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RESEARCH PAPER

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Examining the Relationship between Water-Equivalent Diameter (D_w) and Body Mass in Breast Cancer Patients

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ABSTRACT

Breast cancer is the most prevalent cancer worldwide, necessitating precise imaging techniques for effective treatment planning. This study aims to analyze the Water-Equivalent Diameter (D_w) in breast cancer patients using Computed Tomography (CT) and investigate its relationship with patient body mass. This research contributes to enhancing the accuracy of radiation dose estimations by exploring the impact of Region of Interest (ROI) selection and patient-specific parameters on D_w values. The medical imaging data from 30 breast cancer patients, aged 23–66 years, was reviewed to calculate D_w using three methods: contour ROI, elliptical ROI, and without ROI. The average D_w values were 28.68 cm, 29.184 cm, and 30.255 cm, respectively, indicating that contour ROI provides the smallest D_w due to its precision in targeting cancerous areas. A strong positive linear correlation was identified between D_w and body mass (R^2 = 0.7743), highlighting that higher body mass leads to increased D_w values. The study incorporated statistical analysis with IndoseCT software to evaluate dosimetric parameters under different ROI settings, comparing the implications of each on D_w measurements. The findings emphasize the significant influence of ROI selection and patient body mass on accurate radiation dose calculations. In conclusion, the contour ROI method is the most precise for D_w estimation, and the observed positive relationship between D_w and body mass is vital for enhancing radiation dose calculations and optimizing treatment planning in breast cancer management. This can ultimately lead to safer, patient-specific imaging protocols that effectively balance radiation exposure with diagnostic accuracy and clinical outcomes.

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1. INTRODUCTION

Breast cancer is the leading cause of cancer-related deaths that commonly affects most women worldwide [1]. In 2022, according to data from the Global Cancer Observatory, breast cancer remained the most prevalent case globally, accounting for 23.1% of cases. Similarly, in Indonesia, breast cancer is also the most common cancer case among other cancer cases, with 20.6% of the total. The treatment for breast cancer includes surgery, chemotherapy, radiotherapy, endocrine therapy, and immunotherapy. To ensure effective treatment, the size, location, and severity of the cancer are first detected. One of the tools used for detecting breast cancer is Computed Tomography (CT).

Computed Tomography (CT) is a medical imaging technique that uses X-rays to produce detailed images of the internal structures of the human body or other objects [2]. The basic principle of CT imaging involves X-ray radiation emitted from the CT machine passing through the body and being detected by a scanner on the opposite side. A computer then uses this data to create cross-sectional images (image reconstruction), providing detailed views of internal structures [3]. This technology is highly beneficial for diagnosis, disease evaluation, and treatment planning, as it offers more detailed images.

CT scans have a relatively higher radiation dose compared to other radiology tools. The high dose from a CT scan comes not only from the primary radiation of each slice but also from the scattered radiation from adjacent slices [4]. Prolonged exposure to this high radiation dose can damage tissues, cause skin redness, hair loss, and even lead to cancer [5]. Therefore, the dose a patient receives must be calculated by considering the device parameters and the patient's characteristics, resulting in different dose values for each patient.

According to Report AAPM No. 220 [6], the radiation dose from a CT scan must be estimated through the Size-Specific Dose Estimate (SSDE), which includes both the CT scan's output parameters and the patient's size. The calculation of SSDE allows for more specific radiation dose estimation for each patient, helping to reduce the risk of excessive radiation, especially in patients with extreme body sizes (e.g., children or obese patients) [7].

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This SSDE value is used to assess the potential long-term risks of radiation exposure and to adjust imaging protocols to meet the clinical needs of the patient. By accounting for body size of patients, SSDE provides a basis for optimizing the balance between radiation dose and image quality [8].

