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ARTICLE

THE COMPARISON OF SURFACE DOSE IN VIVO DOSIMETRY USING 3D-CRT AND IMRT TECHNIQUE ON BREAST CANCER CASE

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ABSTRACT

Verification of surface radiation dose in breast cancer cases using the in vivo dosimetry method with TLD-100 at the Radiation Oncology Installation of Andalas University Hospital has been conducted. The aim of this study is to verify the adequacy of the surface radiation dose calculated by the Treatment Planning System (TPS) using 3DCRT and IMRT technique with the dose measured by the TLD-100, referring to the report of the American Association of Physicists in Medicine Task Group No.219 (AAPM-TG No.219). This research process began with annealing the TLD-100, followed by scanning the TLD-100 on the surface of the slab phantom using a CT Simulator. In addition, the TLD-100 was calibrated with different radiation doses (0; 20; 50; 80; 100; 150; 200; 250; 370) cGy. Calculating the TPS surface dose by Patient Specific Quality Assurance (PSQA) and comparing it with the dose measured by the TLD-100 are done to verify the surface radiation dose. The result is radiation techniques such as IMRT are more conformal than 3D-CRT because they precisely control dose intensity, making the TLD dose in IMRT closer to that of TPS. Both techniques have discrepancy between TLD and TPS measurement is below the AAPM-TG 219 tolerance limit, with an average discrepancy of 2,84% for IMRT and 3,15% for 3D-CRT.

Keywords: Surface radiation dose; breast cancer; TLD-100; verification.

АБСТРАКТ

В отделении радиационной онкологии университетской клиники Андалас была проведена проверка дозы поверхностного облучения при раке молочной железы методом дозиметрии in vivo с помощью TLD-100. Целью данного исследования является проверка адекватности дозы поверхностного излучения, рассчитанной системой планирования лечения (TPS) с использованием методик 3DCRT и IMRT, с дозой, измеренной прибором TLD-100, в соответствии с отчетом целевой группы № 219 Американской ассоциации физиков в медицине (AAPM-TG No.219). Процесс исследования начался с отжига TLD-100, после чего TLD-100 был отсканирован на поверхности фантома плиты с помощью симулятора компьютерной томографии. Кроме того, TLD-100 был откалиброван с помощью различных доз излучения (0; 20; 50; 80; 100; 150; 200; 250; 370) сГр. Расчет поверхностной дозы TPS с помощью системы обеспечения качества для конкретного пациента (PSQA) и сравнение ее с дозой, измеренной TLD-100, проводятся для проверки поверхностной дозы облучения. В результате такие методы облучения, как IMRT, являются более конформными, чем 3D-CRT, поскольку они точно контролируют интенсивность дозы, что делает дозу TLD при IMRT более близкой к дозе TPS. В обеих методиках расхождение между измерениями ДВУ и ТПС ниже предела допуска AAPM-TG 219, в среднем 2,84% для IMRT и 3,15% для 3D-CRT.

Ключевые слова: Поверхностная доза излучения; рак молочной железы; TLD-100; верификация.

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INTRODUCTION

Breast cancer is one of the most common diseases among women worldwide. Breast cancer can occur when cells in the breast tissue develop abnormally and uncontrollably. This disease can spread to surrounding tissues and to other parts through the lymphatic or circulatory system, making it one of the leading causes of death in women[1].

According to Globocan data in 2022, breast cancer had the highest incidence in Indonesia with 66,271 patients, accounting for 16.2% of the total 408,661 cancer cases. Breast cancer is also the leading cause of death, accounting for 22,598 cases or 9.3% of the total 242,988 cancer deaths[2]. Therefore, radiotherapy is the adjuvant treatment after surgery and an important modality in the treatment of breast cancer. Radiotherapy is a cancer treatment method that uses ionizing radiation to damage and destroy cancer cells while minimizing damage to surrounding healthy tissue[3].

