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

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:

Selecting the right tube voltage is important to optimize CT scan image quality, with 120 kV and 135 kV recommended for organs such as the kidney, liver, and lungs as they produce better SNR and CNR. Organs with significant attenuation differences show increased SNR and CNR, while soft tissues such as fat experience decreased contrast at high voltages. The use of tube voltage must be adjusted to diagnostic needs and evaluated through quality control according to BAPETEN regulation Number 2 of 2018.

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

1. INTRODUCTION

Computed Tomography Scanner(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 scans 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. Adjusting tube voltage is crucial as it can improve image resolution and enhance contrast between anatomical structures. Although higher tube voltage reduce noise, they can also reduce contrast in soft tissue. Noise, which is measured as the standard deviation of CT numbers in homogeneous materials, is influenced by exposure factors, detector sensitivity, and slice thickness[2].Optimizing tube voltage not only improves diagnostic accuracy by producing clearer images, but also enhances operational efficiency in hospitals, reducing the need for repeat scans and thereby saving time and costs. For patients, this optimization helps minimize unnecessary radiation exposure while maintaining diagnostic image quality. Clearer protocols also benefit medical staff, increasing both productivity and safety in their work environment[3].

1.1 X-ray

X-rays are a form of electromagnetic radiation 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[4]. 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[5]. The heated electron cloud releases energy and 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[6].

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[5].

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, derlin, acrylic, nylon, and polypropylene[7].

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 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 shown in Figure 1.

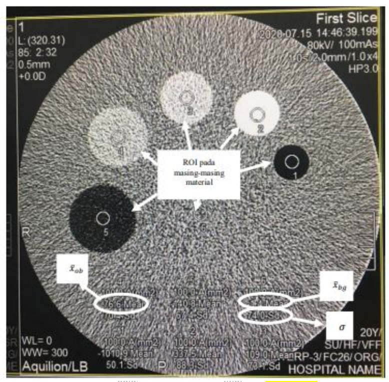

Figure 1. Phantom CT scan image.

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[8]. 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.

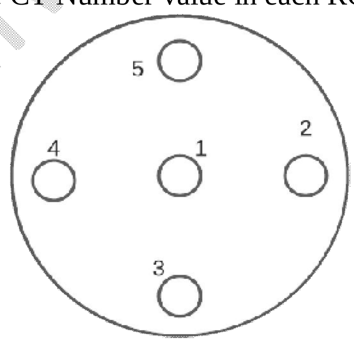

Figure 2. Illustration of the location of the CT Number value in each ROI.

The number 1 indicates the location of the CT 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. Several factors can affect the SNR value in CT scan, namely, Tube voltage (kV), tube current (mA), slice thickness, and Field of View (FOV)[9]. Systematically SNR can be written as follows:

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

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. The 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[10]. Systematically, CNR can be written as follows:

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

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 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 results 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.

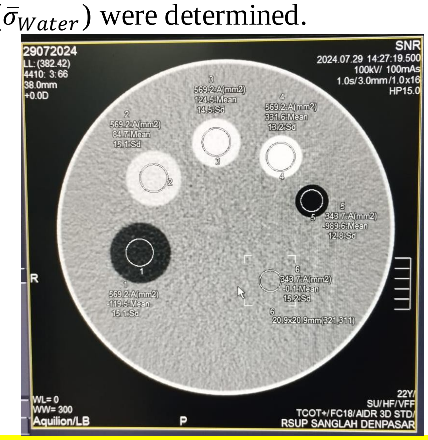

Figure 3. ROI reading at 100kV tube voltage phantom image.

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.

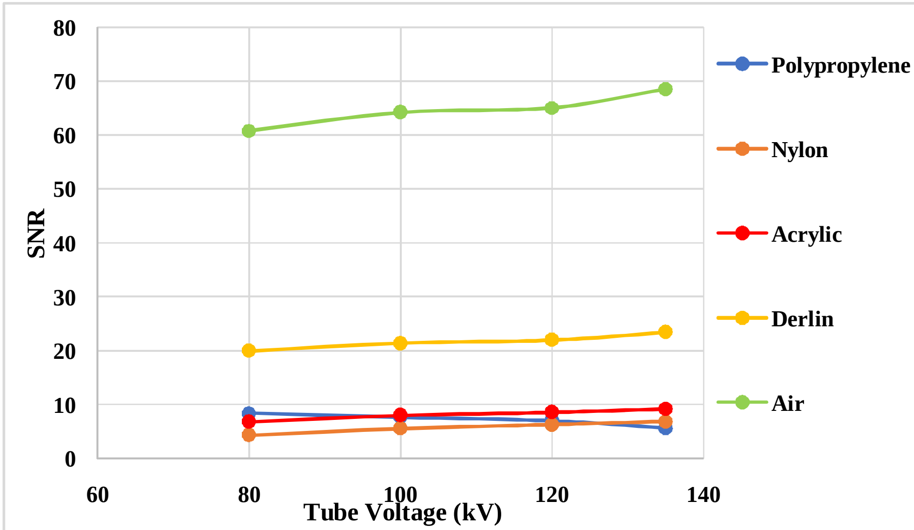

Figure 4. Graph of the relationship between tube voltage (x) and SNR value (y).

