

Impact of Tube Voltage, Tube Current, and Slice Thickness on CT Number Accuracy and Image Uniformity in Comparison with IAEA Standards

Thanakrit Chanchayanon, MSc¹, Suttharat Suwanmanee, BSc¹, Seri Sakjirapapong, MSc¹, Natee Ina, MSc¹,
Suthinee Teerajaruwat, MD¹, Jongwat Cheewakul, MSc¹

¹ Department of Radiology, Faculty of Medicine, Prince of Songkla University, Songkhla, Thailand

ABSTRACT

Background: Reliable quantitative computed tomography (CT) imaging requires rigorous quality control. Scan parameters such as tube voltage (kVp), tube current (mA), and slice thickness can affect CT number accuracy, image uniformity, and image noise.

Objective: To investigate the effects of tube voltage, tube current, and slice thickness on CT number accuracy, image uniformity, and noise in comparison with the International Atomic Energy Agency (IAEA) standards.

Materials and Methods: CT number uniformity and image noise were assessed using a water phantom, while CT number accuracy was evaluated using a TOS phantom containing six materials of different densities: air, water, Delrin, acrylic, nylon, and polypropylene. The linear relationship between CT numbers and material density was analyzed using regression analysis (R^2), and the results were compared with IAEA tolerances.

Results: No significant differences ($p > 0.05$) were observed between reference and measured CT numbers across the tested materials. Increasing tube current did not significantly affect CT numbers or image uniformity, although higher tube current reduced image noise. CT number linearity remained strong across all tube current settings, with R^2 values consistently above 0.9. Image noise for all settings remained within the IAEA tolerance range. However, at 80 kVp, image uniformity exceeded the ± 10 HU limit, whereas 100-135 kVp complied with the standard.

Conclusion: CT number linearity and accuracy were highly stable across variations in tube current and slice thickness, whereas image uniformity was affected at low tube voltage. These findings emphasize the importance of selecting an appropriate kVp, particularly 120 kVp, to preserve image quality and maintain compliance with IAEA quality control standards. The results provide evidence-based support for optimizing CT imaging protocols.

Keywords: CT number accuracy; Image uniformity; SNR; kVp; mA; Slice thickness; IAEA standards; CT image quality

Received 10 November 2025 | Revised 29 April 2026 | Accepted 8 May 2026

J Med Assoc Thai 2026;109(10):828-34

<https://doi.org/10.35755/jmedassothai.2026.10.03932>

Computed tomography (CT) is an essential diagnostic tool in modern medicine, providing cross-sectional imaging with high spatial resolution and rapid acquisition. The accuracy and reliability of CT images are critical for clinical diagnosis, treatment planning, and follow-up. One of the most important aspects of CT quality assurance is the consistency of quantitative parameters, particularly CT numbers

Correspondence to:

Cheewakul J.
Department of Radiology, Faculty of Medicine, Prince of Songkla University,
Songkhla 90110, Thailand.
Phone: +66-99-2467351
Email: jongwatcheewakul@hotmail.com
ORCID: 0009-0002-2995-8119

How to cite this article:

Chanchayanon T, Suwanmanee S, Sakjirapapong S, Ina N, Teerajaruwat S, Cheewakul J. Impact of Tube Voltage, Tube Current, and Slice Thickness on CT Number Accuracy and Image Uniformity in Comparison with IAEA Standards. J Med Assoc Thai 2026;109:828-34.

What is already known about this topic?

CT is an essential diagnostic imaging modality that provides high-resolution cross-sectional images for diagnosis, treatment planning, and follow-up. The accuracy and reliability of CT imaging depend on rigorous quality control, particularly the consistency of CT numbers, image uniformity, and image noise. It is well established that scanning parameters such as tube voltage (kVp), tube current (mA), and slice thickness can influence image quality and patient dose. The IAEA has established tolerance limits to support reproducibility and standardization in CT quality control. Previous phantom-based studies have also shown a strong linear relationship between CT numbers and material density; however, deviations in image performance may occur under certain acquisition conditions, particularly at lower kVp settings and with changes in slice thickness.

What does this study add?