Calculating the CT scan's output involves considering the energy and tube current used, based on the source's specifications. This can be expressed through the Computed Tomography Dose Index (CTDI) [9,10]. When determining patient size parameters, the calculation of Effective Diameter (Deff) is used [11]. However, this calculation alone is insufficient to define the patient's characteristics. This is because the body composition, such as the organs surrounding the cancer, must also be considered [12-13].

When detecting breast cancer located in the chest cavity, the largest part is typically the lungs, which are filled with air, appearing black in the CT scan images. This is closely related to the attenuation coefficient, which measures how much radiation intensity is absorbed by the body's tissues. The patient's size parameter, which accounts for organs when determining diameter, is called the water equivalent diameter (D_w) and water equivalent area (A_w) [14, 6]. These are critical metrics for accurately estimating how much radiation the body's tissues absorb, as they adjust for tissue composition and density, unlike simple geometric measures that effective diameter did. D_w ensures personalized dose calculations, which are critical for detecting subtle differences in breast tissue that may indicate cancer. It also helps in avoiding excessive radiation exposure, particularly in organs like the breasts that have lung and heart.

These values can be calculated using CT numbers represented in a specific area or Region of Interest (ROI) [14]. In this study, the IndoseCT software was used to identify and analyze dosimetric parameters, including Water Equivalent Diameter (D_w), as part of the research. Several studies have demonstrated the effectiveness of IndoseCT in calculating Size-Specific Dose Estimate (SSDE) values based on CT scan images. For instance, one study investigated SSDE calculation from CT scan images of pediatric patients' heads using axial routine head, helical routine head, and pediatric head protocols. The findings revealed that IndoseCT displayed significantly lower SSDE values with the pediatric head protocol compared to the axial and helical routine protocols [15]. Additionally, another study utilizing IndoseCT to calculate SSDE, Water Equivalent Diameter (D_w), and CTDIvol from thorax CT images of 100 patients found a linear correlation between patient body weight and Dw, while noting that body weight did not influence the radiation dose received, reflected in CTDIvol and SSDE values [16]. Furthermore, research evaluating the accuracy of effective diameter (D-eff) measurements in CT images of a polyester-resin (PESR) phantom highlighted IndoseCT's ability to measure D-eff values accurately and precisely, supporting dose estimation calculations using the SSDE concept [17]. Lastly, a study focused on estimating the radiation dose to the gallbladder and pancreas, which are primary radiation-exposed organs in abdominal CT scans, found that the SSDE values obtained using IndoseCT showed small percentage differences of 4.26% and 1.99%, respectively, when compared to those calculated via Monte Carlo simulations [18].

While there have been some studies using IndoseCT for cancer-related cases, such applications are still not widespread. Therefore, in this study, SSDE calculations will be performed using IndoseCT on cancer scan data to determine the radiation dose received by cancer-affected organs and nearby organs at risk of incidental radiation exposure in patients. This will help provide a more comprehensive understanding of the dosimetric parameters relevant to cancer imaging.

This study aims to explore two main aspects in detail. The first aspect investigates the relationship between the selection of the Region of Interest (ROI) and its impact on the calculated D_w value. In this study, three different ROI approaches were applied: contouring ROI, elliptical ROI, and the without ROI. Accurate determination of ROI is crucial, as it directly influences the precision and reliability of D_w measurements. The second aspect examines whether there is a significant correlation between a patient's body mass and the magnitude of D_w. Body mass is an important parameter that can potentially affect D_w, as it is linked to variations in tissue density and distribution, which are key factors in medical imaging calculations.

By addressing these two aspects, the study aims to provide a comprehensive understanding of how technical factors, such as ROI selection, and patient-specific characteristics, like body mass, affect D_w values. The findings will offer valuable insights for improving imaging protocols and ensuring accurate and consistent measurement methodologies in clinical and research applications:

a. Improving Imaging Protocols: The findings help refine imaging protocols to enhance accuracy and reliability.
b. Accurate and Consistent Measurements: The study provides insights for achieving precise Dw calculations and consistent methodologies.
c. Optimizing Radiation Dose: By identifying the best ROI method and the correlation with body mass, the research supports safer and more effective radiation dose planning.

