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Analysis of the Effects of kVp, mAs, and Filter on Radiation Dose and Digital Mammography Image Quality

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ABSTRACT

This study analyzes the influence of variations in tube voltage (kVp), tube current (mAs), and filter type on radiation dose and digital mammography image quality. Using simulated data, this study evaluated radiation dose and image quality based on visual detection of structures (fibers, microcalcifications, and masses) in a phantom. The results indicate that radiation dose increases with kVp and mAs, with the W/Al filter consistently yielding the highest dose, whereas the W/Ag filter yields lower doses. Image quality, assessed by the number of detected structures, also improved with increasing kVp and mAs, with the W/Al filter tending to provide better detail visibility than W/Ag. Although improved image quality often implies a higher radiation dose, the analysis found that the combination of 26 kVp, 100 mAs, and the W/Ag filter is optimal. This combination yields a relatively lower radiation dose (3.2 mGy) while still achieving good image quality with detected structures meeting diagnostic standards (4.5 fibers, 3.5 microcalcifications, and 4.0 masses). This research emphasizes the importance of balancing diagnostic image quality and patient dose protection in mammography practice.

Keywords:
Mammography; Radiation dose; Image quality; kVp; mAs; Filter.

Introduction

Breast cancer is the malignancy most frequently diagnosed in women (Soekersi, Azhar and Akbari, 2022). Global data for 2022 recorded 19.9 million new cancer cases and 9.7 million deaths. In Indonesia, breast cancer ranks first with 66,271 cases (16.2% of all cancers) and is the second-highest cause of cancer death (9.3%), after lung cancer (Global Cancer Observatory, 2022).

Mammography has proven to be the most effective diagnostic modality for early breast cancer screening and is regarded as the gold standard (Soekersi, Azhar and Akbari, 2022). Its ability to detect microcalcifications at an early stage, before clinical signs appear, is crucial, enabling early therapeutic intervention that can potentially reduce mortality rates (Nur, 2019). Early screening or detection increases the chances of survival (Solikhah, 2019). As a key technology in modern breast imaging (Timmermans et al., 2014), mammography image quality is critically important for early screening (Anggraini, Haryanto and Budi, 2023). To ensure optimal quality, global guidelines recommend technique standardization and periodic evaluation using a breast phantom (Barufaldi et al., 2015).

Despite its benefits, the mammography X-ray unit has the potential to cause negative side effects due to excessive radiation exposure, which is harmful to the tissue surrounding the breast (Safitri and Yufita, 2017). Breast tissue is highly sensitive to ionizing radiation; uncontrolled exposure risks becoming a carcinogenic trigger (Juliana et al., 2016). High-energy ionizing radiation is capable of releasing electrons from atoms (Akhadi, 2000), and excessive exposure can cause changes in biological material, particularly the genetic material within cells (Aryawijayanti, Susilo and Sutikno, 2015). The effect of radiation depends on the dose received (Miftahul Jannah Al Zubaidy et al., 2022). Therefore, controlling radiation dose and image quality is essential for accurate and safe diagnosis for patients (Eric A. Berns et al., 2020). Mammography dose is influenced by breast size and composition as well as exposure settings (Dance et al., 2014).

Diagnostic image quality is vital; suboptimal images can lead to diagnostic errors, making image-quality control absolutely necessary in diagnostics (Asni & Utami, 2023). Radiographic image quality is the ability to produce a clear depiction of anatomical structures (Dartini et al., 2016).

Mammography images should ideally be high-resolution to visualize microcalcifications (Asriningrum et al., 2021). Image quality generally encompasses density, contrast, sharpness, and distortion (Ningtias et al., 2016).

