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STUDY OF THE OPTIMUM FILTRATION FOR MAINTAINING IMAGE QUALITY AND REDUCING THE DOSE ON THE RADIODIAGNOSTIC

Rizka Indra Prasetya, Mahrus Salam*, Heryuli Aditesna, Vemi Ridantami, Wuntat Oktawijaya, Bilqis Latifah, Isti Rahmawati, Fath Priyadi, Fajar Panuntun, Selvi Lutfiana P., Siswanti, Nurhidayat Supriyanto, Jasmi Budi Utami, Thomas Candra A., Sofyan Adisaputra

Directorate of Nuclear Facility Management – National Research and Innovation Agency (BRIN), Jl. Babarsari PO BOX 6101 YKBB, Special Region of Yogyakarta, 55281, Indonesia

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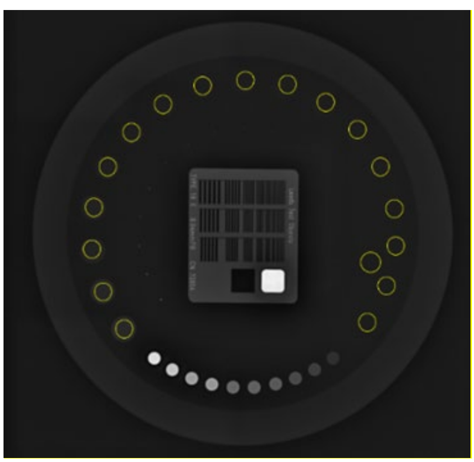
*Corresponding author
mahrus.salam@brin.go.id

Graphical abstract



Abstract

X-ray medical imaging serves as a cornerstone in diagnostic procedures, offering essential insights into anatomical structures conditions. The optimization of image quality and patient safety in x-ray imaging is carried out by using appropriate filtration for x-ray beam. This paper presents a comparative analysis of aluminium (Al), copper (Cu) filters and combination of both materials for evaluating the effectiveness in attenuating low-energy photons and minimizing patient radiation exposure while maintaining image quality. This study investigates the TOR CDR phantom as an object with the exposure factor of 70 kV and 5 mAs, examining variations in thickness and filter materials to evaluate low and high contrast imaging procedures. The obtained dose values are compared with Signal-to-Noise Ratio (SNR) as well as Contrast-to-Noise Ratio (CNR) values, which represent the quality of the image to evaluate the impact of filtration on diagnostic image quality. The results indicate that for low contrast imaging a 5 mm Al filter is recommended, where it increases the SNR value by 41.3%, the dose decreases by 65.4%, but it may reduce the contrast by 31.7%. Meanwhile, for the high contrast imaging the recommended filter variation is 0.1 mm Al and 1 mm Cu. It can increase the SNR value by 52.7%, the dose decreases by 55.4%, but it may reduce CNR by 6.7%.

Keywords: X-ray, Image, Filtration, SNR, CNR

1.0 INTRODUCTION

For the medical purposes, x-rays are commonly used to obtain images of organs and structures within the human body. Furthermore, medical images can be used to monitor the progression of a patient's condition, assess the effectiveness of treatment, and guide surgical procedures [1]. Diagnostic radiology has developed rapidly in the last few decades. A significant development in medical imaging is the adoption of imaging modalities that use computer technology, such as Computerized Radiography (CR) and Digital Radiography (DR) [2]. Both modalities have a significant impact, especially on improving the image quality [3]. However, the patient doses on the digital radiography tend to be higher than on the film screen or conventional radiography [4]. Although the increase of the dose value is below the DRL (Dose Reference Level), but the optimization must be carried out [5]. Optimizing radiation protection is essential to maintain that patients do not receive unnecessary radiation dose during digital radiography, in accordance with the ALARA (As Low as Reasonably Achievable) principle [6].

