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Analysis of the Effect of Tube Current, Slice Thickness, and Tube Voltage on Ct *Scan* Image *Noise* using the *Noise* Power Spectrum (NPS) Method

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Abstract

This study was conducted to analyze CT scan images in order to determine the effect of tube current, slice thickness, and tube voltage on noise using the Noise Power Spectrum (NPS) method. Moreover, this study was also aimed to identify the optimal range of tube current, slice thickness, and tube voltage values to minimize noise formation in CT scan images while maintaining the safe dose for the patients. The research parameters included variations in tube current values with slice thickness variations, using tube voltages of 80 kV and 120 kV. The tube current (mAs) variations used were 150 mAs, 200 mAs, 250 mAs, 300 mAs, and 350 mAs, while the slice thickness variations were 0.8 mm, 1.6 mm, 3.2 mm, 4.8 mm, and 9.6 mm. A Phillips 16-slice access CT scan with a water phantom was utilized as the material for the research. The obtained image data were analyzed using ImQuest and ImageJ software. The results show that as the variations in tube current (mAs), slice thickness (mm), and tube voltage (mV) increase, the noise values decrease. This was demonstrated by the smallest area under the curve (AUC) values, which were 24.46 variance for the tube current variation at 120 kV and 3.57 variance for the slice thickness variation at 120 kV. Thus, to minimize the noise, it is recommended to increase the tube current, slice thickness, and tube voltage.

Keywords: CT *scan*, Noise, Noise Power Spectrum, Slice thickness, Tube current, Tube voltage.

INTRODUCTION

The utilization of medical instrumentation such as Computed Tomography Scans (CT Scans) has become a routine practice, capitalizing on technological advancements. Diseases necessitating diagnostic imaging through Computed Tomography Scans (CT Scans) typically involve conditions related to internal organs such as traumatic brain injuries, pulmonary embolisms, kidney stones, tumors, and various other ailments. The quality of CT Scan images can vary depending on the sophistication of the imaging modality in use

Quality control in radiology equipment is undoubtedly an important concern, including for CT Scans. Quality control for CT Scans is performed on a daily, weekly, monthly, and yearly basis. The implementation of CT Scan quality control is carried out by equipment technicians, medical physicists, and radiographers. Each of them has different roles and functions in ensuring the reliability of the CT Scan machine. Within the CT Scan itself, there are indicators that can be used as benchmarks for evaluating image quality. Indicators that affect quality include spatial resolution, contrast resolution, distortion, artifacts, and noise. Among these indicators, noise, which is similar to unwanted background interference, can be observed. To control the quality of noise in a machine, several methods can be employed.

One commonly used calculation method is SNR (Signal to Noise Ratio) and CNR (Contrast to Noise Ratio). Image noise can be calculated using NPS (Noise Power Spectrum), which provides a more comprehensive method because it explains both the magnitude and characteristics of the noise. [6]

In 2019, Almuslimiati analyzed noise in CT Scans with kernel reconstruction and slice thickness variation using the SNR method. It was concluded that the noise values obtained for all the reconstruction kernels used were within tolerance limits, and there was an impact of slice thickness. In 2020 [1], Putra Doharmansyah evaluated noise with exposure variation using the NPS method. The study found that exposure variation had an impact on the CT Scan system, and the NPS method was found to be a good approach [13].

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In this research, an analysis of noise was conducted by varying tube current, slice thickness, and tube voltage, but using the NPS method. It is hoped that a more detailed evaluation can be performed using NPS with the applied variations, and efforts to minimize the noise values produced in the analyzed image quality can be achieved by adjusting parameters while ensuring patient safety.

EXPERIMENTAL METHOD

The experiment was conducted using equipment and materials provided by the Radiology Department of RS Borromeus Bandung, and with the assistance of radiographer Mr. Adi Wasono, who helped with the image acquisition process for the CT Scan.

The CT Scan device used was a Philips Access 16 Slices CT Scan machine with the included Water phantom called Philips CT 16 Extended Phantom Kit (Brilliance Model), P. N 4550 122 01471 S. N 1471 200 10216. The analysis was performed using ImQuest software, focusing on the Noise Power Spectrum (NPS) curve analysis, with 5 Regions of Interest (ROI) specified in the images.

(a) (b)

Fig 1. (a) Philips RS Borromeus CT Scan Machine (b) Phantom installed on the CT Scan machine.

