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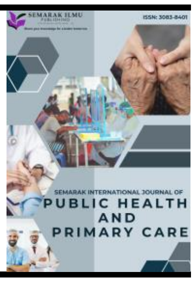

Optimising Breast Ultrasound Image Quality: Impact of Body Mass Index on Breast Carcinoma Detection on Women

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ABSTRACT

Breast carcinoma remains a leading cause of cancer-related mortality among women globally, with early detection being critical for improving prognosis and survival rates. While mammography is widely used for screening, its limitations in young women and those with dense breast tissue have led to the increased use of ultrasound (US) imaging as a complementary tool. However, the quality of breast US images can vary significantly, with body mass index (BMI) emerging as a potential influencing factor. This study investigates the correlation between BMI and breast US image quality, focusing on its implications for breast carcinoma detection in Malaysian women. A prospective observational study was conducted in a hospital in Alor Setar, Kedah, involving 18 female patients with breast lesions classified as Bi-RADS 4 or above. Participants were categorized into normal (18.5–24.9 kg/m²), overweight (25–29.9 kg/m²), and obese (≥30 kg/m²) BMI groups. Breast US images were evaluated for pathology demonstration, spatial resolution, and contrast resolution using a subjective scoring survey assessed by five medical officers. Statistical analysis, including Spearman correlation and Cronbach's Alpha coefficient, was performed to determine the relationship between BMI and image quality.The results revealed a weak negative correlation between higher BMI and inferior image quality, particularly in obese patients. However, the impact of BMI was not as significant as initially expected, with minimal disparities observed between normal and overweight groups. The normal BMI group achieved superior image quality, attributed to smaller breast volumes and optimal acoustic properties. Overweight patients demonstrated comparable image quality, likely due to adipose tissue acting as an acoustic interface. In contrast, obese patients exhibited the lowest image quality scores, primarily due to increased breast thickness and ultrasound wave attenuation. Despite these challenges, image quality in obese patients remained acceptable for clinical use. The study highlights that while BMI influences breast US image quality, other factors such as breast composition, lesion characteristics, and operator expertise play a more substantial role. Variability in breast tissue density and the skill of the sonographer were identified as critical determinants of image quality. These findings underscore the need for tailored imaging protocols and advanced technologies, such as high-frequency transducers and three-dimensional US, to optimize diagnostic accuracy across all BMI categories.

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1. Introduction

Breast carcinoma, one of the most prevalent and life-threatening disease, is the primary cause of cancer-related mortality in women in the globe. In Malaysia, female breast carcinoma, accounts for 32.9% of all cancer cases, with reference to the GLOBOCAN 2020 report [1]. Early detection and diagnosis are crucial in improving prognosis and survival rates in patients. Several randomised screening studies conducted in various countries have indicated the lowering of mortality among menopausal women by mammography screening. However, screening has long been challenged because of concerns with overdiagnosis and poor sensitivity in young women and breast-dense women [2].

Over the last 15 to 20 years, ultrasound (US) imaging has become a useful complementary tool, especially in women having dense breast tissue. US imaging is advantageous in various aspects, such as the omission of ionizing radiation, excellent ability in differentiation of cystic lesions and solid masses, real-time imaging capability, and utilization in guided needle-biopsy to rule out malignancy of breast lesions [3]. Despite these advantages, significant variability in US image quality is observed among patients. Body Mass Index (BMI) may be an influencing determinant of image quality, affecting the efficacy of breast US and breast carcinoma detection rates.

Obesity is a notable risk factor for development and progression of breast carcinoma. Numerous studies have demonstrated a direct positive correlation between obesity, as measured by BMI, and the risk of developing postmenopausal breast carcinoma, posing a significant public health concern. Prevalence of obesity in female Malaysian increased from 4.1% in 1985 to 17.9% in 2016 [4]. This upward trend highlights the urgent need for understanding how obesity may impact breast examination, particularly in US imaging.

