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Metaheuristic Analysis of Silicone Rubber Eyeshield on CT Image Quality in Head CT Examination

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Abstract The eye lens is one of the most radiosensitive organs during head computed tomography (CT) examinations. Eyeshields can reduce lens dose, but they attenuate X-rays and may degrade image quality, so their effect on quantitative image quality parameters requires further investigation. This study evaluated the effect of RTV48 silicone rubber eyeshields of different thicknesses on CT image quality and identified the thickness that best preserves diagnostic quality. A water phantom with an acrylic insert was scanned without an eyeshield, with a 1 cm eyeshield, and with a 1.5 cm eyeshield. Acquisitions used a constant tube voltage of 80 kV and tube current-time products of 70, 120, and 170 mAs. Image quality was assessed quantitatively using signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) from ten image slices per condition. Statistical analysis used the Kruskal–Wallis test followed by Dunn's post hoc test at a significance level of $p < 0.05$. Increasing mAs generally improved SNR and CNR in all conditions, whereas the eyeshields reduced both parameters through photon attenuation, with larger reductions at greater thickness. Most SNR differences between the no-eyeshield and eyeshield conditions were not statistically significant ($p > 0.05$), except for the 1.5 cm eyeshield at 120 mAs ($p = 0.008$). In contrast, all CNR comparisons differed significantly ($p < 0.05$), indicating that eyeshields affect image contrast more strongly than noise characteristics. The 1 cm eyeshield preserved image quality better than the 1.5 cm eyeshield. These findings show that RTV48 silicone rubber eyeshields mainly degrade CT image quality through reduced CNR rather than SNR, and that a 1 cm thickness offers the best balance between image quality preservation and lens shielding.

Keywords: Eyeshield, Silicone Rubber, SNR, CNR, computed tomography, Water Phantom, image quality.

I. Introduction

Radiation-based medical imaging plays an important role in diagnostic healthcare, although the use of ionizing radiation requires appropriate consideration of radiation risks. Radiation-based medical imaging plays an important role in diagnostic healthcare, although the use of ionizing radiation requires appropriate consideration of radiation risks[1]. One of the most widely used radiation-based technologies in diagnostic radiology is X-ray imaging, including computed tomography (CT), which provides detailed information about internal anatomical structures[1] [2]. The utilization of X-rays continues to develop across various medical imaging modalities, including Computed Tomography (CT), CT is also an important modality for low-contrast imaging, and its image quality is influenced by acquisition and reconstruction parameters[2]. Radiodiagnostic examinations such as X-ray and head CT are widely used to detect abnormalities in bone structures, soft tissues, and organs in the head area[3]. Advances in CT image quality and acquisition time efficiency have significantly increased its use, making CT one of the main sources of diagnostic radiation exposure [4].

Despite providing substantial diagnostic benefits, the use of ionizing radiation in head CT examinations requires attention to radiation safety, particularly for radiosensitive organs such as the eye lens[3][5]. The eye lens is highly sensitive to ionizing radiation, and radiation exposure has been associated with radiation-induced cataract formation[6][7]. Therefore, optimization of radiation protection during head examinations is important to minimize radiation dose to the eye lens without compromising diagnostic image quality. One approach for protecting the eye lens from radiation exposure is the use of an eyeshield placed over the orbital region during radiological examinations[8][9]. Although lead-based shielding provides high attenuation, its weight and potential toxicity have encouraged the development of alternative lead-free and flexible shielding materials[6][10]. The eyeshield functions to reduce the intensity of radiation reaching the eye lens through the attenuation mechanism. Protective materials made of lead (Pb) are known to have excellent radiation attenuation capabilities; however, they possess several limitations, including toxicity to the body and environment, relatively high weight, and limited user comfort[11]. These limitations encourage the development of alternative shielding materials that are effective, safe, flexible, and capable of maintaining diagnostic image quality.

Silicone rubber has attracted attention as an alternative material for radiation shielding because of its flexibility and suitability for fabrication into conformable protective devices. Previous studies have investigated silicone-rubber-based materials and polymer composites for radiation protection applications[12][13][14]. These characteristics make silicone rubber a promising material for eyeshield development in radiological examinations. Several studies have investigated methods for reducing

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eye-lens exposure during medical imaging. These approaches include tube-current modulation and physical shielding materials such as tungsten and other radiation-attenuating composites[15][16]. Studies have shown that shielding can reduce radiation dose to the eye lens, although it may also influence CT number, image noise, and image quality [17][16]. Previous studies have demonstrated that these methods can reduce radiation dose to the eye lens; however, the use of shielding materials may also influence image quality due to increased attenuation and image artifacts[18] [19].

In addition to radiation dose evaluation, radiographic image quality is an important parameter in assessing the effectiveness of radiation shielding materials. Image quality is commonly evaluated using quantitative parameters such as Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR), which describe the relationship between signal, contrast, and image noise. In addition to radiation dose evaluation, radiographic image quality is an important parameter for assessing the effectiveness of radiation shielding materials. Quantitative CT image quality can be evaluated using parameters such as Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR), which provide information about signal strength, contrast, and image noise[20][21]. High SNR and CNR values indicate better image quality, whereas the use of shielding materials has the potential to alter radiation intensity distribution and consequently affect these parameters[18][22]. Therefore, image quality assessment is essential to ensure that radiation protection can be achieved without significantly compromising diagnostic performance.

Several studies have investigated eye protection methods during head CT examinations to reduce radiation exposure to the eye lens while maintaining diagnostic image quality. Lee et al. reported that eye shields reduced lens radiation dose but could also produce image artifacts and affect orbital image quality [18]. Similarly, Kosaka et al. demonstrated that tungsten functional paper combined with organ-based tube current modulation could reduce eye-lens dose while maintaining image quality under appropriate conditions[16]. Wulandari et al. developed a silicon-rubber-based eye shield containing lead and evaluated its effect on eye-lens dose and image quality during head CT examinations[23]. Other studies have also demonstrated the potential of flexible polymer-based materials for radiation shielding applications[13][14][24]. However, most previous studies have focused primarily on radiation dose reduction, attenuation characteristics, or composite materials containing metallic fillers such as bismuth, tungsten, lead, graphite, or aluminum oxide. Quantitative investigations evaluating the influence of pure RTV48 silicone rubber shielding on CT image quality remain limited, particularly with respect to different shield thicknesses. Therefore, a clear knowledge gap remains regarding how variations in the thickness of pure RTV48 silicone rubber eyeshields affect image quality parameters such as Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) in head CT examinations. The novelty of this study lies in the use of pure RTV48 silicone rubber as an eyeshield material without the addition of metallic fillers and in the quantitative evaluation of image quality based on SNR and CNR at different shield thicknesses. This approach provides important information for determining the optimal balance between radiation protection effectiveness and preservation of diagnostic image quality.