In breast cancer radiotherapy management, there are two main techniques that are commonly used, namely three-dimensional conformal radiotherapy (3D-CRT) and intensity modulated radiotherapy (IMRT). Radiation beam is used in 3D-CRT technique focusing on breast cancer tumors by considering the shape and size of the tumor in three dimensions. Thus, it is possible to deliver a more precise radiation dose to the cancer target[4]. Meanwhile, IMRT is a radiotherapy technique that allows adjustment of the intensity of the radiation dose at each point in the cancer target, to provide a more precise radiation dose and reduce damage to surrounding healthy tissue[5].

Delivering an appropriate dose of radiation in breast cancer radiotherapy is very important because the treatment target may extend to the surface of the skin. Cancer that grows inside the breast has the potential to spread and affect surrounding tissue structures, so delivering the right dose of radiation to the surface helps reduce the risk of cancer recurrence or growth of remaining cancer cells[6]. Accuracy of surface radiation dose plays an important role in reducing the risk of radiation side effects on skin tissue[7]. Therefore, measuring the surface radiation dose is n crucial step in ensuring that the dose delivered is as planned.

Surface radiation dose refers to the amount of radiation received by the patient's skin surface during radiation treatment. Efforts to optimize the measurement of surface radiation dose during radiation therapy can be accomplished by verifying the surface radiation dose. In vivo dosimetry method is used as the verification. It is a method of monitoring the radiation dose received by the patient during the radiotherapy treatment process[8].

The in vivo dosimetry method using thermoluminescence dosimeters (TLDs) has proven to be effective in measuring the radiation dose received by the patient's skin surface during radiotherapy. Verification of radiation dose by in vivo dosimetry is one of technique to ensure that patients receive the optimal radiation dose. Rudat et al. investigated surface doses in breast cancer patients undergoing adjuvant radiation with 7-field IMRT, tangential beam IMRT, and tangential beam 3D-CRT utilizing in vivo Gafchromic film dosimetry. The study assessed the influence of various radiation methods on surface dose while minimizing confounding variables. Based on these findings, the most current study published in this journal stresses the need of precise surface dose assessments. This study looks at the differences between TPS estimates and Thermoluminescent Dosimeter (TLD-100) measurements in both IMRT and 3D-CRT. The study found that, while both procedures adhere to AAPM TG-142 limits, TPS surface dose estimations via PSQA provide a mechanism for evaluating the correctness of radiation treatment plans on TPS for particular patients. The combination of in vivo dosimetry with TLD-100 in this context provides a more reliable verification of the actual administered dose, improving the precision and safety of breast cancer radiation.

The linac's surface radiation dose is verified by comparing the radiation dose measured with TLD to the surface radiation dose

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computed in TPS using PSQA calculations. The use of TLD has the advantage of being sensitive to radiation, relatively like to body tissue, highly accurate, and not affected by the environment. Placement of TLDs in the center of the radiation field is done because it can represent the area receiving the highest dose, so it can measure the most critical and important areas in radiotherapy treatment[9]. Surface dose calculation at TPS by PSQA calculation is to improve the accuracy of radiotherapy planning. Surface dose calculation by PSQA has the advantage of planning radiation doses according to patient characteristics[10]. Evaluation of surface radiation dose in 3D-CRT and IMRT techniques is very essential in radiotherapy due to the high complexity of the technique, the need for dose precision, irradiation optimization and minimal risk of side effects. Both techniques have complex radiation dose distributions and surface dose assessment that is required to ensure compliance with the treatment plan on TPS. This helps to minimize the risk of adverse effects and improve the safety and efficacy of radiotherapy treatment.

MATERIAL AND METHODS

Verification of surface radiation dose is done by comparing the radiation dose planned in TPS with the radiation dose measured using TLD-100. The steps taken in the verification of radiation dose include scanning and contouring the slab phantom and TLD-100 in the CT Simulator, measuring the 6 MV photon beam, calibrating the TLD-100, measuring the surface dose of breast cancer patients, and verifying the surface radiation dose in breast cancer cases.