Numerous studies have highlighted the correlation between body fat, as measured by BMI, and US image quality across different body parts. For example, research by Brahee *et al.,* [5] demonstrated that patients with high (BMI 30–34.9) or moderate (BMI 25–29.9) body fat produce abdominal US images of inferior quality compared to those with a normal BMI (18.5–24.9). Similar findings are corroborated in echocardiography studies, such as those by Siadecki *et al.,* [6], which indicate a decline in imaging quality as BMI increases, especially above a BMI of 40.

Conversely, some studies suggest that overweight patients may yield better US image quality during specific assessments, such as trauma imaging, indicating that the relationship between obesity and imaging quality can be complex. Research by Ifelayo *et al.,* [7] and Jeeji *et al.,* [8] found no significant effect of obesity on the competency of focused assessments in sonography for trauma and abdominal aortic imaging.

To investigate the correlation between obesity and breast US image quality, this study is designed to compare the breast US image quality in normal weight, overweight, and obese women, grouped according to BMI, and determine any correlation between image quality and BMI.

2. Methodology

2.1 Study Design

This study was a prospective observational study to examine the impact and correlation of BMI on breast US image quality in detecting breast carcinoma in women. The study was conducted in the US suite of the Radiology Department in a hospital in Alor Setar, Kedah.

Female patients undergoing breast US examination from April 14 to May 2, 2024, with lesions highly suspicious of malignancy (Bi-RADS 4 or above) were included, with reference to Table 1 below, the final assessment categories for Bi-RADS. The sample size was calculated by Eq. (1) [9]. All female patients aged 18 years or older with normal, overweight, or obese BMI, according to Table 2 below, the classification of underweight, normal, overweight and obese, who underwent breast screening or diagnostic US with an impression of Bi-RADS 4, 5, or 6 were included in the study. Patients aged under 18, those with lesions not classified as Bi-RADS 4 or above, underweight patients, and those unwilling to participate were excluded. During the study, a total of 20 patients met the inclusion criteria for participation, 18 patients ultimately agreed to take part, resulting a participation rate of 90%.

$$\text{Sample size} = \frac{Z_{1-\alpha/2}{}^{2}\,p(1-p)}{d^{2}} \tag{1}$$

Table 1
Final assessment categories for Bi-RADS [10]

Category	Management	Likelihood of cancer
0: Incomplete	Requires further imaging examinations	N/A
1: Negative	Requires routine screening	Essentially 0% likelihood of malignancy
2: Benign	Requires routine screening	Essentially 0% likelihood of malignancy
3: Probably benign	Requires short interval (6-month) follow-up or continued surveillance	< 0% but ≤ 2% likelihood of malignancy
4: Suspicious	Requires tissue diagnosis	>2% but < 95% likelihood of malignancy
5: Highly suggestive of malignancy	Requires tissue diagnosis	≥ 95% likelihood of malignancy
6: Known biopsy-proven malignancy	Requires surgical excision when clinically appropriate	N/A

Table 2
Classification of underweight, normal, overweight, and obese [11]

Classification	BMI (kg/m^2)
Underweight	< 18.50
Normal	18.50 – 24.90
Overweight	≥ 25.00
Obese	≥ 30.00
Obese (Class I)	30.00 – 34.90
Obese (Class II)	35.00 – 39.90
Obese (Class III)	≥ 40.00

2.2 Equipment and Data Collection

Height and weight of participants were measured using an electronic scale and height rod. BMI was calculated by Eq. (2) to classify patients into three categories, normal, overweight, and obese group [12]. A LOGIQ V2 portable US machine was used for breast examinations, obtaining images in both longitudinal and transverse views. Each image set, consisting of two images, with longitudinal and transverse view of the lesion, were downloaded in digital format, then displayed digitally to the assessors on tablets.

