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Evaluation of the influence of factors on $CTDI_{vol}$ and CNR in CT-Scan thorax procedures

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Abstract

This study investigates the effect of exposure parameter variations in CT-Scan on image quality and radiation dose during thoracic examinations. The exposure parameters analyzed were tube voltages of 80, 100, and 120 kV, along with tube currents of 100, 200, and 300 mA. A quantitative approach was employed using a Cannon TOS air phantom at the Radiology Department of Bhayangkara Hospital Jambi with a Toshiba 16-slice CT-Scan unit. Radiation dose was obtained from $CTDI_{vol}$ values displayed on the CT console, while image quality was evaluated using the Contrast to Noise Ratio (CNR) calculated with RadiAnt DICOM Viewer software. The research method included obtaining the Computed Tomography Dose Index volume (CTDIvol) directly from the scanner console for each exposure setting, while the Contrast-to-Noise Ratio (CNR) was calculated by measuring the mean intensity of the region of interest (ROI) on the phantom and the standard deviation of the background area to quantify image contrast relative to noise. The findings demonstrate that both tube voltage and current strongly influence $CTDI_{vol}$ and CNR. Higher exposure settings increased radiation dose, with several combinations exceeding the recommended safety threshold. At 100 mA, all tube voltages remained below the BAPETEN regulatory limit of 11 mGy for non-contrast thoracic scans. Similarly, 200 mA at 80 and 100 kV remained within safe limits, while 200 mA at 120 kV slightly exceeded the threshold. Doses rose markedly at 300 mA, particularly at 120 kV, reaching values far above the permissible limit.

Keywords: CT-Scan; exposure factors; $CTDI_{vol}$; CNR; thorax.

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INTRODUCTION

Advancements in health technology, particularly in the field of radiology, utilize various medical imaging techniques for disease diagnosis and treatment. Radiology employs technologies such as X-rays, CT scans, and MRI to produce detailed images of internal organs (Fitriani et al., 2020). Computed Tomography Scan (CT Scan) is a medical imaging technique that uses X-ray radiation to generate detailed images of the internal structures of the human body. CT scans are widely used in clinical practice to support the diagnosis of various conditions, such as examinations of the head, chest cavity, and abdominal cavity (Siregar et al., 2020). In thoracic examinations, CT scans play an important role in detecting infections, tumors, and other abnormalities through spiral or axial scanning techniques. However, due to the relatively high radiation dose compared to other imaging methods, dose optimization is necessary to minimize risks to patients (Nurhayati et al., 2019).

Exposure factors are parameters that control the characteristics of X-ray photons in terms of quantity and quality during radiographic image production (Melti et al., 2024). The main exposure factors in CT scans include tube voltage (kV), tube current (mA), scan time (mAs), and slice thickness. Tube voltage determines the energy of the generated X-ray photons, which affects their penetration ability through body tissues. Tube current is related to the number of X-ray photons produced per unit time, while scan time determines the duration of exposure.

Variations in exposure factors have a direct impact on the radiation dose received by the patient and the quality of the resulting image. Increases in tube voltage and current tend to raise the radiation dose, which is measured by the Computed Tomography Dose Index volume (CTDIvol). Higher kV and mA settings can improve image quality by reducing noise and enhancing the Contrast-to-Noise Ratio (CNR). Therefore, optimizing image quality while limiting radiation dose is essential to ensure patient safety and diagnostic effectiveness (Kartasasmita et al., 2021).

A study conducted by Noveranty (2024) analyzed the effect of varying kV and mA on CNR and CTDIvol in CT scan examinations. The study utilized abdominal examination parameters using a phantom. The findings showed that changes in exposure factors affected CTDIvol values, while CNR values did not exhibit a consistent pattern with increasing tube voltage or current, and were also influenced by other technical factors. Meanwhile, research by Sukanta et al. (2022), which analyzed the effect of voltage variation on CNR and CTDI, revealed that changes in kV affected CTDI, with higher kV values corresponding to an increase in CTDI.

This study aims to investigate how changes in tube voltage and current in CT scans affect image quality and radiation dose in thoracic examinations, referring to several previous studies. The study uses CNR and CTDIvol parameters as the main indicators to assess image quality and radiation dose levels. Although many studies have examined exposure factors in CT scans, research specifically focusing on thoracic examinations remains limited. Therefore, this study is expected to provide strategies for optimizing thoracic CT scan protocols to achieve optimal diagnostic image quality with minimal radiation dose, while also contributing to improving the quality of radiology services at Bhayangkara Hospital Jambi.

