The Effect of Tube Voltage Variations on CT Scan Image Quality at Prof. I G. N. G. NgoerahGeneral Hospital, Denpasar

ABSTRACT

Aims:

1. Knowing the SNR and CNR values obtained from the image results that have been varied in the tube voltage.
2. Knowing the effect of variations in the tube voltage value on the quality of the CT Scan image that will be produced.

Place and Duration of Study:
Radiology installation of Prof. I G. N. G. Ngoerah General Hospital, Denpasar from May 2024 to August 2024.

Methodology:
This study used a Canon Aquilion LB CT Scanner to scan a TOS phantom containing 6 materials (polypropylene, nylon, acrylic, derlin, air, and water) with varying tube voltages (80 kV, 100 kV, 120 kV, 135 kV). The data were analyzed using PSPP and Excel to calculate SNR and CNR, and statistical tests for normality, Pearson correlation, and simple regression were performed.

Results:
The image data analyzed includes the average value of the object ROI, the average ROI background, and the standard deviation of the background. The data is grouped based on the variation of the tube voltage, the average value and standard deviation of the ROI on each material, and the standard deviation of the background. The results obtained for the relationship between the variation of the tube voltage and the SNR value are that the tube voltage affects the SNR value by 94,02% in polypropylene, 97,79% in nylon, 97,71% in acrylic, 96,42% in derlin, and 94,22% in air. And for the relationship between the tube voltage and the CNR value, the tube voltage affects the CNR value by 93,65% in polypropylene, 97,35% in nylon, 96,81% in acrylic, 95,62% in derlin, and 94,65% in air.

Conclusion:
Voltages of 120 kV and 135 kV are recommended for materials such as nylon, acrylic, air, and derlin because they produce better SNR and CNR. The relationship between tube voltage and SNR and CNR depends on the physical properties and attenuation of the material. Materials with significant attenuation differences, such as derlin and air, show improved image quality. Conversely, materials such as polypropylene experience a decrease in quality when the tube voltage is too high.

Keywords: CT Scan; SNR; CNR; tube voltage; image quality

1. INTRODUCTION

Computed Tomography (CT Scan) is a medical diagnostic tool that was first used in the 1970s, CT Scan uses radiation energy to detect abnormalities in organs or body tissues[1]. The use of CT Scan in diagnosing abnormalities of organs or body tissues involves the use of image quality obtained from the results of the scanning process. The quality of the resulting image is determined by several parameters such as tube voltage, tube current, and slice thickness. The use of the right tube voltage can increase image resolution, contrast between anatomical structures and clarity of CT Scan images. Image quality is determined by several factors, one of which is noise. Noise is the standard deviation of the CT number value in homogeneous tissue or material which is influenced by exposure factors, detectors and slice thickness [2].

1.1 X-ray

X-rays are a form of electromagnetic radiation that is used to diagnose abnormalities in the body. X-rays need to be considered in their use because they have short-term and long-term effects on those who have been exposed[3]. The formation of X-rays through a process consisting of several stages, namely, Heating the filament to a temperature of more than 2000°C generates an electron cloud from the filament[4]. The heated electron cloud releases energy when it interacts with other electrons orbiting the atomic nucleus. Then, the electron cloud that collides with the target when given a high potential difference produces 99% heat energy and 1% X-rays.

1.2 CT Scan

CT Scan is a diagnostic tool that uses radiographic techniques that produce cross-sectional images of the body. CT Scan uses X-ray radiation as an imaging source, the X-rays are used to produce internal images of the human body. CT Scan uses special equipment connected to a computer with supporting performance to process optimal scan results[5].

1.3 Tube Voltage

The tube voltage in a CT scan affects image quality by affecting X-ray absorption, contrast, and spatial resolution. Increasing the voltage increases X-ray penetration, but can reduce contrast in soft tissue. Conversely, decreasing the voltage increases contrast but can increase the radiation dose to the patient[4].