1. 6 MV Photon Beam Measurement

Photon beam measurement aims to ensure that the Linac is in optimal condition before irradiation. The 6 MV photon beam measurement was carried out in accordance with the TRS 398 protocol using a farmer-type ionization chamber detector. Measurements were made on a phantom slab measuring 30 × 30 cm^2, Source to Surface Distance (SSD) 100 cm, with a field area of 10 × 10 cm^2, at a depth of 10 cm with a radiation dose of 200 cGy. The 6 MV photon beam output value is within the tolerance limit set by IAEA TRS 398 of ±2%. Equation [1] describes the measurement of the 6 MV energy photon beam at a depth of 10 cm.

$$D_{w,Q}(z.ref) = M_Q . N_{D,wQ_0} . k_{Q,Q_0} \quad [1]$$

The absorbed dose inside the slab phantom ($D_{w,Q}$) is calculated from charge measurements (M_Q) that have been corrected using temperature and pressure, humidity, polarity, recombination, and electrometer calibration. N_{D,w,Q_0} represents the reference's water absorption dose calibration coefficient. k_{Q,Q_0} is the correction factor for the discrepancy between the ionization detector's response in the calibration beam quality and the actual beam quality. Linac photon output beam deviation is the ratio of output at the reference maximum dose and the measured maximum dose with a tolerance of ±2%.

2. TLD-100 Calibration

TLD calibration was carried out to determine the relationship between the dose value read by the TLD-100 and the radiation dose at the TPS. TLD-100 was put on the surface of the phantom slab at the center of the irradiation field 10 × 10 cm^2, 100 cm SSD, and irradiated at 6 MV energy with varying radiation doses. The radiation dose of TPS given was (0, 20, 50, 80, 100, 150, 200, 250, 370) cGy. The TLD-100 readings will be compared to the radiation dose calculated by the TPS, resulting in a mathematical equation used to convert TLD-100 readings into radiation dose. The TLD-100 reading result (TL_b) is the difference between the total TLD reading (TL_t) and the background TLD reading (TL_l). To get the TLD reading result mathematically, it is shown by Equation [2].