$$\text{BMI} = \frac{\text{weight in kg}}{\text{height}^2 \text{ in m}} \tag{2}$$

A subjective scoring survey for US image quality, which takes reference from the study done by Brahee *et al.,* [5] and Cantin *et al.,* [13], was utilized, focusing on pathology demonstration, spatial resolution, contrast resolution, and the correlation between adipose tissue and image quality. Five medical officers come the sonographers from Radiology Department served as assessors for the subjective image quality scoring survey. Four of them having five to eight years of clinical experience and another one with three years of clinical experience. The medical officers who assessed the images were blinded to the BMI categories of the participants. This blinding helps to eliminate any bias that might influence their scoring based on preconceived notions about how BMI affecting the image quality.

The evaluation of image quality was based on three key criteria: pathology demonstration, spatial resolution, and contrast resolution. For pathology demonstration, a score of 'very good' indicated exceptional clarity and visibility of lesions, allowing assessors to easily distinguish between normal and abnormal tissues. In contrast, a 'poor' score reflected a lack of visibility, where lesions were obscured or indistinct. Regarding spatial resolution, assessors focused on the ability to differentiate closely located structures, with higher scores assigned to images that clearly depicted the boundaries of adjacent tissues without blurring. Lastly, contrast resolution assessed the ability to distinguish varying tissue densities and echogenicity levels. A high score in this category indicted that the assessors could discern subtle differences in shades, enhancing the visibility of potential lesions against the surrounding tissue. Images were assessed based on the above criteria, quantitatively on a 5-point Likert scale, which five marks stands for 'Very good', four stands for 'Good', three stands for 'Acceptable', two stands for 'Poor' and one stands for 'Very poor'.

To ensure the consistency in evaluation of image quality, a brief training session were conducted prior to assessment, to clarify the definitions of each parameter. Assessors were encouraged to discuss and demonstrate their understanding of the concepts, hence, examples of how previous assessors rated the sample images were included as reference points, to guide assessors in applying the scoring scale uniformly and reducing the subjective bias.

2.3 Statistical Analysis

The result, image quality scores, were presented in frequencies, and were compared. Inter-assessor agreement of image quality survey scores was calculated using Cronbach Alpha's coefficient. Acceptance of interrelatedness was in accordance with Tavakol *et al.,* [14] interpretation, which Alpha coefficient should lie between .70 to .95. The association between three BMI classification and quality on images were evaluated using regression analysis, Spearman correlation coefficient.

3. Results
3.1 Participants' Demographics

Participants' demographics was summarised and presented in Table 3 below. The majority of participants were Malay (61.1%), followed by Chinese (22.2%), Indian (11.1%), and Thai (5.5%). The age distribution showed that 83.3% of participants were within the 40 to 60 years age range. Regarding BMI, 27.8% of the participants were classified as normal, 44.4% as overweight, and 27.8% as obese. The mean BMI for normal participants was 21.6 (SD 1.42), for overweight participants was

27.2 (SD 1.44), and for obese participants was 33.0 (SD 2.12). The distribution, compared to normal BMI distribution, is shown in Figure 1.

Table 3
Participants' demographics

	Frequency	Percentage, %
Ethnicity		
Malay	11	61.1
Chinese	4	22.2
Indian	2	11.1
Thai	1	5.5
Age range		
20 – 40	1	5.5
40 – 60	15	83.3
60 – 80	2	11.1

