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Analysis of Breast Cancer Radiation Dose Distribution Using Bolus Density in 3DCRT Technique Radiotherapy Planning at Andalas University Hospital

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ABSTRACT

Analysis of breast cancer radiation dose distribution using bolus density in radiotherapy planning of the Three-Dimensional Conformal Radiotherapy (3DCRT) technique has been conducted. This research aims to analyze radiation dose distribution in breast cancer patients using bolus density in radiotherapy planning of the 3DCRT technique. Five images of breast cancer patients were processed using TPS Eclipse software. The bolus density values used were a mixture of beeswax and petroleum jelly, playdough, silicone rubber, and 3D Polylactic Acid. CI and HI values were calculated based on the International Commission on Radiation Units and Measures (ICRU) Reports 62 and 83. Radiation dose in OAR was verified based on the Quantitative Analysis of Normal Tissue Effect in the Clinic (QUANTEC) standard. The results showed that all four bolus densities can be used in breast cancer patients, with CI values the CI value ranges from 0.93 to 0.98 by ICRU Report 62 standards and HI values close to ICRU Report 83 standards. In cardiac OAR, one patient exceeded the QUANTEC standard, while for lung OAR, all patients were below the QUANTEC standard. Using bolus density provides optimal radiation dose distribution on breast cancer targets.

1. INTRODUCTION

Breast cancer ranks as the leading contributor to cancer-related deaths in Indonesia. According to Global Cancer Statistics (GLOBOCAN, 2025), there were 70,219 cases of breast cancer in Indonesia, accounting for a significant portion of the 433,966 total cancer cases. This highlights the urgent need for effective treatments to reduce mortality and improve the quality of life for breast cancer patients. Various treatment modalities have been developed, including surgery, chemotherapy, hormone-blocking therapy, and radiotherapy (Symonds et al., 2012). Among these, radiotherapy has emerged as a critical approach due to its targeted application and effectiveness in managing cancer progression.

Radiotherapy utilizes ionizing radiation to treat cancer by delivering a controlled dose to the affected area while minimizing exposure to healthy tissues. In surface cancers such as breast cancer, electron beams are often employed because of their ability to deliver a homogeneous dose to the surface. However, the inherent limitation of electron beams, such as the skin-sparing effect, often results in suboptimal surface radiation doses. This shortfall underscores the necessity of bolus materials, which are designed to enhance surface dose delivery by mimicking tissue characteristics and addressing uneven tissue surface (Podgorsak, 2005; Mayles et al., 2007).

Bolus materials play a crucial role in optimizing radiotherapy outcomes. They are placed on the skin surface to increase the surface radiation dose, reduce the depth dose, and ensure even dose distribution. Over the years, various materials have been investigated and developed for use as boluses, including plasticine (Fitriani et al., 2022; Pramita et al., 2023), play-doh (Carina et al., 2020; Pramita et al., 2023), alginate (Guswantoro et al., 2020), superflab (Aras et al., 2020), natural rubber (Aisyah et al., 2020; Endarko et al., 2021), virtual bolus (Rafli et al., 2021), silicone rubber (Chantika et al., 2022), a mixture of beeswax and petroleum jelly (Ningsih et al., 2022), and 3D polylactic acid (Yuliandari et al., 2024). These materials differ in their physical properties, ease of application, and effectiveness in enhancing radiation dose distribution. A tissue-equivalent bolus is usually used to increase the surface dose in patients with breast cancer undergoing radiation therapy after mastectomy. The skin and chest wall doses are related to the frequency of bolus applications. Covering bolus throughout the entire radiotherapy planning process can lead to excessive surface dose and significant side effects. An appropriate bolus application frequency can keep the skin dose within the acceptable range while ensuring adequate chest wall dose to prevent a recurrence (Tian et al., 2024).

The introduction of modern Treatment Planning Systems (TPS) has further revolutionized radiotherapy by enabling precise dose calculation and optimization. TPS employs advanced algorithms to plan radiation therapy by considering the Planning Target Volume (PTV) and Organs at Risk (OAR). According to the International Commission on Radiation Units (ICRU) Report 62, PTV represents the primary target volume, while OAR refers to healthy tissues sensitive to radiation exposure. Effective use of bolus materials within the TPS framework ensures that the prescribed dose reaches the cancer target (PTV) while minimizing exposure to OAR, such as the heart and lungs (Su et al., 2014). The Dose Volume Histogram (DVH) is a critical tool in TPS for evaluating the conformity and homogeneity of dose distributions, measured through the Conformity Index (CI) and Homogeneity Index (HI).