1.4 Phantom

CT Scan phantoms are made from a variety of materials that have a similar density to body organs, such as water, air, delrin, acrylic, nylon, and polypropylene[6].

a) Air: Air is used to simulate soft tissue or low-density materials, such as lungs or soft organs.

b) Derlin: Derlin is a type of plastic that mimics the density of soft tissue. It is used to simulate organs such as the liver or kidneys, which have a slightly higher density than air.

c) Acrylic: Acrylic is a transparent plastic that is often used to simulate bone or high-density materials.

d) Nylon: Nylon is a type of plastic used to simulate medium-density materials, such as muscle tissue. Its density is higher than air but lower than acrylic, making it suitable for simulating various types of tissue.

e) Polypropylene: Polypropylene is a type of plastic used to simulate high-density materials, such as bone or metal.

f) Water is also used as a phantom material to simulate the presence of gas in the body, such as in the lungs or digestive tract.

This phantom is used to ensure the uniformity of CT Number and image noise, and to help the detector calibrate with tolerance values for beam hardening of different patient sizes. An example of a phantom image is as shown in Figure 1.

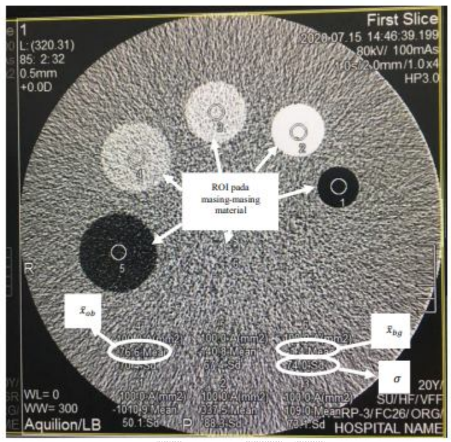

Figure 1. Phantom CT Scan image.

1.5 CT Number

CT Number represents the X-ray attenuation coefficient, which is influenced by the initial energy of the X-ray and the atomic number of the object it passes through. Tube voltage, X-ray filtration, and object thickness also affect the CT Number value[7]. The X-ray attenuation coefficient value of a voxel is represented in Hounsfield Units (HU) on the CT image. The illustration of the location of the CT Number value in each ROI is shown in Figure 2.

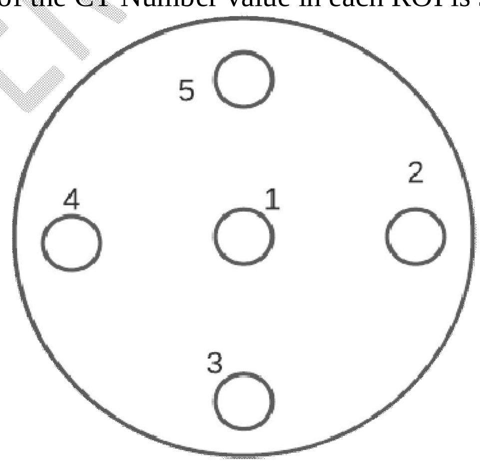

Figure 2. Illustration of the location of the CT Number value in each ROI.

With the number 1 indicating the location of the CT Number in the center of the image, the number 2 on edge 1, the number 3 on edge 2, the number 4 on edge 3, and the number 5 on edge 4.

1.6 Signal to Noise Ratio (SNR)

Signal to Noise Ratio (SNR) is the signal strength to noise detected in the image, noise is one of the factors that can affect image quality in CT Scan. There are several factors that can affect the SNR value in CT Scan, namely, Tube voltage (kV), tube current (mA), slice thickness, and Field of View (FOV)[8]. Systematically SNR can be written as follows:

$$\text{SNR} = \left|\frac{\bar{X}_{ob}}{\bar{\sigma}_{Water}}\right| \tag{1}$$

With $\bar{X}_{ob}$ is the average value of the material signal intensity in HU units, and $\bar{\sigma}_{Water}$ is the standard deviation value of the background signal intensity.

1.7 Contrast to Noise Ratio (CNR)

Contrast to Noise Ratio (CNR) is one of the parameters for measuring image quality as a comparison between the difference between the mean ROI material and the mean ROI background with the standard deviation of the background. Increasing the use of tube voltage (kV) increases CNR because higher photon energy increases penetration power and reduces noise relative to the signal. However, it is necessary to pay attention to the balance of the right settings to maximize image quality[9]. Systematically, CNR can be written as follows:

$$\text{CNR} = \left|\frac{\bar{X}_{ob}-\bar{X}_{Water}}{\bar{\sigma}_{Water}}\right| \tag{2}$$

Where $\bar{X}_{ob}$ is the average value of the material signal intensity in HU units, $\bar{X}_{Water}$ is the average value of the background signal intensity in HU units, and $\bar{\sigma}$ is the standard deviation value of the background signal intensity.