The contributions of this study are: (1) Developing a silicone rubber-based eyeshield as an alternative for protecting the eyes during head examinations. (2) Evaluating the effect of using a silicone rubber-based eyeshield on radiographic image quality using the Signal-to-Noise Ratio (SNR) parameter. (3) Evaluating the effect of using silicone rubber-based eyeshields on radiographic image quality using the Contrast-to-Noise Ratio (CNR) parameter. (4) Providing recommendations regarding the use of silicone rubber materials that are more flexible and comfortable to use, thereby improving patient comfort during head examination procedures.

This study is organized as follows. Section II describes the research methodology, including the materials and fabrication of the silicone rubber-based eyeshield, the experimental design, and computed tomography (CT) scans using a water phantom with variations in eyeshield thickness and mAs parameters. Section III presents the research results, including Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) values in CTi images with and without the silicone eyeshield. Section IV discusses the effects of eyeshield thickness and mAs on image quality based on the measurement results and statistical analyses, and compares them with previous studies. Section V presents the research conclusions, summarizes the main findings, explains how the research objectives were achieved, outlines the study's limitations, and provides recommendations for future research.

II. Materials and Method

A. Materials and Fabrication of The Silicone Rubber Eyeshield

The eye protectors were made using RTV48 silicone rubber, which was chosen for its flexibility, moldability, and ability to conform to the contours of the phantom's surface. The eye protectors were made in two thickness variations, namely 1 cm and 1.5 cm, using mica molds measuring 64 × 5 × 1 cm and 64 × 5 × 1.5 cm. The silicone rubber and catalyst were mixed in a 25:1 ratio, following a previously reported silicone-rubber fabrication approach[25]. For the 1.5 cm-thick sample, approximately 500 g of silicone rubber was used, while the amount of material for the 1 cm sample was adjusted proportionally to the mold volume. The mixture was stirred gently until homogeneous to prevent the formation of excessive air bubbles, then poured gradually into the mold. The curing process was conducted at room temperature for 24 hours until the material fully hardened. Based on the mold dimensions and the mass of material used, the density of the eye

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shield was estimated at approximately 1.15 g/cm³.

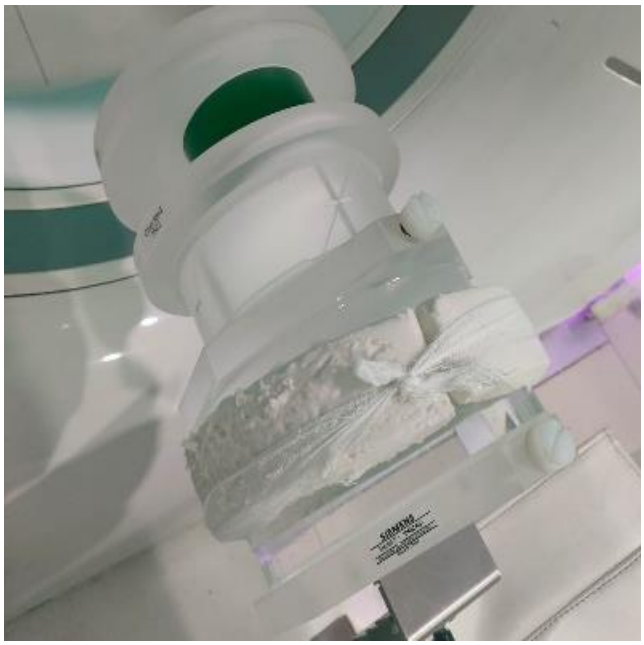


Fig. 1. Fabricated eyeshield and its positioning on the phantom during imaging acquisition.

After the curing process is complete, the eye protectors were removed from the mold and visually inspected to ensure uniform thickness, a smooth surface, and the absence of air bubbles or visible surface defects. Efforts to minimize air bubbles were made during the mixing and molding processes, as air pockets within the material could potentially cause variations in X-ray attenuation. The inspection results showed no surface defects or air bubbles. The eye shield is designed to be elongated to fit the phantom area and ensure optimal protection coverage during radiographic examinations, so that the protective material is distributed more evenly over areas at risk of radiation exposure.

B. Experimental Setup and Imaging Procedure

Imaging was performed using a Siemens SOMATOM Perspective CT scanner (Siemens Healthineers, Germany) equipped with a solid-state multibar detector system. A water phantom with an acrylic insert was used, with the insert placed at the center of the phantom as the test object.

Scanning was carried out under three conditions: without an eyeshield, with a 1 cm thick RTV48 silicone rubber eyeshield, and with a 1.5 cm thick RTV48 eyeshield. All scans were performed at a constant tube voltage of 80 kV with tube current-time products of 70, 120, and 170 mAs.The phantom was positioned at the scanner isocenter with a source-to-isocenter distance of 53.5 cm, a 50 cm field of view (FOV), and a pitch of 0.35–1.5. Region of interest (ROI) analysis was performed by defining two areas: the object ROI located on the acrylic insert and the background ROI placed in the surrounding area. The ROI size was kept constant across all images to ensure consistency, and automated positioning was used to maintain uniform placement across all slices. Mean and standard deviation values were extracted from each ROI and used to calculate the Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR). Each condition was analyzed using 10 image slices to improve data reliability. Statistical analysis was performed using the Kruskal–Wallis test followed by Dunn's post hoc test, with a significance level of $p < 0.05$.