In Indonesia, plasticine boluses are widely used for their availability and cost-effectiveness. However, studies indicate plasticine boluses may not provide the best outcomes compared to modern alternatives such as virtual boluses or 3D-printed boluses. Research revealed that virtual boluses achieve better CI and HI values, enhancing dose uniformity and coverage (Rafli et al., 2021). Demonstrated that 3D-printed polylactic acid (PLA) boluses offer superior thickness uniformity and dose distribution compared to commercial plasticine boluses. These advancements align with the increasing adoption of 3D printing technology in medical physics, which facilitates the customization of bolus shapes and densities to suit individual patient anatomies (Yuliandari et al., 2024).

The physical properties of bolus materials significantly influence their performance. Silicone rubber boluses, for instance, have shown greater effectiveness than plasticine boluses in reducing the range of absorbed doses at depth (Chantika et al., 2022). Likewise, a mixture of beeswax and petroleum jelly has emerged as a promising bolus material due to its ability to increase surface dose without compromising dose uniformity (Ningsih et al., 2022). Comparative studies highlighted that silicone rubber boluses closely resemble the density of water and muscle tissue, making them ideal for achieving optimal dose distribution in clinical settings (Pramita et al., 2023). These findings emphasize the need for continued innovation and evaluation of bolus materials to meet the evolving demands of radiotherapy.

This study offers an innovative contribution by directly comparing the clinical effectiveness of various bolus materials, including a mixture of beeswax and petroleum jelly, playdough, silicone rubber, and 3D PLA, in the distribution of radiation dose during breast cancer therapy. The primary advantage lies in the evaluation of both local and modern materials' performance based on treatment planning parameters such as the Conformity Index (CI), Homogeneity Index (HI), and Dose to Organs at Risk (OAR) derived from DVH curves. This approach provides comprehensive insights that can enhance the optimization of radiotherapy treatments in clinical facilities, particularly at Andalas University Hospital.

This study conducts a detailed comparison of the dosimetric evaluation and treatment planning outcomes using various types of bolus materials. Additionally, it emphasizes the importance of utilizing modern technologies, such as 3D-printed boluses and advanced planning techniques, to enhance patient care quality. By addressing gaps in previous literature and incorporating the latest innovations in materials and technology, the results of this research are expected to serve as a valuable reference for future studies and to support more accurate and effective clinical practices in the field of radiotherapy.

2. METHOD

2.1 Breast Cancer Patient Image Selection and Contouring

This study involved obtaining patient images of breast cancer through CT-Simulator procedures, followed by contouring of the target volume and organs at risk (OAR) such as the lungs and heart in accordance with the guidelines specified in (ICRU Report 62, 1999). Radiotherapy planning was conducted using the Eclipse Treatment Planning System (TPS) employing the 3DCRT technique, with bolus density values determined based on relevant literature and prior research on suitable dosimetric materials, including a mixture of beeswax and petroleum jelly, playdough, silicone rubber, and 3D polylactic acid. Dose distribution analysis involved calculating the Conformity Index (CI) and Homogeneity Index (HI), as well as evaluating the doses received by OAR following standard doses outlined in QUANTEC and ICRU guidelines to ensure adequate target coverage and organ protection. Methodologically, this research represents a dosimetric simulation supported by patient imaging data and scientifically selected bolus materials to optimize radiotherapy treatment for breast cancer patients. At this stage, the image obtained by the CT-Simulator is contoured so that the PTV and OAR of the cancer can be seen; the image's contents include GTV, CTV, ITV, PTV, and OAR in Figure 1.

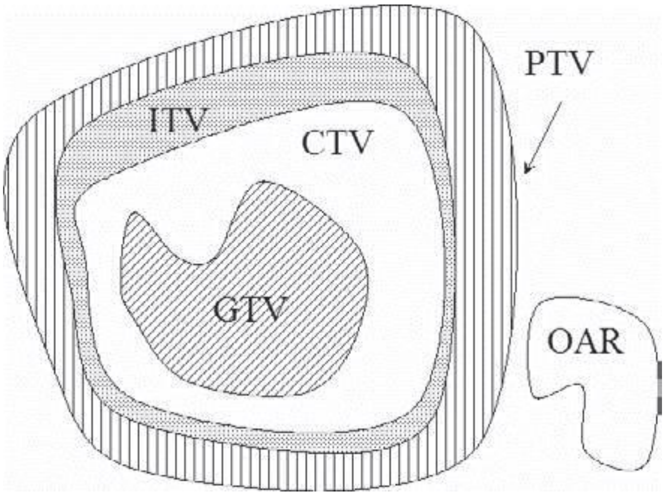


Figure 1 Target and OAR identification chart (Podgorsak, 2005)