This study demonstrates that CT number accuracy and linearity remain highly stable across variations in tube current and slice thickness, with R^2 values consistently above 0.99. However, imaging at 80 kVp resulted in image uniformity exceeding the IAEA tolerance limit of ± 10 HU, whereas higher tube voltages (100-135 kVp) remained within acceptable limits. Tube current variations from 50 to 300 mA did not affect CT number accuracy, but higher mA values significantly reduced image noise. Similarly, slice thickness had minimal impact on CT number accuracy, although thicker slices reduced image noise. These findings support the use of an optimal 120 kVp protocol to maintain image homogeneity and ensure compliance with IAEA quality control standards.

(Hounsfield units, HU), image uniformity, and image noise, all of which are directly influenced by scanning parameters such as tube voltage (kVp), tube current (mA), and slice thickness^(1,2). Optimizing these parameters is fundamental not only for image quality but also for patient safety, as inappropriate settings can lead to inaccurate CT numbers, increased image noise, or non-uniformity, ultimately affecting diagnostic confidence^(3,4). International guidelines, such as those issued by the International Atomic Energy Agency (IAEA), recommend strict tolerances for CT number accuracy and image uniformity to ensure reproducibility across clinical settings⁽⁵⁾. Phantom-based quality control studies have been widely used to assess scanner performance and compliance with international standards. These studies consistently report strong linearity of CT numbers across different materials, with coefficients of determination (R^2) exceeding 0.9 in most cases^(6,7). However, deviations are often observed at low kVp values or with increased slice thickness, highlighting the need for protocol optimization tailored to both patient safety and diagnostic requirements⁽⁸⁾. Given the increasing clinical reliance on quantitative imaging biomarkers, maintaining CT number accuracy and image uniformity is of paramount importance. This study was therefore designed to investigate the impact of tube voltage, tube current, and slice thickness on CT number accuracy, image uniformity, and image noise in comparison with IAEA standards. The findings provide evidence-based insights into CT protocol optimization while ensuring compliance with international quality assurance guidelines⁽⁹⁻¹²⁾.

MATERIALS AND METHODS

Equipment Preparation

The first step in the CT scanning procedure was equipment preparation. The TOS phantom and water phantom (Canon Medical Systems, Inc., USA) were prepared, and the CT quality control protocol used at Songklanagarind Hospital was reviewed. The TOS phantom contains materials of different densities and was used to evaluate the linear relationship between measured CT numbers (HU) and linear attenuation coefficients (cm^{-1}), as shown in Figure 1. The CT number was calculated using the following equation⁽¹³⁾:

$$\text{CT numbers} = \frac{\mu_{\text{material}} - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1,000$$

μ_{material} = linear attenuation coefficients of material

μ_{water} = linear attenuation coefficient of water, and linear attenuation coefficients of the attenuation

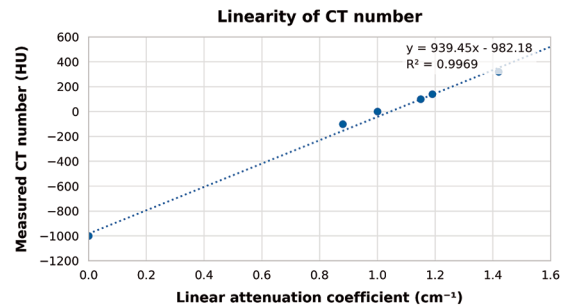


Figure 1. The relationship between measured CT number (HU) and linear attenuation coefficient (cm^{-1}).

of X-ray photons were assumed to follow the Beer-Lambert law as shown⁽¹⁴⁾.

$$I = I_0 e^{-\mu x}$$

I = intensity at the end of the X-ray beam of the CT scan

I_0 = Intensity at the initial of the X-ray beam of the CT scan

μ = linear attenuation coefficient of the material (cm^{-1})

x = thickness of the material (cm)

CT-Scanner Parameters

The CT scanner employed in this study was an Aquilion Prime (Canon Medical Systems, Inc., USA), featuring 160 slices and 80 detector rows. The protocols utilized various tube voltage peaks of 80, 100, 120, and 135 kVp, along with tube current settings of 50, 100, 150, 200, 250, and 300 mA and slice thicknesses of 1, 2, 3, and 4 mm as shown in Table 1.