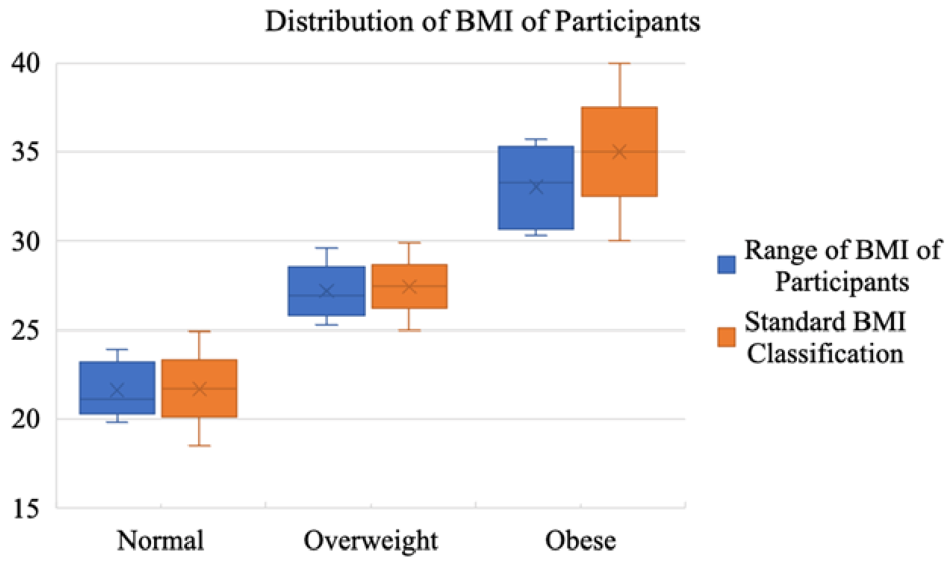

Fig. 1. Box and whisker plot of patients' respective BMI and standard BMI classification

3.2 Image Quality Scores

Image quality scores were evaluated across the three aspects: demonstration of pathology, spatial resolution, and contrast resolution.

3.2.1 Demonstration of pathology

As the number of participants in each BMI category is not evenly distributed, the scores for respective aspect were presented and compared in percentage. Percentages of scores for demonstration of pathology were shown in Figure 2. The normal BMI group had the highest mean score of 4.40 (SD .58), the overweight group scored 4.28 (SD .75), and the obese group scored the lowest with a mean of 3.60 (SD 1.12). The Spearman correlation coefficient for this aspect was -.30, with a p-value of .004, indicating a statistically significant negative and weak correlation between BMI category and image quality.

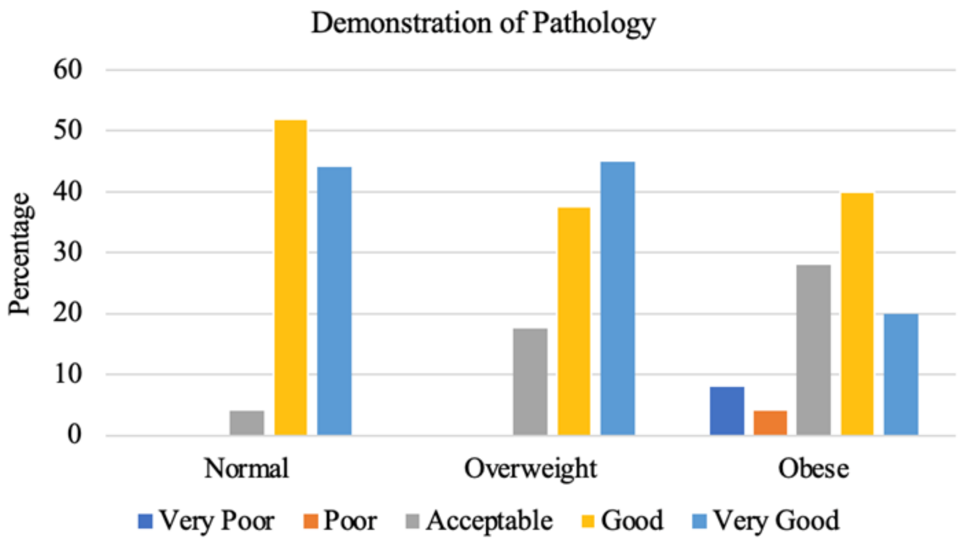

Fig. 2. Percentages of scores for demonstration of pathology according to BMI category

3.2.2 Spatial resolution

The scores for spatial resolution were presented and can be compared in Figure 3 below. The normal BMI group achieved a mean score of 4.12 (SD .73), while the overweight group scored slightly higher at 4.20 (SD .82). The obese group had the lowest mean score of 3.36 (SD .95). The Spearman correlation for spatial resolution was -.29, also significant with a p-value of .005, indicating a statistically significant negative and weak correlation between BMI category and image quality.