2. MATERIALS AND METHOD

A. Data and Parameters

This study uses CT image data of breast cancer patients obtained from The Cancer Imaging Archive (TCIA), a publicly accessible resource funded by the U.S. National Cancer Institute (NCI). TCIA can be accessed via link https://www.cancerimagingarchive.net/access-data/. TCIA provides de-identified medical imaging data, primarily in DICOM format. Data contributors are

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supported with de-identification and curation, while TCIA promotes the sharing of derived analyses such as tumor segmentations and radiomics for collaborative cancer research.

To ensure privacy, patient data is anonymized, retaining only relevant information such as body mass, age, and gender. The repository, supported by NCI and the University of Arkansas for Medical Sciences (UAMS), includes both publicly accessible and confidential data, some of which may be subject to copyrights or require licensing for commercial use.

Users are required to follow ethical guidelines, including avoiding attempts to re-identify individuals from de-identified data. Privacy safeguards adhere to HIPAA (Health Insurance Portability and Accountability Act) regulations, and users are responsible for handling the data securely and responsibly.

The study analyzed 30 breast cancer samples obtained from the Cancer Imaging Archive (TCIA). The patients' ages ranged from 23 to 66 years, with body masses varying between 61 and 109 kg. The image samples from these patients were scanned using a CT Scan machine manufactured by GE Medical System Discovery STE, with a voltage of 120 KV and a tube current of 80-120 mA.

B. D_w Calculation

Before calculating the water equivalent diameter (D_w), the CT value for the object being used first must be determined. The CT value is calculated relative to the attenuation coefficient of water [6]. The CT value is calculated using Eq. (1) [6] as follows:

$$CT(x,y) = \left(\frac{\mu(x,y)-\mu_{water}}{\mu_{water}}\right) \times 1000 \quad (1)$$

with $\mu(x,y)$ is the linear attenuation coefficient at position (x,y) for a voxel in the axial CT image.

The water equivalent area (A_w) can also be represented in terms of the CT value. Thus, the value of A_w can be calculated using the following Eq. 2 [6]:

$$A_w = \frac{1}{1000}\overline{CT(x,y)}_{ROI}\, A_{ROI} + A_{ROI} \quad (2)$$

With $\overline{CT(x,y)}_{ROI}$ is the average CT value of the voxels within the ROI (Region of Interest), and A_{ROI} is the area of the pixels in the CT image, where the value of A_{ROI} takes into account the attenuation coefficient or absorption coefficient of each material. Thus, the value of D_w is obtained by Eq. 3 [6]:

$$D_w = 2\sqrt{\left[\frac{1}{1000}\overline{CT(x,y)}_{ROI} + 1\right]\frac{A_{ROI}}{\pi}} \quad (3)$$

The calculation of D_w is performed using the IndoseCT software with three different ROIs [19]. The first calculation uses a contour ROI, the second uses an elliptical ROI following the Report AAPM No. 220 protocol, and the third is done without an ROI. The water equivalent diameter (D_w) with circular ROI has been investigated to encompass all the target regions in the CT image with circular shape [14]. The circular ROI assumes a uniform distribution of body mass and tissues within the selected region. The circular ROI may not perfectly represent the actual shape of the patient's body. But, in this study change this method to the elliptical ROI, because represents the cross-sectional shape of the human body consideration, especially for non-circular regions like the chest or abdomen The other method is without ROI, that means the entire CT image, including the patient and extraneous objects like table or air, can make inaccuracies in D_w estimation by inflating the area. Last, the contour ROI approach contours the actual shape of the patient, providing the most precise representation of the patient's body. It typically requires advanced tools or manual adjustments to match the body's contours [20].

Fig. 1. The calculation of D_w using the contour ROI.