Image Data Acquisition

The TOS phantom and water phantom were positioned at the CT scanner isocenter using the same centering procedure for each scan, so that the center of each phantom aligned with the scanner's central axis within the field of view. This positioning was kept consistent across all predefined protocols. Proper centering is crucial for obtaining accurate and reproducible measurements.

Variables Measurement

CT numbers for air, Delrin, acrylic, nylon, polypropylene, and water were measured by averaging pixel values obtained from multiple regions of interest (ROIs) within the TOS phantom, as shown in Figure 2. CT number uniformity in the water phantom was assessed using five ROI locations, also shown in Figure 2. Image noise was evaluated by drawing an ROI in the water phantom and measuring the standard

Table 1. Scanning parameters used for tube current, tube voltage, and slice thickness variations in CT quality control measurements

No.	Parameters	Tube current variation	Tube voltage variation	Slice thickness variation
1	Display FOV (mm)	320	320	320
2	Scan mode	Helical	Helical	Helical
3	Pitch factor	0.625	0.625	0.625
4	Helical pitch	25	25	25
4	Time rotation (s)	0.75	0.75	0.75
5	Tube voltage (kVp)	120	80, 100, 120, 135	120
6	Tube current (mA)	50, 100, 150, 200, 250, 300	50	50
7	Rotation time (sec)	0.5	0.5	0.5
8	Tube current × Rotation time (mAs)	25, 50, 75, 100, 125, 150	25	25
7	Slice thickness (mm)	0.5	0.5	1, 2, 3, 4
8	Total scan time	5.8	5.8	5.8

FOV=field of view

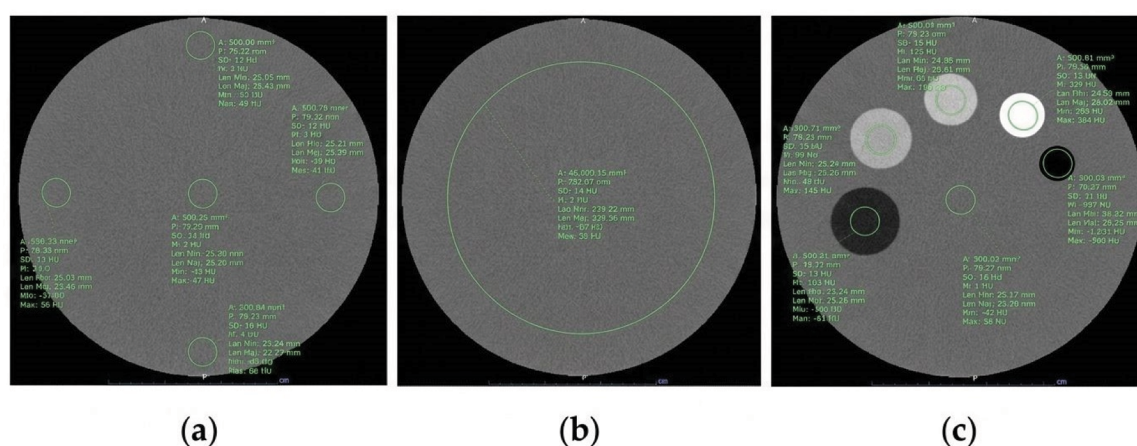


Figure 2. TOS phantom and Water phantom measurements. (a) Water phantom with central and peripheral ROIs for image uniformity assessment. (b) Water phantom with a large central ROI for image noise measurement. (c) TOS phantom with ROIs positioned in different material inserts for CT number accuracy and linearity assessment.

deviation of pixel values.

Figure 2 has been revised to improve image clarity and presentation. The three phantom images were rearranged into clearly labeled panels, and the brightness, alignment, and resolution were adjusted while preserving the original ROI positions and measurement information.