The results of the scanning images will be analyzed based on the quantity of noise visible in the images and the NPS curve for each variation, which will undergo detailed analysis. Differences observed will include variations in the shape and size of the NPS curves. [16]

RESULTS AND DISCUSSION

a. Image and Noise Analysis with Tube Current (mAs) Variations.

In the first variation, we examined CT scan images generated under different tube current settings (150 mAs, 200 mAs, 250 mAs, 300 mAs, 350 mAs), while keeping the slice thickness constant. We also used two different tube voltages, 80 kV and 120 kV, as shown in Figure 2 and Figure 3.

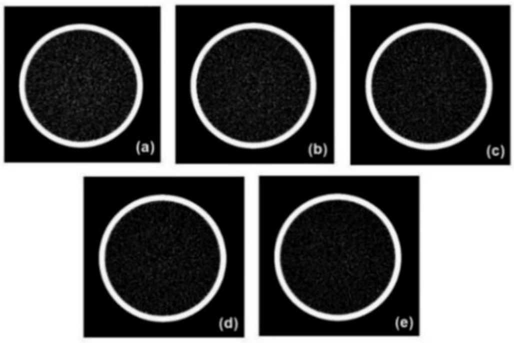

Fig 2. Result of CT Scan Images for Tube Current Variation with 80 kV 0.8 mm.

It's evident from the scanning results of the CT scan images in Figure 2 and Figure 3, from (a) to (e), that they produce different images, particularly in terms of clarity and smoothness. The CT scan images obtained using 120 kV tube voltage appear differently compared to those using 80 kV tube voltage.

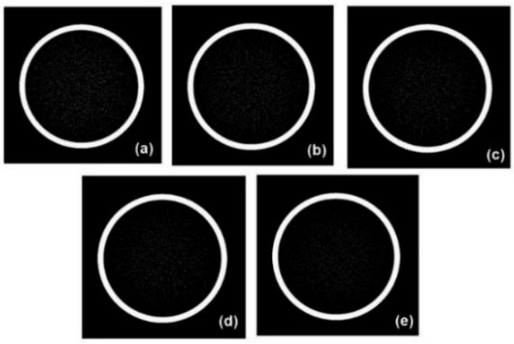

Fig 3. Result of CT Scan Images for Tube Current Variation with 120 kV 0.8 mm.

Next, we conducted measurements of the average standard deviation (Noise STD). The average standard deviation values obtained from these images are presented in a graph in Figure 4.

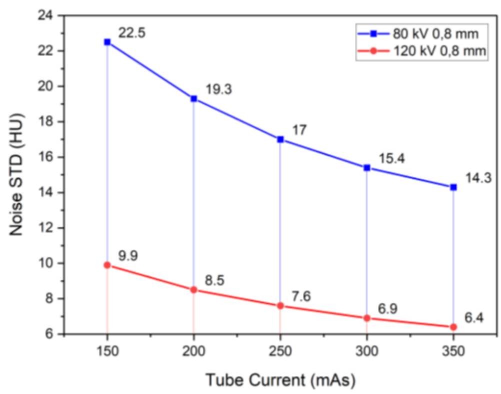

Fig 4. Curve Showing the Relationship between Average Noise and Tube Current (mAs) Variation at 80 kV and 120 kV.

The graph demonstrates a noticeable change: as the tube current values increase, there is a corresponding decrease in noise values. This decrease in noise values suggests that the resulting images will have reduced contrast and increased blurriness, resulting in lower image detail.

Following the scanning process, we obtained a graph that illustrates the Noise Power Spectrum (NPS) data for various variations, as depicted in Figure 5 for images captured with an 80 kV tube voltage and Figure 5 for those with a 120 kV tube voltage.

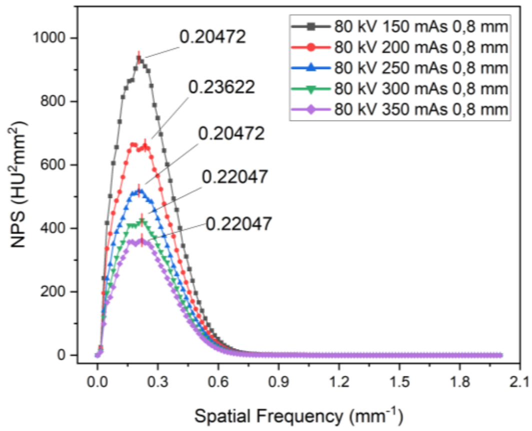

Fig 5. Displays the NPS Curve for Image Results with Tube Current Variation (mAs) at 80 kV and 0.8 mm.