(a) (b) (c)

Fig. 2. Phantom irradiation testing: (a) phantom irradiation without eyeshield, (b) phantom irradiation with 1 cm eyeshield (c) phantom irradiation with 1,5 cm eyeshield

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Table 1 Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) of head CT images using silicone rubber eyeshields at various thicknesses and mAs values

Condition	kV	mAs	SNR	CNR
No shield	80	70	16.422 ± 4.037	6.059 ± 0.692
No shield	80	120	20.830 ± 6.668	8.372 ± 0.246
No shield	80	170	25.711 ± 10.073	9.999 ± 0.401
1 cm shield	80	70	12.892 ± 2.166	4.321 ± 0.304
1 cm shield	80	120	15.170 ± 4.529	5.699 ± 0.701
1 cm shield	80	170	21.907 ± 5.603	6.664 ± 0.356
1,5 cm shield	80	70	12.870 ± 1.905	3.893 ± 0.222
1,5 cm shield	80	120	12.090 ± 3.814	3.658 ± 1.341
1,5 cm shield	80	170	19.404 ± 7.730	5.695 ± 0.876

C. Theoretical Background

X-rays are ionizing radiation widely used in diagnostic radiology due to their ability to penetrate body tissues and produce images based on differences in material attenuation. In head examinations, X-rays interact with tissues through absorption and scattering, generating image information for medical diagnosis. However, this process also has the potential to expose sensitive organs near the imaging area to radiation, as these organs are highly sensitive to ionizing radiation[26][27]. Eyeshields made from protective materials typically use high-density materials such as lead; however, their use is limited by the material's toxicity and weight[28]. Recent research is focused on the development of non-lead composite-based materials, including the use of polymers such as silicone rubber combined with specific fillers to enhance radiation attenuation characteristics while maintaining flexibility and comfort during use[29][13].

In addition to protection, radiographic image quality is also a key parameter in evaluating imaging results. Image quality is affected by noise resulting from the interaction between radiation and the detection system. Noise refers to random fluctuations in pixel intensity that do not represent actual anatomical structures and can reduce the diagnostic quality of the image[30]. Therefore, quantitative parameters are needed for image quality evaluation, namely the Signal-to-Noise Ratio (SNR) and the Contrast-to-Noise Ratio (CNR)[31]. The SNR parameter is expressed in Eq. (1) as follows[32]:

$$\mathrm{SNR} = \left| \frac{object\ mean\ value}{noise\ standard\ deviation} \right| \quad (1)$$

The Signal-to-Noise Ratio (SNR) is a parameter that indicates the ratio of the main signal to the noise in a region of interest (ROI)[33].

The CNR parameter is expressed in Eq. (2) as follows[34]:

$$\mathrm{CNR} = \left| \frac{mean\ object\ ROI - mean\ background\ ROI}{background\ standard\ deviation} \right| \quad (2)$$

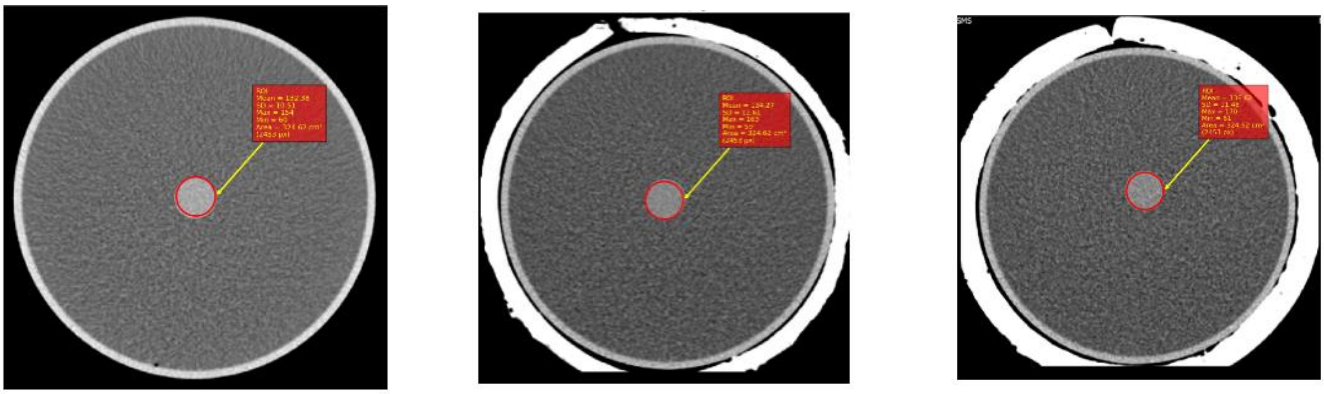
The Contrast-to-Noise Ratio (CNR) indicates an image's ability to distinguish objects from their background[30].

III. RESULTS

Fig. 1 shows the design of this device, namely an eye shield used during head examinations with a water phantom, as an effort to reduce radiation exposure in the area corresponding to the width of the eye shield. This eye shield was made by thoroughly mixing RTV48 silicone rubber with a catalyst, then pouring it into a mica mold according to the designed dimensions. Fig. 2 shows the testing of the eye shield during head examinations using a water phantom under three conditions: without an eye shield, using a 1 cm eye shield, and using a 1.5 cm eye shield. Exposures were performed 9 times with three different mAs variations 70 mAs, 120 mAs, and 170 mAs and a single kV setting of 80 kV.

Table 1 presents the SNR and CNR results obtained from the average of 10 image slices for each condition at 80 kV, with varying mAs values (70, 120, and 170) and eye shield thicknesses (no shield, 1 cm, and 1.5 cm). In general, these results indicate that mAs values and eye shield thickness consistently affect image quality. A clear upward trend is observed in both SNR and CNR as mAs increases across all conditions. Under the no-shielding condition, SNR increased from 16.422 at 70 mAs to 20.830 at 120 mAs and 25.711 at 170 mAs, representing an approximate 56% increase from 70 to 170 mAs. A similar pattern is also observed in the CNR, which increased from 6.059 to 9.999, an increase of approximately 65%, indicating improved image quality at higher mAs values. Conversely, the use of an eyeshield resulted in a consistent decrease in SNR and CNR at all mAs levels. At 70 mAs, the SNR value decreased to 12.892 at a thickness of 1 cm and 12.870 at a thickness of 1.5 cm. This indicates a decrease of approximately 21% for the 1 cm eyeshield and 22% for the 1.5 cm eyeshield compared with no shield. The CNR experienced a greater decrease, namely 4.321 at a thickness of 1 cm and 3.893 at a thickness of 1.5 cm. This indicates a reduction of approximately 29% for the 1 cm eyeshield and 36% for the 1.5 cm eyeshield compared to no shielding, demonstrating that the eyeshield has a greater impact on image contrast quality, as shown in Fig. 3.