$$TL_b = TL_t - TL_l \quad [2]$$

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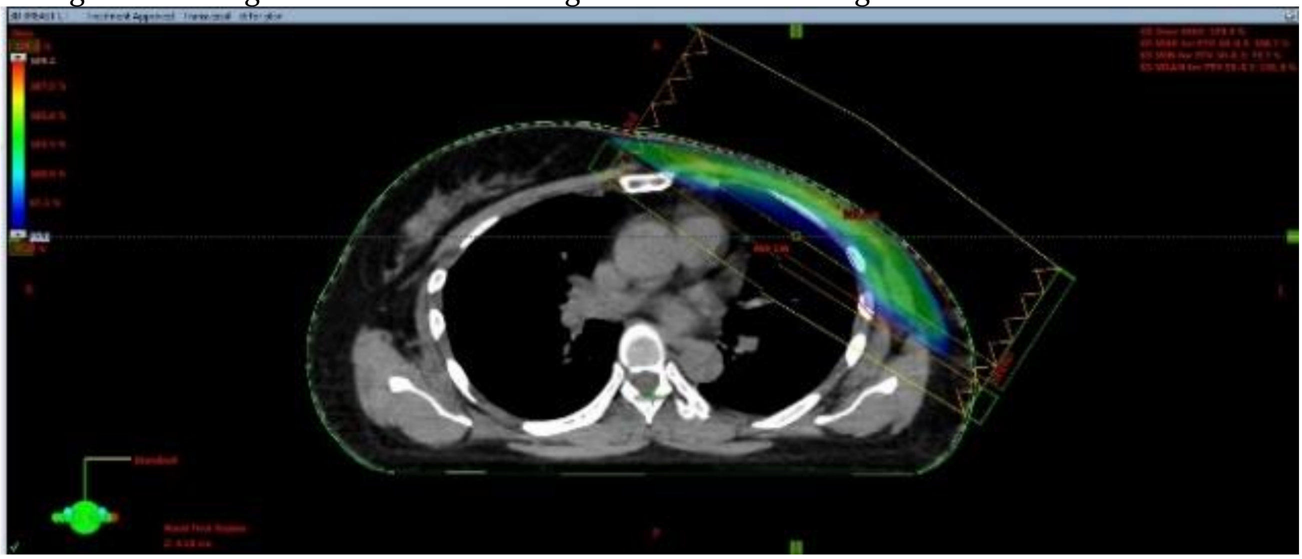
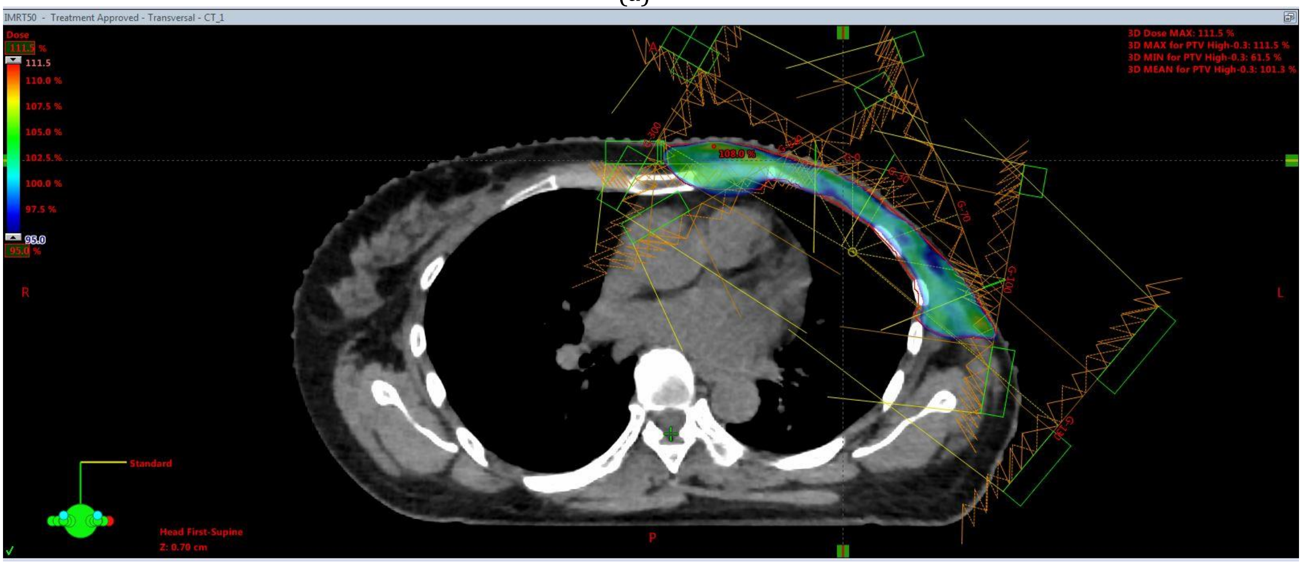
3. Calculation and Measurement of Surface Radiation Dose

Patient irradiation planning aims to build an accurate irradiation picture in the TPS and determine the optimal radiation dose. The initial step involved setting up 20 slab phantoms and placing 6 TLD chips at the center point of the irradiation field. Next, a scanning process was performed on the slab phantom and TLD-100 using a CT-Simulator, resulting in a 3D image or Dicom format image to be used in irradiation planning. The 3D image is then transferred to TPS, where a contouring process is performed to determine the irradiation target and surrounding healthy organs. After that, 3D-CRT and IMRT irradiation technique planning is organized with tangential and gantry orientation 0^{o} and transfer of patient planning to the slab phantom and TLD in TPS. Treatment palnning of breast cancer 3D-CRT and IMRT technique can be seen in Figure 1.



