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Linearity Test of CT Number and Spatial Resolution Using ACR 464 Phantom for Image Quality Assessment on a 16-Slice CT Scanner

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ABSTRACT

This study was conducted to test the linearity of CT Numbers and spatial resolution in CT scan images using the American College of Radiology (ACR) 464 Phantom. The objectives of this study are to determine the correlation coefficient of the linear relationship between CT Numbers and electron density, as well as to determine the spatial resolution and the effect of slice thickness on CT scan image quality. The slice thickness variations used were 1.0 mm, 2.0 mm, and 4.0 mm. CT Numbers were obtained by placing a circular ROI with a diameter of 20 mm, using a tube voltage of 120 kV and a tube current of 300 mA. The measurement results showed that the linearity correlation coefficients between CT Numbers and electron density were 0.9997 for a slice thickness of 1.0 mm, 0.9996 for 2.0 mm, and 0.9995 for 4.0 mm, with all values passing the test requirement of $R^2 \geq 0.99$. The spatial resolution measurements resulted in values of 0.5 lp/mm, 0.6 lp/mm, and 0.7 lp/mm for each slice thickness, all of which met the minimum requirement of 0.5 lp/mm according to the BAPETEN Regulation No. 2 of 2018 regarding the acceptance criteria for X-ray CT scanner conformity tests.

Keywords: ACR 464 Phantom, CT-Number Linearity, CT-Scan, ROI, Spatial Resolution

ABSTRAK

Penelitian ini dilakukan untuk menguji linearitas CT Number dan resolusi spasial pada citra CT-Scan menggunakan American College of Radiology (ACR) 464 Phantom. Tujuan penelitian ini adalah untuk menentukan koefisien korelasi dari linearitas hubungan antara nilai CT Number dan densitas elektron, serta untuk menentukan nilai resolusi spasial dan pengaruh ketebalan irisan (slice thickness) terhadap kualitas citra CT-Scan. Variasi ketebalan irisan yang digunakan adalah 1.0 mm, 2.0 mm, dan 4.0 mm. Nilai CT Number diperoleh dengan penempatan ROI berbentuk lingkaran berdiameter 20 mm, menggunakan tegangan tabung sebesar 120 kV dan arus tabung sebesar 300 mA. Hasil pengukuran menunjukkan koefisien korelasi linearitas antara CT Number dan densitas elektron pada ketebalan irisan 1.0 mm sebesar 0,9997; 2.0 mm sebesar 0,9996; dan 4.0 mm sebesar 0,9995, dengan semua nilai memenuhi syarat uji $R^2 \geq 0{,}99$. Pengukuran resolusi spasial menunjukkan nilai masing-masing untuk ketebalan irisan yaitu 0,5 lp/mm; 0,6 lp/mm; dan 0,7 lp/mm, yang semuanya memenuhi syarat minimal 0,5 lp/mm sesuai dengan standar peraturan BAPETEN No. 2 Tahun 2018 tentang parameter uji kesesuaian pesawat sinar-X CT-Scan.

Kata kunci: ACR 464 Phantom, CT-Scan, Linearitas CT Number, Resolusi Spasial, ROI

1. Introduction

Modern CT scanners offer isotropic spatial resolution, enabling the creation of high-quality three-dimensional (3D) images, including axial, coronal, and sagittal sections. Such advanced imaging capabilities are crucial for meeting clinical examination requirements and ensuring accurate diagnostic results. Image quality testing is an integral part of CT scan quality assurance programs, as it directly influences diagnostic accuracy and overall patient care. Adherence to BAPETEN regulations is essential, as these guidelines stipulate testing for various parameters, including CT number accuracy, uniformity, linearity, spatial resolution, and slice thickness conformity [1]-[3].

The reliability of CT scan image quality testing depends significantly on the use of phantoms. The American College of Radiology (ACR) 464 Phantom is widely recognized and extensively utilized. Numerous multicenter studies have demonstrated its effectiveness in evaluating and monitoring image quality, making it a valuable tool for ensuring consistent imaging performance over time [4]-[7].

Among the critical parameters assessed during image quality testing is CT number linearity. [8]-[10] This measurement evaluates whether the imaging system accurately reflects the density of the object being imaged, with higher-density objects appearing brighter in the images. Additionally, spatial resolution is assessed to determine the level of detail the imaging system can display, particularly the smallest discernible objects [1]. Both parameters are essential for ensuring the imaging system meets the high standards for precise diagnostics.

This study aims to test CT number linearity and spatial resolution using the ACR 464 Phantom. It also investigates how variations in slice thickness affect CT image quality, providing a comprehensive analysis of key factors that influence imaging performance.