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(a) (b) (c)

Fig. 3. Phantom image results: (a) 80 kV, 70 mAs no eyeshield (b) 80 kV, 70 mAs 1 cm eyeshield (c) 80 kV, 70 mAs 1,5 cm eyeshield

At 120 mAs, the same pattern persists, with SNR decreasing to 15.170 at a thickness of 1 cm and 12.090 at a thickness of 1.5 cm. This indicates a decrease of approximately 27% for the 1 cm eyeshield and 42% for the 1.5 cm eyeshield compared to no shield. CNR experienced a greater decrease, namely 5.699 at a thickness of 1 cm and 3.658 at a thickness of 1.5 cm. This indicates a decrease of approximately 32% for the 1 cm eyeshield and 56% for the 1.5 cm eyeshield compared to without protection. Although there was a decrease due to the eyeshield, the increase in mAs was still able to improve image quality compared to the 70 mAs condition, as shown in Fig. 4.

At 170 mAs, the decrease in SNR due to the eyeshield was 21.907 for a thickness of 1 cm and 19.404 for a thickness of 1.5 cm. This indicates a decrease of approximately 15% for a 1-cm-thick eyeshield and 25% for a 1.5-cm-thick eyeshield compared to without a shield. Meanwhile, the decrease in CNR due to the eyeshield was 6.664 at a thickness of 1 cm and 5.695 at a thickness of 1.5 cm. This indicates a decrease of approximately 33% for a 1 cm thick eyeshield and 43% for a 1.5 cm thick eyeshield compared to without a shield. The magnitude of this reduction is smaller compared to low mAs values, indicating that at high mAs, the quality-reducing effect of the eyeshield becomes relatively smaller, as shown in Fig. 5. Overall, increasing mAs improves image quality through increased SNR and CNR, whereas increasing eyeshield thickness consistently reduces image quality. The significant reduction in CNR, particularly with thicker eyeshields, indicates a clinically relevant impact on contrast reduction that may affect the visibility of fine structures in diagnostic imaging.

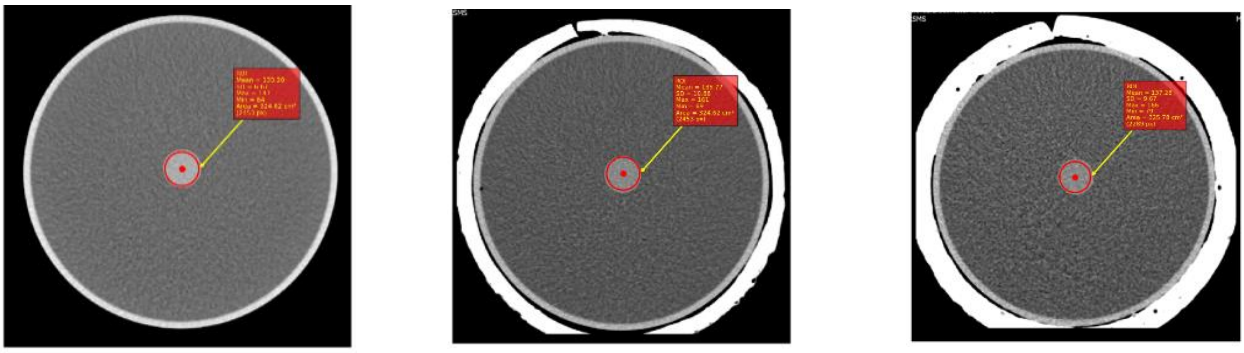
Table 2. Results of Kruskal–Wallis test for SNR and CNR values at different eyeshield conditions

Parameter	mAs	H	p value
SNR	70	4.9396	0.08460105
SNR	120	9.1587	0.01026151
SNR	170	3.0566	0.21690933
CNR	70	20.6047	0.00003355
CNR	120	25.3006	0.00000321
CNR	170	21.9818	0.00001685

To evaluate the statistical significance of differences in image quality across conditions, a normality test was first performed on the SNR and CNR data obtained from 10 image slices for each condition. Since the data did not fully satisfy the assumption of a normal distribution, nonparametric statistical analysis was used. The Kruskal–Wallis test was used to determine the presence of overall differences in SNR and CNR values between mAs variations (70, 120, and 170) and phantom conditions (no shielding, 1 cm, and 1.5 cm). If significant differences were found, a Dunn post hoc test was performed to compare pairs of conditions, namely between no shielding vs. 1 cm and no shielding vs. 1.5 cm for the SNR and CNR parameters. The results of the statistical tests for the SNR and CNR values are presented in Table 2 and Table 3.

In Table 2. the results of the Kruskal–Wallis test indicate that there are varying differences in SNR and CNR values across mAs conditions and the use of an eyeshield. For the SNR parameter, a significant difference was found only at the 120 mAs condition ($H = 9.1587$; $p = 0.0103$), whereas at 70 mAs ($p = 0.0846$) and 170 mAs ($p = 0.2169$) no significant differences were observed ($p > 0.05$). Conversely, for the CNR parameter, all mAs conditions showed highly significant differences. The H values obtained at 70 mAs ($H = 20.6047$; $p = 0.00003355$), 120 mAs ($H = 25.3006$; $p = 0.00000321$), and 170 mAs ($H = 21.9818$; $p = 0.00001685$) indicate that there is a significant effect of condition differences on the CNR value ($p < 0.05$). In general, these results indicate that the CNR parameter is more sensitive to changes in conditions than SNR, as it shows consistently significant differences across all mAs variations, whereas SNR only shows significant differences under specific conditions.