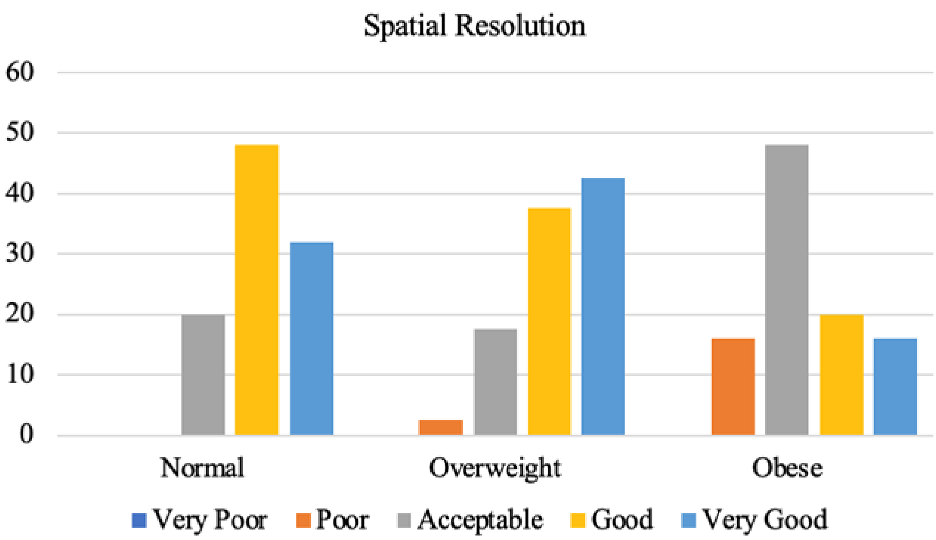

Fig. 3. Percentages of scores for spatial resolution according to BMI category

3.2.3 Contrast resolution

The scores for contrast resolution were presented and can be compared in Figure 4 below. The normal BMI group had the highest mean score of 4.04 (SD .98), the overweight group scored 3.98 (SD .92), slight difference of .06 compared to the normal BMI group. The obese group scored the lowest of 3.16 (SD 1.11). The Spearman correlation coefficient for contrast resolution was -.30, with a p-value of .003, indicating a statistically significant negative and weak correlation between BMI category and image quality.