The radiation dose emitted by an X-ray unit is influenced by tube voltage (kVp) and tube current (mAs), where an increase in either correlates with an increase in the number and energy of X-ray photons; image quality is also influenced by these parameters as well as by the type of filter used (Wibowo et al., 2016). The exposure factor is a key determinant of radiation quality and quantity (Sparzinanda et al., 2017). kVp setting is a major factor affecting image quality (Cahyani et al., 2021). The X-ray spectrum is controlled by tube voltage, target material, and the type and thickness of the metal filter, including the increasingly common use of a tungsten target with aluminum, rhodium, or silver filters (Dance et al., 2014). Filtration selectively removes low-energy X-rays that do not contribute to imaging but increase patient dose; filter material is chosen based on atomic number for this purpose (Bushberg, 2012). Aluminum filters, for example, can produce an X-ray spectrum optimized for improved image contrast (Alkhalifah et al., 2020).

Previous research has indicated that variations in kVp and filter material affect digital mammography image quality when using an ACR phantom (Anggraini, 2022; Anggraini et al., 2023). Increasing kVp can improve X-ray penetration but risks reducing contrast, while appropriate filter selection optimizes image quality under controlled doses (Anggraini, 2022). Another study also evaluated image quality using a mammography phantom under different exposure parameters (Celina et al., 2023). Lestari's (2017) research likewise evaluated radiation beam quality using technical parameters such as kVp, mAs, HVL, and dose. A study by Fadhilah et al. (2023) compared the Mean Glandular Dose (MGD) resulting from the use of Molybdenum (Mo) and Rhodium (Rh) filters.

Building on this background, this study aims to analyze the effect of kVp value and filter type on image quality and the output radiation dose of a digital mammography unit. Radiation dose analysis was carried out through direct measurement using a multimeter. Image quality was evaluated visually through Visual Grading Analysis (VGA) by counting the number of detected microcalcification, fiber, and mass structures.

Methods

This study was a quantitative experimental study conducted at Gunung Jati Regional Hospital, Cirebon. The main instruments consisted of a Metaltronica Helianthus DBT digital mammography unit, a RaySafe X2 MAM Sensor multimeter, and a PASMAM image-quality phantom.

The research procedure involved two stages of data simulation. First, radiation dose measurements were taken using the multimeter, and the dose was recorded. Second, image acquisition was simulated using the same exposure parameters on the PASMAM phantom.

Data analysis covered dose (visualized graphically) and image quality. Image quality was evaluated visually (counting the number of fiber, microcalcification, and mass structures based on BAPETEN scoring). The best parameter combination was determined based on the optimal balance between high image quality (many detected structures) and low radiation dose.

Data Collection
Radiation dose and image data were obtained from the varied parameters, namely tube voltage (kVp) at 24, 26, and 28 kVp; tube current (mAs) at 100 and 150 mAs; and Al (Aluminum) and Ag (Silver) filters.

Data Analysis
Data analysis in this study was carried out to evaluate the effect of exposure-factor variation on radiation dose and digital mammography image quality. The data analyzed comprised the simulated measurement results for radiation dose and image quality.

Radiation Dose Data Analysis
The radiation dose data produced by each combination of tube voltage (kVp: 24, 26, 28 kVp), tube current (mAs: 100, 150 mAs), and filter type (Aluminum and Silver) were tabulated and visualized graphically. This visualization aimed to identify trends in radiation-dose values across the varied

exposure parameters. This analysis provides an understanding of how increasing kVp and mAs, as well as filter selection, affect the magnitude of the radiation dose emitted by the mammography unit.

Image Quality Data Analysis
Image quality was evaluated through a visual approach. Visual image-quality assessment was carried out by counting the number of structures (fibers, microcalcifications, and masses) detected in the phantom image. Each structure was scored according to its visibility: a full score (1) for objects seen intact, a half score (0.5) if contrast was insufficient or the object was only partially visible, and a zero score (0) if the object was not visible at all. These results were then compared against the quality standard set by BAPETEN Regulation Number 2 of 2022, which requires that at least 4 fibers, 3 microcalcifications, and 3 masses be detected in the phantom test.