(a)



(b)

Figure 1. Treatment planning of breast cancer case (a) 3D-CRT, (b) IMRT technique

Surface dose measurements and calculations were carried out using the results of patient planning performed by medical physicists from TPS. The scanning procedure begins with the placement of 20 slab phantom sheets and 6 TLD-100 chips in the irradiation field's center. CT-Simulator scanning provides a 3D Dicom picture of the slab phantom and TLD-100, which is then loaded into TPS Eclipse version 11.0 for contouring. The slab phantom

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is used to perform PSQA on 3D-CRT and IMRT planning. Surface dose measurement and computation are performed after patient planning by TPS medical physicists, exported to a Dicom picture with PSQA verification, and dose calculated using TPS. Surface dose estimations are based on TLD data from Linac irradiation, which is part of the PSQA-verified patient irradiation plan, as shown in the Figure 2.

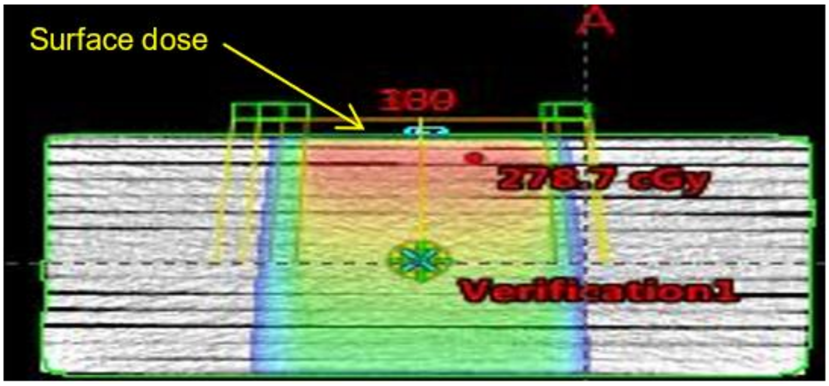

Figure 2. Dose distribution of PSQA evaluation on TPS Eclipse

Verification of Surface Radiation Doses in Breast Cancer Patients is performed to ensure that the radiation dose measured on the TLD is consistent with the patient's planned radiation dose. The surface radiation dose verification is obtained from the difference between the surface radiation dose planned at the TPS (D_{TPS}) and the surface radiation dose measured with the TLD-100 (Measured). Verification results are obtained using Equation [3].

$$Discrepancy\ (\%) = \frac{D_{measured} - D_{plan}}{D_{plan}}\ x\ 100\% \quad [3]$$

Discrepancy is the difference between planning dose on the TPS (D_{plan}) and the radiation dose measured using TLD-100 ($D_{measured}$).

RESULT

1. 6 MV Photon Beam Output

The Linac 6 MV photon beam output values at a reference depth of 10 cm (z_{ref}) and a maximum depth of 1.5 cm (z_{max}) that are shown in Table 1.

Table 1. 6 MV photon beam output

M_Q (nC)	D z_{ref} (cGy)	D z_{max} (cGy)	D TPS z_{max} (cGy)	Deviation (%)
28,01	133,79	200,58	200	0,29

Table 1 shows that the 6 MV photon beam output is within deviation values of the IAEA TRS 398 tolerance limit. The measurement results show that Linac has optimal performance in delivering accurate and precise radiation dose during radiotherapy treatment.