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(a) (b) (c)

Fig. 4. Phantom image results: (a) 80 kV, 120 mAs no eyeshield (b) 80 kV, 120 mAs 1 cm eyeshield (c) 80 kV, 120 mAs 1.5 cm eyeshield

Table 3. Pairwise statistical comparison of SNR values between no eyeshield and eyeshield conditions using dunn's post hoc test

Parameter	mAs	Comparison	p value	Significance
SNR	70	no eyeshield vs 1 cm eyeshield	0.170	not significant
SNR	70	no shield vs 1.5 cm eyeshield	0.155	not significant
SNR	120	no eyeshield vs 1 cm eyeshield	0.142	not significant
SNR	120	no shield vs 1.5 cm eyeshield	0.008	significant
SNR	170	no eyeshield vs 1 cm eyeshield	1.000	not significant
SNR	170	no shield vs 1.5 cm eyeshield	0.274	not significant

In Table 3, the results of the Dunn post hoc test show that, for the SNR parameter, most comparisons between conditions did not reveal significant differences. At 70 mAs, no significant differences were found between the no eyeshield vs. 1 cm eyeshield condition ($p = 0.170$) or the no shield vs. 1.5 cm eyeshield condition ($p = 0.155$). A similar pattern was also found at 120 mAs for the comparison of no eyeshield vs. 1 cm eyeshield ($p = 0.142$), as well as at 170 mAs for both comparisons ($p = 1.000$ and $p = 0.274$). The only significant difference in SNR was found at 120 mAs for the comparison of no shield vs. 1.5 cm eyeshield, with $p = 0.008$. Conversely, for the CNR parameter, all comparisons showed significant results. At 70 mAs, both the no-eyeshield vs. 1 cm eyeshield comparison yielded $p = 0.044$, and the no-eyeshield vs. 1.5 cm eyeshield comparison yielded $p < 0.001$, indicating significant differences. The same pattern was also observed at mAs 120 and 170, where all comparisons between eyeshield conditions showed significant differences with $p < 0.05$, with a very small p-value in the comparison between no shield and 1.5 cm eyeshield, namely $p \leq 0.000017$, as shown in Table 4.

Overall, these results indicate that the effect of eyeshield use on SNR is not statistically consistent, whereas CNR shows significant and consistent differences across all conditions, suggesting that CNR is more sensitive to changes in conditions than SNR.

As an additional analysis of the data distribution, boxplots of the SNR and CNR were visualized for each mAs variation to examine the overall distribution, median, and variability of the data, as shown in Fig 6. In the SNR boxplots, all three conditions showed significant overlap between the boxes across all mAs variations, particularly at 170 mAs, where the No Shield IQR was very wide, approximately 20–35, and the Shield 1 cm whiskers still extended into the No Shield value range. This reflects high SNR data variability between images, which is one reason why differences between conditions are difficult to detect statistically. In the CNR boxplot, a different pattern is observed, where the three boxes for each mAs variation show clear separation without significant overlap. No Shield consistently ranks highest with a narrow IQR, followed by Shield 1 cm in the middle, and Shield 1.5 cm at the lowest position.

IV. Discussion

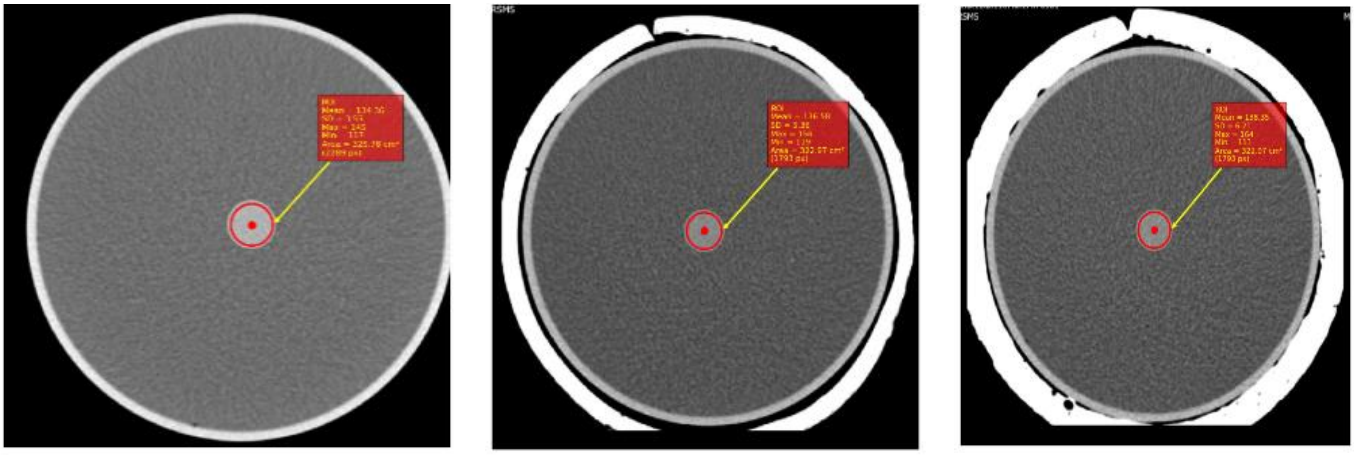
The results of this study indicate that SNR and CNR values are influenced by two main factors: variations in mAs and eyeshield thickness. These two factors act in opposite directions: an increase in mAs tends to increase SNR and CNR values, while an increase in eyeshield thickness tends to decrease SNR and CNR values.

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The effect of eyeshield thickness is clearly evident from a comparison of the different conditions. For every mAs variation, the 1.5 cm eyeshield consistently produced lower SNR and CNR values compared to the 1 cm eyeshield, and the 1 cm eyeshield consistently produced lower values compared to the condition without an eyeshield.

not reached a point that could alter the clinical interpretation of the image.

Under the 1.5 cm eyeshield condition, the decrease in SNR and CNR values was greater than that under the 1 cm condition. The reduction in SNR was statistically significant only at 120 mAs ($p = 0.008$), whereas the



(a) (b) (c)

Fig. 5. Phantom image results: (a) 80 kV, 170 mAs no eyeshield (b) 80 kV, 170 mAs 1 cm eyeshield (c) 80 kV, 170 mAs 1,5 cm eyeshield

This is consistent with the principle that the thicker the protective material, the greater its ability to attenuate photons, but simultaneously, the greater its impact on increasing image noise. At an eyeshield thickness of 1 cm, SNR and CNR decreased across all mAs variations compared with the condition without an eyeshield. Nevertheless, the pattern of increase with rising mAs remained consistent. Statistically, this decrease is not significant; the p-value for SNR is 0.129, indicating that the p-value is >0.05, meaning there is no significant decrease in image quality. The p-value for CNR is 0.077, indicating that the p-value is >0.05, signifying that image quality does not decrease significantly compared to the condition without an eyeshield. This means that, mathematically, the values do decrease, but the decrease is not large enough to be considered a change in the image. This indicates that the attenuation produced by a thickness of 1 cm has

reduction in CNR was significant at all mAs levels ($p < 0.05$) compared with the condition without an eyeshield. Under this condition, CNR values were 3.893, 3.658, and 5.695 at 70, 120, and 170 mAs, respectively, corresponding to reductions of approximately 36%, 56%, and 43% relative to no shielding. Additionally, a non-linear pattern was observed in the SNR values, specifically a decrease from 12.870 at 70 mAs to 12.090 at 120 mAs before rising again to 19.404 at 170 mAs. This pattern was not observed under the other conditions and suggests that, at a thickness of 1.5 cm, the silicone rubber material begins to interact more complexly with the X-ray beam, resulting in a less stable distribution of photons reaching the detector at low to medium mAs values. At 170 mAs, a sufficiently large number of photons is able to compensate for this effect, causing the SNR value to increase again.