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 in air, it is 0.9422, meaning that 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%.

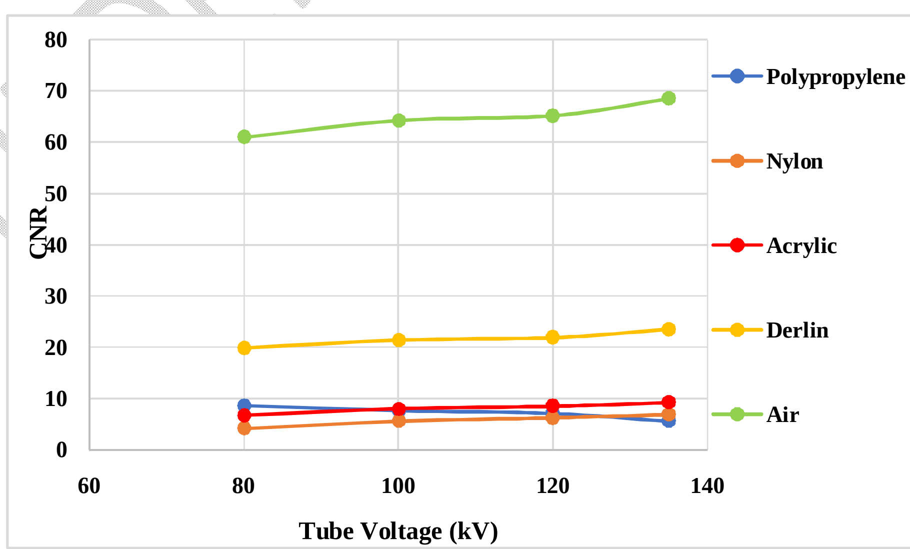

Figure 5. Graph of the relationship between tube voltage (x) and CNR value (y).

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)for the CNR value. The results show 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 the relationship between tube voltage and SNR and CNR values. It can be seen that higher tube voltage leads to higher SNR and CNR for nylon, acrylic, derlin, and air materials. However, for polypropylene, increasing the tube voltage results in a decrease in SNR and CNR values. In the context of medical imaging, organ simulations with various materials show a similar pattern. Derlin is used to simulate the liver or kidney, nylon for muscle tissue, acrylic for the abdomen, and air for the lungs. For these materials, SNR and CNR increase with increasing tube voltage.

Higher tube voltage produces more X-ray photons that reach the detector, directly improving SNR and CNR. This is crucial for obtaining clearer and more accurate images. At higher voltages, X-rays penetrate various materials more effectively, enhancing the signal and reducing noise, which contributes to the increase in SNR and CNR. However, materials like polypropylene, which resemble soft tissues such as fat, exhibit a decline in SNR and CNR at higher voltages[11]. This occurs because the difference in X-ray attenuation between polypropylene and other materials becomes smaller at higher voltages. The difference in material responses to increasing tube voltage is influenced by the X-ray attenuation properties of each material. Materials such as nylon, derlin, acrylic, and air show significant increases in SNR and CNR at 120 kV and 135 kV, due to the clear contrast between these materials and others. In contrast, polypropylene demonstrates a decrease in SNR and CNR as the difference in attenuation diminishes at higher voltages.

Tables 6 and 7 indicate that tube voltage significantly affects the SNR and CNR values. Higher tube voltage yields a better signalratio and improves the contrast ratio between the object and the background, both of which are essential factors in determining SNR and CNR. Tube voltage plays a crucial role in determining the quality of CT scan images. The voltage level used depends on the diagnostic requirements of the object being examined[12]. Therefore, it is important to regularly perform quality control and accuracy evaluation of the tube voltage to ensure optimal and accurate imaging results in accordance with BAPETEN Regulation Number 2 of 2018 concerning the Suitability Test of Diagnostic and Interventional Radiology X-Ray Machine[13].

4. CONCLUSION

Based on the results of this study, it can be concluded that choosing the right tube voltage is very important to optimize the quality of CT Scan images. For kidneys, liver, lungs, abdomen, and muscle tissue, a voltage of 120 kV and 135 kV is recommended because it produces better SNR and CNR. The relationship between tube voltage and SNR and CNR is greatly influenced by the physical properties and attenuation of the material/organ being scanned. Organs that have significant attenuation differences such as the liver, kidneys, and lungs show a significant increase in SNR and CNR. Conversely, soft tissues such as fat experience a decrease due to small attenuation differences as the tube voltage increases too high. The use of tube voltage in CT Scan must be adjusted to diagnostic needs and evaluated accurately through quality control, according to BAPETEN regulation Number 2 of 2018 concerning the Suitability Test of Diagnostic and Interventional Radiology X-Ray Machines.