Data Analysis and Comparison with IAEA Standards

The measured variables were analyzed to assess CT number accuracy, CT number uniformity, and image noise. CT number uniformity was calculated as the maximum absolute difference between the CT number in the central ROI and those in the peripheral ROIs of the water phantom, according to the following equation:

$$\text{CT number uniformity} = \text{Maximize}_{0 \leq i \leq j} |(\text{CT number}_{\text{center}} - \text{CT number}_{\text{peripheral}})_{0 \leq i \leq j}|$$

$\text{CT number}_{\text{center}}$ =mean of pixel value at the center of the water phantom

$\text{CT number}_{\text{peripheral}}$ =mean of pixel value at the periphery of the water phantom

The maximum absolute difference among the ROIs was used to evaluate image homogeneity. CT number linearity was determined by assessing the relationship between the measured CT numbers and the known material densities of the phantom inserts, using the coefficient of determination (R^2). Image noise was evaluated as the standard deviation (SD) of pixel values within the ROI placed in the water phantom and was compared with the SD obtained during the commissioning test, as shown below:

$$\text{Image noise percentage} = \frac{\text{SD}_{\text{measurement}} - \text{SD}_{\text{references}}}{\text{SD}_{\text{references}}} \times 100$$

$\text{SD}_{\text{measurement}}$ =standard deviation of that measurement from the water phantom

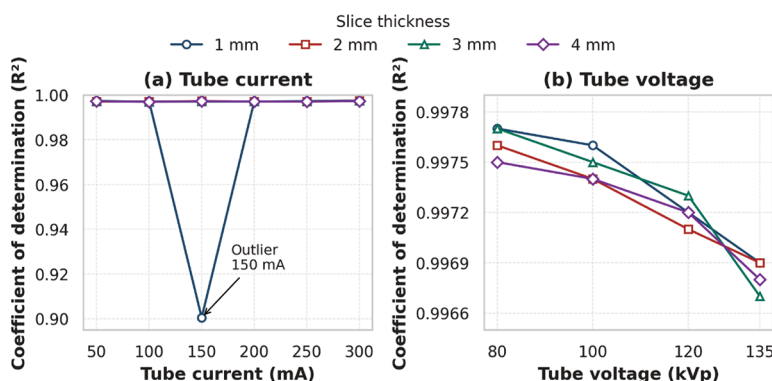


Figure 3. Effect of tube current and tube voltage on CT number linearity. The coefficients of determination (R^2) were calculated from the linear relationship between CT numbers and physical densities of phantom materials. Panel A shows R^2 values across tube current settings, and Panel B shows R^2 values across tube voltage settings. Each line represents a different slice thickness. An isolated decrease in R^2 was observed at 150 mA with 1-mm slice thickness.

$SD_{\text{references}}$ = standard deviation of the measurement from the water phantom in the commissioning test

The measured values were then compared with the quality assurance criteria recommended by the IAEA (No. 19). For CT number accuracy, measurements were considered acceptable when the deviation from the reference value was within ± 5 HU and achievable when within ± 4 HU. For CT number uniformity, the acceptable and achievable limits were ± 10 HU and ± 4 HU, respectively. For image noise, the acceptable limit was within $\pm 25\%$ of the baseline value, and the achievable limit was within $\pm 10\%$ of the baseline value. All analyzed data were interpreted according to these predefined IAEA criteria to determine scanner performance and compliance.

Ethical Approval

This study was approved by the Ethics Committee of Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University (REC.68-181-7-7).

RESULTS

A total of forty phantom-based measurements were performed by systematically varying tube voltage, tube current, and slice thickness. Tube voltage settings included 80, 100, 120, and 135 kVp. Tube current was varied from 50 to 300 mA, and slice thickness was varied from 1 to 4 mm. CT number accuracy, CT number linearity, image uniformity, and image noise were analyzed and compared with the IAEA quality control criteria.

CT Number Accuracy and Linearity

Across the evaluated scanning conditions, the CT

numbers of the phantom materials, including air, Delrin, acrylic, nylon, polypropylene, and water, showed a strong linear relationship with physical density. The coefficients of determination were consistently high, with R^2 values greater than 0.9 in all measurements. Most conditions demonstrated R^2 values above 0.996, indicating stable CT number linearity across the tested acquisition parameters.

The measured CT numbers remained close to the reference values for all evaluated tube current settings. No statistically significant differences were observed between the reference and measured CT numbers across tube current settings if statistical comparison was performed, or the measured values showed no relevant deviation from the reference values if assessed descriptively. Therefore, tube current variation did not substantially affect CT number accuracy.