Table 4. Pairwise statistical comparison of CNR values between no eyeshield and eyeshield conditions using dunn's post hoc test

Parameter	mAs	Comparison	p value	Significance
CNR	70	no eyeshield vs 1 cm eyeshield	0.044	significant
CNR	70	no shield vs 1.5 cm eyeshield	0.000017	significant
CNR	120	no eyeshield vs 1 cm eyeshield	0.028	significant
CNR	120	no shield vs 1.5 cm eyeshield	0.000001	significant
CNR	170	no eyeshield vs 1 cm eyeshield	0.009	significant
CNR	170	no shield vs 1.5 cm eyeshield	0.000012	significant

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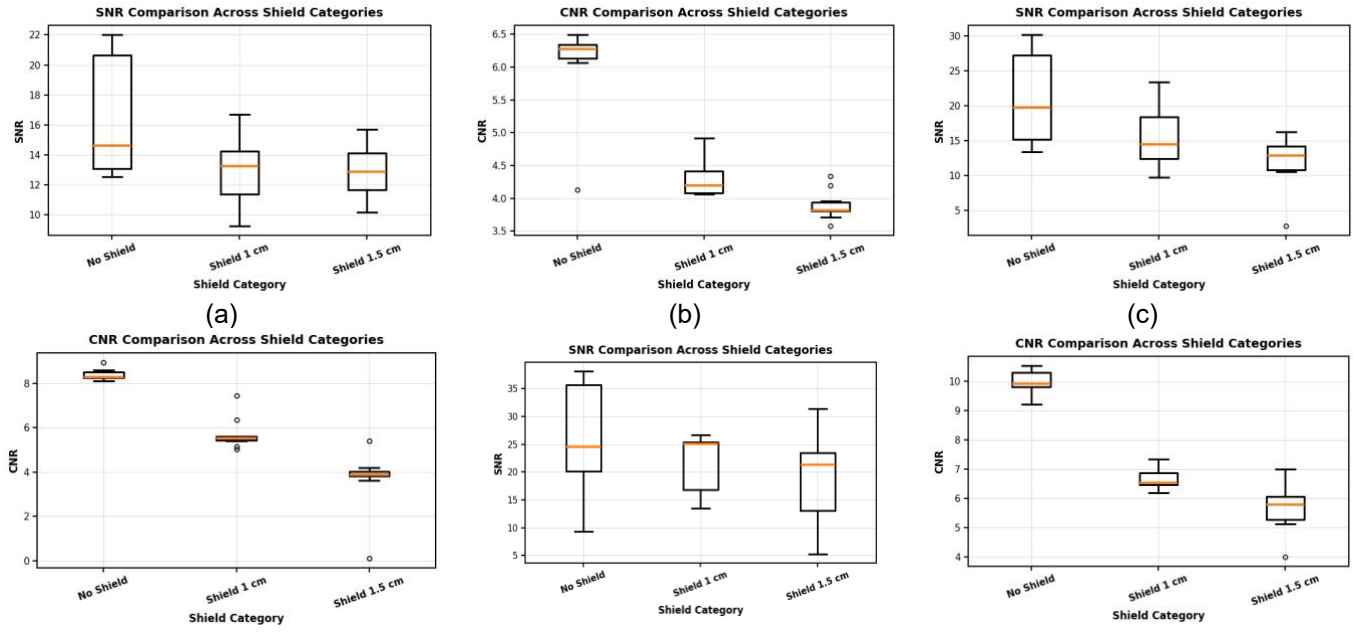


Fig. 6. Boxplot comparison of SNR and CNR across eyeshield conditions at 80 kV: (a) SNR at 70 mAs, (b) CNR at 70 mAs, (c) SNR at 120 mAs, (d) CNR at 120 mAs, (e) SNR at 170 mAs, (f) CNR at 170 mAs.

The results of this study indicate that the SNR and CNR values are influenced by two main factors: variations in mAs and eyeshield thickness. These factors have opposite effects: increasing mAs consistently improves SNR and CNR, whereas increasing eyeshield thickness decreases both parameters. Increasing mAs from 70 to 170 resulted in an increase in SNR and CNR under all eyeshield conditions. This increase occurs because the number of photons reaching the detector increases, thereby enhancing the received signal, while the relative contribution of noise becomes lower. This pattern indicates that mAs is the dominant factor in improving image quality, as evidenced by the consistent upward trend in SNR and CNR across all groups. Conversely, the use of an eyeshield demonstrates a thickness-dependent reduction in image quality. Based on the Kruskal-Wallis test and Dunn's post hoc analysis, the reduction in SNR was not always statistically significant, with most comparisons yielding p-values > 0.05. This indicates that the change in SNR resulting from the use of an eyeshield is not statistically significant under certain conditions. In contrast to SNR, the CNR parameter yields more consistent results. Dunn's post hoc test showed that most comparisons between the no-eyeshield and eyeshield conditions, whether 1 cm or 1.5 cm, resulted in significant differences ($p < 0.05$). This indicates that CNR is more sensitive to changes in eyeshield thickness than SNR, particularly in depicting contrast changes between tissues. This significant decrease in CNR indicates that the eyeshield provides an attenuation effect that impacts the system's ability to distinguish contrast between the object and the background. Clinically, this can affect the visibility of fine structures, although an increase in mAs can partially compensate for this reduction. Furthermore, although there is a difference in thickness between the 1 cm and 1.5 cm eyeshields, statistical test results show that this difference is not always significant, indicating that the primary effect on image quality degradation is more pronounced when compared to conditions without a shield. Overall, these results demonstrate that mAs plays a primary role in improving image quality, whereas the eyeshield contributes to a decrease in image quality, particularly in the CNR parameter, which is more sensitive to changes in contrast. These findings confirm the existence of a trade-off between radiation protection and image quality that must be considered in clinical applications.