It highlights differences in the peak heights of the NPS generated for each variation. For a comparison involving voltage variations, you can examine the amplitudes of the NPS curves generated for both 80 kV and 120 kV tube voltages.

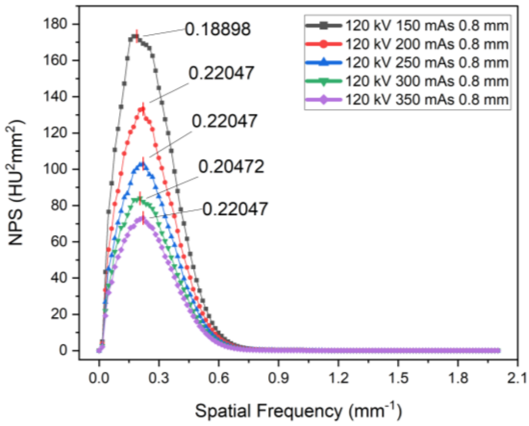

Fig 6. NPS Curve for Image Results with Tube Current Variation (mAs) at 120 kV and 0.8 mm.

After conducting an analysis of tube current and tube voltage variations, the next step involved analyzing the Area Under Curve (AUC) as a comparison between different tube current variations at different tube voltage values. Figure 7 represents a graph of AUC values that display the difference in curves between using a tube voltage of 80 kV and 120 kV.

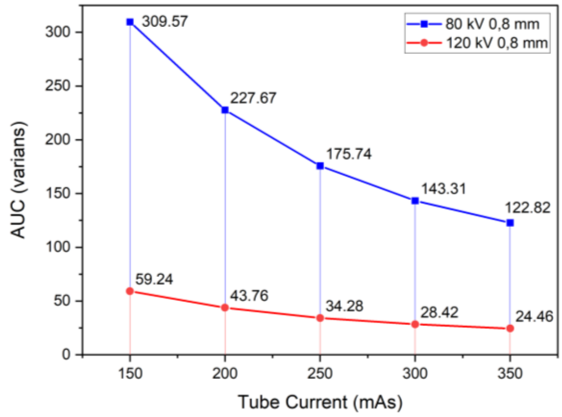

Fig 7. AUC Curve for Tube Voltage Images at 80 kV and 120 kV using Tube Current Variation (mAs) of 0.8 mm.

The AUC values themselves clearly show a decreasing trend as the tube current values used in an imaging system increase. This can serve as an indicator that the choice of tube current indeed influences the reduction in noise values in the images. From the curve, it is evident that there is a significant change in the AUC curve for the 80 kV tube voltage.

Next, it's essential to calculate the CTDIvol values obtained. CTDIvol values have become one of the critical parameters to consider when conducting experiments using input parameters in CT scans.

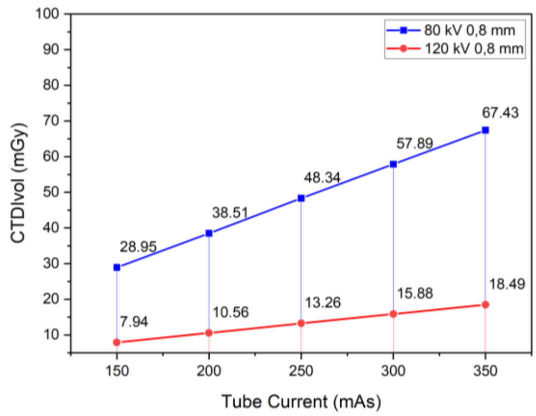

Fig 8. CTDIvol Curve with mAs Variations at 80 kV and 120 kV.

Figure 8 shows an increase in CTDIvol values as the tube current (mAs) and tube voltage (kV) values used in the CT scan increase. According to the American College of Radiology, a safe CTDIvol value for adult head CT scans is typically 80 mGy [8]. The CTDIvol values obtained in this research are below this tolerance limit. Therefore, the use of tube current and tube voltage variations with the slice thickness used is considered safe and acceptable for patients.

b. Image and Noise Analysis with Slice Thickness (mm) Variations.

For the second variation, we used different slice thicknesses with a tube current of 200 mAs and tube voltages of 80 kV and 120 kV. The slice thickness variations included 0.8 mm, 1.6 mm, 3.2 mm, 4.8 mm, and 9.6 mm.