Figure 3 shows the CT number linearity according to tube voltage and tube current. Tube voltage showed a narrow R^2 distribution, ranging from 0.9970 to 0.9975. Tube current demonstrated slightly greater variability; however, R^2 values remained within an acceptable range for CT number linearity. These findings suggest that variations in tube voltage and tube current had minimal effects on CT number linearity under the evaluated scanning conditions.

CT number linearity remained strong for both tube voltage (kVp) and tube current (mA), with R^2 values consistently above 0.996. Tube voltage demonstrated a narrower distribution (0.9970-0.9975), while tube current showed slightly wider variability but still within IAEA standards. These results confirm that variations in kVp and mA have a negligible influence on CT number linearity.

Effect of Tube Voltage (kVp)

CT number uniformity was maintained within the IAEA tolerance of ± 10 HU at 100, 120, and 135 kVp. However, at 80 kVp, uniformity values exceeded the tolerance, indicating deviation from the standard. The reduced photon energy at this lower voltage likely contributed to beam attenuation variability and decreased image homogeneity. These findings support the clinical preference for 120 kVp in routine protocols to ensure both accuracy and image consistency.

Effect of Tube Current (mA)

Variation of mA between 50 and 300 did not significantly affect CT number accuracy or image uniformity. Mean CT numbers for all materials remained stable across the tested mA settings. Image noise, however, decreased with increasing tube current, ranging from 38.2 at 50 mA to 24.1 at 300 mA (1 mm slice thickness), demonstrating the expected inverse relationship between mA and image noise. Figure 4 demonstrates that the coefficient of determination (R^2) remained consistently high (>0.98) across most tube current values and slice thicknesses, indicating stable CT number linearity. A single outlier was observed at 150 mA ($R^2=0.90$), but overall results still complied with IAEA standards. These findings confirm that variations in mA and slice thickness exert minimal influence on CT number accuracy.

Effect of Slice Thickness

Slice thickness variation (1-4 mm) showed minimal effect on CT number accuracy and uniformity. At all thickness levels, CT numbers remained within IAEA acceptance criteria. Nonetheless, image noise was influenced by slice thickness, with thicker slices (4 mm) producing lower noise values compared to thinner slices (1 mm). For example, noise decreased from 38.2 at 1 mm to 26.3 at 4 mm (80 kVp, 50 mA). Figure 5 shows that CT number linearity (R^2) remained consistently high (>0.9968) across all kVp settings, demonstrating a strong correlation between CT numbers and material density. Slight variations were observed, with the highest R^2 values occurring at 80-100 kVp and a gradual decrease at higher voltages. Overall, the results confirm that kVp variation has minimal influence on CT number accuracy, maintaining compliance with IAEA standards.

Overall Findings

CT number accuracy and linearity were consistently maintained across all tested conditions, with $R^2 > 0.9$ in every case. Both mA and slice thickness variations

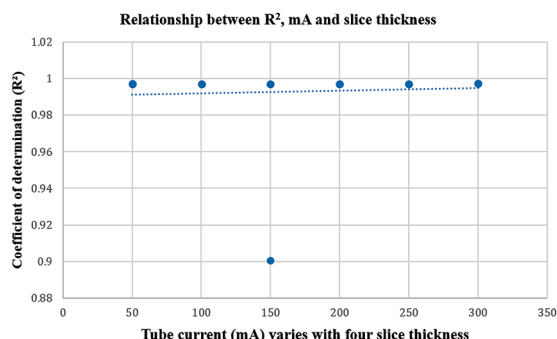


Figure 4. Relationship between R^2 , tube current (mA), and slice thickness.

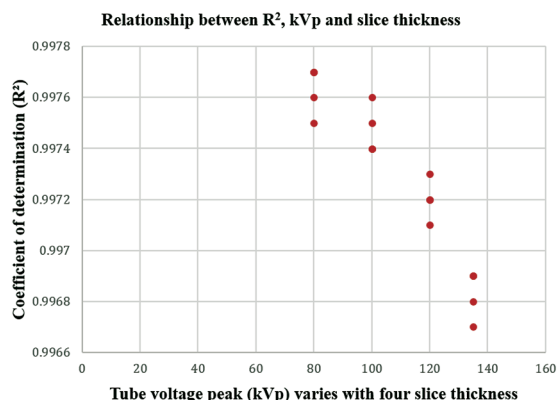


Figure 5. Relationship between R^2 , tube voltage peak (kVp), and slice thickness.

exerted negligible effects on CT number stability, while kVp demonstrated the most significant impact on image uniformity, particularly at 80 kVp. These results confirm that proper selection of kVp is critical for compliance with IAEA standards and ensuring reliable CT quantitative performance.