The boxplot analysis in Fig. 6 provides a visual representation that supports these statistical results. For SNR, the distributions overlap across the three conditions, particularly at low to medium mAs, indicating high variability between slices. This explains why most of the differences in SNR are not statistically significant, as the distributions across groups are not consistently distinct. Although a tendency toward median separation is observed at high mAs 170 mAs, overlap between the whiskers still occurs, so the differences are not always statistically robust. In contrast, the CNR boxplots show a clearer and more consistent separation pattern between the no-eyeshield, 1 cm, and 1.5 cm conditions across all mAs values. The median CNR in the no-eyeshield condition is consistently higher, with an interquartile range that shows relatively little overlap with the eyeshield conditions, particularly at 1.5 cm. This pattern is consistent with the results of the Kruskal-Wallis and Dunn tests, which showed strong statistical significance in most CNR comparisons. Overall, the integration of numerical results, statistical analysis, and boxplot visualization indicates that mAs plays a role in improving image quality by increasing SNR and CNR, whereas the eyeshield has

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Table 5. Comparison of the present study with previous studies

Author	Modality/Material	Parameter/Focus	Main Findings	Comparison with Present Study
Zahroh et al. [35]	Digital radiography; SR-Pb	SNR and CNR	No significant changes in SNR and CNR compared with images without shielding.	Similar evaluation using SNR and CNR; the present study used pure RTV48 silicone rubber without lead.
Ying et al. [17]	CT; shielding material	CT number, noise, and dose	Shield thickness affected CT number and image noise.	Consistent with the effect of shield thickness on SNR and CNR in the present study.
Amin et al. [36]	CT; shielding material	Image quality and dose	Shielding influenced image quality and radiation exposure.	Supports evaluating shielding together with image-quality effects.
Anam et al. [37]	CT phantom	CNR; tube current	Increasing tube current increased CNR.	Supports the observed increase in CNR with increasing exposure parameters.
Okda et al. [24]	Polymer–$BaSO_4$ composite	Shield thickness and attenuation	Greater thickness produced greater attenuation.	Consistent with greater SNR/CNR reduction at 1.5 cm compared with 1 cm.
Yoshida et al. [15]	CBCT; bismuth eye shield	Eye-lens dose	Eye shielding reduced crystalline-lens exposure.	The present study focused on CT image quality rather than direct eye-lens dosimetry.
Larjava et al. [38]	CT; shielding	Dose distribution and image quality	Shielding may alter dose distribution and imaging conditions.	Supports evaluating both protection and image quality.

a more dominant negative effect on image quality as measured by the CNR parameter. These findings indicate a trade-off between radiation protection and image quality, where increasing the thickness of the eyeshield enhances protection but potentially reduces the ability to detect clinically relevant fine structural contrasts.

A comparison between the present study and previous studies is summarized in Table 5. These findings are consistent with studies that evaluated the effect of shielding materials on radiographic image quality. Zahroh et al. evaluated the use of silicone rubber-lead (SR-Pb) as a gonad shield in digital radiography using SNR and CNR parameters and found that SNR and CNR did not show significant changes compared to reference images without a shield. The difference with this study lies in the material composition; SR-Pb contains 5% lead as an additional attenuation agent, whereas this study used pure silicone rubber without metal additives, so its attenuation capability depends entirely on the material's density. This explains the numerically detected decrease in SNR and CNR in this study[35][9]. A similar study conducted by Yulia et al. on computed radiography (CR) using SR-Pb as an additional filter also showed no significant difference in CNR and SNR values, with 5% SR-Pb capable of reducing the dose by approximately 50%. These findings support the argument that silicone rubber-based materials, with or without lead, can still maintain image quality at certain thicknesses[37].

Studies conducted by Ying et al. and Amin et al. found that the degree of change in CT number and noise is directly proportional to the thickness of the shield, and that a single-layer shield can reduce the surface dose by 7.2–15.5% with a decrease in CNR that remains within acceptable limits. A similar pattern was observed in this study, where a 1.5 cm eyeshield resulted in greater reductions in SNR and CNR of 22% and 36%, respectively, compared to a 1 cm eyeshield (21% and 29%) at 70 mAs, with the difference narrowing at 170 mAs to 15% vs. 25% for SNR, confirming that higher mAs values can compensate for the shield's attenuation effect [39][36]. Previous phantom studies have demonstrated that the use and positioning of shielding materials can

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influence CT image noise, CT number, and CNR [17][16]. Regarding improvements in SNR and CNR values, several studies have shown that increasing exposure parameters such as kVp and mAs consistently leads to higher SNR and CNR values and reduced noise, thereby improving image quality; this pattern has been demonstrated to hold true for both radiography and CT scans, including under various phantom conditions and when protective devices such as eyeshields are used [40][41]. In this study, the same phenomenon was observed, where variations in mAs values and the use of eyeshields of different thicknesses on a water phantom resulted in changes in SNR and CNR values measured experimentally. These findings indicate that SNR and CNR parameters can be used as quantitative indicators to evaluate image quality and assess the effect of shielding on image quality degradation due to radiation attenuation. Elkut et al. reported that in chest CT scans, increasing the mAs from 180 to 480 mAs resulted in an increase in SNR from 9 to 14.99 and CNR from 11 to 24.7, although this increase began to slow down after approximately 230 mAs [42]. These findings are consistent with the results of this study, in which an increase in mAs from 70 to 170 also improved SNR by approximately 56% (from 16.422 to 25.711) and CNR by approximately 65% (from 6.059 to 9.999). This suggests that increasing mAs can be a strategy to improve image quality when an eyeshield is used, although the improvement effect is not always linear at higher values. Anam et al. reported a 60% increase in CNR when the tube current increased from 80 to 200 mA in a CT phantom, comparable to the 65% increase observed in this study. They also confirmed no significant difference between manual and automatic ROI measurement methods ($p > 0.05$), supporting the validity of the measurement method used in this study [43]. Regarding the effect of shield thickness on image quality, these findings align with Okda et al., who showed that increasing the thickness of the polymer–$BaSO_4$ composite material consistently enhances radiation attenuation. Although SNR and CNR were not measured, that study reported that increasing the layer thickness to 1.53 mm could achieve 84.73% attenuation at 60 keV.