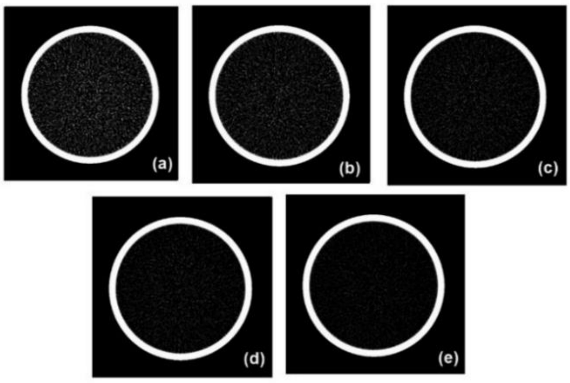

Fig 9. CT Scan Image Results for Slice Thickness Variations (a) 0.8 mm, (b) 1.6 mm, (c) 3.2 mm, (d) 4.8 mm, (e) 9.6 mm at 80 kV 200 mAs.

In Figure 9, there are differences in the images produced for each slice thickness variation. The level of blurriness and contrast appears to be significantly influenced by the slice thickness variations used.

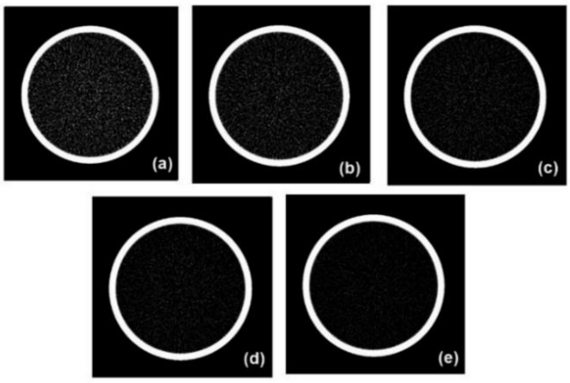

Fig 10. CT Scan Image Results for Slice Thickness Variations (a) 0.8 mm, (b) 1.6 mm, (c) 3.2 mm, (d) 4.8 mm, (e) 9.6 mm at 120 kV 200 mAs.

It is evident that thicker slices result in lower contrast, while with slice thickness variations, the contrast tends to be clearer in terms of black and white differentiation. The blurriness also increases as the slice thickness used becomes thicker. A similar trend is observed for slice thickness variations with a different tube voltage, i.e., 120 kV. In Figure 10, it is noticeable that there is a relationship between slice thickness variation and the presence of fewer white spots or grain noise as the slice thickness increases.

It can be observed that for the same slice thickness, a tube voltage of 120 kV results in a decreased noise STD. This demonstrates that higher tube voltages can reduce noise production. For a clearer depiction, refer to Figure 11.

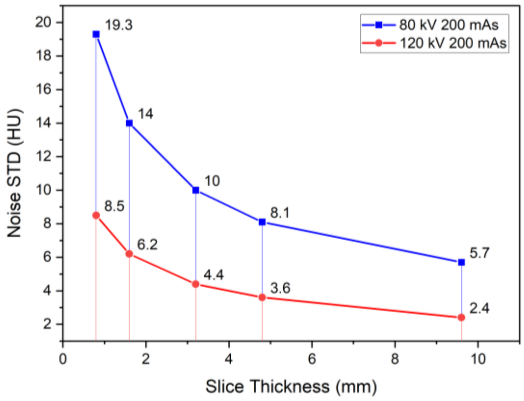

Fig 11. Curve Depicting the Relationship between Average Noise and Slice Thickness Variations (mm) at 80 kV, 120 kV, and 200 mAs.

Referring to Figure 11, it is evident that the slice thickness values used have a clear impact on the noise values generated in an image. After conducting the scanning process, graphs displaying NPS (Noise Power Spectrum) data for various variations are obtained, as shown in Figure 12 for images with an 80 kV tube voltage and Figure 13 for 120 kV.

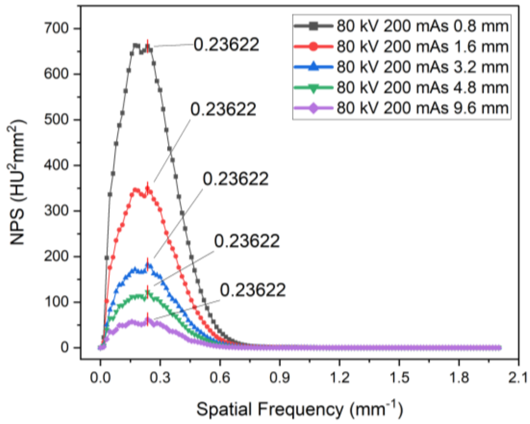

Figure 12. NPS Curve for Image Results with Slice Thickness Variations (mm) at 80 kV and 200 mAs.

