Measurement of X-ray Beam Quality and Patient Dose Information from Analog Mammography

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Abstract. Measurement of X-ray beam quality and patient dose information from analog mammography have been studied by using an X-ray multimeter from 2016-2018. Parameters in the study are voltage accuracy, reproducibility test, radiation output linearity, radiation beam quality test, and patient dose information. The patient dose information using PMMA phantom with a thickness 4 cm in the Mean Glandular Dose (MGD) obtained dose values in 2016, 2017, 2018 are 0.982 mGy, 0.982 mGy, 0.953 mGy, respectively. This study aims to determine the feasibility of mammography, while patient doses are compared with the standards set by the IAEA. The results showed that the suitability test of X-ray beam quality and patient dose information still comply the requirements recommended by the IAEA.

1. Introduction
Mammography is an X-ray examination used to examine and detect cancer in the breast. Breast cancer is the most common type of cancer among women worldwide and it can cause death. Diagnosis results in more than millions of breast cancer cases that have occurred in the last few years. To overcome this, mammography is used for early detection and diagnosis of breast cancer as one of the most effective and reliable imaging method, one of mammography type is analog mammography. Examinations arising from X-ray radiation exposure from analog mammography use low energy ionizing radiation to produce mammogram which is two-dimensional projection on radiography [1-3].

Increased public awareness of the usefulness and benefits of mammography has been shown to reduce mortality for breast cancer sufferers. Technically, mammography is a radiographic producer who has a high level of accuracy [4, 5]. The high level of accuracy of a mammography invites researchers to produce a new innovation related in this field. Among others, determining value of the mean glandular dose (MGD) using X-ray mammography ionizing radiation and age variations [6, 7], monitoring and improving the quality of mammography [8, 9], determining the average gland dose due to the effect of a combination of anode/filter on mammography [10], evaluating the quality and accuracy of diagnostic mammograms [11], etc.

Several of the studies above certainly have advantages and disadvantages. The advantages, they discuss about usefulness and benefits of mammography as a solution in the process of healing breast cancer, but the disadvantage is the mammography can also cause a bad risk to patients and non-patients caused by X-ray radiation exposure if it is not well controlled [3, 6-11]. Therefore, we will do measurement of X-ray beam quality and patient dose information from mammography. This measurement is expected to provide information to alleviate the concerns and fears of patients about the risks that can be caused from X-ray radiation exposure, and produce feasibility test values in according with the standards set by the International Atomic Energy Agency (IAEA) [12, 13].
2. Method

Measurement of X-ray beam quality test and patient dose information on the Philips brand of analog mammography by using X-ray multimeter, meter/ruler, and materials are PMMA phantom with a thickness 4 cm and aluminum filter 0.10 mm.

Figure 1. Measurement procedures of X-ray beam quality test includes: (a) accuracy and reproducibility of voltage, (b) linearity of radiation output, (c) half value layer (HVL), and (d) patient dose information.

This measurement includes a voltage accuracy suitability test conducted by placing the detector in a perpendicular position facing to the tube on the patient's table at a distance 4 cm from the edge of the chest wall as shown in Figure 1 (a). The exposure process is carried out on several variations of kVp with fixed mAs condition. Likewise, the reproducibility test is carried out in the same way with the voltage accuracy suitability test as shown in Figure 1 (a), but the exposure process is repeated 5 times under fixed mAs and fixed kVp. Determination of accuracy of kVp is calculated by using the percentage deviation equation, while reproducibility is calculated by using the coefficient of variation (CV) equation such as equations (1) and (2) below [13]:

\[
\text{Deviation} = \frac{kVp_{set} - kVp_{measured}}{kVp_{set}} \times 100\% \tag{1}
\]

\[
CV = \frac{SD}{\bar{x}} = \frac{1}{\bar{x}} \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{2}
\]

Where \(kVp_{set}\) is tube voltage setting, \(kVp_{measured}\) is the measured tube voltage, \(CV\) is coefficient of variation for repeatability and kerma, \(SD\) is deviation standard, \(\bar{x}\) is the average number of data, and \(n\) is the number of data.

The suitability test of radiation output linearity is carried out by placing a PMMA phantom 4 cm on the patient’s table. The detector is placed above the compression pedal with a distance 4 cm from the edge of the chest wall as shown in Figure 1 (b). The exposure process is carried out on fixed kV condition with variations in mAs. HVL test to determine the radiation beam quality, it is carried out by placing the detector in a perpendicular position facing to the tube on the patient's table at a distance 4 cm from the edge of the chest wall as shown in Figure 1 (c). Exposure process is carried out under fixed mAs and fixed kVp. The value of air kerma measured without additional filter (Do). Exposure process by adding an aluminum filter that produces more than half of the dose Do without filter. Radiation output linearity determined using coefficient of linearity (CL) equation (3) and HVL using equation (4) below [13]:

\[
CL = \frac{X_{max} - X_{min}}{X_{max} + X_{min}} \tag{3}
\]
Where $CL$ is the coefficient of linearity, $X_{\text{max}}$ is the maximum current, $X_{\text{min}}$ is the minimum current, $HVL$ is the Half Value Layer/thickness of absorbent material, $D_o$ is the initial or unfiltered dose, $D_a$ is the readable dose in the value smaller than $D_o/2$, $D_b$ is the readable dose in the value larger than $D_o/2$, $t_a$ is the thickness of material when the dose value read smaller than $D_o/2$, and $t_b$ is the thickness of material when the dose value read greater than $D_o/2$.