2.2 Inverse Planning

Inverse planning involves the adjustment of radiation dose, number of fractions, treatment fields, and gantry angles through optimization procedures performed using a Treatment Planning System (TPS) software. In this study, the data utilized are simulated and based on medical records and dosimetric data from five breast cancer patients, which were analyzed through the Eclipse TPS. The materials used for bolus fabrication include various substances such as a mixture of beeswax and petroleum jelly, playdough, silicone rubber, and 3D-printed polylactic acid. These materials received approval and consent from the relevant institutional authorities in accordance with applicable regulations. The prescribed radiation dose was 200 cGy per fraction, administered over 25 fractions, resulting in a total dose of 5000 cGy. The 3DCRT planning involved five different field configurations, arranged according to the target volume's position, with field angles adjusted to align with the target's orientation. Planning parameters were determined collaboratively by the research team, medical physicists, and radiation oncologists at the Radiotherapy Installation of Andalas University Hospital, in adherence to ethical standards and regulatory requirements.

2.3 3DCRT Optimization and Density Value Input

The 3DCRT optimization *planning* process involves using computer algorithms to calculate the optimal radiation dose distribution, namely by modifying the radiation doses in PTV and OAR, so that planning obtains intensity maps and intensity levels. The optimization process in the *Eclipse TPS software* is done by entering the values of the prescription and priority radiation doses into the PTV and OAR radiation dose optimization dialog box. Optimization is performed iteratively by continuously adjusting the radiation dose value and priority until the desired optimization value is achieved. The density values of the four types of boluses, namely boluses made from a mixture of *beeswax* and *petroleum jelly* (Ningsih et al., 2022)*, playdough* (Pramita et al., 2023), *silicone rubber* (Chantika et al., 2022), and 3D *polylactic acid* (Yuliandari et al., 2024), were taken based on the results of previous research.

2.4 Dosimetry Analysis

The dosimetric analysis consists of PTV and OAR analysis. PTV and OAR analysis were obtained based on the DVH curve in radiotherapy planning. Radiation dose distribution analysis on PTV is reviewed based on CI and HI values. The CI value can be obtained using Equation 1, while the HI value can be obtained using Equation 2.

$$CI = \frac{V_{95}}{V_{PTV}} \tag{1}$$

where CI is the ratio between the volume of the target receiving the desired dose and the total volume of the target exposed to the radiation dose, V_{95} is the volume of PTV that receives 95% of the prescribed radiation dose (%), and V_{PTV} is the total volume of PTV (cm^3).

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \tag{2}$$

with HI is the uniformity of radiation dose distribution in the target volume. $D_{2\%}$ is the radiation dose that covers 2% of the PTV volume (Gy), $D_{98\%}$ is the radiation dose that covers 98% of the PTV volume (Gy), and $D_{50\%}$ is the average radiation dose (Gy).

CI value is ideally 1, meaning the prescribed radiation dose covers the entire PTV by ICRU Report 62 (1999). Ideally, the HI value is 0, meaning the entire radiation dose to the PTV is homogeneous, according to ICRU Report 83 (2010). The OAR radiation dose analysis on the DVH curve was compared with the radiation dose set by QUANTEC. The maximum radiation dose received by breast cancer patients will be compared with the radiation dose recommended by (ICRU Report 62, 1999).