2. METHODS

This study was conducted using a Canon Aquilion LB CT Scan at Prof. Dr. I. G. N. G. Ngoerah General Hospital, Denpasar, with primary data from the results of the Toshiba phantom scanning experiment type PX 78-01377. The phantom contains 6 types of materials: polypropylene, derlin, nylon, acrylic, air, and water. The exposure factors used include tube voltages of 80 kV, 100 kV, 120 kV, and 135 kV, time current of 100 mAs, and slice thickness of 3 mm. The process includes phantom irradiation and ROI value reading with 10 repetitions at a voltage of 100 kV. The image data analyzed include the average value of the object ROI, background, and background standard deviation. Data are grouped based on variations in tube voltage, average value and standard deviation of ROI on each material, and background standard deviation. SNR and CNR values are calculated using equations 1 and 2. The analysis was carried out with PSPP and Ms. Excel through normality test, Pearson correlation test, and simple regression test to see the effect of voltage variation on SNR and CNR.

3. RESULTS AND DISCUSSION

The image of the TOS phantom scanning result on a CT Scan with a time current of 100 mAs, a FOV of 382.42 mm, a slice thickness of 3 mm and an X-ray tube voltage of 100 kV is shown in Figure 3. From the phantom image, the mean value of the material signal intensity ($\bar{X}_{ob}$), the mean value of the background intensity ($\bar{X}_{Water}$), and the standard deviation value of the background intensity ($\bar{\sigma}_{Water}$) were determined.

Figure 3. ROI reading at 100kV tube voltage phantom image. The results of the material ROI reading at each tube voltage of 80 kV, 100 kV, 120 kV, and 135 kV as a whole are shown in Table 1. The results of this ROI reading will be used to calculate the SNR and CNR values for image quality.

Table 1. ROI reading results

Tube Voltage (kV)	**Reading to-**	**$\bar{X}_{ob}$ (HU)**					**$\bar{X}_{Water}$ (HU)**	**$\bar{\sigma}_{Water}$ (HU)**
		Polypropylene	**Nylon**	**Acrylic**	**Derlin**	**Air**		

80	1	-138.6	68.7	111.8	328	-994.9	0.9	15.4
	2	-139.1	81.1	113.3	318.4	-988.2	-0.4	16.1
	3	-137.6	76.4	112.8	326.1	-995.4	2.7	17.4
	4	-137.4	70.6	112.7	328.3	-996.4	4	17.7
	5	-138.8	69.2	112.3	328.2	-995.2	4.2	15.6
	6	-138.7	69.2	110.7	327.3	-995	2.8	14.8
	7	-137.4	69.7	112.9	328.3	-994.8	2.8	14.9
	8	-139.2	70	111.6	327.4	-994.4	0.1	16.9
	9	-140.9	69.1	112.9	327.8	-995.3	0.9	17.1
	10	-139.4	69.3	110.6	328	-996.5	0.1	17.6
100	1	-119.6	84.9	123.1	323.8	-989.2	-1.4	15
	2	-118.1	93.9	124.7	329.1	-985.2	-0.4	17.2
	3	-118.8	89.3	125.7	330.3	-987.8	-0.2	14.3
	4	-118.7	86.3	125	330.2	-989.1	-0.4	13.9
	5	-119.5	85.4	124.4	329.1	-989.4	1	15.5
	6	-118.5	83.9	123.4	330.9	-990.1	-1.3	16.3
	7	-118.5	84.3	123.2	330.3	-988.4	0.9	16.8
	8	-117.5	85.4	122.6	329.8	-988.9	0.6	14.6
	9	-118.3	85	123.4	330.5	-987.5	0.5	15.2
	10	-118.8	85.4	123.8	331.6	-990	-0.1	15.2
120	1	-107.2	95.5	131.2	334.6	-990.2	2.5	15.3
	2	-107.1	102.2	130.6	331.2	-985.6	-1	14.5
	3	-107.2	99.5	132.3	335	-988.8	-0.3	15.5
	4	-107.6	95.1	132	335.1	-989.2	-0.1	14.8
	5	-107.9	94	131.2	335.3	-988.7	0.8	15.1
	6	-107.8	93.8	131.6	334.8	-990.5	0	15.7
	7	-107.9	94.4	130.4	334.3	-990.8	2	16.1
	8	-107.2	95.5	131.2	334.6	-990.2	2.5	15.3
	9	-107.5	94.6	130.8	335.4	-989	1	15.1
	10	-108	94.7	129.9	335.1	-988.9	1.5	14.6
135	1	-102.2	99	132.9	337.3	-989.9	-0.8	13.7
	2	102.6	102.5	133.3	332.5	-986.9	-0.2	13.8
	3	-103.1	99.7	134.3	336.3	-989.4	-0.5	14.9
	4	-103.1	99.3	133.5	337.1	-990.5	-0.5	14.9
	5	-102.4	98.5	133.5	337.4	-989.8	-0.4	13.9
	6	-102.8	98.5	132.9	337.1	-991	-1.1	15.2
	7	-102.1	99.1	133.1	337.7	-990.4	-0.2	15.1
	8	-102.1	99.1	133.5	363.3	-990.1	-0.1	14.1
	9	-102.6	99.3	134.1	336.9	-990.3	-0.3	14.3
	10	-102.4	99.7	133.2	337.7	-990.2	-0.4	14.6