This pattern is consistent with this study, where increasing the eyeshield thickness from 1 cm to 1.5 cm consistently resulted in greater decreases in SNR and CNR. At 70 mAs, the SNR decreased by 21% (1 cm) and 22% (1.5 cm), respectively, while the CNR decreased by 29% and 36%. This trend indicates that the thicker the shield, the greater the attenuation effect, which results in a decrease in image quality[24]. The findings of this study can also be considered alongside the results reported by Yoshida et al., who evaluated the dose-reduction effect of a bismuth eye shield using an anthropomorphic phantom during cone-beam computed tomography[15]. Their study demonstrated that the use of an eye shield could reduce crystalline lens exposure, supporting the potential of eye shielding as a radiation protection strategy for radiosensitive ocular tissues. In contrast to their study, which primarily focused on radiation dose reduction, the present study focused on the effect of different RTV48 silicone rubber eyeshield thicknesses on quantitative CT image quality using SNR and CNR. Similarly, Larjava et al. emphasized that the use of shielding in CT examinations may produce unintended effects on patient dose distribution. This finding highlights the importance of evaluating shielding not only based on its potential to reduce radiation exposure but also based on its effects on the imaging conditions and resulting image quality[38]. Consistent with this consideration, the present study demonstrated that increasing eyeshield thickness from 1 cm to 1.5 cm produced a greater reduction in SNR and CNR. Therefore, the selection of shielding thickness should consider the balance between radiation protection and preservation of diagnostic image quality.

Although this study indicates that the use of a silicone rubber eyeshield affects image quality, statistical analysis reveals that this effect is not always significant, particularly for the SNR parameter, while CNR exhibits greater sensitivity to changes in shield thickness. Under most conditions, the 1 cm eyeshield did not produce a significant difference compared to the condition without a shield, whereas a more pronounced effect was observed with the 1.5 cm eyeshield, which tended to reduce image quality, particularly in terms of CNR. Several key limitations should be noted. The use of a water phantom does not fully represent clinical conditions because it does not reflect the complexity of human head anatomy and actual tissue variations. Additionally, the silicone rubber material used is still a base material without the addition of high-density materials, so its attenuation capability is lower compared to bismuth- or lead-based shielding materials. This study evaluated image quality using only SNR and CNR. Other image quality metrics, such as SSIM, PSNR, and MSE, were not included and may be considered in future studies involving image reconstruction or image processing approaches. Furthermore, this study did not perform direct measurements of radiation dose reduction in the eye lens, so the effectiveness of the eyeshield's protection cannot yet be quantitatively assessed. The evaluation was limited to image quality parameters SNR and CNR, so the radioprotection aspect cannot yet be fully confirmed.

Although this study has several limitations, the results still make an important contribution in showing that silicone rubber eyeshields can still be used without a significant reduction in image quality at a thickness of 1 cm, while increasing the thickness to 1.5 cm begins to show a more pronounced decline in image quality, particularly in terms of CNR. These findings suggest that 1 cm is a more optimal thickness for balancing protection and image quality. Furthermore, the silicone rubber eyeshield used in this study can serve as an initial prototype for the development of safer, lighter, and more flexible lead-free radiation protection materials. However, further research using anthropomorphic phantoms or clinical subjects, as well as direct dosimetry measurements on the eye lens, is needed to quantitatively confirm the effectiveness of protection under more realistic clinical conditions.

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V. Conclusion

This study aimed to evaluate the effect of RTV48 silicone rubber eyeshields with thicknesses of 1 cm and 1.5 cm on CT image quality in head examinations using a water phantom, and to identify the thickness that best preserves image quality. Without an eyeshield, increasing the tube current-time product from 70 to 170 mAs raised the SNR from 16.422 to 25.711 (approximately 56%) and the CNR from 6.059 to 9.999 (approximately 65%). The eyeshields reduced both parameters in a thickness-dependent manner. At 170 mAs, the 1 cm eyeshield lowered the SNR to 21.907 (approximately 15%) and the CNR to 6.664 (approximately 33%), whereas the 1.5 cm eyeshield lowered the SNR to 19.404 (approximately 25%) and the CNR to 5.695 (approximately 43%). Most SNR differences were not statistically significant ($p > 0.05$), except for the 1.5 cm eyeshield at 120 mAs ($p = 0.008$), whereas all CNR comparisons were significant ($p < 0.05$). Thus, CNR is more sensitive to eyeshield attenuation than SNR, and the 1 cm eyeshield offers the better balance between image quality preservation and shielding. These findings are limited by the use of a water phantom and the absence of direct lens dosimetry. Future work should therefore use anthropomorphic phantoms or clinical data, include direct eye lens dose measurements, and investigate higher-density fillers, such as bismuth, in the silicone matrix, together with additional image quality metrics.

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Author Contributions

Nasywa Alifia Hanum contributed to the conceptualization, methodology, data collection, image analysis, formal analysis, visualization, manuscript drafting, and manuscript revision. Dodi Zulherman contributed to methodology validation, supervision, manuscript review, and critical revision of the manuscript. Irmayatul Hikmah contributed to supervision, manuscript review, and final approval of the submitted manuscript. All authors have read and approved the final version of the manuscript.

Use of Generative AI and AI-Assisted Technologies in Writing

During the preparation of this manuscript, the authors used Claude (Anthropic) to assist with language editing, rewriting the abstract to meet the word limit, drafting the conclusion, and improving clarity and readability. All AI-assisted content was critically reviewed, verified, and revised by the authors, who take full responsibility for the scientific content, accuracy, references, data interpretation, and conclusions of the final manuscript. Generative AI was not credited as an author.

Data Availability

The data generated and analyzed in this study were obtained from experimental measurements using a water phantom. The dataset includes radiographic image data and quantitative image quality measurements, including Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR), obtained under different mAs settings and eyeshield conditions. The data are not publicly available but can be obtained from the author upon reasonable request.

Code Availability

The code used for data processing, statistical analysis, and visualization was developed and executed using Google Colab. The code is available from the author upon reasonable request.

Ethical Approval

This study was approved by the Research Ethics Committee under Ethical Approval Number 000.9.2/03215. As this study used a water phantom and did not involve human participants, patient medical records, or animal subjects, no human or animal ethical procedures applied.

Consent to Participate

Not applicable. This study used a water phantom and did not involve human participants.

Consent for Publication

Not applicable. This study did not involve human participants or personally identifiable information.

Competing Interest

The authors declare that they have no conflict of interest.

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