Several techniques can be used to reduce patient radiation doses during digital radiography, and one of these techniques involves using the appropriate filter [7]. However, when reducing patient radiation doses during digital radiography, it is important to consider the quality of the resulting image, as structures within the body must still be clearly visible and detectable. The main purpose of filtering is to reduce the dose and enhance the image's clarity by removing any noise, distortions, or unwanted features [8]. The filter absorbs low-energy photons that has no significant impact on the resulting image, where the addition of a filter will affect the quality of the resulting image. In medical imaging, Al and Cu filters are commonly used [9], [10]. One method used to assess the quality of radiological images is using Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) measurements [11]. These metrics help evaluate the clarity and detectability of structures within the image while considering the amount of noise present in the image [12].

The optimization of radiation protection in this study was performed by investigating the effects of varying the thicknesses of the filters that mostly used in diagnostic radiology which are Al and Cu, as well as the potential benefits of combining for both filters. From previous studies, it has been mentioned that Al and Cu filters are very effective in reducing doses in certain diagnostic radiology examinations [13], [14]. By using a 0.1 mm Cu filter, a 19% reduction in DAP can be achieved in chest x-ray [15]. In this study, the TOR CDR Phantom is used to evaluate the impact of using different types of filters on both the image quality and the patient dose for low contrast as well as high contrast imaging procedures. The low radiographic contrast is the radiographic images that the adjacent regions have a low-density difference (black to grey), while high radiographic contrast is the radiographic that the density differences are notably distinguished (black to white) [16]. The main objective of this study is to determine the optimum filter thickness for achieving a balance for both image quality and the optimization radiation dose that received by patient during radiodiagnostic procedure.

2.0 METHODOLOGY

In this study is The Siemens Multix DR x-ray was used, equipped with a flat panel detector (FPD) technology. The Entrance Surface Dose (ESD) value is measured using an R/F RaySafe X2 detector, which is a highly sensitive device for measuring radiation dose in real-time. In medical imaging, Al and Cu filters are commonly used to improve image quality and to reduce the patient dose in radiodiagnostic. The Cu filter has a better ability to absorb photons, so the thickness of Cu used is much thinner compared to Al [17]. The combinations of Cu and Al filters used are shown in Table 1.

Table 1 The Filters Combination

Combination No.	Thickness *Cu* (mm)	Thickness *Al* (mm)
1	0	0
2	0.1	0
3	0.2	0
4	0.3	0
5	0	1
6	0	2.5
7	0	5
8	0.1	1
9	0.1	2.5
10	0.1	5
11	0.2	1
12	0.2	2.5
13	0.2	5
14	0.3	1
15	0.3	2.5
16	0.3	5

2.1 Acceptance Test

An acceptance test was performed to validate the x-ray machine condition trough several parameters such as tube voltage accuracy, output linearity, and reproducibility [18], [19]. Tube voltage accuracy testing was conducted to ensure that the voltage set on the control panel corresponds to the voltage that comes out. Equation 1 was used to calculate the error, where the maximum error that allowed is 10%. The output linearity testing is used to observe the linearity coefficient (CL) between the current and the dose output from the x-ray machine. The CL value can be calculated using Equation 2, where the allowable CL is less than 0.1. Reproducibility is the third parameter that is tested to validate the x-ray machine stability, where this test was carried out by calculating the variation coefficient (CV) using Equations 3 to 5 [20], respectively. The acceptable CV is less than 0.05.

$$Error = \frac{Vp_{set} - Vp_{measured}}{Vp_{set}} \times 100\% \tag{1}$$

$$CL = \left| \frac{\left(\frac{D_i}{I_i}\right)_{max} - \left(\frac{D_i}{I_i}\right)_{min}}{\left(\frac{D_i}{I_i}\right)_{max} + \left(\frac{D_i}{I_i}\right)_{min}} \right| \tag{2}$$

$$CV_{vp} = \frac{\sigma_{Vp}}{\overline{Vp}} \quad (3)$$

$$CV_t = \frac{\sigma_t}{\bar{t}} \quad (4)$$

$$CV_D = \frac{\sigma_D}{\bar{D}} \quad (5)$$

where,

Vp_{set}	:	x-ray voltage that determined
$Vp_{measured}$	:	actual x-ray voltage that measured by detector
D_i	:	radiation dose output
I_i	:	tube current
$\sigma_{Vp,t,D}$	:	standard deviation of x-ray Voltage, exposure time and dose, respectively