From Table 1, calculations are carried out by determining the mean value of the material signal intensity, the mean value of the background intensity and the standard deviation value of the background intensity, then the SNR calculation can be carried out using ($\bar{X}_{ob}$) and ($\bar{X}_{Water}$). For CNR, $\bar{X}_{ob}$, $\bar{X}_{Water}$,$\bar{\sigma}_{Water}$ can be used. The average results of the SNR and CNR values for each material are shown in Tables 2 and 3.

Table 2. Average result of SNR value calculation

Tube Voltage (kV)	**SNR**				
	Polypropylene	**Nylon**	**Acrylic**	**Derlin**	**Air**
80	8,483792049	4,362691	6,859939	19,98654	60,83242
100	7,703246753	5,609091	8,047403	21,4	64,19221
120	7,075	6,311184	8,626316	22,00921	65,07829
135	5,676124567	6,883737	9,23391	23,48304	68,50173

Table 3. Average result of CNR value calculation

Tube Voltage (kV)	**CNR**

	Polypropylene	Nylon	Acrylic	Derlin	Air
80	8,594495413	4,251988	6,749235	19,87584	60,94312
100	7,698051948	5,614286	8,052597	21,40519	64,18701
120	7,133552632	6,252632	8,567763	21,95066	65,13684
135	5,644982699	6,914879	9,265052	23,51419	68,47059

Furthermore, from Table 2 and Table 3, normality and homogeneity tests can be carried out as a requirement for the ANOVA test and Pearson correlation test to determine the effect of tube voltage on SNR and CNR. The results of the Pearson correlation test on each material are shown in Table 4 and Table 5.

Table 4. Pearson correlation test results on SNR

Correlations

		Tube Voltage	SNR Polypropylene	SNR Nylon	SNR Acrylic	SNR Derlin	SNR Air
Tube Voltage	Pearson Correlation	1.000	-.970	.990	.988	.982	.971
	Sig. (2-tailed)		.030	.010	.012	.018	.029
	N	4	4	4	4	4	4
SNR Polypropylene	Pearson Correlation	-.970	1.000	-.944	-.950	-.989	-.984
	Sig. (2-tailed)	.030		.056	.050	.011	.016
	N	4	4	4	4	4	4
SNR Nylon	Pearson Correlation	.990	-.944	1.000	.999	.977	.971
	Sig. (2-tailed)	.010	.056		.001	.023	.029
	N	4	4	4	4	4	4
SNR Acrylic	Pearson Correlation	.988	-.950	.999	1.000	.982	.978
	Sig. (2-tailed)	.012	.050	.001		.018	.022
	N	4	4	4	4	4	4
SNR Derlin	Pearson Correlation	.982	-.989	.977	.982	1.000	.998
	Sig. (2-tailed)	.018	.011	.023	.018		.002
	N	4	4	4	4	4	4
SNR Air	Pearson Correlation	.971	-.984	.971	.978	.998	1.000
	Sig. (2-tailed)	.029	.016	.029	.022	.002	
	N	4	4	4	4	4	4