X-rays are a form of electromagnetic radiation that belong to the same group as radio waves and ultraviolet rays but have much shorter wavelengths, allowing them to penetrate various types of materials. This radiation has several physical characteristics, including penetrating ability, scattering, absorption, photographic effects, ionization, and biological effects (Souisa et al., 2014). CT Scan, or Computed Tomography Scan, is a medical imaging technique that uses X-rays to produce cross-sectional images of the body. The scanning process in CT involves rotating the X-ray source around the patient, producing a series of cross-sectional images of the body. Although CT scans provide highly valuable diagnostic information, it is important to minimize patient exposure to radiation. Therefore, radiation dose control and the use of proper techniques are essential to ensure patient safety during the procedure (Prameswari et al., 2024).

The radiation dose in thoracic CT scan examinations refers to the amount of ionizing radiation received by the patient during the imaging procedure. This dose is measured using several parameters, including CTDI and DLP. CTDI provides an estimate of the radiation dose absorbed by body tissues during a single scan, while DLP measures the total radiation dose based on the length of the scanned area (Raharjo et al., 2015).

On the other hand, optimal image quality in CT scans refers to images that have high contrast, good sharpness, and minimal noise, allowing for accurate detection of anatomical structures and abnormalities. Image quality is crucial in medical diagnosis because clear and informative images assist physicians in making accurate clinical decisions. To achieve optimal image quality, it is important to carefully adjust technical parameters such as tube voltage, current, and slice thickness (Irsal et al., 2021).

RadiAnt DICOM Viewer is a software application designed to display and process medical images in the DICOM (Digital Imaging and Communications in Medicine) format. The software supports various imaging modalities, including Digital Radiography (CR, DX), Mammography (MG), Computed Tomography (CT), Ultrasonography (USG), Nuclear Medicine (NM), and others. RadiAnt DICOM Viewer can handle various types of DICOM files, both monochromatic and colored, static and dynamic, as well as compressed and uncompressed images (Medixant, 2021).

METHODS

Type of Research

This study employs a quantitative research method, which produces measurable data expressed numerically through experimentation. The research was conducted in the Radiology Department of Bhayangkara Hospital Jambi using a Toshiba 16-slice CT Scan machine. The object of study utilized a phantom as a representation of the human body in medical imaging, while image quality analysis was performed using the RadiAnt DICOM Viewer software.

Image Scanning

The scanning process was carried out by positioning the water phantom on the CT table following the thorax protocol, entering fictitious patient data, and determining the scan area. The phantom was placed at the gantry isocenter using alignment lasers and aligned with the longitudinal axis of the table to ensure accurate positioning. The examination utilized fixed parameters including a rotation time of 0.75 seconds, slice thickness of 5 mm, a pitch of 1.0, and an FOV of 350 mm, while the varied parameters included tube voltage (80, 100, and 120 kV) and tube current (100, 200, and 300 mA). The scanning length was set to 150 mm to cover the central portion of the phantom and ensure homogeneous imaging. Each parameter combination was repeated three times in a single session to maintain consistency and avoid variation caused by repositioning. The scanning results were obtained in DICOM format and analyzed using RadiAnt DICOM Viewer, while the CTDIvol values used as radiation dose indicators were taken directly from the CT system display.

Data Analysis

Determining the $CTDI_{vol}$ Value

In this study, data acquisition was performed three times for each parameter combination to ensure consistency. However, in CT examinations, the CTDIvol value is an automated output generated by the CT system based on the selected exposure parameters. This value is fixed and does not change as long as the same scanning parameters are applied. Consequently, even though the data were collected in three repetitions, the CTDIvol values obtained were identical in every measurement. The $CTDI_{vol}$ value was analyzed based on the phantom scanning results following the thoracic examination procedure. CTDIvol (Computed Tomography Dose Index Volume) represents the amount of radiation dose absorbed by the body or phantom during one CT scan session. CTDI is calculated based on the radiation dose profile generated by the CT scanner and serves as an important indicator for assessing the safety and effectiveness of the CT procedure (Bushberg et al., 2012). The CTDIvol value is automatically displayed on the computer console after the phantom scanning process is completed using the CT scanner (Alzufri & Dede, 2023).