2.2 Image Capture

In this study, the TOR CDR phantom was used as the object, with exposure factors of 70 kV and 5 mAs, as recommended in the manual of TOR CDR Phantom, and variations in filter thickness as shown in Table 1. The image that obtained was analyzed by observing the SNR and CNR values using ImageJ software. SNR measures the relationship between the signal and the noise within an image. It assesses the extent to which the signal is distinguishable from the background noise, making it a valuable metric for evaluating image quality and the visibility of fine details. Meanwhile, CNR goes further by assessing the difference between the signal of interest (Is) and the background signal (Ib), normalized by the noise standard deviation (σ). It provides a measure of how effectively an object or feature can be distinguished from its background [12]. Contrast is a measure to observe the difference between the signal and the background. The greater the contrast value, the easier it is to distinguish the signal from the background. The SNR and CNR value were calculated using Equation 6 and 7, respectively.

$$SNR = \frac{I_s}{\sigma} \quad (6)$$

$$CNR = \frac{I_s - I_b}{\sigma} \quad (7)$$

where I_s is the signal height, I_b is the background height, and σ is the standard deviation value of the background area [21]. By using the TOR CDR Phantom, low and high contrast sensitivity were observed. High contrast radiography is an image that the density differences are clearly visible (black to white), meanwhile low contrast radiography is an image where the adjacent regions have a low-density difference (black to grey) [9]. Low contrast sensitivity is measured by evaluating the image results of 17 large circles (11 mm), whereas high contrast sensitivity is measured by evaluating the image results of 17 small points (0.5 mm), as shown in Figure 1.

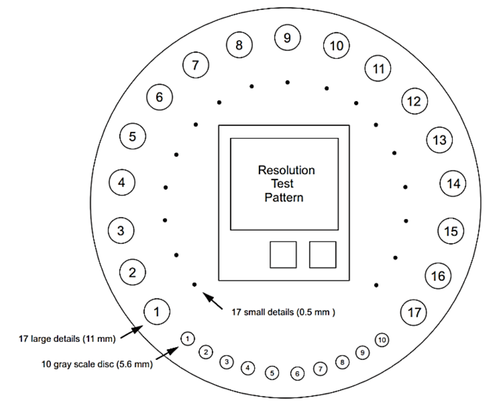


Figure 1 Layout of TOR CDR phantom

By adding Al and Cu filters with certain thickness variations will changes the image quality, in which by looking at the values of SNR and CNR in each image with filter thickness variations, the effect of filter type and thickness on the resulting image quality can be observed.

3.0 RESULTS AND DISCUSSION

3.1 The Acceptance Test

The acceptance test was carried out to validate the x-ray machine condition through several parameters. The first parameter is voltage accuracy, in which this test was conducted by keeping the x-ray tube current (mAs) constant and varying the voltage (kV) starting from 60 kV to 102 kV with an interval of 10 kV. The error value is calculated using Equation 1, with the maximum error value of 1.78% observed at a voltage of 90 kV, as depicted in Figure 2. This error value is below the acceptance criteria which is less than 10% [18].