Table 5. Pearson correlation test results on CNR

Correlations

		Tube Voltage	CNR Polypropylene	CNR Nylon	CNR Acrylic	CNR Derlin	CNR Air
Tube Voltage	Pearson Correlation	1.000	-.968	.987	.984	.978	.973
	Sig. (2-tailed)		.032	.013	.016	.022	.027
	N	4	4	4	4	4	4
CNR Polypropylene	Pearson Correlation	-.968	1.000	-.949	-.954	-.991	-.990
	Sig. (2-tailed)	.032		.051	.046	.009	.010
	N	4	4	4	4	4	4
CNR Nylon	Pearson Correlation	.987	-.949	1.000	.999	.979	.977
	Sig. (2-tailed)	.013	.051		.001	.021	.023
	N	4	4	4	4	4	4
CNR Acrylic	Pearson Correlation	.984	-.954	.999	1.000	.984	.982
	Sig. (2-tailed)	.016	.046	.001		.016	.018
	N	4	4	4	4	4	4
CNR Derlin	Pearson Correlation	.978	-.991	.979	.984	1.000	1.000
	Sig. (2-tailed)	.022	.009	.021	.016		.000
	N	4	4	4	4	4	4
CNR Air	Pearson Correlation	.973	-.990	.977	.982	1.000	1.000
	Sig. (2-tailed)	.027	.010	.023	.018	.000	
	N	4	4	4	4	4	4

Furthermore, from Table 2 and Table 3, a graph can be made of the effect of tube voltage on the SNR and CNR values for each material, as shown in Figure 4 and Figure 5, and the coefficient of determination (R^2) values are shown in Table 6 and Table 7.

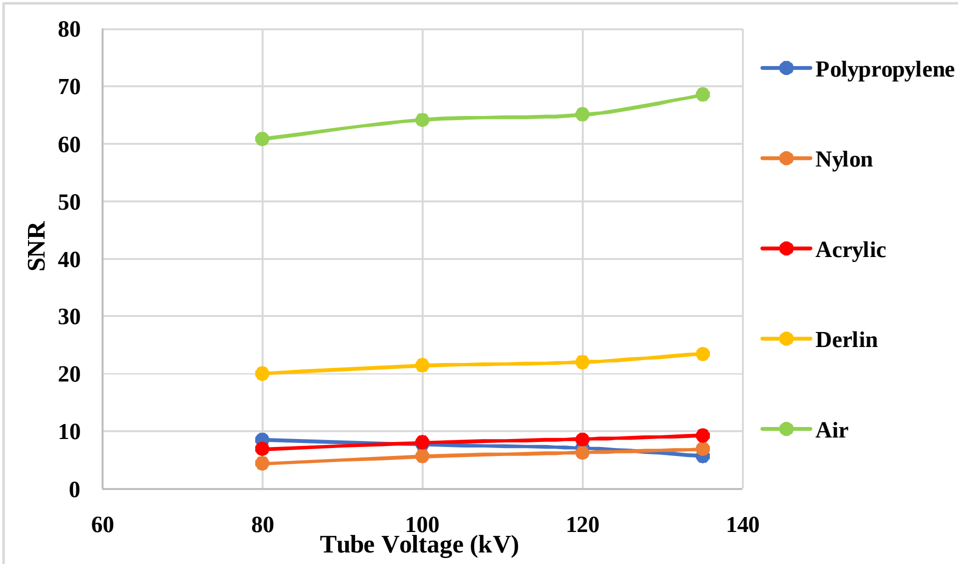

Figure 4. Graph of the relationship between tube voltage (x) and SNR value (y).

Table 6. Relationship function (y) and coefficient of determination (R^2)

Material	y	R^2
Polypropylene	-0,0481x + 12,468	0,9402
Nylon	0,0449x + 0,9075	0,9779
Acrylic	0,0481x + 3,649	0,9771
Derlin	0,0594x+ 15,225	0,9642
Air	0,1278x + 50,751	0,9422

Table 6 shows the coefficient of determination (R^2) of each material, in polypropylene it is 0.9402, nylon it is 0.9779, acrylic it is 0.9771, derlin it is 0.9642, and air it is 0.9422, meaning that the tube voltage affects the SNR value which is 94.02% in polypropylene, in nylon it is 97.79%, in acrylic it is 97.71%, in derlin it is 96.42%, and in air it is 94.22%.