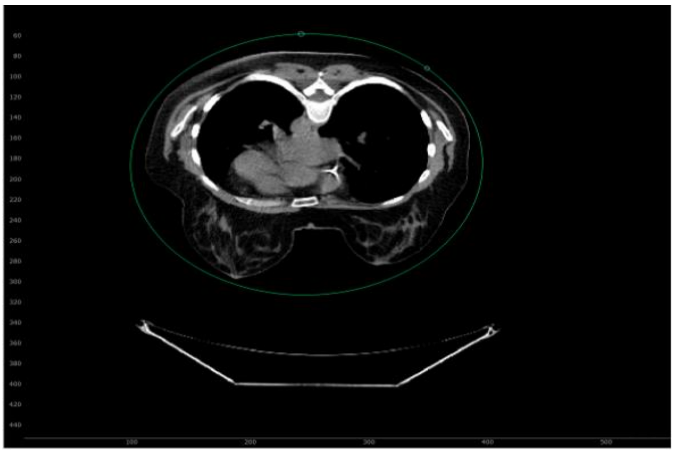

Fig.2. The calculation of D_w with the elliptical ROI.

The calculation of D_w with the contour ROI is conducted using a red boundary that matches the outline of the patient's body, as shown in Fig. 1. The D_w calculated using the elliptical ROI utilizes a region with an elliptical boundary, as shown in the Fig. 2. The size of the boundary area is designed to closely match the patient's body size, as indicated by the green boundary line. The D_w without an ROI calculates the entire area exposed to

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radiation in a square shape without including an ROI. This area, without an ROI is square-shaped, as shown in Fig. 3.

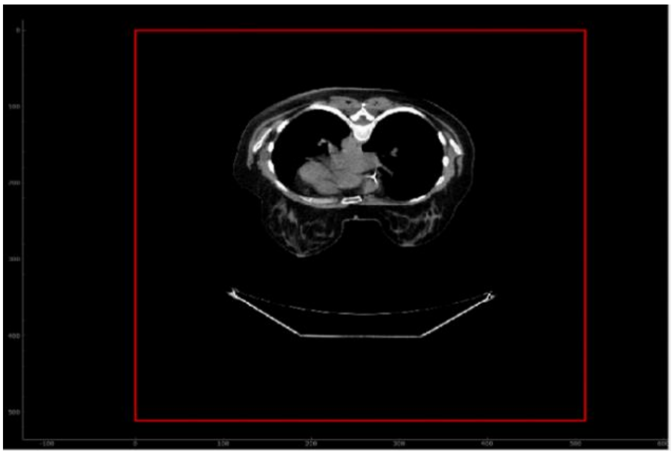

Fig.3. The calculation of D_w without an ROI.

The relationship between the Water Equivalent Diameter (D_w) values calculated with different ROI methods (Contour ROI, Elliptical ROI, and without ROI). The differences among the three ROI methods were tested using ANOVA and post-hoc Tukey HSD to compare the means. Additionally, the correlation between Dw values and patient body mass was assessed using the Pearson correlation test. A p-value of less than 0.001 was considered to indicate a statistically significant difference.

3. RESULTS

A. Results of the D_w calculations from 3 types of ROI

The D_w values for each patient, calculated using IndoseCT software in centimeters for three types of ROIs, were averaged. The comparison of the average D_w values for each ROI is presented in a graph in Fig. 4. Based on Fig. 4, it can be observed that the average D_w from the contour ROI has the smallest value, while the D_w without an ROI has the largest value.

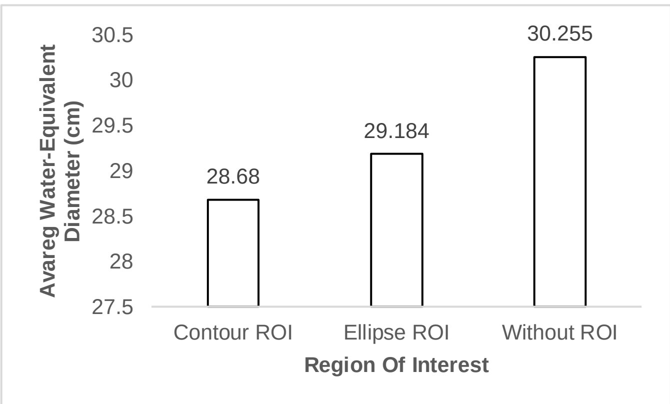

Fig. 4. Graph of the average D_w values for each ROI.