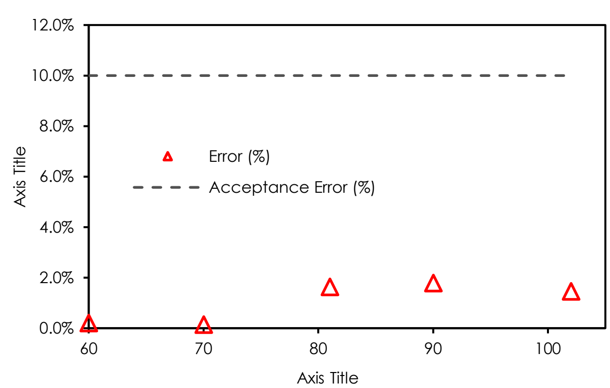


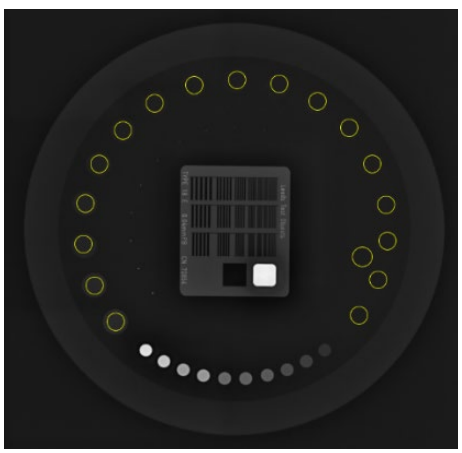
Figure 2 The Result of Tube Voltage Accuracy Test

The second parameter that observed is the output linearity test to obtain the correlation between the x-ray tube current and dose value, where the dose value will increase as the x-ray tube current increases linearly. This correlation can be observed through the CL value that is calculated using Equation 2. In this study, the CL value obtained through Equation 2 is 0.07, therefore it meets the acceptance criteria.

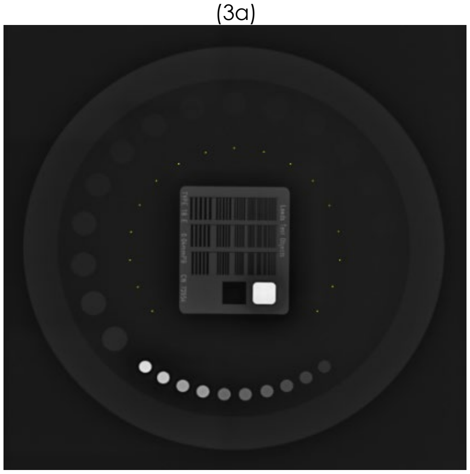
The last parameter is Reproducibility, which is used to see the stability of the x-ray machine that was used in this study. The calculated CV values for the x-ray voltage, exposure time, and output dose are 0.003, 0.000 and 0.002, respectively. These values still meet the acceptance criteria which is less than 0.05. The results of the acceptance test indicate that all parameters meet the acceptance criteria, therefore the x-ray machine is in good condition and can be used for the next stage.

3.2 Image Analysis

A total of 16 images were obtained in this study. Furthermore, image quality analysis was carried out using ImageJ software by looking at the SNR and CNR values at low and high contrasts. ROI in the high and low contrast analysis was described in Figure 3, meanwhile the comparison of SNR and CNR values analysis for each filter thickness variation are shown in Figure 4.



(3a)



(3b)

Figure 3 (a) ROI for low contrast, (b) ROI for high contrast

From Figure 4, the two highest SNR values for low contrast were obtained in filter variations no. 7 (5 mm Al) and no. 3 (0.2 mm Cu) with values of 83.8 and 79.8, respectively. Meanwhile, the two highest CNR values in low contrast were obtained in filter variations no. 5 (1 mm Al) and no. 6 (2.5 mm Al) with values of 6.2 and 5.5, respectively. In addition, the two highest SNR values in high contrast were obtained in filter variations no. 8 (0.1 mm Cu + 1 mm Al) and no. 3 (0.2 mm Cu) with values of 201.3 and 160.3, respectively. Meanwhile, the two highest CNR values in high contrast were obtained in the same filter variations as the SNR, which are no. 8 (0.1 mm Cu + 1 mm Al) and no. 3 (0.2 mm Cu) with values of 62.3 and 61.9, respectively.