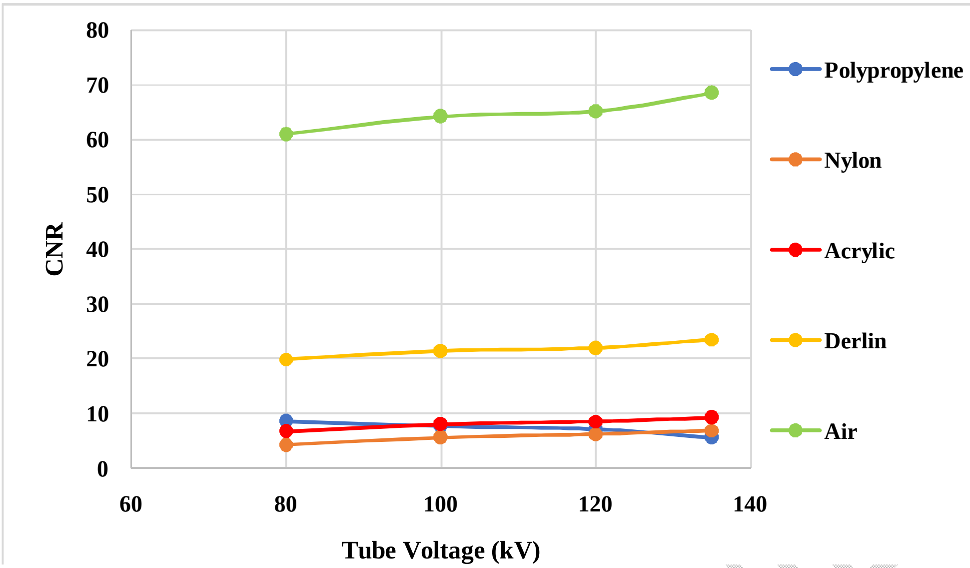

Figure 5. Graph of the relationship between tube voltage (x) and CNR value (y).

Table 7. Relationship function (y) and coefficient of determination (R^2)

Material	y	R^2
Polypropylene	-0,05x + 0,9365	0,9365
Nylon	0,0468x + 0,06657	0,9735
Acrylic	0,0437x + 3,4072	0,9681
Derlin	0,0614x+ 15,013	0,9562
Air	0,1259x + 50,993	0,9465

Table 7 shows the coefficient of determination (R^2)of each material for the CNR value. The results shown are that polypropylene material has a coefficient of determination value of 0.9365, nylon of 0.9735, acrylic of 0.9681, derlin of 0.9562, and air of 0.9465. So, the magnitude of the influence of tube voltage on the CNR value is 93.65% in polypropylene, 97.35% in nylon, 96.81% in acrylic, 95.62% in derlin, and 94.65% in air. Figures 4 and 5 show that there is a change in the SNR value due to the use of tube voltage, the greater the tube voltage, the greater the SNR and CNR values, which means that the image quality is getting better, except for polypropylene material which decreases with increasing tube voltage[10]. In Table 6 and Table 7 it can be observed that the tube voltage with SNR and CNR has a strong influence. This is because the comparison of the contrast ratio and the ratio between signal strength to noise and tube voltage has an important role in determining the SNR and CNR values. The size of the use of tube voltage depends on the diagnostic needs of the object to be examined[11]. After knowing that tube voltage is one of the important factors in the use of CTScan, it is necessary to have quality control and accuracy for evaluating tube voltage on CTScan[12].

4. CONCLUSION

This study shows that proper selection of tube voltage is very important for CT scan image quality. Voltages of 120 kV and 135 kV are recommended for materials such as nylon, acrylic, air, and derlin because they produce better SNR and CNR. The relationship between tube voltage and SNR and CNR depends on the physical properties and attenuation of the material. Materials with significant attenuation differences, such as derlin and air, show improved image quality. Conversely, materials such as polypropylene experience deterioration when the tube voltage is too high.

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