2. TLD-100 Calibration Curve

The TLD calibration process involves placing the TLD on the surface dose of the phantom slab at the center point of the irradiation field. Various radiation doses are administered (0, 20, 50, 80, 100, 150, 200, 250 370) cGy at 100 cm SSD and 6 MV energy. These doses are chosen to cover a range of radiation levels for calibration purpose. After exposure to radiation, the TLD-100 readings are obtained and compared with the radiation dose calculated by TPS. A mathematical equation is derived to convert the TLD-100 readings into radiation dose. The TLD-100 reading result (TL_b) is calculated as the difference between the total TLD reading (TL_t) and the background TLD reading (TL_l) using Equation[2]. Further details on the specific calculations and conversion factors used in this process can be provided for a more comprehensive understanding. Figure 1 shows the relationship between the radiation dose at TPS (cGy) and the net TL reading (nC). The TLD-100 calibration curve in Figure 1 shows a

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linear relationship, meaning that the greater the radiation dose of TPS, the greater the TLD-100 reading. The linear equation obtained from the TLD-100 calibration curve was used to convert the TLD-100 reading (nC) into the surface radiation dose value (cGy). The equation obtained is y = 0.0223x + 6.6513 with variable y is the dose value (cGy) and variable x is the TLD-100 reading. The linear relationship between TPS dose (cGy) and TLD-100 reading (nC) is also reinforced by the regression value of R^2 = 0.9931. The regression value close to 1 indicates a strong correlation between the TPS radiation dose and the TLD-100 reading. It indicates that the TLD-100 has a high accuracy of the response. The Calibration curve of TLD-100 can be seen in Figure 3.

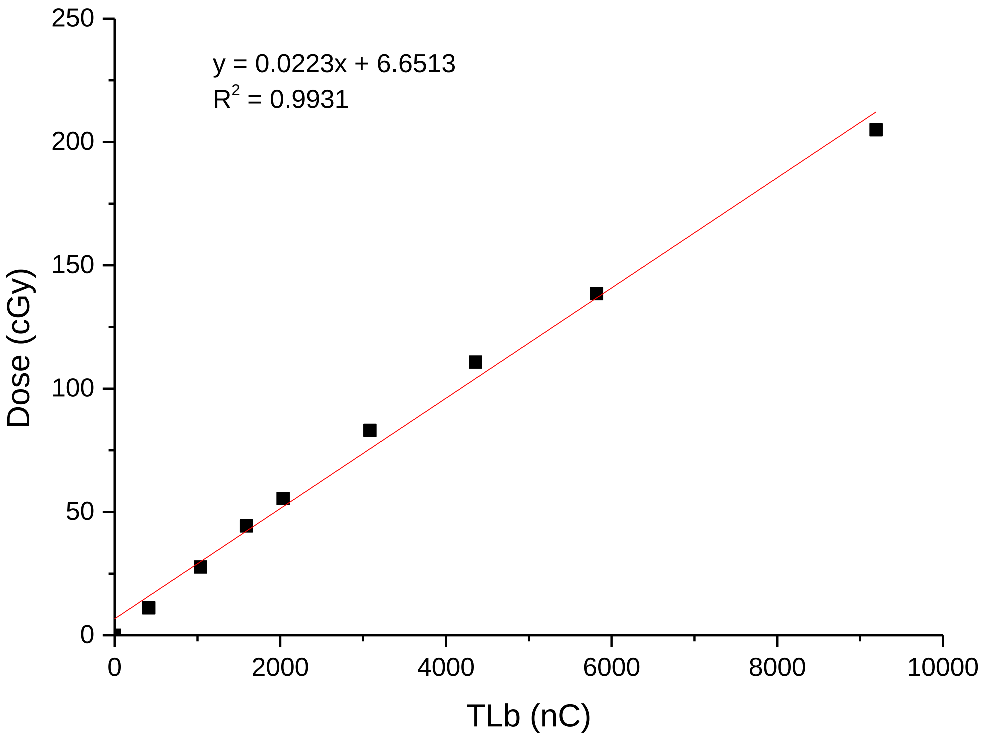

Figure 3. TLD-100 Calibration Curve

3. Calculation and Measurement of Surface Radiation Dose

The verification of surface radiation dose involves comparing the dose measured by the TLD-100 with the dose planned by the TPS. This comparison is crucial for ensuring that the actual radiation dose delivered matches the intended dose for effective treatment.