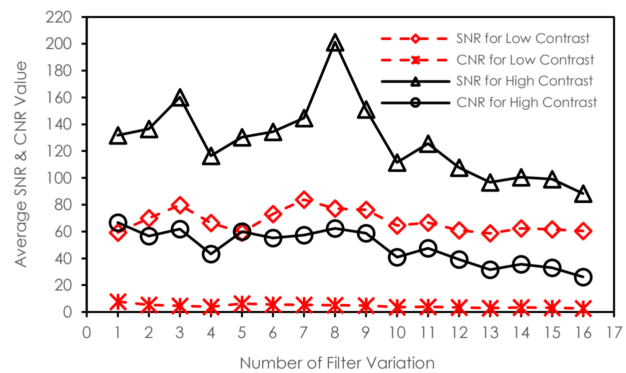


Figure 4 The comparison of SNR and CNR values for low and high contrast

In diagnostic imaging, apart from evaluating SNR values, another important consideration was the radiation dose for the patient. In this study, an analysis of filter variations toward the radiation dose that received by patient was also carried out, in which the dose value was measured using the Raysafe x2 detector. The comparison between dose value and SNR value for the several filter variations for high and low contrast are presented in Figure 5. Figure 5 shows that the lowest dose values were obtained from filter combinations no. 16 (0.3 mm Cu + 5 mm Al) and no. 13 (0.2 mm Cu + 5 mm Al), with values of 24.0 μGy and 31.6 μGy, respectively.

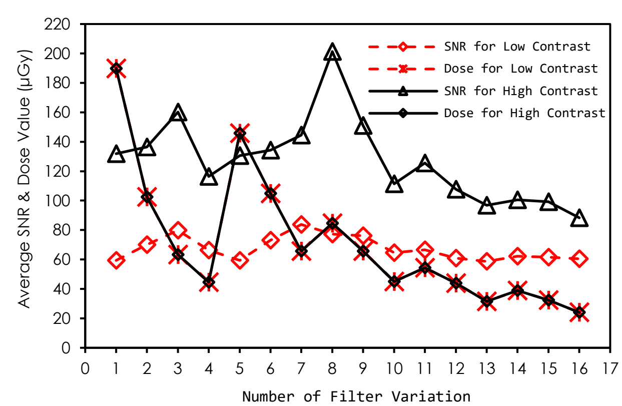


Figure 5 The comparison of dose values with SNR for low and high contrast

Filtering is a very common technique used in image processing. The purpose of filtering is to enhance the image's clarity by removing any noise, distortions, or unwanted features. There are multiple types of filters that can be used depending on the desired effect. In medical imaging, filters are used to improve the image quality as well as to reduce the dose received by the patient. However, there is a trade-off between patient dose and image quality. If the dose is reduced too much, image quality can suffer, and structures may be harder to detect. Therefore, it is essential to find the optimal balance to achieve both objectives.

In the low contrast, the SNR value increased in almost all variations of filter combinations as shown in Figure 4. This indicates that the filter is effective in reducing noise in low contrast images. A detailed overview of the percentage changes in SNR and CNR values based on filter combinations compare to image without additional filtration in low-contrast and high-contrast images can be observed in Figure 6 and 7 respectively. The value is obtained by dividing the difference between the SNR or CNR values for specific filter variations and the reference value (without additional filters) by the reference value. A negative value indicates that the SNR or CNR value is below the reference (without a filter).

As depicted in Figure 5, the dose values vary for each filter variation. The appropriate filtration selection will reduce the dose received by the patient, while still maintaining acceptable image quality. In Figures 6 and Figure 7, it can be observed that almost all CNR values are negative, while most SNR values are positive.