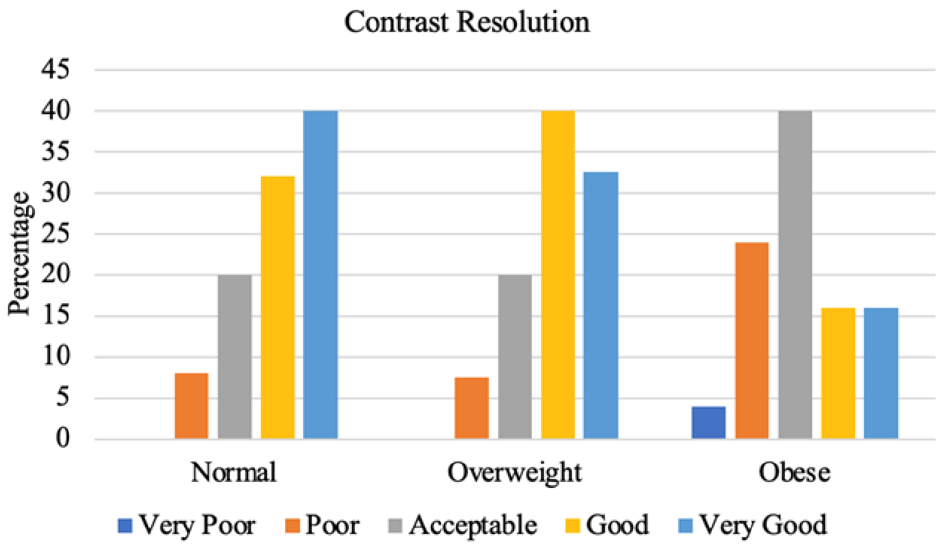

Fig. 4. Percentages of scores for contrast resolution according to BMI category

3.3 Inter-Assessor Reliability

Lastly, the reliability of the assessments was evaluated using Cronbach's Alpha coefficient, which yielded a value of .855. This result indicates good reliability and high internal consistency among the five assessors in completing the subjective scoring survey.

4. Discussion

4.1 Prevalence of Obesity and Overweight in Malaysian Women

The study revealed a higher prevalence of overweight (44.4%) and obese (27.8%) participants compared to the national average, underscoring the growing public health concern of obesity among Malaysian women. This elevated prevalence aligns with the increased risk of breast carcinoma associated with higher BMI, particularly in postmenopausal women, due to factors such as increased adipose tissue and elevated oestrogen levels.

4.2 Impact of BMI on Breast US Image Quality

4.2.1 Superior image quality in normal BMI group

Patients with a normal BMI (18.5–24.9 kg/m^2) consistently demonstrated superior breast US image quality across all evaluated parameters, including demonstration of pathology, spatial resolution, and contrast resolution.

With respect to breast volume and tissue composition, women with a normal BMI typically have smaller breast volumes, ranging from 325 to 550 mL, and thinner breast tissue with less adipose content [15]. This reduces the attenuation of US waves, allowing for better penetration and clearer visualization of lesions. The optimal beam focus of linear transducers (1–2 cm from the epidermis) aligns well with the average breast thickness (3–4 cm) in normal BMI patients, ensuring minimal distortion and high-resolution imaging [17].

Regarding acoustic properties, minimal adipose tissue in normal BMI patients reduces acoustic impedance, enabling clearer differentiation between glandular and pathological tissues. This enhances the ability to distinguish lesions from surrounding tissues, particularly in terms of echogenicity and edge definition. Normal BMI patients may also have technical advantages for US imaging. US hardware and software are typically optimized for average breast sizes and tissue compositions, which are more common in normal BMI patients [16]. This alignment ensures that imaging parameters, such as frequency and focal depth, are ideally suited for this group, resulting in superior image quality.

Despite these advantages, the presence of minimal adipose tissue can sometimes pose challenges in distinguishing tissues with similar densities. However, these limitations are outweighed by the overall high image quality observed in normal BMI patients.

4.2.2 Comparable image quality in overweight BMI group

The overweight BMI group (25–29.9 kg/m²) achieved image quality scores that were comparable to those of the normal BMI group, particularly in spatial resolution and contrast resolution. This finding challenges the assumption that higher BMI invariably leads to poorer image quality.

While overweight patients have more adipose tissue than normal BMI patients, this additional fat can act as an acoustic interface, reflecting ultrasound waves and enhancing tissue differentiation [17]. This effect compensates for the increased breast thickness, maintaining high image quality. Moreover, overweight patients often have breast volumes that remain within the range for which US equipment is designed (575–825 mL). This ensures that the technical limitations associated with excessive breast thickness are not yet significant enough to degrade image quality [15].

Similar findings have been reported in studies evaluating other types of ultrasound imaging, such as e-FAST (extended focused assessment with sonography for trauma). For example, Brahee *et al.*, [5] found that overweight patients achieved the highest standard of image quality, contradicting the expectation that normal BMI patients would consistently outperform other groups.