2. Methods

2.1. CT Number Linearity Test Method

The phantom was placed on the examination table and scanned using predetermined exposure factors and slice thicknesses. A Region of Interest (ROI) was defined for each material in the phantom to obtain the resulting CT number values. These CT number values were recorded, and a graph of CT number versus electron density was created to analyze the relationship between the two. The linear regression coefficient (R^2) was used to determine the extent to which the regression line accurately predicts the relationship between CT number and electron density.

2.2. Spatial Resolution Test Method

The phantom was placed on the examination table and scanned using predetermined exposure factors and slice thicknesses. After the scan was completed, the results obtained from the phantom scan were evaluated. This evaluation aimed to assess the spatial resolution and overall image quality.

3. Results and Discussion

3.1. CT Number Linearity Test

The CT number linearity test aims to determine the correlation coefficient of the linear relationship between CT number values and electron density. Figures 1(a), 1(b), and 1(c) depict the image results of the CT number linearity test under different slice thicknesses.

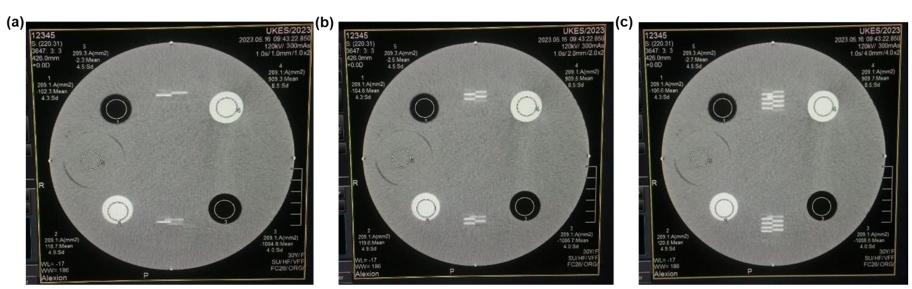

Figure 1. Image results of CT number linearity test under different slice thicknesses: (a) 1.0 mm, (b) 2.0 mm, and (c) 4.0 mm.

Table 1 shows the CT Number and electron density values for slice thickness variations. The electron density values are as follows: 0 g/cm³ for air, 0.94 g/cm³ for polyethylene, 1.02 g/cm³ for water, and 1.15 g/cm³ for acrylic. According to [11], a higher electron density in a material corresponds to a higher CT number value. CT number represents the average attenuation of X-rays for each pixel in the CT image. The composition and density of the tissue in each patient voxel determines the linear attenuation coefficient. Higher electron density in a tissue increases the likelihood of X-ray interaction with the tissue, resulting in higher attenuation. This means tissues with higher electron densities will exhibit more significant attenuation and, therefore, higher CT numbers.

Table 1. CT Number and electron density values for slice thickness variations.

Slice Thickness (mm)	Materials	Electron Density (g/cm^3)	CT Number (HU)
	Air	0	-1004.8
1.0 mm	Polyethilene	0.94	-102.3
	Water	1.02	-2.3
	Acrylic	1.15	118.7
	Air	0	-1006.7
2.0 mm	Polyethilene	0.94	-104.6
	Water	1.02	-2.5
	Acrylic	1.15	119.6
	Air	0	-1008.6
4.0 mm	Polyethilene	0.94	-106.6
	Water	1.02	-2.7
	Acrylic	1.15	120.5

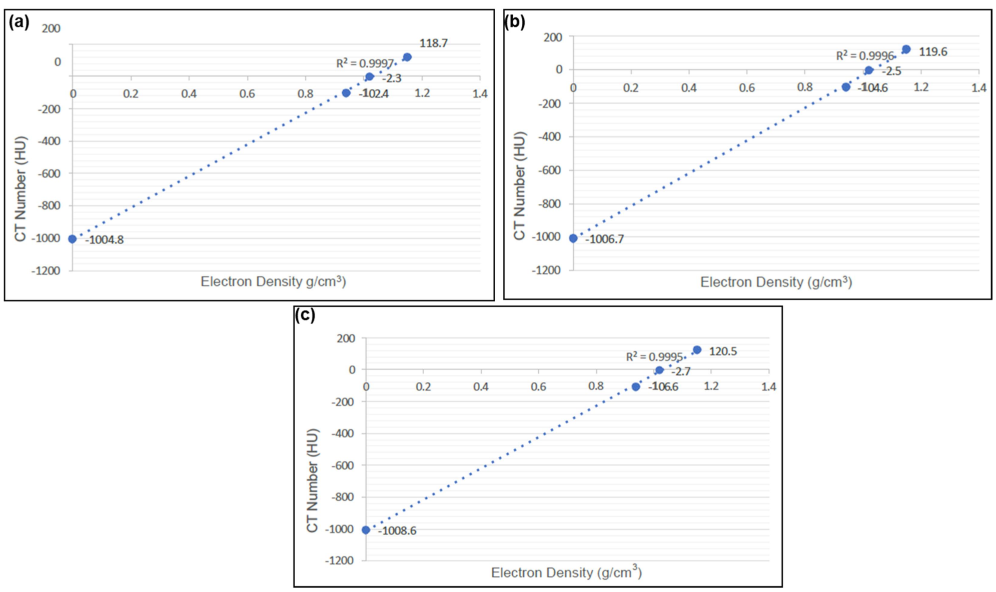

Figure 2. Graph of CT number values vs. electron density at different slice thickness: (a) 1.0 mm, (b) 2.0 mm, (3) 4.0 mm.