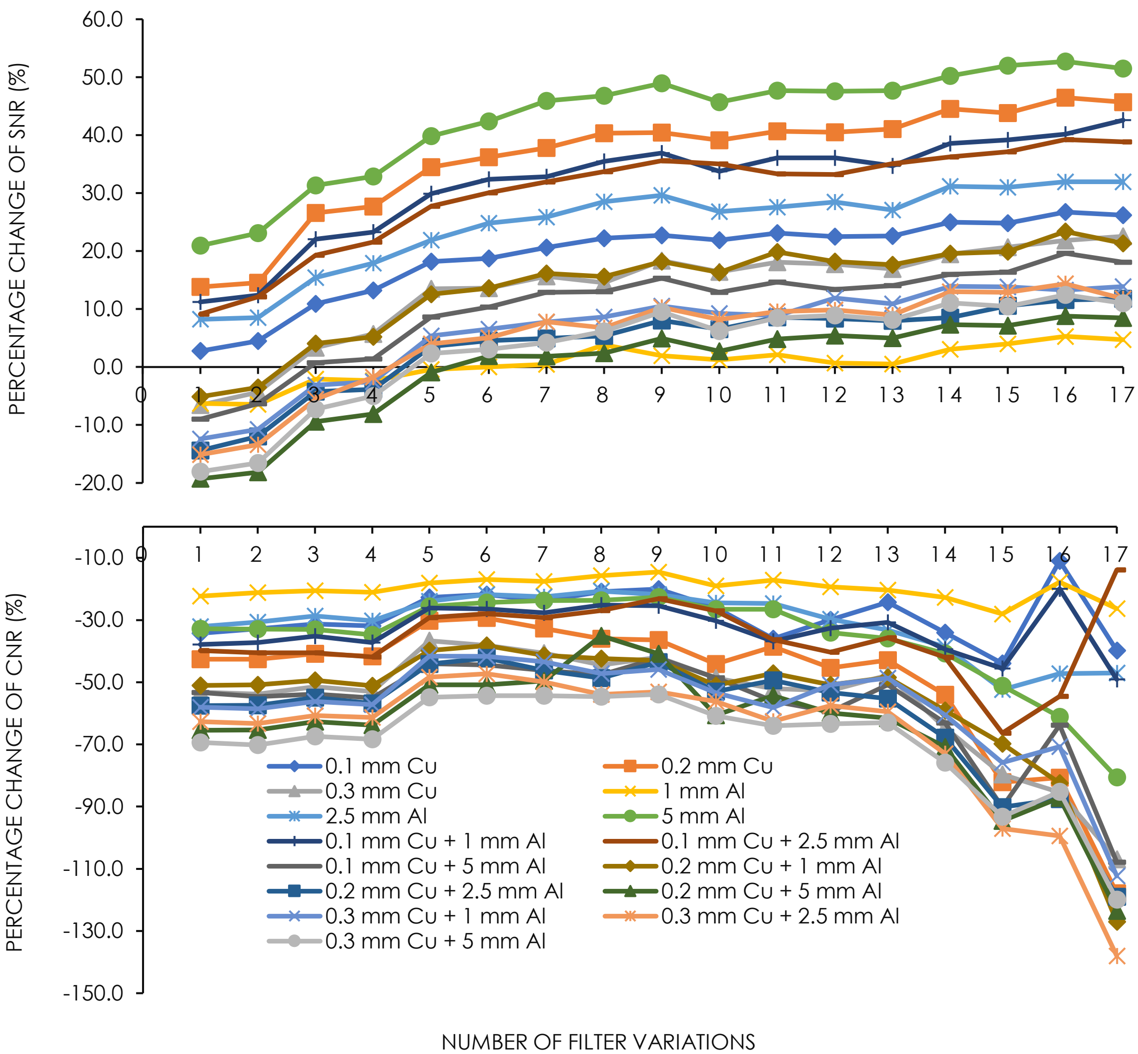


Figure 6 The percentage change in SNR and CNR based on filter combinations compared to the image without filters in low contrast imaging

This indicates that the addition of filters affects the image. This aligns with previous research, that the addition of filters in diagnostic radiology can reduce image quality [22], [23]. Filters are used to absorb low-energy photons from the X-ray spectrum that do not significantly contribute to image formation (they only add noise or dose). As a result, the noise from low-energy photons decreases, and the SNR value increases. However, for contrast between the object and background, when a filter is added, the higher energy photons that dominate after filtration are less effective at increasing the absorption difference between the object and the background. As a result, the contrast (CNR) between the object and background decreases, because the difference in linear attenuation coefficients between tissues becomes less significant at higher energies.

