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Analysis of The Effect of The X-Ray Tube Current on Uniformity Image Noise Values

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Abstract

This research aimed to evaluate the effects of the current X-ray tube on the uniformity value of computerized tomography (CT) image noise. This research used the CT images of Siemens head water phantom. The phantom was scanned with a Siemens Somatom Scope CT scanner for various current tubes (i.e., 180 mAs, 200 mAs, 220 mAs, 240 mAs, and 260 mAs) on tube voltage 110 kV, slice thickness 3 mm, and FOV 240 mm. The uniformity values in CT image noise were analyzed using the standard deviation value (SD). The SD was measured by the ROI process in 5 different locations, in the center and at 3 o'clock, 6 o'clock, 9 o'clock, and 12 o'clock on the images CT. Based on the result of a simple linear regression test using IBM SPSS ver 25, it was found that the current tube significantly affected the uniformity value of image noise (r^2=0,9768, p<0,05). This result showed that increasing the current tube can reduce image noise uniformity. The highest image noise uniformity value was at a current at 180 mAs with 0,217 HU, and the lowest value at 260 mAs with 0,031 HU. This result also shows that all the values are less than 2 HU and still within the acceptable limit by the BAPETEN standard regulation.

Introduction

In recent years, the progression of technology shines more and rapidly can be seen and experienced by all sectors, no exception for medical science especially. One of those is the establishment of the Computed Tomography Scan, known as CT-Scan. CT-Scan is a development of conventional x-ray imaging. CT-Scan imaging uses ionizing radiation x-rays to get images of the tissues without a surgical operation on the patient [1]. Another advantage of CT-Scan is more sophisticated, saves time, and makes the images' quality clear compared to conventional x-rays [2]. With CT-Scan, the patient's condition can be ascertained in high-quality detail. However, the risk of error and calibration system failure of the x-ray generating system in the x-ray tube could have happened. It can affect the image quality and the dose of radiation X-rays given to the patient [3]. Therefore, it is necessary to carry out Quality Control (QC) of the CT-Scan to ensure the best image quality and keep the radiation dose for patient safety within the given tolerance limits [4,5].

The quality of an image is essential because the proper diagnosis depends on the image produced. A good image will help the doctor to strengthen the diagnosis of a disease in the patient. The standard parameter for image quality can be seen from the conformity of the CT number values expressed in the Hounsfield Unit (HU) [6]. The CT number in the image CT is defined as the value of the coefficient of attenuation or attenuation of x-rays on an object [7]. According to the Nuclear Energy Regulatory Agency (BAPETEN) regulation of Indonesia, number 2 of 2018, the conformity test of the CT image quality can be reviewed by the value of the accuracy of CT number, uniformity of image noise, and the value of uniformity of CT number.

Uniformity of image noise is the variation in CT number values for a homogeneous area. Image noise is based on the CT number's standard deviation (SD) for the uniform anatomical region [8], which is used a water phantom as an object to simulate the human body or parts of it. Phantom is used to calibrate imaging systems, evaluate CT performance, and ensure the correct operation of imaging systems before scanning humans or an object. The component of this phantom is water because that makes the soft tissues in the human body, which is about 90% [3]. So that measurements during testing can be carried out repeatedly and the results are more accurate.

Image noise of CT-Scan is affected by the patient size, tube voltage, tube current, slice thickness, scan time, helical pitch, etc. Some studies suggest scanning with a high tube current can reduce phantoms' noise. Tube current reduction from 500 mAs to 100 mAs has increased the noise by about 40% [9]. In Addition, the mAs also improve the image's detectability [10]. Therefore, this study aimed to investigate the effect of the variations tube current on the image quality by the uniformity value of image noise using a water phantom.

Experimental Method

This study was conducted at the Radiology Unit of Bali Jimbaran General Hospital, Jimbaran, Badung, Bali. The analysis was performed using a Siemens Somatom Scope CT Scanner (Fig.1), and the phantom used is the water phantom by Siemens with model number 10355224 (Fig.2).