The analysis of exposure factors on CTDIvol was performed by organizing the data in tables using Microsoft Excel and presenting them in graphical form. In this study, Microsoft Excel was used solely as a supporting tool to organize the collected data into tables, generate visual graphs, and facilitate the comparison of results across the three scan parameter variations. Excel was not employed as the primary analytical platform; all statistical analyses were conducted independently based on the calculation of mean values, standard deviations, and the evaluation of statistical significance using appropriate statistical methods. The purpose of utilizing Excel was strictly to provide visual representation and to enhance the clarity of observed trends in CTDIvol and CNR values among the different parameter settings, thereby enabling a more objective interpretation of the data. The use of spreadsheet software for graphical visualization is commonly adopted in radiological research to optimize the presentation of results without influencing the integrity of statistical analysis. The results were then verified according to BAPETEN Regulation No. 1211/K/V/2021 concerning diagnostic dose guidelines for CT scans and general radiography. This study focuses on non-contrast thoracic CT scans with a reference dose of 11 mGy.

Determining the CNR Value

CNR (Contrast-to-Noise Ratio) is a measurement used to assess how clearly or distinctly an object appears in a CT scan image compared to its background. A high CNR value indicates that the object appears clear and easily distinguishable from its surroundings, while a low CNR value suggests that the image appears blurry (Listiyani et al., 2021). The images obtained in DICOM format were processed using the RadiAnt DICOM Viewer software to calculate the mean object value, mean background value, and standard deviation through the determination of the Region of Interest (ROI) in the image. ROI refers to a specific area in a medical image selected for detailed analysis. ROIs are classified into two types: object ROI and background ROI. The object ROI was placed on an area representing the primary structure, such as phantom materials like acrylic, delrin, or nylon, while the background ROI was positioned on a homogeneous region representing water or air as a reference. The ROI size was kept constant at approximately ±5 mm² to ensure uniformity across all measurements, preventing variability in results caused by differences in ROI placement or size. Accurate ROI positioning is crucial, as inaccuracies in selecting the location, size, or homogeneity of the analysis area may lead to calculation errors and reduce the reliability of image quality evaluation outcomes. (Alzufri & Nurmiati, 2023). Steps for Determining the CNR Value:

a. After scanning, the phantom images are saved in DICOM format.
b. The images are opened using the RadiAnt DICOM Viewer software.
c. Two regions, known as ROIs, are determined — one for the object and one for the background. The object ROI is positioned in the area representing the main tissue, while the background ROI is placed in a low-contrast area.

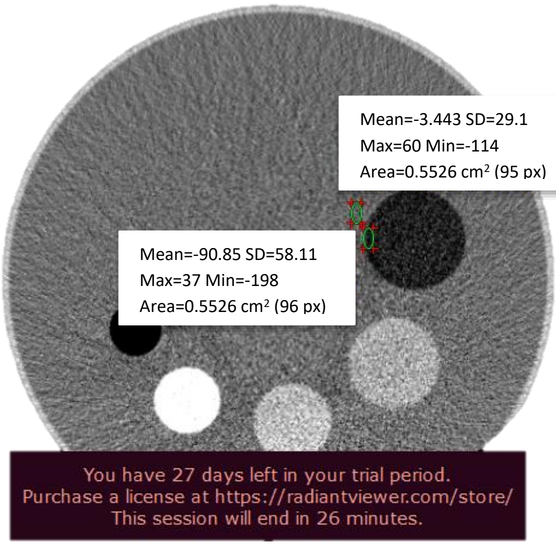

Figure 1. ROI Selection on the Image.

d. From each ROI, the mean object value, mean background value, and standard deviation (SD) are obtained, as shown in Figure 1.
e. Once the data are collected, the CNR value is calculated using Equation 1.

$$CNR = \frac{\bar{X}_{ob} - \bar{X}_{bg}}{\sigma} \quad (1)$$

Where $\bar{X}ob$ represents the mean value of the object ROI (HU), $\bar{X}bg$ represents the mean value of the background ROI (HU), and σ represents the standard deviation value of the background ROI.