DISCUSSION

The present study evaluated the influence of tube voltage (kVp), tube current (mA), and slice thickness on CT number accuracy, image uniformity, and noise, using both TOS and water phantoms, and compared the findings with the IAEA quality control standards. Overall, CT numbers demonstrated strong linearity with material densities, with coefficients of determination (R^2) consistently exceeding 0.9, thereby confirming compliance with IAEA guidelines. Our findings are consistent with the results⁽¹⁾, which reported that CT number linearity using the TOS phantom exhibited R^2 values above 0.9, supporting its robustness for routine quality control. Similarly, emphasized that CT number linearity is fundamental for accurate tissue

characterization and quantitative imaging, highlighting the importance of maintaining stable values across varying imaging parameters⁽³⁾. In our study, both kVp and mA variations exerted negligible influence on linearity, except for a slight deviation observed at 80 kVp, where uniformity exceeded the ± 10 HU tolerance recommended by the IAEA. This observation aligns with clinical practice, where 120 kVp is commonly selected to ensure optimal image homogeneity.

Regarding tube current, our results showed that mA variation had little impact on CT number accuracy or uniformity but significantly influenced image noise, with higher mA values reducing noise levels. This trend is in agreement with that increasing mA improves image quality by reducing noise, though at the expense of increased radiation dose⁽⁹⁾. The inverse relationship between mA and noise observed in our study underscores the balance required between image quality and radiation safety.

However, the isolated decrease in R^2 at 150 mA with 1-mm slice thickness likely reflects incidental experimental variability rather than a true effect of tube current on CT number linearity. Tube current mainly affects image noise, whereas CT number linearity is generally expected to remain stable under unchanged scanning and reconstruction conditions. Possible contributors include minor measurement uncertainty, subtle differences in phantom positioning or ROI placement, and small scanner fluctuations during acquisition. This single outlier did not change the overall finding that CT number linearity remained robust across the tested mA range.

Slice thickness variation (1-4 mm) also did not significantly alter CT number accuracy or uniformity, though thicker slices yielded lower noise levels, a finding comparable with Euler et al. (2019), who reported improved signal-to-noise ratios with increased slice thickness in phantom studies⁽¹¹⁾. Such results reinforce the utility of optimizing slice thickness in protocol design to enhance image quality without compromising quantitative accuracy.

In summary, this study confirms that CT number linearity is highly robust across a range of scanning parameters, with deviations primarily noted at low tube voltage. These results validate the use of phantoms for quality assurance in CT imaging and are consistent with prior reports highlighting the importance of maintaining kVp settings above 100 for clinical imaging. Furthermore, the findings provide practical evidence to guide parameter optimization, ensuring both compliance with international standards and improved diagnostic reliability.

CONCLUSION

This study demonstrated that CT number accuracy and linearity remained highly consistent across variations in tube current, tube voltage, and slice thickness, with R^2 values exceeding 0.9 in nearly all measurements, thereby fulfilling IAEA quality assurance standards. Tube current (mA) and slice thickness exerted minimal influence on CT number accuracy and image uniformity, though higher mA and thicker slices effectively reduced image noise. In contrast, low tube voltage (80 kVp) was associated with deviations in image uniformity, emphasizing the importance of selecting optimal kVp values—particularly 120 kVp—for maintaining reliable quantitative performance. Overall, the findings confirm that phantom-based quality control provides robust evaluation of CT imaging performance and support the optimization of scanning protocols to balance diagnostic accuracy with patient safety. These results offer practical guidance for ensuring compliance with international standards and improving reproducibility in quantitative CT applications.

Acknowledgement

The authors would like to thank the Department of Radiology, Faculty of Medicine, Prince of Songkla University, for providing the facilities, equipment, and technical support necessary for the completion of this study.