In radiation protection for medical imaging, the ALARA (As Low as Reasonably Achievable) principle is applied to minimize patient dose while considering the potential decrease in image quality. Based on the analysist that performed, the recommended filter for low contrast imaging is 5 mm Al filter, where the SNR value increases by 41.3% and the dose received by patient decreases by 65.4%, although it may reduce the contrast by 31.7%. However, low contrast radiograph would produce an image that has very little difference in brightness between adjacent areas or structures within the body. Therefore, it will be difficult to distinguish the different types of tissue or structures within the image. Some examples of radiographs with low contrast are chest x-rays and abdominal x-rays.

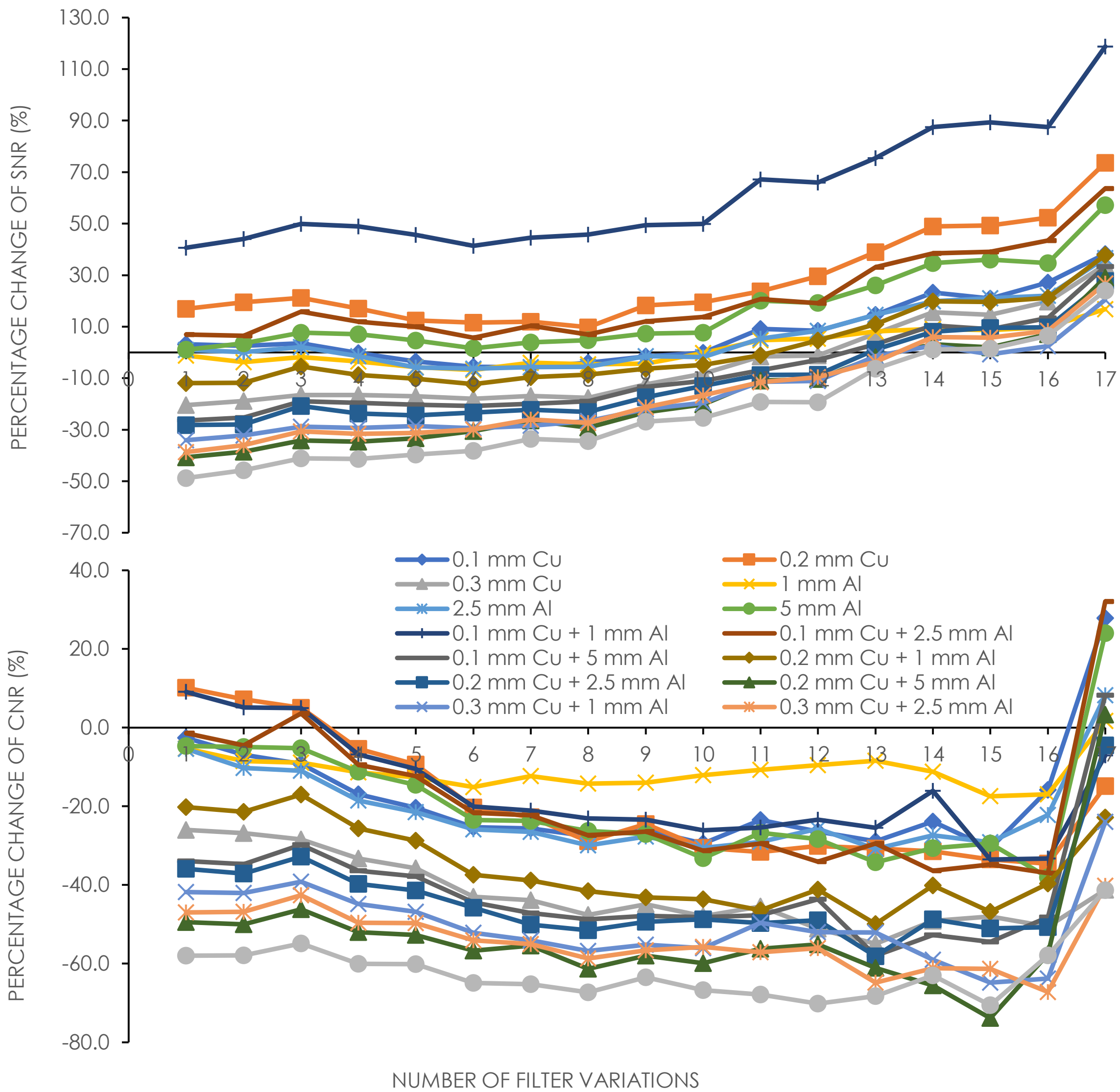


Figure 7 The percentage change in SNR and CNR based on filter combinations compared to the image without filters in high contrast imaging

