due to variation in their physical characteristics.[23] Gerbi's overresponse correction factors were calculated for the Markus chamber for different beam energies at different depths up to 5 mm and are in good agreement with the literature values. Commercially available treatment algorithms show significant variations in dose estimation in the near-surface regions, confirming that patient-specific QA plays an important part in the early prediction of overdose or underdose to the skin and skin-related reactions.[24] For postmastectomy patients, for example, underdose of the skin might result in tumor recurrence, whereas overdose can cause acute skin toxicity.

Potential factors that may have contributed to the uncertainty in the present study include errors in the nonreproducible setup position and dose measurement, manual dose calculation using various factors including Gerbi's correction factor, TPS inaccuracies in contouring and dose calculation, and the finite size of the Markus chamber.

A study by Court and Tisher compared the dose estimation by Eclipse TPS and micro-MOSFETs for measuring skin dose under different irradiation conditions, namely, open fields, physical wedges, dynamic wedges, and various SSDs, both for 6-MV and 10-MV photon beams. They observed a dose agreement within ± 20% for 95% of all measured points.[6] In another study by Chung *et al*., a comparison of dose estimation and validation of two TPSs (Pinnacle and CORVUS) was done using radiochromic film; they found an overestimation of surface dose by 7.4%−18.5%.[3] Calculation of surface doses for various open fields and energies using Markus chamber and EBT2 film was done.[7-9] Recently, Senugupta *et al*. used MOSFETs for measuring skin doses for patients undergoing total body irradiation to see the dose variation throughout the body, finding that 85.5% of the points showed dose variation within the acceptable range of ± 10% from the expected value.[10] In another study by Wong *et al*., a deviation of up to 3.4% was observed between CMS XiO-calculated doses and TLD-measured doses.[25] The difference between measured dose by parallel-plate chambers or other dosimeters and TPS-calculated doses varies for different dose calculation algorithms. The accuracy of the dose calculated by CMS Xio TPS and Monte Carlo simulation for organs outside the radiation field in the treatment of the breast cancer by 2DCRT, 3DCRT, and IMRT techniques was conducted by Joosten, *et al*.; they found a difference as high as 70% depending on the technique used.[26] The reason for such a huge variation with CMS XiO TPS is mainly due to two reasons: the inadequate head scatter calculation by the TPS and its limited extension of the calculation volume outside the target fields. There is a scarcity of data in the literature that shows a dose agreement for CMS Xio TPS-calculated doses with a superposition dose algorithm and Markus chamber-measured dose for conformal radiotherapy fields planned for breast cancer patients. The present study observed a mean variation of up to 26% in dose estimation which is consistent with results from other groups.