3. RESULTS AND DISCUSSION

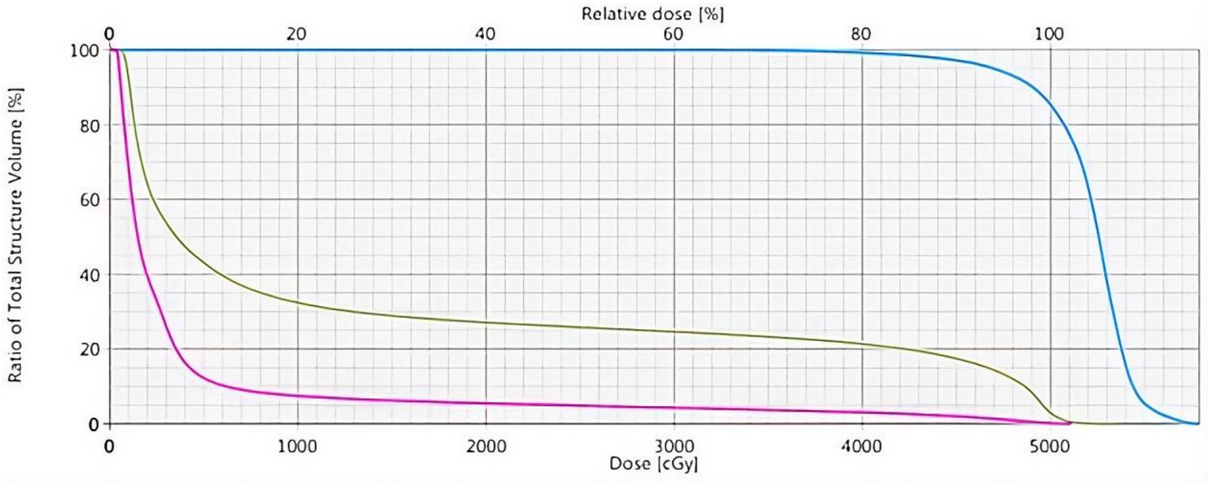
3.1 Planning Target Volume (PTV) Analysis

Planning was conducted in the TPS planning room of Andalas University Radiotherapy Installation, utilizing data from five medical records of breast cancer patients. The radiation therapy treatment planning was conducted using the Eclipse TPS software, employing the 3DCRT technique with the incorporation of bolus density values. These density values were derived from previous research, consisting of beeswax and petroleum jelly mixture with a density of -103, silicone rubber with a density of -169, playdough with a density of 1200, and 3D polylactic acid with a density of -10. Each bolus had a thickness of 1 cm to ensure optimal and precise dose distribution. The utilization of these specific density values is crucial for accurately modeling the physical properties of the materials relative to ionizing radiation, thereby enhancing the dose calculation accuracy and the overall efficacy of radiotherapy for breast cancer patients. The analysis of the radiation dose distribution within TPS was performed based on the Planning Target Volume (PTV), with evaluation parameters including the

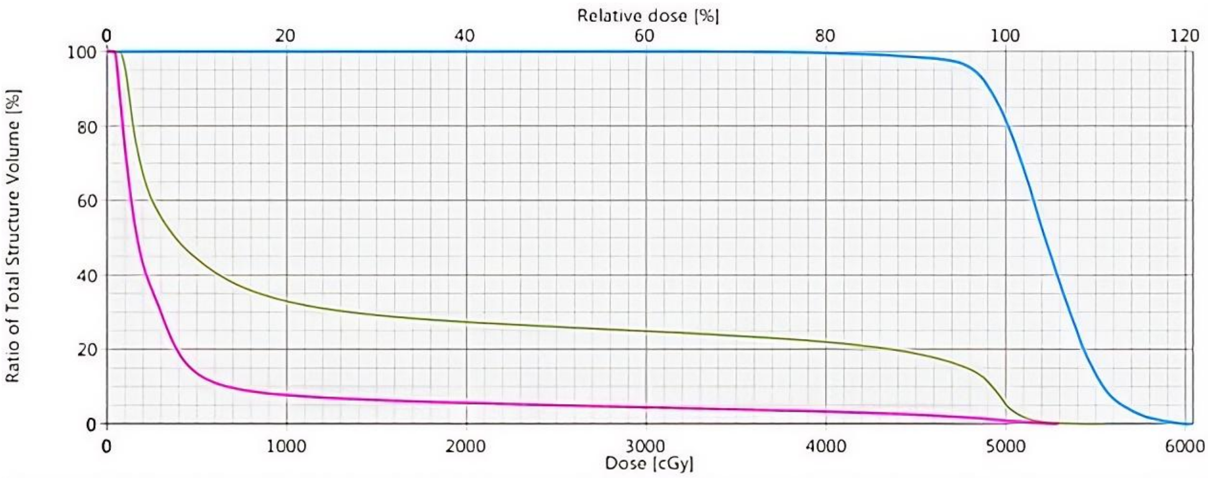
Conformity Index (CI) and Homogeneity Index (HI), as well as an assessment of the Organ At Risk (OAR).