The suitability test of patient dose information is carried out by placing the PMMA phantom and detector on the patient’s table. The edges of phantom and detector are placed parallel to the edge of the chest wall shown in Figure 1 (d). The compression pedal is lowered until it attaches to the phantom. Radiation process is carried out in the Automatic Exposure Control (AEC) mode. Phantom is released and then exposure is carried out using radiation conditions obtained in the AEC mode. In this study, we use Mo/Mo material. Patient dose information is determined using calculation of MGD in equation (5) following [13]:

$$MGD = C_{DG50,Ki,PMMA} \cdot s \cdot Ki$$

Where $MGD$ is the mean glandular dose, $C_{DG50,Ki,PMMA}$ is a conversion factor, $s$ is a correction factor that depends on the anode/filter, and $Ki$ is air Kerma.

3. **Result and Discussion**

This research was conducted in one of the leading Radiology Installation Hospital in Makassar about the suitability test of mammography from 2016-2018. Measurement of X-ray beam quality test and patient dose information using the Philips brand of mammography analog made in Germany with a maximum condition of 35 kv and 560 mAs. Based on the results obtained from the measurement of voltage accuracy tests on mAs-set 20 and kVp 24, 26, 30 as shown in Figure 2 below:

**Figure 2.** Graph of voltage accuracy is change in percentage deviation from 2016-2018.

Based on the graph from Figure 2 shows the relationship of changes in the percentage deviation of voltage accuracy from 2016-2018. It shows that the percentage deviation is lower in the kVp-set 30. The level of correlation for each kVp-set is 24, 26 and 30 at $r = 0.866$. This states that the graph in
Figure 2 correlates perfectly, which is the r value between 0.81 until 1.00.

The next research is measurement of the reproducibility test in repeatability and air kerma using CV calculation with kVp-set 28 and mAs-set 20. The measurement data is taken 5 times. The measurement results can be seen in Figure 3 below:

![Figure 3](image-url)

**Figure 3.** Graph of reproducibility test is change in CV of repeatability and kerma from 2016-2018.

The measurement of reproducibility test as shown in Figure 3 shows that the level of correlation of tube voltage variation and radiation output is \( r = 0.866 \). This states that the graph in Figure 3 correlates perfectly. The measurement results of X-ray beam quality and patient dose information can be calculated using equations (1) - (5) seen in Table 1 below:

| Year | Deviation (%) | CV | Repeatability (kV) | Kerma (mGy) | CL | HVL | MGD |
|------|---------------|----|-------------------|--------------|----|-----|-----|
| 2016 | 0.92 1.04 0.10 | 0.0015 0.0009 | 0.09 0.29 0.982 |
| 2017 | 0.92 1.04 0.10 | 0.0015 0.0009 | 0.09 0.29 0.982 |
| 2018 | 0.96 1.08 0.13 | 0.0017 0.0008 | 0.10 0.28 0.953 |
| Reference | 0.30 [7] 0.30 [7] 0.22 [7] 0.31 [7] 0.99 [7] |

In Table 1 shows the results of measurement of X-ray beam quality test and patient dose information on analog mammography from 2016-2018. There is a reference that each parameter has values that approaching value as reported by Pwamang, et al [7]. Furthermore, each variable uses the one-sample test as a statistical test to determine the significance level which is indicated by the p value produced. The result of percentage deviation shows the lowest at kVp-set 30 and the highest at kVp-set 26. By using the one-sample test obtained p value of 0.000 (p < 0.05) for each kVp-set of 24, 26, 30. Statistically, there is a significant relationship of percentage deviation from 2016-2018. Based on the table, the accuracy test of the voltage marked from the percentage deviation is still within the
tolerance limit recommended by IAEA, which is ≤ 5% [13].

Statistical tests for reproducibility in CV of repeatability and CV of kerma produce the same p value is 0.000 (p < 0.05). This shows that, there is a significant relationship between CV of repeatability and CV of kerma from 2016-2018. The results obtained are still within the tolerance limit recommended by the IAEA, which is ≤ 0.02 [13]. Furthermore, the measurement of the radiation output linearity test produces the largest CL in 2018. The resulting p value is 0.000 (p < 0.05), where there is a significant correlation between CL from 2016-2018. The results of Table 1 show that the linearity test of radiation output is still within the tolerance limit recommended by the IAEA, which is ≤ 0.1 [13].

The HVL test to determine the quality of the radiation beam resulting p value is 0.000 (p < 0.05). That meaning, there is a significant relationship between HVL from 2016-2018. HVL values obtained from 2016-2018 are still within the tolerance limit recommended by the IAEA, which is 0.28 ≤ HVL ≤ 0.4 [13]. While, the feasibility test of the patient dose information with Mo/Mo material is show MGD values from 2016-2018 of 0.982 mGy, 0.982 mGy, and 0.953 mGy. The p value obtained is 0.000 (p < 0.05). That meaning, there is a statistically significant relationship between MGD from 2016-2018. The MGD test results from 2016-2018 are still comply the requirements recommended by the IAEA, which is ≤ 3 mGy [13].

4. Conclusion
This research can be concluded that the test results of the X-ray beam quality and patient dose information on analog mammography from 2016-2018 are still comply the requirements recommended by the IAEA. Several result of parameters are accuracy of voltage ≤ 5%, reproducibility in CV of repeatability and kerma ≤ 0.02, radiation output linearity ≤ 0.1, radiation beam quality 0.28 ≤ HVL ≤ 0.4, and patient dose information ≤ 3 mGy. Patient dose information obtained in MGD values are 0.982 mGy, 0.982 mGy, 0.953 mGy, respectively.

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