This is because the D_w for the contour ROI only considers the area that includes the breast cancer ROI. In contrast, the elliptical ROI boundary approximates the area containing breast cancer. The elliptical ROI still includes other areas, such as the air surrounding the patient's body, which is counted as part of the patient. In the area without an ROI, the calculated D_w yields the largest result due to the larger area of the patient's body being considered.

In the calculation of D_w using Eq. (1) [6], one of the influencing parameters is the area of the patient's body, in this case, A_{ROI}. The larger the A_{ROI} used, the greater the resulting D_w value. This is also related to the calculation of X-ray radiation dose; as the D_w value increases, the radiation dose received by the organs surrounding the breast cancer target also increases [5].

The statistical analysis of the D_w values calculated for each ROI method (Contour ROI, Elliptical ROI, and Without ROI) is summarized in Table 1, which includes the mean, standard deviation (SD), and range. The Contour ROI method had the smallest mean D_w value (28.68 cm) and the smallest standard deviation (3.62 cm), reflecting the consistency of this method in targeting only the cancerous area. In contrast, the method Without ROI exhibited the largest mean D_w (30.25 cm) and the largest standard deviation (3.94 cm), highlighting the greater variability when the entire exposed area was included without focusing on a specific region. The Elliptical ROI method showed intermediate results, with a mean D_w of 29.18 cm and a standard deviation of 3.68 cm.

Table 1. The statistical analysis of the D_w values calculated for each ROI method (Contour ROI, Elliptical ROI, and Without ROI).

ROI Methods	Contour ROI	Elliptical ROI	Without ROI
Mean (cm)	28.68	29.18	30.25
SD (cm)	3.62	3.68	3.94
Min (cm)	17.90	17.90	18.62
Max (cm)	38.91	39.40	39.65

The range of D_w values was also analyzed for each ROI method. The Contour ROI exhibited the narrowest range (17.90 cm to 38.91 cm), indicating a more uniform distribution of values. On the other hand, the method Without ROI had the widest range (18.62 cm to 39.65 cm), showing greater variability due to the inclusion of surrounding tissues and air in the calculation. The Elliptical ROI method presented a range closer to that of the Contour ROI, as it partially focused on the patient's body but included some surrounding areas. The differences in the median D_w values also align with the mean values, supporting the observation that the Contour ROI is the most precise method, while the method Without

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ROI tends to overestimate the Dw due to the inclusion of irrelevant areas.

B. The relationship between D_w and patient body mass

The concept of calculating D_w has been explored by several authors previously; however, none have explained the relationship between the D_w value and the body mass of the patient. As mentioned in the introduction, the calculation of D_w is closely related to patient size parameters. In breast cancer cases, the medical images studied involve the thoracic cavity. The thorax contains several organ components, including the breasts, ribs, lungs, and heart [21]. In determining D_w, the attenuation coefficients for each component are taken into account. The attenuation coefficient for bone is greater than that of soft tissue organs [14].

The relationship between D_w and the body mass of the patient shows a positive linear correlation, as seen in Fig. 5. The figure demonstrates that as the body mass of the patient increases, the D_w value also increases. This is supported by an R^2 value of 0.7743, indicating a positive linear correlation between D_w and body mass in the study of D_w calculations for organs in the thoracic cavity [22-24]. The relationship between Dw values and body mass was analyzed using the Pearson correlation test. The results demonstrated a positive linear correlation between Dw and body mass, with an R^2 value of 0.7743 ($p < 0.001$).