According to the Diagnostic Reference Levels stated in BAPETEN Regulation No. 2 of 2022, a CNR value above 1.0 is considered adequate for adult thoracic images, as it indicates clear contrast and low noise. CNR serves as a benchmark for comparing image results obtained from different combinations of tube voltage (kV) and tube current (mA), thereby helping to determine the optimal exposure settings (Nurhayati, 2019).

RESULTS AND DISCUSSION

Radiation Dose ($CTDI_{vol}$)

In this study, the analysis was carried out using a Toshiba 16-slice CT scanner with a water phantom as the object to evaluate the effect of kV and mA on $CTDI_{vol}$ values. The measurement results are presented in Table 1 as the basis for optimizing exposure parameters.

Table 1. Measurement Results of $CTDI_{vol}$ Values for Variations in Tube Voltage (kV) and Tube Current (mA).

Tube Current (mA)	Rotation Time (s)	Tube Voltage (kV)	$CTDI_{vol}$ (mGy)
		80	2,1
100	0,75	100	3,7
		120	5,8
		80	4,2
200	0,75		7,5

Tube Current (mA)	Rotation Time (s)	Tube Voltage (kV)	$CTDI_{vol}$ (mGy)
		100	11,6
		120	
		80	6,3
300	0,75	100	12,3
		120	19,2

In a medical imaging procedure such as a CT scan, it is essential to understand how imaging parameters influence the radiation dose received by patients. One commonly used indicator to evaluate radiation exposure levels is $CTDI_{vol}$. This value reflects the amount of radiation administered during the examination and is influenced by several factors, primarily tube voltage and tube current. Understanding the relationship between these parameters and $CTDI_{vol}$ values is crucial for maintaining a balance between image quality and patient safety.

In CT scan examinations, parameters such as tube voltage (kV) and tube current (mA) have a significant impact on both the radiation dose received by the patient and the quality of the resulting images. Increasing the tube voltage produces X-rays with higher energy and greater penetration power, allowing more photons to pass through and be absorbed by body tissues. This directly leads to an increase in radiation dose. However, on the other hand, higher X-ray energy can reduce image noise and improve the Contrast-to-Noise Ratio (CNR), resulting in clearer and more informative images.

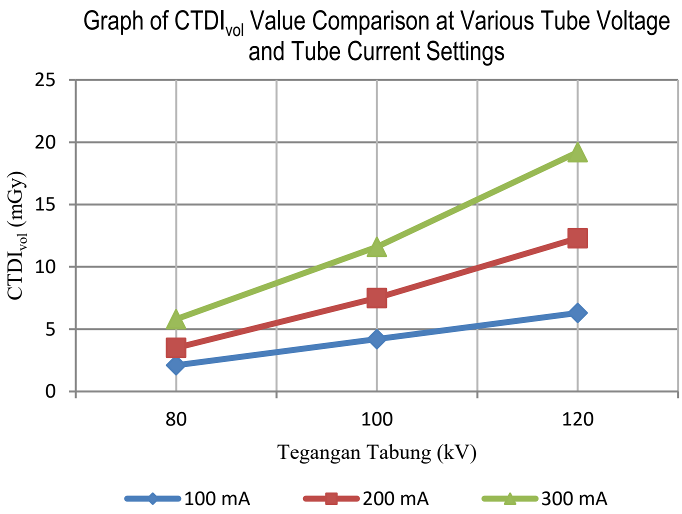

Figure 2. Distribution of $CTDI_{vol}$ Values at Various Tube Voltage (kV) and Tube Current (mA) Settings

Based on the analysis in Figure 2, it can be observed that $CTDI_{vol}$ values increase with rising tube voltage (kV) and tube current (mA). This is consistent with the fundamental principles of radiation physics, where higher voltage accelerates electrons from the cathode to the anode, producing high-energy X-rays with greater penetrating power (Sukanta et al., 2022). This condition causes more radiation to be absorbed by body tissues, thus increasing the patient's radiation dose. Meanwhile, tube current controls the number of electrons in motion, which directly affects the number of X-ray photons generated. The simultaneous increase in both parameters amplifies the overall radiation dose effect.