PTV analysis was performed by calculating the CI value according to (ICRU Report 62, 1999) and the HI value according to (ICRU Report 83, 2010). CI and HI values were analyzed to see the prescribed radiation dose (planning dose) that covers the entire volume of the cancer target using bolus density. Cancer target volume data were obtained from the DVH curve in each breast cancer patient's medical record. The green and purple DVH curves in Figure 2 represent the OAR in breast cancer, which are the lungs and heart, and the blue curve represents PTV. DVH data retrieval followed the same procedure for all patients. Figure 2(a) shows one patient's DVH curve using beeswax and petroleum jelly bolus. Figure 2(b) shows the DVH curve of one patient using a playdough bolus. Figure 2(c) displays the DVH curve of one patient using a silicone rubber bolus. Figure 2(d) displays the DVH curve of one patient using a 3D polylactic acid bolus.

In Figure 2, the DVH curve indicates, which displays the radiation dose received by PTV and OAR against organ volume. The blue PTV line is needed to obtain the value of the CI calculation at $\mathbf{V_{95\%}}$, while at $D_{98\%}$, $D_{50\%}$, and $D_{2\%}$, the HI calculation value is derived. The green and purple DVH curves in Figure 2 represent the OAR in breast cancer, namely the lungs and heart. These curves provide insights into the dose distribution and its conformity to clinical standards, offering a detailed overview of the effectiveness of different bolus densities.



(a)



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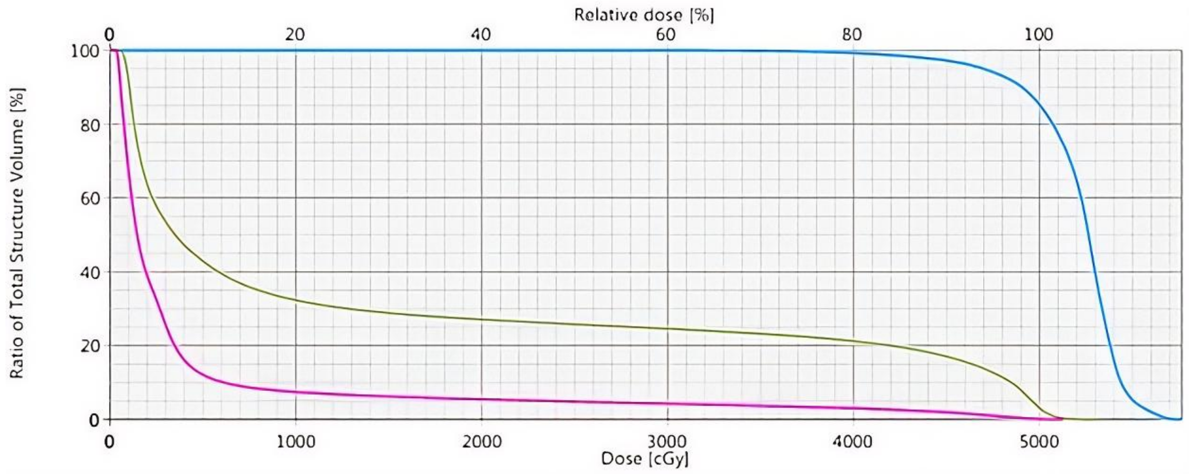

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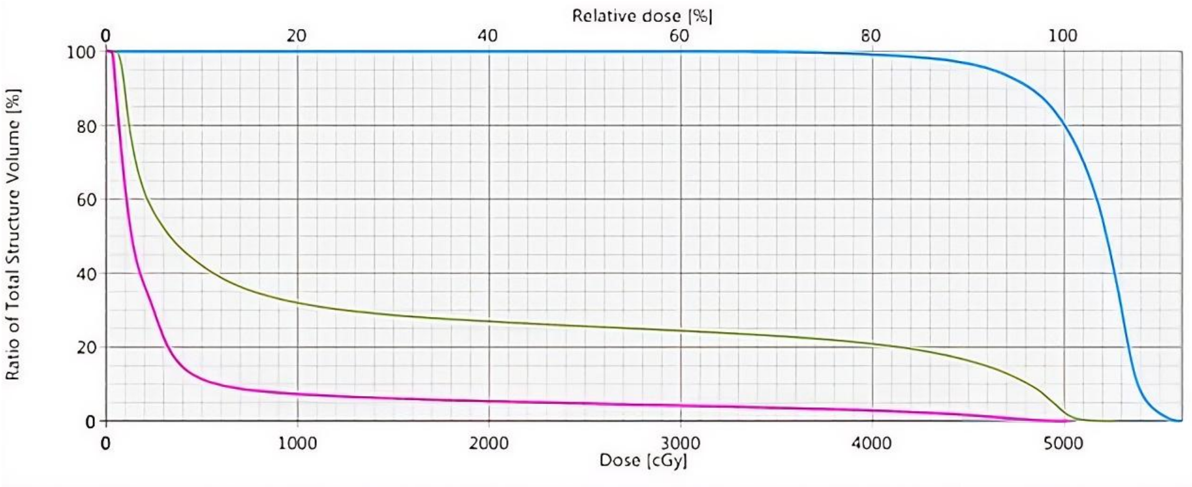