According to AAPM Report No. 220, calculations of D_w for phantom tissue-equivalent thorax at various sizes showed that the smallest D_w measured 20.9 cm and the largest was 33.2 cm [6]. In this study, as presented in Fig. 4, there were no D_w values smaller than the recommended range. However, three patients had D_w values exceeding the AAPM Report No. 220 recommendations, specifically patients 28, 29, and 30. Upon investigation, it was found that these three patients fell into the overbody mass category, resulting in significantly larger D_w values.

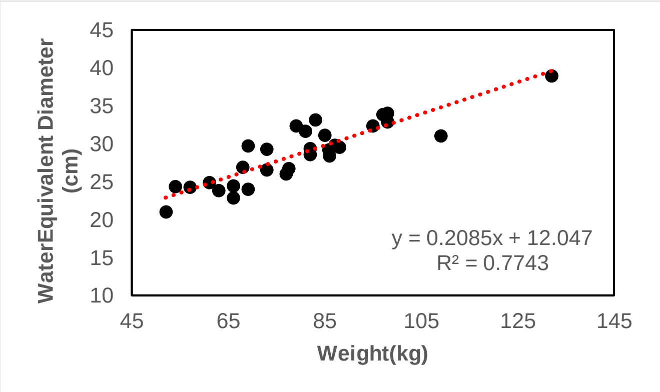

Fig. 5. Graph of D_w versus the body mass of the patient.

Another article mentioned research on patient size parameters during CT scans of the thoracic cavity, which included samples from both men and women. It was found that the average D_w value for the thoracic cavity was 23.77 cm with a standard deviation of 2.54 cm [25]. However, another study revealed that over body mass patients exhibited D_w values in the thoracic cavity ranging from 37 cm to 43 cm [22].

4. DISCUSSION

A. ROI Analysis

The study demonstrates that the choice of Region of Interest (ROI) significantly influences the Water-Equivalent Diameter (D_w) values. The contour ROI, which focuses specifically on the cancerous area, produced the smallest average D_w (28.68 cm). This is expected because the contour ROI excludes surrounding tissues, targeting only the specific area affected by cancer. In contrast, the elliptical ROI, which approximates the patient's body with an elliptical boundary, resulted in a slightly larger average D_w (29.184 cm). The inclusion of air and tissues surrounding the targeted area in the calculation contributed to this increase. The largest average D_w (30.255 cm) was observed when no ROI was used, as this method considers the entire area exposed to radiation without discriminating between relevant and non-relevant regions.

To further assess the differences among the three methods, a one-way ANOVA test was conducted. The analysis yielded an F-value of 15.67 and a p-value of less than 0.001, indicating a statistically significant difference in mean Dw values across the methods. A post-hoc Tukey HSD test revealed significant differences between the Contour ROI and Elliptical ROI methods ($p = 0.03$), the Contour ROI and Without ROI methods ($p < 0.001$), and the Elliptical ROI and Without ROI methods ($p = 0.02$). These results confirm that the choice of ROI method significantly influences Dw values, with the Without ROI method consistently producing the highest values due to the inclusion of larger, irrelevant areas.

The results underline the importance of ROI selection in determining accurate D_w values [26]. For instance, the contour ROI provides a more focused measurement pertinent to cancer treatment, ensuring precise radiation dose delivery. On the other hand, methods using larger regions, such as without ROI, may overestimate D_w due to the inclusion of irrelevant body areas. This overestimation could lead to unnecessary radiation exposure to surrounding tissues, which might compromise patient safety. These findings suggest that ROI selection should align with specific clinical objectives to optimize both accuracy and safety in radiation planning [27].

B. The correlation between D_w and patient body mass

The study reveals a positive linear correlation between D_w and body mass, with an R^2 value of 0.7743 indicating a strong relationship. This finding implies that as a patient's body mass increases, the D_w value also rises. The increased D_w in individuals with larger body mass can be attributed to the higher attenuation coefficients associated with greater tissue volume and density [28]. These

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parameters directly affect the calculation of D_w, which considers the average CT value and area within the ROI.