This study started with preparing the CT Scanner used. At this step, a warm-up was carried out with the CT scanner. Then, the phantom is mounted on the couch and positioned in the middle of the gantry (helped by a laser for the centration). The next step is to do an early scanned to obtain the topogram of the whole water phantom. This step was to determine the area to be reconstructed. Input parameters scanned the phantom at a fixed 110 kV tube voltage, 3 mm slice thickness, 240 mm (Field of View) FOV, and 40 mm scan length. In this study, the tube current was varied to evaluate the effects of image noise uniformity. The tube currents were 180 mAs, 200 mAs, 220 mAs, 240 mAs, and 260 mAs.


Figure 1. Siemens Somatom Scope CT-Scanner (left), and Siemens Water phantom (right)

Table 1. Spesification of Siemens Somatom Scope CT-Scanner

Technical Specifications	
Type	M-CT-Scan-160
Serial number	30216181
Diameter gantry	70 cm
Gantry tilt	± 30˚
Tube voltage	80 kV, 110 kV, 130 kV
Tube current	25-345 mAs
Slice thickness	0.6-19,2 mm
Maximal table load	200 kg or 441 lbs
Table feed speed	1-100 mm/s
Reconstruction matrix	512 x 512
Topogram views	Anterior- Postero (AP), Postero-Anterior (PA), Lateral

The ROI (Region of Interest) process was measured by drawing circles of 12,56 cm^2 in 5 different locations on, in the center and at 3 o'clock, 6 o'clock, 9 o'clock, and 12 o'clock on the images CT. This process was measured at five image slices for each current variation. The mean and standard deviation (SD) were obtained from the ROI process. The values are displayed on the image whenever a ROI is drawn.

The difference between the SD maximum and SD minimum can determine the uniform image noise value. Because the scanning was not performed using BAPETEN standard parameters (i.e, 120 kV, 300 mAs, and 8 mm slice thickness), the noise values were converted to all four edges first (SD at the center minus SD in each of the edges). This value is called the measured noise value (σ_m). And then the σ_m was converted to obtain the normalized noise value or noise value in BAPETEN standard (σ_s) using Eq. (1).

$$\sigma_s = \sigma_m \frac{kV_m}{120\ kV}\sqrt{\frac{mAs_m \times slicethickness_m}{300\ mAs \times 8\ mm}} \qquad (1)$$

where σ_s is the normalized noise value (HU), σ_m is the measured noise value (HU) at each edge while kV_m, mAs_m, and slice $thickness_m$. The parameters set are tube voltage, current, and slice thickness. Analysis continued to find the uniformity value of image noise (HU) by calculating the difference between $\sigma_{s\ maks}$ and $\sigma_{s\ min}$ from each edge.

$$\text{Uniformity Image Noise} = \sigma_s \text{ maks} - \sigma_s \text{ min} \qquad (2)$$

where $\sigma_{s\ maks}$ is the maximum normalized noise value (HU) and $\sigma_{s\ min}$ is the minimum normalized noise value (HU). After obtaining the uniformity value of the image noise (HU) for each image slice, the calculation continued by finding the average of the five image slices.

The results of the calculations were used for statistical analysis by a simple linear regression test. This test was used to assess the effect of tube current on uniformity values image noise with IBM SPSS version 25. A p-value for statistically significant was set at 0,05. In this study, the null hypothesis (H_o) was used that variations in tube current have no significant effect on the uniformity value of image noise. On the other hand, the alternative hypothesis (H_i) is that tube current variations significantly affect image noise uniformity. If the p-value is less than 0,05 (< 0,05), it indicates that H_o is rejected while the H_i is accepted and the other way around. The final result of the uniformity values of image noise is also compared with BAPETEN standard regulation, which must not deviate by ≤ 2 HU.