Based on $CTDI_{vol}$ measurements, the results show that radiation dose tends to increase in line with the rise of both parameters. At a tube current of 100 mA with tube voltages of 80 kV, 100 kV, and

120 kV, all $CTDI_{vol}$ values remain within the safety limits recommended by BAPETEN, which is 11 mGy for non-contrast thoracic examinations. A similar trend is observed at a tube current of 200 mA with voltages of 80 kV and 100 kV, where the radiation dose remains within the standard range. However, at the combination of 200 mA and 120 kV, the dose increases to 11.6 mGy, slightly exceeding the recommended threshold. A more significant increase in dose occurs at 300 mA, with CTDIvol values reaching 12.3 mGy at 100 kV and 19.2 mGy at 120 kV. This condition indicates a risk of radiation overexposure if such parameters are applied. Therefore, exposure factor optimization is necessary to maintain adequate diagnostic image quality while ensuring that radiation doses remain within safe limits for patients.

Hence, optimization of all technical parameters is essential to achieve a balance between keeping radiation doses as low as reasonably achievable and maintaining diagnostic image quality, in accordance with the ALARA (As Low As Reasonably Achievable) principle.

Image Quality

Image quality in CT scan examinations plays a crucial role in ensuring the accuracy of diagnostic information, thereby supporting clinical decision-making by medical professionals. One of the quantitative parameters commonly used to assess image quality is the Contrast-to-Noise Ratio (CNR), which represents the ratio indicating how distinctly the target object can be differentiated from the background in the presence of noise in the image. A higher contrast value allows for easier distinction between signal and background.

Table 2. Measurement Results of CNR Values at Various Tube Voltage and Tube Current Settings

Tube Current (mA)	Tube Voltage (kV)	Area ROI (cm^2)	ROI Objek		ROI Background		CNR
			Mean (HU)	SD	Mean (HU)	SD	
100	80	0,555	-103,12	43,93	-3,58	2,64	2,64
	100	0,557	-90,85	58,11	-3,44	29,1	3,00
	120	0,552	-96,35	22,69	-2,59	28,74	3,26
200	80	0,552	-135,3	38,97	-13,0	38,95	3,13
	100	0,552	-99,18	28,16	-4,66	28,05	3,36
	120	0,552	-84,4	26,44	-1,86	3,54	3,54
300	80	0,555	-93,66	58,99	-4,58	29,65	2,98
	100	0,555	-94,66	37,57	-9,97	26,83	3,15
	120	0,554	-82,21	17,65	2,074	32,71	3,42

Based on Table 2, it can be seen that the CNR values vary across the three combinations of tube voltage and tube current. The following graph illustrates the comparison of CNR values in thoracic CT scan examinations.

Based on the analysis presented in Figure 3, it can be observed that the CNR value increases as the tube voltage (kV) and tube current (mA) are increased. This indicates that both parameters have a significant influence on the image quality produced in CT-Scan examinations. Higher tube voltage contributes to an increase in X-ray photon energy, while higher tube current generates a larger number of X-ray photons, which overall enhances image contrast and reduces noise.

In the graph shown in Figure 3, the highest CNR value was obtained at the combination of 120 kV and 200 mA, reaching 3.54. Meanwhile, the combinations of 120 kV with 100 mA and 300 mA produced CNR values of 3.26 and 3.42, respectively. This demonstrates that increasing tube current does not always produce a linear increase in CNR. At 80 kV and 100 mA, the CNR value was 2.64, while at 300 mA it was 2.98, and at 200 mA it increased to 3.13. Although theoretically, increasing the tube current (mA) should increase the number of photons, thereby reducing noise and improving CNR, the results of this study show that 200 mA produced a higher CNR value compared to 300 mA.