(d)

Figure 2 (a) DVH curve for PTV and OAR bolus beeswax, (b) DVH curve for PTV and OAR bolus playdough, (c) DVH curve for PTV and OAR bolus silicone rubber, (d) DVH curve for PTV and OAR bolus polylactic acid.

3.1.1 Conformity Index Value Analysis (CI)

Figure 3 illustrates the CI values obtained using bolus densities for five medical records of breast cancer patients; the CI ranged from 0.93 to 0.98 in all patients. The CI value, which measures how well the prescribed dose conforms to the target volume, has consistently approached the ideal value of 1 as per ICRU Report 62 standards. All four bolus densities demonstrated compliance with the ICRU standard among the five patients. However, the CI value for patient S was comparatively lower. This discrepancy is attributed to the proximity of the patient's breast cancer target to the OAR, resulting in reduced dose conformity due to the need to limit exposure to sensitive organs.

Based on the ICRU Report 62 standard, the radiation dose distribution achieved using the four bolus densities is clinically acceptable for breast cancer patients. Among the bolus types, the mixed density of beeswax and petroleum jelly achieved the highest CI value, indicating superior conformity. This finding aligns with the study, which reported that beeswax and petroleum jelly boluses significantly enhance surface radiation dose and improve dose uniformity. Silicone rubber and 3D PLA boluses also performed well, with their CI values surpassing those of playdough boluses, likely due to their closer resemblance to tissue density (Ningsih et al., 2022). As noted, bolus materials that effectively replicate tissue characteristics optimize dose delivery to the target and reduce unintended radiation to surrounding healthy tissues (Khan and John, 2014). These results underscore the clinical importance of selecting appropriate bolus materials to achieve optimal outcomes in radiotherapy.