Result and Discussion

In this study, the data SD was taken with the effect of variations in the tube current on the uniformity of image noise in the CT image of the water phantom. The phantom was scanned with a Siemens Somatom Scope CT scanner for various current tubes (i.e., 180 mAs, 200 mAs, 220 mAs, 240 mAs, and 260 mAs) on fixed tube voltage 110 kV, slice thickness 3 mm, and FOV 240 mm. The SD of the CT number obtained from the ROI process at 5 locations of the image CT (Fig.3). All the SD values from each image slice for tube current variations are shown in Table 1.

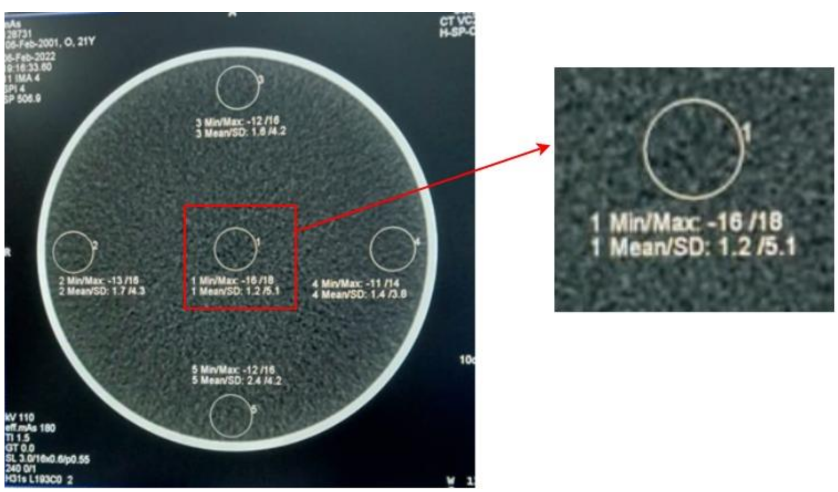

Figure 2. The standard deviation of CT number by ROI process

Table 2. The SD values from each image slice with the influence of tube current by ROI process

Tube Current (mAs)	*Slice*	SD Values (HU)				
		Center	at 3 o, clock	at 6 o, clock	at 9 o, clock	at 12 o, clock
180	*Slice* 1	5,1	3,8	4,2	4,3	4,2
	Slice 2	5,4	4,4	4,1	4,2	3,9
	Slice 3	5	4,3	4	4,2	3,8
	Slice 4	5	4,4	4,1	3,9	4,2
	Slice 5	5,3	4,3	3,8	3,9	3,8
200	*Slice* 1	4,9	4	3,9	4	3,6
	Slice 2	5	3,7	3,9	3,8	4,1
	Slice 3	4,6	3,7	4	3,7	4,1
	Slice 4	5,1	3,6	3,7	4	3,8
	Slice 5	4,5	3,6	3,9	3,9	4
220	*Slice* 1	4,6	3,8	3,8	3,8	3,5
	Slice 2	4,6	3,7	3,7	3,6	3,4
	Slice 3	4,8	3,7	3,8	3,5	3,8
	Slice 4	4,6	3,6	3,9	3,7	3,6
	Slice 5	5	3,5	3,8	3,7	3,6
240	*Slice* 1	4,6	3,7	3,6	3,8	3,6
	Slice 2	4,7	3,6	3,6	3,8	3,6
	Slice 3	4,5	3,4	3,5	3,6	3,5
	Slice 4	4,6	3,7	3,5	3,6	3,6
	Slice 5	4,6	3,5	3,7	3,5	3,5
260	*Slice* 1	4,4	3,3	3,3	3,4	3,4
	Slice 2	4,4	3,3	3,2	3,3	3,2
	Slice 3	4,2	3,4	3,4	3,4	3,3
	Slice 4	4,6	3,4	3,4	3,4	3,4
	Slice 5	4	3,3	3,3	3,3	3,3

The SD values on the image were processed to obtain the σ_m (the measured noise value) and σ_s (the normalized noise value). The σ_m and σ_s on the whole, the image based on the influence of tube current is shown in Table 2.