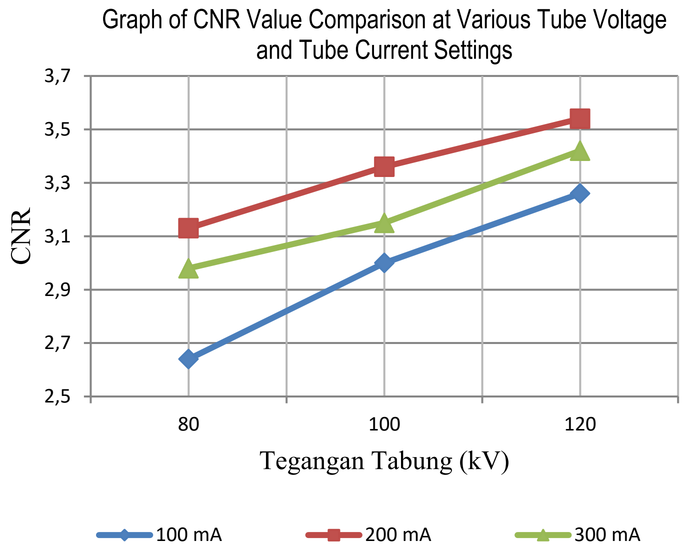

Figure 3. CNR Values at Different Tube Voltage and Tube Current Variations

According to Bushberg et al. (2012) in The Essential Physics of Medical Imaging, CT detector response has a saturation limit, in which increasing X-ray intensity no longer results in a proportional increase in signal due to the limitations of detector energy conversion efficiency. This leads to a compensatory effect in the calculation of the contrast-to-noise ratio (CNR). At the 300 mA setting, the CNR value decreases due to saturation effects and increased scatter radiation detected by the system. This indicates that although the number of photons increases, it does not always correspond to an improvement in image quality because the detector signal approaches its optimal threshold.

These findings suggest that the combination of tube voltage and tube current must be optimized to achieve the best possible image quality. The irregular increase in CNR values is likely caused by increased image noise resulting from higher scatter radiation at greater voltages. As explained by Nurhayati (2019), increasing voltage and current simultaneously does not always produce a stable improvement in CNR. Meanwhile, according to Herlinda (2019), increasing tube voltage raises X-ray photon energy and shortens the wavelength, thereby reducing X-ray attenuation in tissues and affecting the resulting image contrast.

According to regulations issued by the Nuclear Energy Regulatory Agency (BAPETEN), a CNR value above 1.0 is considered adequate for clinical diagnosis, consistent with diagnostic image quality standards used by radiology practitioners in Indonesia, as outlined in BAPETEN's publication at the 2023 Nuclear Safety Seminar (SKN). Therefore, selecting appropriate imaging technical parameters is essential to ensure optimal image quality while keeping radiation dose as low as possible. In practice, exposure parameter settings must be adjusted based on the type of examination, patient body size, and anatomical location being evaluated. The use of an Automatic Exposure Control (AEC) system can efficiently regulate imaging parameters to produce high-quality images while maintaining radiation exposure within acceptable safety limits.

Based on the results of this study, the combination of a 100 kV tube voltage and 200 mA tube current was found to be the most optimal setting for thoracic CT-Scan examinations. This combination produced high-quality images with a high CNR value while maintaining the radiation dose at a safe level. The obtained CTDIvol value remained below the recommended limit established in BAPETEN Regulation No. 1211/K/V/2021 for non-contrast thoracic examinations, which is 11 mGy. Thus, this protocol is considered effective in achieving a balance between diagnostic image quality and patient safety. The highest CNR value was achieved at 200 mA because, at this current, the number of X-ray photons produced was sufficient to suppress image noise, thereby improving image quality optimally. In comparison, at 100 mA, the lower number of photons resulted in higher noise and lower CNR, whereas at 300 mA, despite producing more photons, the increase in CNR was not significant and resulted in a higher radiation dose. Therefore, the use of the 100 kV and 200 mA combination is recommended as the optimal protocol because it provides high-quality images while keeping radiation exposure within safe limits, consistent with the ALARA (As Low As Reasonably Achievable) principle.

CONCLUSION

Based on the results of this study on the effect of variations in exposure factor parameters on $CTDI_{vol}$ and CNR values in thoracic CT scan examinations using a water phantom, it can be concluded that:

Variations in tube voltage and tube current were proven to influence $CTDI_{vol}$ and CNR values, where an increase in both parameters led to a rise in radiation dose. The variations in tube voltage at constant tube currents of 100 mA and 200 mA produced radiation doses that remained within the safety limits set by BAPETEN Regulation No. 1211/K/V/2021 (2021) for non-contrast thoracic examinations, which is 11 mGy.

The increase in tube voltage and tube current also affected the rise in CNR values. All obtained CNR values were above 1.0, exceeding the Diagnostic Reference Level (DRL) stated in BAPETEN Regulation No. 2 of 2022 for non-contrast thoracic CT scan examinations. Therefore, these results are considered safe and in accordance with the ALARA (As Low As Reasonably Achievable) principle.

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