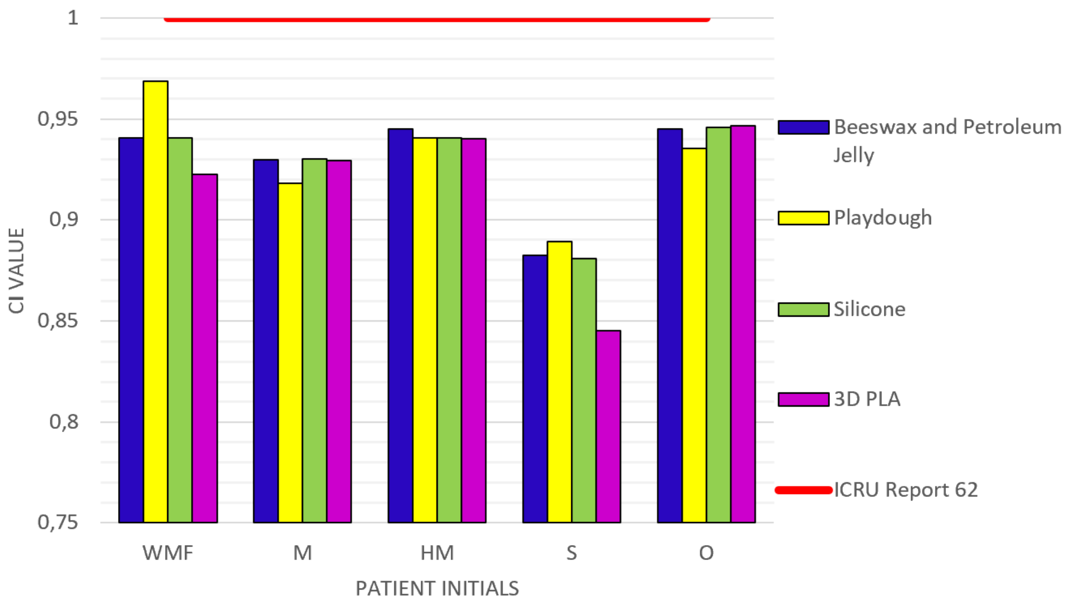

Figure 3 Graph of CI values with bolus for breast cancer patients

3.1.2 Homogeneity Index Value Analysis (HI)

The HI value is analyzed to see the uniformity of radiation dose distribution in the target volume. The calculation results are represented in Figure 4. The ideal value of HI is 0, meaning that all radiation doses in the target volume are homogeneous. The HI value obtained is close to the ideal value of the HI standard, as determined by (ICRU Report 83, 2010), which is close to 0, and proves that therapy planning can be used in breast cancer patients. The bolus density has a significant effect on the radiation dose distribution of breast cancer. The bolus mixture of beeswax and petroleum jelly produces a more homogeneous radiation dose distribution than other boluses.

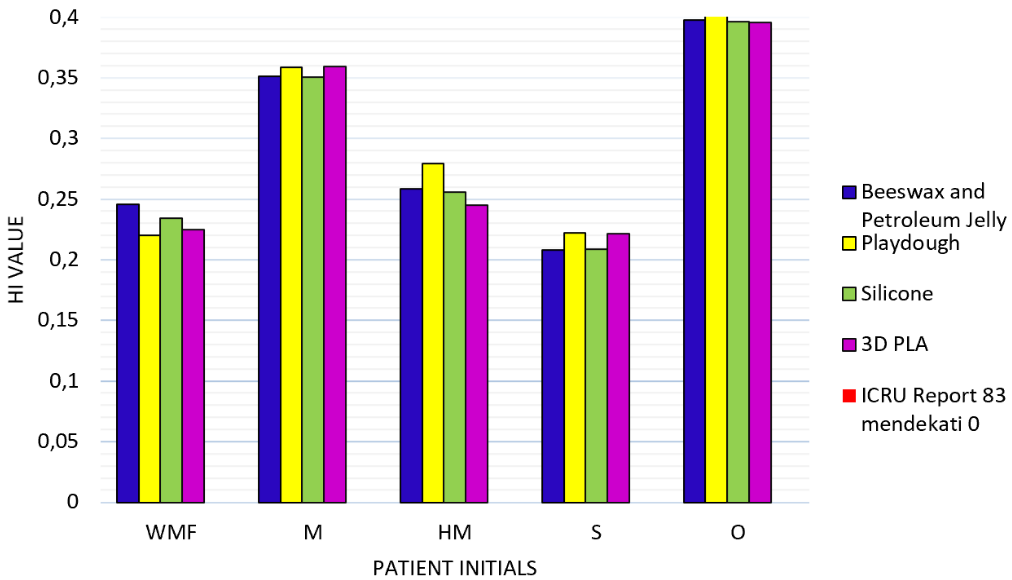

Figure 4 Graph of HI values with bolus for breast cancer patients.

3.2 Organ At Risk Analysis (OAR)

OAR analysis is done by examining the radiation dose of healthy organs around the cancer and adjusting it to the Quantitative Analysis of Normal Tissue Effect in the Clinic (QUANTEC) standard. Healthy organs around breast cancer are the heart and lungs. Data collection and how to read the percentage of OAR volume that receives radiation dose on the DVH curve is done the same way for each breast cancer patient.

3.2.1 Heart Organ

Table 1 shows the percentage of heart organ volume that received a radiation dose of 2500 cGy. Based on QUANTEC rules, the heart organ in breast cancer patients is limited to receiving a radiation dose of V25 < 10%, meaning that only 10% of the heart volume can receive a maximum dose of 2500 cGy. In this study, one patient with the initials M received a 12% radiation dose, which exceeded the QUANTEC threshold. This discrepancy occurred because the breast cancer target in patient M was located near the heart, making it challenging to minimize radiation exposure to the organ. Figure 5 displays the OAR image of patient M, highlighting the spatial overlap between the target volume and the heart.