DISCLAIMER

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

REFERENCES

[1] S. Wahyuni and L. Amalia, "Perkembangan Dan Prinsip Kerja Computed Tomography (CT Scan)," *Galen. J. Kedokt. dan Kesehat. Mhs. Malikussaleh*, vol. 1, no. 2, p. 88, 2022, doi: 10.29103/jkkmm.v1i2.8097.

[2] I. N. Karimah, "Optimalisasi Kualitas Citra CT Scan dengan Variasi Arus Tabung dan Metode Scan," Surabaya, 2020. [Online]. Available: https://repository.unair.ac.id/102915/1/1. HALAMAN JUDUL.pdf

[3] A. Noveranty, S. Purwaningsih, and Y. Fendriani, "35155-Article Text-108444-1-10-20240805," vol. 9, no. 3, pp. 53–59, 2024.

[4] Y. Pertiwi, V. M. Sella, and J. Iskandar, "Analysis of Quality Control Computerized Tomography Scan (Ct Scan) Results in Indonesia Based on National and International Standards," no. 2021, pp. 108–116, 2021.

[5] A. Dwi Prastanti *et al.*, "Jurnal Imejing Diagnostik Optimalisasi Tegangan Tabung (kVp) Terhadap Kejelasan Informasi Anatomi dan Dosis Radiasi Pada Pemeriksaan CT SCAN Kepala Area Basis Cranii," *J. Imejing Diagnostik*, vol. 8, pp. 141–148, 2022, [Online]. Available: http://ejournal.poltekkes-smg.ac.id/ojs/index.php/jimed/index

[6] M. Alshipli and N. A. Kabir, "Effect of slice thickness on image noise and diagnostic content of single-source-dual energy computed tomography," *J. Phys. Conf. Ser.*, vol. 851, no. 1, 2017, doi: 10.1088/1742-6596/851/1/012005.

[7] I. A. P. A. Hutami, G. N. Sutapa, and I. B. A. Paramarta, "Analisis Analisis Pengaruh Slice Thickness Terhadap Kualitas Citra Pesawat CT Scan Di RSUD Bali Mandara," *Bul. Fis.*, vol. 22, no. 2, p. 77, 2021, doi: 10.24843/bf.2021.v22.i02.p04.

[8] L. P. R. Kusumaningsih, I. B. M. Suryatika, N. L. P. Trisnawati, and R. Irhas, "Pengaruh Slice Thickness terhadap Signal to Noise Ratio (SNR) dari Hasil Penyinaran CT Scan di RSUP Prof. Dr. I.G.N.G Ngoerah," *Kappa J.*, vol. 7, no. 2, pp. 326–330, 2023, doi: 10.29408/kpj.v7i2.7675.

[9] T. Mustafidah, R. Rulaningtyas, and A. Muzammil, "Mustafidah T, Rulaningtyas R, Muzammil A, Katherine. CT-Scan Image Opti- mization with Tube Current Variation in Some Kernel Filters Based on Signal to Noise Ratio (SNR) Value. Hell J Radiol 2022; 7(4): 2-11.," vol. 7, no. 4, pp. 2–11, 2022.

[10] A. Y. Nurhayati, N. N. Nariswari, B. Rahayuningsih, and Y. C. Hariadi, "Analisis Variasi Faktor Eksposi dan Ketebalan Irisan Terhadap CTDI dan Kualitas Citra Pada Computed Tomography Scan," *Berk. Sainstek*, vol. 7, no. 1, p. 7, 2019, doi: 10.19184/bst.v7i1.9913.

[11] X. Ma, M. Buschmann, E. Unger, and P. Homolka, "Classification of X-Ray

Attenuation Properties of Additive Manufacturing and 3D Printing Materials Using Computed Tomography From 70 to 140 kVp," *Front. Bioeng. Biotechnol.*, vol. 9, no. November, pp. 1–13, 2021, doi: 10.3389/fbioe.2021.763960.

[12] Louk, A. Christian, Suparta, and G. Bayu, "Pengukuran Kualitas Sistem Pencitraan Radiografi Digital Sinar-X Quality Measurement of Imaging System of X-ray Digital Radiography," *Berk. MIPA*, vol. 24, no. 2, pp. 149–166, 2014.

[13] N. K. Abdulkareem, S. I. Hajee, F. F. Hassan, I. K. Ibrahim, R. E. H. Al-Khalidi, and N. A. Abdulqader, "Investigating the slice thickness effect on noise and diagnostic content of single-source multi-slice computerized axial tomography," *J. Med. Life*, vol. 16, no. 6, pp. 862–867, 2023, doi: 10.25122/jml-2022-0188.