Figures 2(a), 2(b), and 2(c) further illustrate the analysis of the CT number values vs. electron density graph at a 1.0 mm, 2.0 mm, and 4.0 mm slice thickness, respectively. The R^2 value represents the correlation coefficient of the linear relationship between CT number and electron density values on the CT scanner. This R^2 value is compared with the passing criteria set by BAPETEN Regulation No. 2 of 2018. Figure 2(a) shows the linearity graph of CT number versus electron density at a 1.0 mm slice thickness, with an R^2 value of 0.9997. Figure 2(b) presents the graph at a 2.0 mm slice thickness, showing an R^2 value of 0.9996. Figure 2(c) displays the graph at a 4.0 mm slice thickness, with an R^2 value of 0.9995. These results indicate that the CT number values are linearly related to electron density across different slice thicknesses. According to [4], a high R^2 value suggests that the relationship between the CT number and the density of the scanned object material is linear. This means that the CT images accurately represent the grayscale differences according to the density of the scanned objects. Therefore, the CT scanner meets the BAPETEN Regulation No. 2 of 2018, with an R^2 value of ≥ 0.99, indicating that it passes the test criteria.

3.2. Spatial Resolution Test

The spatial resolution test determines the spatial resolution value across various slice thicknesses. Spatial resolution is assessed by distinguishing small objects that are closely spaced together. This test evaluates the imaging system's ability to resolve fine details and differentiate between objects in the scanned image. The results from the spatial resolution test provide insight into the imaging system's performance in displaying detailed structures (Figure 3).

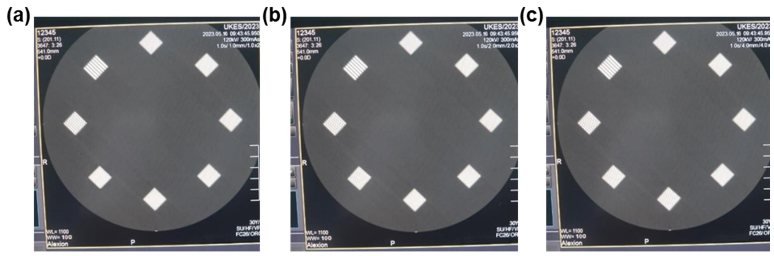

Figure 3. Resolution test images at different slice thicknesses: (a) 1.0 mm, (b) 2.0 mm, (c) 4.0 mm.

Table 2. Spatial resolution values at each slice thickness.

Slice Thickness (mm)	Test Results (lp/mm)	Minimum Pass Value	Status
1.0	0.5	≥ 0.5	Pass
2.0	0.6	≥ 0.5	Pass
4.0	0.7	≥ 0.5	Pass

Table 2 presents the measurement results for spatial resolution values across different slice thicknesses: 1.0 mm, 2.0 mm, and 4.0 mm. For a 1.0 mm slice thickness, the spatial resolution was 0.5 lp/mm; for a 2.0 mm slice thickness, it was 0.6 lp/mm; and for a 4.0 mm slice thickness, it was 0.7 lp/mm. These values meet the minimum passing criterion of BAPETEN Regulation No. 2 of 2018, which is ≥ 0.5 lp/mm. Higher spatial resolution indicates better image quality, allowing for the visualization of more minor line pairs, reflecting the imaging system's capability to discern finer details. Based on the BAPETEN Regulation No. 2/2018 guidelines for image quality testing, the spatial resolution values obtained in this study meet the required standards. Therefore, the CT scanner used in this study produces high-quality images.

4. Conclusion

The CT number linearity test, conducted with varying slice thicknesses, yielded correlation coefficients of 0.9997 for 1.0 mm slice thickness, 0.9996 for 2.0 mm slice thickness, and 0.9995 for 4.0 mm slice thickness. All these values exceed the BAPETEN Regulation No. 2 of 2018 passing criterion of $R^2 \geq 0.99$. The spatial resolution tests, performed with different slice thicknesses, showed spatial resolution values of 0.5 lp/mm for 1.0 mm slice thickness, 0.6 lp/mm for 2.0 mm slice thickness, and 0.7 lp/mm for 4.0 mm slice thickness. These results are above the minimum passing standard of ≥ 0.5 lp/mm set by BAPETEN Regulation No. 2 of 2018. In conclusion, both CT number linearity and spatial resolution tests demonstrate that the CT scanner meets the required quality standards, indicating that it performs well in producing accurate and high-quality images.

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