Conclusions

From the present study, it can be concluded that there is a mean dose disagreement of up to approximately 26% between the CMS XiO TPS-calculated doses and Markus chamber-measured doses within the first 5 mm depth of buildup region in 3DCRT/IMRT conformal fields used for breast cancer treatment. Since variation in TPS-calculated surface doses has been observed in the present study, this deviation should be kept in mind when evaluating the treatment plans of postmastectomy breast patients where the chest wall including the skin is the target volume and needs proper dose coverage.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Thomas SJ, Hoole AC. The effect of optimization on surface dose in intensity modulated radiotherapy (IMRT). Phys Med Biol 2004;49:4919-28.
2. Gershkevitsh E, Schmidt R, Velez G, Miller D, Korf E, Yip F, *et al.* Dosimetric verification of radiotherapy treatment planning systems: Results of IAEA pilot study. Radiother Oncol 2008;89:338-46.
3. Chung H, Jin H, Dempsey JF, Liu C, Palta J, Suh TS, *et al.* Evaluation of surface and build-up region dose for intensity-modulated radiation therapy in head and neck cancer. Med Phys 2005;32:2682-9.
4. Akbas U, Kesen ND, Koksal C, Bilge H. Surface and buildup region dose measurements with Markus parallel plate chamber, Gafchromic EBT3film and MOSFET detector for high energy photon beams. Adv High Energy Phys 2016. DOI:10.1155/2016/8361028.
5. Fraass B, Doppke K, Hunt M, Kutcher G, Starkschall G, Stern R, *et al.* American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning. Med Phys 1998;25:1773-829.
6. Court LE, Tisher RB. Experimental evaluation of the impact of different head -and –neck intensity modulated radiation treatment planning techniques on the doses to the skin and shallow targets. Int J Radiat Oncol Biol Phys 2007;69:607-13.
7. Bilge H, Cakir A, Okutan M, Acar H. Surface dose measurements with GafChromic EBT film for 6 and 18MV photon beams. Phys Med 2009;25:101-4.
8. Bilge H, Ozbek N, Okutan M, Cakir A, Acar H. Surface dose and build-up region measurements with wedge filters for 6 and 18 MV photon beams. Jpn J Radiol 2010;28:110-6.
9. Mutic S, Low DA. Superficial doses from serial tomotherapy delivery. Med Phys 2000;27:163-5.
10. Sengupta A, Wilke DR, Cherpak A, Chytyk-Praznik K, Schella J, Yewondwossen M, *et al.* Surface dosimetry of patients undergoing total body irradiation: A retrospective analysis for quality assurance. Cureus 2020;12:e6900.
11. Singh R, Oinam AS, Trivedi G, Kainth HS, Shahi JS, Singh B, *et al.* A comparative study for surface dose evaluation in conventional treatment of carcinoma breast patients irradiated with Co-60 and 6 MV radiation beam. J Cancer Res Ther 2019;15:1035-41.
12. Han MJ, Yang SW, Bae SI, Moon YM, Jeon W, Choi CW, *et al.* Evaluation of monoxide film-based dosimeters for surface dose detection in electron therapy. PLoS One 2021;16:e0251441.
13. Le Deroff C, Pérès EA, Ledoux X, Toutain J, Frelin-Labalme AM. *In vivo* surface dosimetry with a scintillating fiber dosimeter in preclinical image-guided radiotherapy. Med Phys 2020;47:234-41.
14. Quach KY, Morales J, Butson MJ, Rosenfeld AB, Metcalfe PE. Measurement of radiotherapy x-ray skin dose on a chest wall phantom. Med Phys 2000;27:1676-80.
15. Lobo D, Banerjee S, Saxena PU, Ravichandran R, Srinivas C, Putha SK, *et al.* Clinical implementation of brass mesh bolus for chest wall postmastectomy radiotherapy and film dosimetry for surface dose estimates. J Cancer Res Ther 2019;15:1042-50.
16. Neves LP, Silva EA, Perini AP, Maidana NL, Caldas LV. Characterization of an extrapolation chamber for low-energy X-rays: Experimental and Monte Carlo preliminary results. Appl Radiat Isot 2012;70:1388-91.
17. Gerbi BJ, Khan FM. Measurement of dose in the buildup region using fixed-separation plane-parallel ionization chambers. Med Phys 1990;17:17-26.
18. International Atomic Energy Agency. Absorbed Dose Determination in External Beam Radiotherapy, Technical Report Series No. 398. Vienna: International Atomic Energy Agency; 2000.
19. Kapsch RP, Gomola I. Beam quality correction factors for plane-parallel chambers in photon beams. In Proceedings of an International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry, Vienna, Austria. 2010; IAEA-CN-182:35-36.
20. Mellenberg DE Jr.Determination of build-up region over-response corrections for a Markus-type chamber. Med Phys 1990;17:1041-4.
21. Sjögren R, Karlsson M. Electron contamination in clinical high energy photon beams. Med Phys 1996;23:1873-81.
22. Hounsell AR, Wilkinson JM. Electron contamination and build-up doses in conformal radiotherapy fields. Phys Med Biol 1999;44:43-55.
23. Panettieri V, Barsoum P, Westermark M, Brualla L, Lax I. AAA and PBC calculation accuracy in the surface build-up region in tangential beam treatments. Phantom and breast case study with the Monte Carlo code PENELOPE. Radiother Oncol 2009;93:94-101.
24. Akbas U, Kesen ND, Koksal C, Toraman KO, Altun M, Bilge H. Investigation of surface dose using film dosimerty and commercial treatment planning system for larynx cancer treatment with intensity modulated radiotherapy and volumetric modulated arc therapy. Turk J Oncol 2018;33:12-7.
25. Wong S, Back M, Tan PW, Lee KM, Baggarley S, Lu JJ. Can radiation therapy treatment planning system accurately predict surface doses in postmastectomy radiation therapy patients? Med Dosim 2012;37:163-9.
26. Joosten A, Matzinger O, Jeanneret-Sozzi W, Bochud F, Moeckli R. Evaluation of organ-specific peripheral doses after 2-dimensional, 3-dimensional and hybrid intensity modulated radiation therapy for breast cancer based on Monte Carlo and convolution/superposition algorithms: Implications for secondary cancer risk assessment. Radiother Oncol 2013;106:33-41.