These results suggest that breast US screening remains effective in overweight patients, with no significant compromise in image quality or diagnostic accuracy.

4.2.3 Inferior image quality in obese BMI group

The obese BMI group (≥30 kg/m²) consistently demonstrated the lowest image quality scores across all parameters, including demonstration of pathology, spatial resolution, and contrast resolution. This decline in image quality can be attributed to several anatomical and technical factors.

Obese patients often have significantly larger breast volumes (770–1225 mL) and thicker breast tissue, which exceed the optimal range for standard ultrasound equipment [18]. This increased thickness limits the penetration of ultrasound waves, particularly for deep-seated lesions. For another, adipose tissue has a higher attenuation coefficient (0.63 dB/cm) compared to other breast tissues, meaning that ultrasound waves lose intensity as they pass through fat [19]. This results in reduced signal strength and poorer visualization of deeper structures.

To compensate for increased breast thickness, lower frequency probes are often used in obese patients. While these probes provide better depth penetration, they sacrifice spatial resolution, leading to images with indistinct edges, lower contrast, and increased background noise [20]. The challenges observed in breast US imaging for obese patients are consistent with findings in other imaging modalities. For example, Finkelhor *et al.*, [21] reported that obese patients had a higher proportion of poor-quality echocardiographic studies, while Siadecki *et al.*, [6] noted similar limitations in focused bedside echocardiography.

Despite these challenges, the image quality in obese patients remains acceptable for clinical use, with most lesions still adequately visualized. However, the inferior image quality highlights the need for tailored imaging protocols and advanced technologies to improve diagnostic accuracy in this population.

4.3 Correlation between BMI and Breast US Image Quality

The primary objective of this study was to investigate the relationship between BMI and breast US image quality. The findings revealed a weak negative correlation, indicating that while higher BMI tends to reduce image quality, the relationship is not statistically significant. This suggests that other factors, such as breast composition, lesion characteristics, and operator expertise, play a more substantial role in determining image quality.

The normal and overweight BMI groups achieved comparable image quality scores, with only a slight decline observed in the obese group. The difference in mean scores between the normal and obese groups was modest (average difference of .84), indicating that BMI alone does not have a profound impact on image quality, the correlation is not as significant.

Variability in breast composition, such as the proportion of glandular versus adipose tissue, significantly affects image quality. For example, younger women or those with predominantly glandular tissue may achieve better image quality despite higher BMI. Progressive replacement of glandular tissue with adipose tissue in older women can also influence image quality, independent of BMI [22].

Regarding the lesion characteristics in participants, smaller or deeper lesions are more challenging to detect, regardless of BMI. The use of lower frequency probes to visualize deep lesions often results in reduced resolution and contrast, further complicating the diagnosis.

The skill and experience of the sonographer also play a critical role in obtaining high-quality images. Experienced operators can adapt imaging techniques, such as adjusting probe pressure or angle, to optimize image quality in patients with higher BMI. The type of ultrasound machine used can impact image quality as well. Portable machines, while convenient, often produce lower-quality images compared to standalone systems [23].

4.4 Implications for Clinical Practices

These findings highlight that while BMI is a contributing factor to image quality, it is not the sole determinant. The variability in results across BMI categories suggests that a multifaceted approach is necessary to improve breast US imaging outcomes. Technological advancements, such as high-frequency transducers and three-dimensional US, along with standardized imaging protocols, can enhance diagnostic accuracy across all BMI categories. Furthermore, addressing the high prevalence of overweight and obesity in Malaysia through targeted public health interventions may reduce the challenges associated with breast imaging in these populations.

4.5 Limitations of the Study

Despite its contributions, this study has several limitations that must be acknowledged. The study relied on a relatively small sample size, with participants selected from a specific timeframe and limited to those with a Breast Imaging Reporting and Data System (Bi-RADS) score of 4 or above. This resulted in an uneven distribution of participants across BMI categories, with fewer individuals in the normal and obese groups. Such sampling bias limits the statistical power and generalizability of the findings to broader populations.