The recommended filter for high contrast imaging is 0.1 mm Cu and 1 mm Al. It can increase the SNR value by 52.7% and the dose decreases by 55.4%, but it may reduce CNR by 6.7%. A radiograph with high contrast would give an image that has a large difference in brightness between adjacent areas or structures within the body. This condition allows for clear differentiation of the different types of tissue or structures within the image. An example of a radiograph with high contrast would be a dental x-ray, where the bright white of the teeth contrasts sharply with the darker areas of the gums and bones. Another example for high contrast radiograph is a bone x-ray, where the dense bone tissue appears bright white and stands out clearly from the surrounding soft tissues. Based on the obtained data, it can be concluded that the recommended filter combinations based on SNR and CNR values can be seen in Table 2.

Table 2 The recommendation for filter combination based on the obtained SNR, CNR, and dose value

The recommendation for filter combination based on SNR values in low contrast			
No.	**Filter Combination**	**SNR Increase (%)**	**Dose Decline (%)**
1.	5 mm Al	41.3	65.4
2.	0.2 mm Cu	34.6	41.2
3.	0.1 mm Cu + 1 mm Al	30.3	55.4
The recommendation for filter combination based on CNR values in low contrast			
No.	**Filter Combination**	**CNR Decline (%)**	**Dose Decline (%)**
1.	1 mm Al	20.3	23.2
2.	2.5 mm Al	29.2	44.8
3.	0.1 mm Cu	30.3	46.0
The recommendation for filter combination based on SNR values in high contrast			
No.	**Filter Combination**	**SNR Increase (%)**	**Dose Decline (%)**
1.	0.1 mm Cu + 1 mm Al	52.7	55.4
2.	0.2 mm Cu	21.6	66.7
3.	0.1 mm Cu + 2.5 mm Al	14.6	65.4
The recommendation for filter combination based on CNR values in high contrast			
No.	**Filter Combination**	**CNR Decline (%)**	**Dose Decline (%)**
1.	0.1 mm Cu + 1 mm Al	6.7	55.4
2.	0.2 mm Cu	7.2	66.7
3.	1 mm Al	10.1	23.2

From Table 2, it can be concluded that for the objects that use high contrast imaging, such as extremity organs that only show bones and soft tissues, the recommended filter combination is 0.1 mm Cu + 1 mm Al. With this filter combination, the SNR value can increase by 52.7%. It shows that the noise in the image is significantly reduced, meanwhile the CNR value only decreases by around 6.7%, and it can also reduce the patient dose by 55.4%. Meanwhile, for low contrast imaging, such as imaging of thoracic and abdominal organs that require details on low contrast, the recommended filter is 5 mm Al, where the SNR value increases by 41.3%. it will reduce the noise in the image significantly, and it can also reduce the dose by 65.4%.

4.0 CONCLUSION

Filtration plays a critical role in image quality and reducing patient radiation exposure in x-ray medical imaging. In this study Al and Cu filters were used to observe the optimum combination for giving good image quality and reducing the dose. It is important to balance the trade-off between patient dose and image quality in X-ray medical imaging. In this study, the analysis of correlation between filter combination with the image quality as well as the dose that received by patient was carried out. By using TOR CDR Phantom as the object and the exposure factor of that used are 70 kV and 5 mAs, the optimum filters combination was observed. For low contrast imaging a 5 mm Al filter is recommended, where it increases the SNR value by 41.3%, the dose decreases by 65.4%, but it may reduce the contrast by 31.7%. Meanwhile, for the high contrast imaging the recommended filter variation is 0.1 mm Cu and 1 mm Al. It can increase the SNR value by 52.7%, the dose decreases by 55.4%, but it may reduce CNR by 6.7%.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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