Verification results are obtained using Equation [3], which calculates the difference between the surface radiation dose planned at the TPS (D_{TPS}) and the surface radiation dose measured with the TLD-100 (Measured). By quantifying this difference, the accuracy and reliability of the TLD-100 measurements in verifying the planned radiation dose can be assessed.

Details on how the TLD-100 is utilized during Linac irradiation, the data recording process, and the steps involved in comparing the measured and planned doses can be outlined to provide a comprehensive overview of the surface radiation dose verification procedure.

Radiation dose measurement and calculation for surface in 3D-CRT and IMRT techniques can be seen in the Table 2.

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Table 2. Surface radiation dose in breast cancer cases

Patient	Irradiation Technique	Surface dose at TLD (cGy)	Surface dose at TPS (cGy)	Discrepancy (%)
1	3D-CRT	109.62	114.90	4.60
2	3D-CRT	120.72	115.95	4.11
3	3D-CRT	147.35	135.50	8.74
4	3D-CRT	120.98	117.80	2.70
5	3D-CRT	115.70	113.30	1.56
6	IMRT	106.67	107.30	0.58
7	IMRT	83.34	88.40	5.72
8	IMRT	90.92	98.35	7.55
9	IMRT	93.52	89.60	4.38
10	IMRT	94.13	90.80	3.67

From the table above, it can be seen that the total surface dose of patients measured by TLD in IMRT technique is lower than that of 3D-CRT. This difference is reflected in the average surface dose, which reaches 4.01 cGy. This can be seen in the average surface dose value of IMRT patients is 101.35 cGy, with the lowest value of 83.34 cGy and the highest value of 106.67 cGy, while the average surface dose value of 3D-CRT patients is 105.36 cGy, with the lowest value of 109.62 cGy and the highest value of 147.35 cGy. These results indicate that the IMRT technique can deliver a more targeted and precise radiation dose to the tumor target, which in turn can minimize radiation exposure to surrounding healthy tissues. Thus, the use of IMRT in the treatment of breast cancer can help reduce the adverse effects of radiation[5].

DISCUSSION

Based on the Table 2, there are differences in the suitability of surface radiation dose between measurements using TLD and radiation dose in TPS planning in 3D-CRT and IMRT techniques. In the IMRT technique, the difference between the measured and planned radiation doses has an average of 2.84% with a range of 0.58% to 7.55%. While the 3D-CRT technique shows an average surface radiation dose difference of 3.15% with a range of 1.56% to 8.74%, indicating a greater difference compared to the IMRT technique. The IMRT technique tends to provide more accurate radiation dose planning results than the 3D-CRT technique[4]. This is due to IMRT's ability to adjust the dose intensity more precisely and according to the shape of the tumor, so that the difference between the dose measured by TLD becomes smaller[11]. In contrast, 3D-CRT has limitations in controlling the larger dose between planning and measurement[12]. Thus, validation of the radiation dose received by patients through measurement with TLD is a critical step in ensuring the effectiveness of radiotherapy treatment in patients. The results of this study are consistent with other studies showing that IMRT can deliver a more targeted and precise radiation dose to the tumor target, thereby minimizing radiation exposure to surrounding healthy tissues[7].

In this study, the difference in dose between IMRT and 3D-CRT techniques, also the dose measured on TLD and TPS, could be due to several factors that must be considered. These factors include patient characteristics, such as anatomy, which can affect radiation dose distribution. Variations in patient anatomy can influence how radiation dose is absorbed by surrounding tissues, resulting in changes in the dose received during radiation therapy [12].

In addition, tumor characteristics such as tumor size, location, and type also affect radiation dose planning and distribution. Different tumors require different dose approaches, so differences in tumor characteristics between patients can lead to differences in planned and received doses[1].