The NPS graphs presented in Figure 12 and Figure 13 demonstrate the influence of slice thickness values. This is evident from the differences in peak heights of the NPS generated for each variation used. For a comparison with tube voltage variations, you can observe the amplitude of the NPS curves generated for both 80 kV and 120 kV tube voltages.

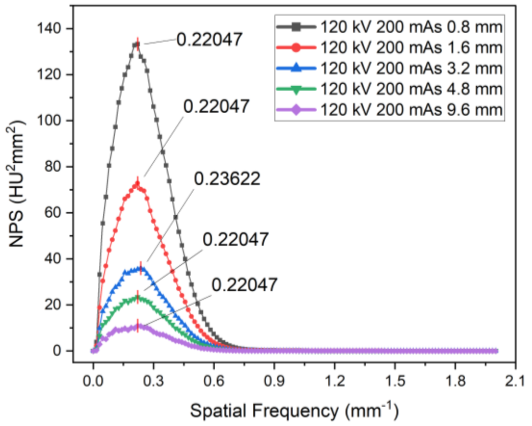

Fig 13. NPS Curve for Image Results with Slice Thickness Variations (mm) at 120 kV and 200 mAs.

After analyzing the NPS curves by calculating the AUC values for slice thickness variations, it was found that the choice of slice thickness indeed has an impact on the area under the NPS curve. Similar trends were also observed for the selected slice thickness variations. Figure 14 illustrates that the relationship observed follows a similar pattern, especially concerning the area under the curve concerning the chosen slice thickness variations.

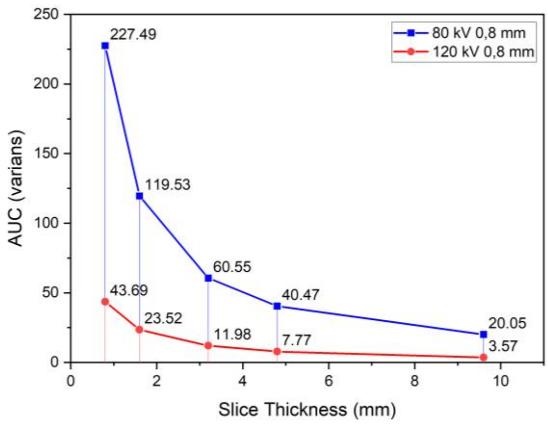

Fig 14. AUC Curve Comparison between 80 kV and 120 kV Tube Voltages using Slice Thickness Variations (mm) at 200 mAs.

Furthermore, there is a clear relationship observed for each tube voltage variation. It is evident that there are differences in the rate of decrease for each slice thickness variation at the tube voltage values used.

In this study, when using variations in slice thickness, there were differences in the impact on CTDIvol compared to when varying the tube current. This is because the slice thickness variations were adjusted on the scanning equipment, specifically by setting the thickness to be scanned.

In other words, the CTDIvol values related to radiation dose were affected only by the equipment settings, not by the object being scanned.

Table 1. CTDIvol Data Table with Slice Thickness Variations (mm)

CTDIvol (mGy)						
Tube Current (mAs)	Tube voltage (kV)	Slice Thickness (mm)				
		0.8	1.6	3.2	4.8	9.6
200	80	10.56	10.56	10.56	10.56	10.56
	120	10.56	10.56	10.56	10.56	10.56

According to the research presented in Table 1, it was found that the CTDIvol values remained the same regardless of the slice thickness variations used.

CONCLUSION

The analysis using the NPS method revealed relationships between noise and variations in tube current, slice thickness, and tube voltage. In the case of tube current (mAs) variations, increasing the tube current led to lower NPS Peak values. This relationship was supported by calculations using pixel standard deviation, where tube current had a proportional impact on Noise STD (Standard Deviation). Similarly, for slice thickness variations, higher slice thickness values resulted in decreased NPS Peak values. The same trend was observed in tube voltage variations, where higher tube voltage values were associated with lower Noise STD and NPS Peak values.

When considering the area under the curve (AUC) for noise variations, the lowest AUC value was 3.57 for the noise curve of the 120 kV and 9.6 mm variation. Importantly, the CTDIvol value for this variation remained below the tolerance limit at 10.56 mGy. In conclusion, to minimize noise production, it is advisable to consider increasing the tube current, slice thickness, and tube voltage.

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