Authors Contributions

All authors meet ICMJE authorship criteria. JC: contributed to the conception and design of the study, acquisition of data, data analysis and interpretation, drafting of the manuscript, and final approval of the version to be published. TC and SS: contributed to the acquisition of clinical data, data analysis and interpretation, and critical revision of the manuscript. SS, NI and ST: contributed to data acquisition, data interpretation, and manuscript revision. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

Data Availability Statement

The de-identified dataset generated and analyzed during the current study is available from the first author upon reasonable request and with appropriate ethics approval. Public sharing of the data is restricted in accordance with the requirements of the Faculty of Medicine, Prince of Songkla University Ethics Committee. This study involved phantom measurements only and did not involve

human participants; therefore, informed consent was not required.

Clinical Trial Registration

Not applicable. This study was a phantom-based experimental study evaluating CT equipment performance and did not involve human or animal subjects. Therefore, clinical trial registration is not required.

Conflicts of Interest

The authors declare no conflict of interest.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University (REC.68-181-7-7). Since the study involved phantom measurements and did not involve human subjects, informed consent to participate was waived.

Funding Disclosure

This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Use of Artificial Intelligence

The authors used ChatGPT 5.5 (OpenAI) as an artificial intelligence tool to assist with literature searching, reference verification, and language editing during manuscript preparation.

REFERENCES

1. Anjani M, Anam C, Sutanto H, Naufal A. An approach for automation of CT number linearity measurement on the TOS phantom image. *Int J Sci Res Sci Technol* 2024;11:229-35.
2. International Atomic Energy Agency (IAEA). Handbook of basic quality control tests for diagnostic radiology [Internet]. Vienna: IAEA; 2023 [cited 2025 Aug 16]. Available from: <https://www.iaea.org/publications/14890/handbook-of-basic-quality-control-tests-for-diagnostic-radiology>.
3. Kalender WA. Computed tomography: fundamentals, system technology, image quality, applications. 3rd ed. Erlangen: Publicis; 2011.
4. Lee HHC, Li B, Duan X, Zhou L, Jia X, Yang M. Systematic analysis of the impact of imaging noise on dual-energy CT-based proton stopping power ratio estimation. *Med Phys* 2019;46:2251-63.
5. Szczykutowicz TP, DuPlissis A, Pickhardt PJ. Variation in CT number and image noise uniformity according to patient positioning in MDCT. *AJR Am J Roentgenol* 2017;208:1064-72.
6. Taddei F, Schileo E, Helgason B, Cristofolini L, Viceconti M. The material mapping strategy influences the accuracy of CT-based finite element models of bones: an evaluation against experimental measurements. *Med Eng Phys* 2007;29:973-9.
7. Les CM, Keyak JH, Stover SM, Taylor KT, Kaneps AJ. Estimation of material properties in the equine metacarpus with use of quantitative computed tomography. *J Orthop Res* 1994;12:822-33.
8. Trattner S, Pearson GDN, Chin C, Cody DD, Gupta R, Hess CP, et al. Standardization and optimization of CT protocols to achieve low dose. *J Am Coll Radiol* 2014;11:271-8.
9. Prakash P, Kalra MK, Kambadakone AK, Pien H, Hsieh J, Blake MA, et al. Reducing abdominal CT radiation dose with adaptive statistical iterative reconstruction technique. *Invest Radiol* 2010;45:202-10.
10. Yu L, Leng S, McCollough CH. Dual-energy CT-based monochromatic imaging. *AJR Am J Roentgenol* 2012;199 (5 Suppl):S9-15.
11. Euler A, Solomon J, Farjat AE, Nelson RC, Samei E, Marin D. High-pitch wide-coverage fast-kilovoltage-switching dual-energy CT: Impact of pitch on noise, spatial resolution, and iodine quantification in a phantom study. *AJR Am J Roentgenol* 2019;212:W64-72.
12. Solomon J, Lyu P, Marin D, Samei E. Noise and spatial resolution properties of a commercially available deep learning-based CT reconstruction algorithm. *Med Phys* 2020;47:3961-71.
13. Hounsfield GN. Computerized transverse axial scanning (tomography). 1. Description of system. *Br J Radiol* 1973;46:1016-22.
14. Brooks RA, Di Chiro G. Principles of computer assisted tomography (CAT) in radiographic and radioisotopic imaging. *Phys Med Biol* 1976;21:689-732.