In radiation approaches like IMRT and 3D-CRT, the dose measured with TLD is close to the anticipated dose with TPS[13]. In addition, changes in detector types, such as TLD, lead to variations in radiation dose measurement findings. Because of the various methodologies, detector features and sensitivity might cause minor discrepancies in the final dose readings[4,5]. Therefore, detector properties should be addressed when comparing doses between TLD and TPS. The dose discrepancies between IMRT and 3D-CRT, as well as TLD and TPS measurements, can be better understood by taking into account the aspects listed above. Continuous assessment of the radiation dose received by patients is required to guarantee the efficacy and safety of the radiation therapy administered[9].

A study by the International Atomic Energy Agency (IAEA) as cited by Demir et al., 2024 found that the TLD uncertainty for megavoltage photon beams is 6%[13]. Several factors contribute to this uncertainty, including recurrent TLD measurement uncertainties, calibration uncertainties related to TLD and Linac, energy dependency of the absorbed dosage, TLD location uncertainties, and energy dependence adjustments. Our study found an 8% difference between calculation and measurement for IMRT and 3D-CRT. Therefore, the results of this study are consistent with previous research[14].

It can be concluded that the percentage of agreement between the radiation dose measured with the TLD and the TPS is below the 20% tolerance limit recommended by AAPM TG 219[15]. This shows that the radiation dose measurements made with the TLD are reasonable and accurate when compared to the planning done with the TPS. This suggests that the TLD can be used as a tool to validate the radiation dose planned by the TPS, ensuring that patients receive the right dose as planned. With a percentage of agreement below the tolerance limit, this indicates a high level of accuracy in the measurement of radiation dose using the TLD.

The studies conducted by Hu et al., 2020 and Zhu et al., 2021 regarding in vivo dosimetry measurements using TLD-100 for surface doses, as well as radiation dose verification on patients' skin[9,12], found that both journals discuss the importance of measuring surface doses using TLD-100 to verify the radiation doses received by patients. The use of TLD-100 is considered an accurate and reliable method to ensure the accuracy of the doses delivered during radiotherapy treatments[16]. This research emphasizes that there is a difference between the doses calculated by the TPS and the doses measured with TLD, highlighting the need for in vivo dosimetry as a crucial step in clinical practice. Another journal discussed the use of TLD-100 in dose measurements for IMRT and 3D-CRT techniques for breast cancer patients, providing crucial information to improve the accuracy and safety of treatments. The journal Yen et al., 2022 and Demir et al., 2024 also noted that variations in TPS algorithms could affect the accuracy of surface dose calculations, further strengthening the argument for conducting in vivo dosimetry as essential validation[13,15]. Overall, based journal Adeneye et al., 2021 underscore the importance of verifying surface doses using in vivo dosimetry with TLD-100 to ensure that patients receive radiation doses as planned, especially in breast cancer treatments using IMRT and 3D-CRT techniques[3]. This also emphasizes the differences in surface doses produced by different radiotherapy devices and the need to understand the factors influencing these measurements.

Most studies focus on comparing the treatment planning outcomes of IMRT and 3D-CRT[17]. However, research discussing measurement results using Gafchromic film is more commonly found than those using TLD[18]. Surface radiation dose measurements with TLD placed on the patient's skin are also rarely conducted. Most other studies place TLD at a certain depth, not on the skin surface[17]. Therefore, research evaluating surface radiation doses with TLD has the potential to make a significant contribution to improving the accuracy and safety of radiation therapy,

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particularly in dose verification on the patient's skin surface.

CONCLUSION

The average surface dose is 101.35 cGy for IMRT and 105.36 cGy for 3D-CRT. The difference between TLD and TPS measurements in IMRT and 3D-CRT is less than the AAPM-TG 219 tolerance level, with an average difference of 2.84% for IMRT and 3.15 percent for 3D-CRT. Both results fall within the 20% tolerance level established by AAPM-TG 219.

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DECLARATIONS

The authors declare no conflict of interest.

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