Table 3. The result of σ_m (the measured noise value) and σ_s (the normalized noise value) on each image slice with the influence of the tube current

Tube Current (mAs)	*Slice*	σ_m (HU)				σ_s (HU)			
		at 3 o,clock	at 6 o,clock	at 9 o,clock	at 12 o,clock	at 3 o,clock	at 6 o,clock	at 9 o,clock	at 12 o,clock
180	*Slice* 1	1,3	0,9	0,8	0,9	0,565	0,391	0,348	0,391
	Slice 2	1	1,3	1,2	1,5	0,435	0,565	0,522	0,652
	Slice 3	0,7	1	0,8	1,2	0,304	0,435	0,348	0,522
	Slice 4	0,6	0,9	1,1	0,8	0,261	0,391	0,478	0,348
	Slice 5	1	1,5	1,4	1,5	0,435	0,652	0,609	0,652
200	*Slice* 1	0,9	1	0,9	1,3	0,413	0,459	0,413	0,596
	Slice 2	1,3	1,1	1,2	0,9	0,596	0,504	0,550	0,413
	Slice 3	0,9	0,6	0,9	0,5	0,413	0,275	0,413	0,229
	Slice 4	1,5	1,4	1,1	1,3	0,688	0,642	0,504	0,596
	Slice 5	0,9	0,6	0,6	0,5	0,413	0,275	0,275	0,229
220	*Slice* 1	0,8	0,8	0,8	1,1	0,384	0,384	0,384	0,529
	Slice 2	0,9	0,9	1	1,2	0,432	0,432	0,481	0,577

	Slice 3	1,1	1	1,3	1	0,529	0,481	0,625	0,481
	Slice 4	1	0,7	0,9	1	0,481	0,336	0,432	0,481
	Slice 5	1,5	1,2	1,3	1,4	0,721	0,577	0,625	0,673
240	*Slice* 1	0,9	1	0,8	1	0,452	0,503	0,402	0,503
	Slice 2	1,1	1,1	0,9	1,1	0,553	0,553	0,452	0,553
	Slice 3	1,1	1	0,9	1	0,553	0,503	0,452	0,503
	Slice 4	0,9	1,1	1	1	0,452	0,553	0,503	0,503
	Slice 5	1,1	0,9	1,1	1,1	0,553	0,452	0,553	0,553
260	*Slice* 1	1,1	1,1	1	1	0,575	0,575	0,523	0,523
	Slice 2	1,1	1,2	1,1	1,2	0,575	0,627	0,575	0,627
	Slice 3	0,8	0,8	0,8	0,9	0,418	0,418	0,418	0,470
	Slice 4	1,2	1,2	1,2	1,2	0,627	0,627	0,627	0,627
	Slice 5	0,7	0,7	0,7	0,7	0,366	0,366	0,366	0,366

The data σ_s values in Table 2 were calculated to find the difference between the maximum and minimum values to obtain the uniformity image noise (HU) by Eq.2. Table 3 shows the result of the uniformity value of image noise in all the image slices and the average of each slice by the variation of the tube current used.

Table 4. The effect of tube current variations on the uniformity value of image noise and the conformity test based on the BAPETEN standard

Tube Current (mAs)	**Uniformity Image Noise (HU)**					**Average**	**Testing Passing Score**
	Slice 1	***Slice 2***	***Slice 3***	***Slice 4***	***Slice 5***		
180	0,217	0,217	0,218	0,217	0,217	**0,217**	≤ 2 HU
200	0,183	0,183	0,184	0,184	0,184	**0,184**	
220	0,145	0,145	0,144	0,145	0,144	**0,145**	
240	0,101	0,101	0,101	0,101	0,101	**0,101**	
260	0,052	0,052	0,052	0	0	**0,031**	

Table 3 shows that the highest uniformity value of image noise was at a current at 180 mAs with 0,217 HU and the lowest value at 260 mAs with 0,031 HU. The relationship between the tube current and the uniformity value of image noise is also shown in the graph in Figure 4.