The relationship between D_w values and body mass was analyzed using the Pearson correlation test, which demonstrated a positive linear correlation between D_w and body mass, with an R^2 value of 0.7743 ($p < 0.001$). This indicates that as the body mass of the patient increases, the D_w values also increase. This finding suggests that larger body mass is associated with higher D_w measurements, which could impact dose calculations and treatment planning in clinical settings. The correlation analysis highlights the importance of considering patient size when interpreting D_w values and planning for optimal radiation exposure. Understanding this relationship is crucial for ensuring that radiation dose calculations are tailored to the patient's body size, which can help minimize unnecessary radiation exposure while maintaining the effectiveness of treatment plans.

Interestingly, the data showed that three patients with D_w values exceeding the recommended range in the AAPM Report No. 220 were categorized as overweight. This highlights the potential challenges in managing radiation doses for patients with higher body mass. Larger D_w values may result in greater radiation exposure to surrounding organs, necessitating careful adjustments in radiation planning to avoid adverse effects [29]. The several studies focus on the calculation of Size-Specific Dose Estimates (SSDE) in computed tomography (CT), providing insights into simple, weight-based methods for estimating radiation doses with patient-specific considerations. That study improved the correlation between weight and D_w, that larger patients generally have higher D_w values [22-24]. Calculating D_w is essential for precise radiation dose estimation for imaging procedures as it accounts for tissue composition and density. It enhances personalized imaging by detecting subtle breast tissue changes and minimizes radiation exposure to critical organs like the lungs and heart.

The observed correlation emphasizes the need to consider patient size parameters in CT-based treatment planning. Tailored approaches, such as adjusting ROI boundaries or modifying radiation protocols, are crucial for maintaining treatment efficacy while minimizing risks [30]. This study contributes to the growing body of evidence that patient-specific factors, particularly body mass, play a critical role in optimizing imaging and radiation procedures in breast cancer treatment [31,32].

The selection of only 30 patients in this study represents a limitation due to the nature of the TCIA database. The database is extensive and contains a wide variety of imaging data, including data from CT, MRI, PET, and mammography. To conduct this study, the data had to be downloaded in its entirety, which involved considerable time and effort to filter out only the relevant CT data. This extensive filtering process limited the number of available CT scans specific to breast cancer, resulting in only 30 patients being included in the analysis. The limited sample size may affect the generalizability of the study's findings and suggests that future research could benefit from a larger, more representative dataset.

5. CONCLUSION

This research aimed to analyze the Water-Equivalent Diameter (Dw) in breast cancer patients using three different Region of Interest (ROI) methods, which are contour ROI, elliptical ROI, and without ROI, and to explore its correlation with patient body mass. Based on the findings, the contour ROI method produced the smallest average Dw value of 28.68 cm, followed by the elliptical ROI at 29.184 cm, and the without ROI method at 30.255 cm. The contour ROI demonstrated the highest precision by focusing solely on the cancerous area, making it the most accurate method for Dw calculation. Furthermore, a strong positive linear correlation (R^2 = 0.7743) was established between Dw and body mass, indicating that an increase in patient body mass results in a higher Dw value. These findings emphasize the importance of using the contour ROI method for accurate Dw estimation and highlight the significant influence of patient body mass in optimizing radiation dose calculations and treatment planning for breast cancer. For future research development, CT image data from Indonesian patients can be used to obtain more representative D_w values. Once the D_w value is determined, the Size Specific Dose Estimation (SSDE) can be calculated, which is an estimate of the dose received by the patient. The more accurate the D_w value, the more precise the calculated patient dose will be.Additionally, D_w values can also be analyzed for different areas, such as in cases of other cancer types. This is necessary to examine the correlation between body mass and D_w in various cancer cases, providing broader insights into radiation dosing strategies across diverse patient profiles.

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