Determination of the Best Exposure Parameter Combination
Determination of the best combination of kVp, mAs, and filter was carried out through a comparative analysis between the image quality and radiation dose produced by each parameter variation. The optimal combination was selected based on a comprehensive evaluation that considered a high number of visually detected structures while remaining within a low radiation-dose range. This approach aimed to identify the parameter combination that achieves an ideal balance between diagnostic imaging efficiency and patient dose protection.

Results and Discussion

Radiation Dose Measurement
The results of the radiation dose measurements are presented in the table 1. The table 1 shows that variations in tube voltage (kVp) and tube current (mAs) produced different radiation dose measurements. The higher the kVp and mAs, the higher the resulting radiation dose. This is due to the increase in the energy and number of X-ray photons reaching the detector or phantom (Susanti et al., 2014).

Table 1. Radiation Dose Measurement Results

kVp	mAs	Filter	Dose (mGy)
24	100	W/Al	6.931
26	100	W/Al	8.990
28	100	W/Al	11.060
24	150	W/Al	10.440
26	150	W/Al	13.510
28	150	W/Al	16.610
24	100	W/Ag	2.802
26	100	W/Ag	3.902
28	100	W/Ag	5.030
24	150	W/Ag	4.190
26	150	W/Ag	5.854
28	150	W/Ag	7.537

The W/Ag filter produced a lower dose compared to W/Al. This shows that appropriate filter selection is very important in optimizing the balance between image quality and radiation-dose protection. This is because filtration serves to remove low-energy X-rays that contribute little to medical imaging but can increase the radiation dose received by the patient (Bushberg, 2012).

Mammography Image Measurement

The results of the mammography image measurements are presented in the table 2. The table 2 shows that image quality in terms of mass detection improved with increasing kVp and mAs values; the W/Al filter showed better results compared to W/Ag and W/Rh.

Table 2. Mammography Image Quality Measurement Results

kVp	mAs	Filter	Fibers	Microcalcifications	Masses
24	100	W/Al	4.0	3.0	4.0
26	100	W/Al	5.0	3.5	4.0
28	100	W/Al	5.5	4.0	4.5
24	150	W/Al	4.5	3.0	4.0
26	150	W/Al	5.5	3.5	4.0
28	150	W/Al	6.0	4.0	4.5
24	100	W/Ag	4.0	3.0	3.5
26	100	W/Ag	4.5	3.5	4.0
28	100	W/Ag	5.0	1.0	4.0
24	150	W/Ag	4.5	3.0	4.0
26	150	W/Ag	4.5	3.5	4.0
28	150	W/Ag	5.0	4.0	4.5

The results of this study show that increasing kVp and mAs values progressively improved the detection of fiber, microcalcification, and mass structures. The higher the exposure factor, the more structures could be clearly identified in the image, reflecting improved image visibility and sharpness.

Conclusion

Based on the results of the analysis and discussion of the simulated data, several conclusions can be drawn regarding the effect of exposure-parameter and filter variation on digital mammography. Radiation dose: the resulting radiation dose increased with increasing tube voltage (kVp) and tube current (mAs); the W/Al filter consistently produced the highest radiation dose, while the W/Ag filter produced a lower dose for the same parameter combinations. Image quality (visual structure detection): image quality, evaluated through the number of detected structures (fibers, microcalcifications, and masses), also increased with increasing kVp and mAs; the W/Al filter tended to yield higher visual structure-detection results than W/Ag, indicating better detail visibility. Optimal combination: although the W/Al filter and increases in kVp and mAs can improve image quality, this comes with a significant increase in radiation dose, so a balance between image quality and dose protection is required. Based on the simulated data analysis, the combination of 26 kVp, 100 mAs, and the W/Ag filter is the optimal choice, as it produces a relatively lower radiation dose (3.9 mGy) while still achieving good image quality, with structure detection meeting diagnostic standards.

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Conflicts of interest

The authors affirm that they have no conflicts of interest.

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