Table 1 Radiation dose received by the heart organ

Patient Initials	Heart Dose Acceptability (V25 %)	Heart Dose Constraint (Quantec %)	Description
WMF	5%	< 10%	Safe
M	12%		Not Safe
HM	0%		Safe
S	0%		Safe
O	0%		Safe

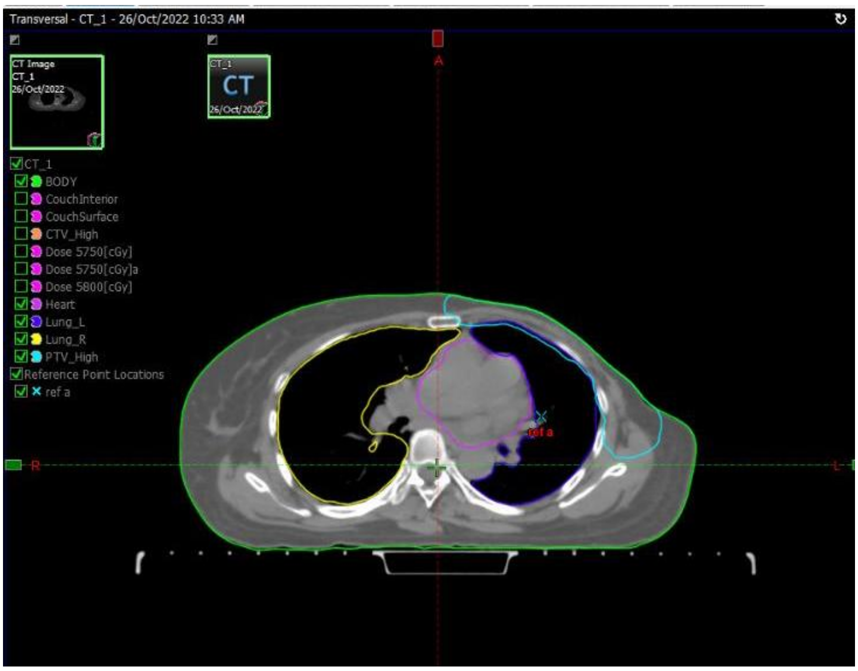

Figure 5 OAR image of patient M

Figure 5 is the OAR in patient M, where the purple line is the OAR of the heart; it can be seen that the location of the blue line breast cancer target is close to the heart organ. The use of bolus materials can help reduce the radiation dose received by the heart in breast cancer patients. The addition of a bolus in this planning process yields results consistent with the research conducted by Su et al. (2014), which aimed to increase the radiation dose to the target while minimizing the risk of overdosing surrounding healthy tissues. Incorporating bolus enhances dose conformity to the tumor volume and helps protect organs at risk, such as the heart, by optimizing dose distribution and reducing unnecessary radiation exposure to these structures.

3.2.2 Lung Organ

Table 2 describes the percentage of lung organ volume that received a radiation dose of 2000 cGy. According to QUANTEC guidelines, the maximum radiation dose limit for the lung organ is V20 < 30% - 35%, meaning that only 30% - 35% of the lung volume can receive a dose of 2000 cGy. The radiation dose received by the lung organ in this study was within the safe range, as none of the patients exceeded the QUANTEC standard.

Table 2 Radiation dose received by the lung organ.

Patient Initials	Lung Dose Acceptability (V20 %)	Heart Dose Constraint (Quantec %)	Description
WMF	27%	< 30% - 35%	Safe
M	29%		Safe
HM	27%		Safe
S	33%		Safe
O	33%		Safe

The radiation dose received by the lungs in the treatment planning for breast cancer patients in this study was within safe limits and did not surpass the thresholds established by QUANTEC. This indicates that radiotherapy planning using bolus density is effective in minimizing the radiation exposure to the lung tissue while adhering to the dose constraints recommended by QUANTEC. The application of appropriate bolus materials contributes to an optimized dose distribution, ensuring the safety of healthy organs surrounding the target volume.

4. CONCLUSION

Based on the research analyzing breast cancer radiation dose distribution using bolus density in 3DCRT planning, it was observed that the Conformity Index (CI) values adhered to the standards set by ICRU Report No. 62, ranging from 0 to 1, while the Homogeneity Index (HI) values approached zero in accordance with ICRU Report No. 83. Additionally, the values for organs at risk (OAR), including the heart and lungs, complied with QUANTEC guidelines, with heart dose volumes remaining below 10% and lung dose volumes below 30%-35%. The utilization of mixed bolus densities comprising beeswax and petroleum jelly, playdough, silicone rubber, and 3D Polylactic Acid contributed to achieving optimal dose distribution targeting breast cancer, thereby enhancing both the conformity and safety of radiotherapy treatment.

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