Figure 4 shows that the R^2 value is 0.9768 by the simple linear regression test using IBM SPSS Statistics ver 25. These results show that the current variation affects 97.68% of the uniformity value of image noise. This test also indicates that the existing tube significantly affected the uniformity of image noise, with a p-value is 0.002 ($p\text{-value} < 0.05$). These results show that the increase in the tube current can reduce the noise in an image. A decrease in the uniformity value of image noise is due to a rise in the number of photons produced by X-ray tubes. Increasing the current given when scanning can increase the number of photons produced and received by the detector to create an image CT [11].

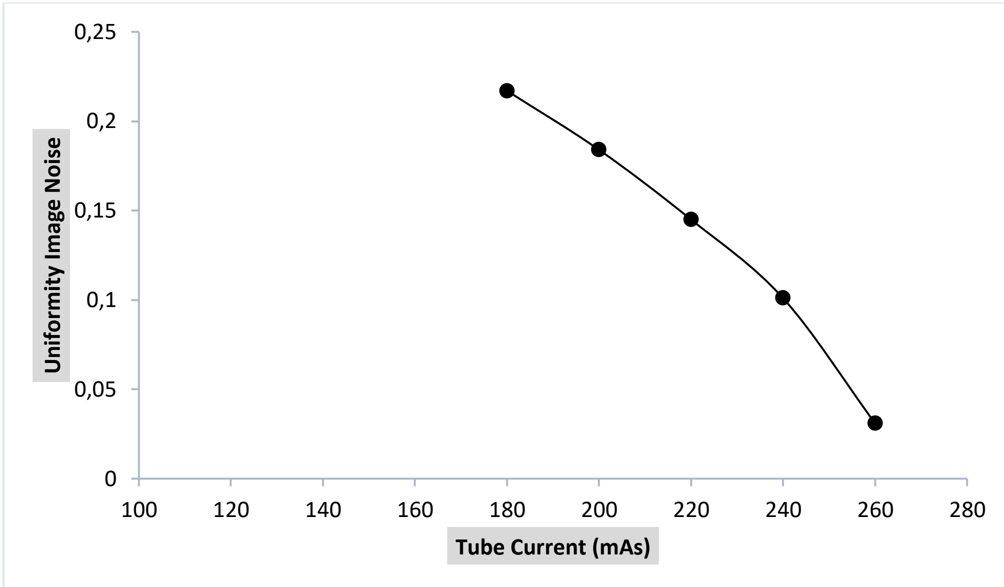

Figure 3. Graphs show the relation between tube current (mAs) and uniformity image noise (HU)

This result also shows that a decrease in the value of the tube current (mAs) means that the radiation dose received on the object has decreased as well, but at the same time, the uniformity value of the image noise in the image has increased [12]. Tube current is also related to object detectability in an image CT [10]. The higher the tube current, the more noise will decrease, and object detectability will increase as the noise decreases [13]. From this result, it can be concluded that the higher the tube current, the better the image CT will be.

Based on the uniformity values of the image noise in Table 2 show that all the values are less than 2 HU and still within the acceptable limit by the BAPETEN standard regulation. The values did not exceed the tolerance limit showing that the dose of the radiation received detector is still the same on objects homogeneous. In Addition, with all the values still up to the standard, it can be said that the detector response is still in good condition. The spread of the radiance dose received by the patient is evenly distributed, which impacts the quality of the image with good density, sharpness, detail, and contrasts when reconstructed. These results also show that the condition of the CT-Scanner at Bali Jimbaran General Hospital is still functioning correctly.

Conclusion

In this study, we have shown that the tube current significantly affected the uniformity value of image noise (p-value < 0.05). By increasing the mAs, therefore, less noise was obtained. The noise is slightly decreased on high the tube current, but still within the acceptable limit by the BAPETEN standard regulation. The result showed that the performance of the CT Scanner is quite good since no found values out of the suggested limits (≤ 2 HU).

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