As conducted in a single region namely Alor Setar, Kedah, the study may not fully represent the demographic and BMI distribution of other regions or countries. Additionally, the reliance on portable US machines, which have lower spatial resolution and imaging capabilities compared to standalone systems, may have influenced the image quality outcomes. Variability in equipment and protocols across healthcare settings further limits the generalizability of the results.

Breast US is highly operator-dependent, while efforts were made to include experienced sonographers, variability in skill levels and techniques may have introduced inconsistencies in image quality assessment. The subjective nature of image quality grading, based on sonographers' interpretations, also introduces potential bias. Although the inter-assessor reliability was statistically validated, the lack of universally accepted criteria for US image quality assessment remains a limitation.

The study focused solely on BMI without accounting for breast composition, which can vary independently of BMI. For example, some normal BMI women may have predominantly fatty breasts, while others may have dense glandular tissue. Addressing this variability in the study may potentially improving the accuracy of conclusions regarding the correlation between BMI and image quality.

Other than breast composition, another variability, lesion characteristics, which were not uniformly controlled or measured, should also be addressed. The size, shape, and depth of lesions can greatly influence US image quality, and smaller or deeper lesions may inherently be more challenging to detect. This variability may lead to inconsistent imaging outcomes across different BMI categories, when some of the lesions may not exhibit the same level of visibility in patients in higher BMI.

As a student researcher, access to advanced tools for objective image quality assessment, such as software like UltraiQ, was limited due to financial constraints. The use of such tools could have provided more precise and unbiased measurements of image quality, enhancing the reliability of the results.

4.6 Recommendations

To address the limitations identified in this study and improve the generalizability of future research, the following recommendations are proposed.

Future studies should aim to recruit a larger and more evenly distributed sample across BMI categories. Extending the data collection period and involving multiple healthcare centres across different regions can reduce sampling bias and enhance the statistical power of the findings. The use of advanced imaging technologies, such as high-frequency transducers (e.g., 22–24 MHz) and three-dimensional US systems, can improve spatial resolution and lesion detection capabilities. Standardizing imaging protocols and equipment across study sites can also enhance the consistency and reliability of results.

By incorporating objective metrics, such as peak signal-to-noise ratio (PSNR) and mean squared error (MSE), subjectivity in image quality evaluation can be minimised. Commercially available software, such as UltraiQ, can provide unbiased and quantitative assessments of image quality, leading to more accurate and reliable results.

Future studies should account for breast composition factors, including the ratio of glandular to adipose tissue, as a variable in the analysis. Utilizing the Bi-RADS classification system, in the breast composition categorisation, breast composition is categorised into three types: homogeneous-fat, homogeneous-fibroglandular, and heterogenous echotexture [10]. This classification to assess breast density can provide a more comprehensive understanding of the factors influencing image quality. Lesion characteristics factor should also be accounted, such as size, shape, and echogenicity can be systematically documented during the evaluation process. These attributes can be assessed by the assessors when conducting the image quality evaluations, ensuring the consistency of the scoring of image quality.

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Emphasizing specialized training for sonographers in handling patients with diverse body types and breast compositions can improve image quality. Standardizing imaging techniques and protocols across operators can further reduce variability and enhance diagnostic accuracy.

5. Conclusion

This study contributes valuable insights into the relationship between BMI and breast US image quality, highlighting the need for a multifaceted approach to optimize diagnostic accuracy across all BMI categories. While BMI is a significant factor, its impact is moderated by other variables such as breast composition, lesion characteristics, and operator expertise. Addressing the limitations of this study through larger, more diverse samples, advanced technologies, and objective assessment tools can pave the way for more robust and generalizable findings. Ultimately, these efforts can enhance breast carcinoma detection rates and improve patient outcomes, particularly in populations with rising obesity rates.

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