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CTDI-Based Assessment of Radiation Dose Output Accuracy in a 128-Slice CT Scanner Using Head and Body PMMA Phantoms

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Abstract

Verification of Computed Tomography Dose Index (CTDI)-based dose output is essential for ensuring the accuracy of radiation delivery and supporting quality assurance in Computed Tomography (CT). This study aimed to verify the radiation dose output of a 128-slice CT scanner at the Radiology Department of RS Jiwa Menur Surabaya using CTDI measurements with standard PMMA head (16 cm) and body (32 cm) phantoms. Dose measurements were performed using a 100 mm pencil ionization chamber under standardized exposure parameters of 120 kV and 200 mA. CTDI100 values were measured at the center and peripheral positions of each phantom and subsequently used to calculate CTDIw and CTDIvol. The measured CTDI values were compared with the corresponding dose indices displayed by the CT scanner to determine the percentage deviation. The measured CTDIvol showed a deviation of 10.65% from the displayed value, while the body phantom exhibited a deviation of 10.16%. Although the measured CTDI values were consistently higher in the head phantom than in the body phantom due to differences in attenuation characteristics and phantom geometry, all deviations remained within the ±20% tolerance limit specified by BAPETEN regulations. These findings indicate that the CT scanner's dose output performance is consistent with the applicable regulatory acceptance criteria. Periodic CTDI-based verification is recommended to support ongoing quality assurance, maintain dosimetric accuracy, and optimize radiation protection practices in accordance with the ALARA principle.

Keywords: Computed Tomography Dose Index (CTDI), CT Dose display accuracy, CT Dosimetri, Radiation Output Verification, CT Quality Assurance

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1. Introduction

The rapid advancement of Computed Tomography (CT) technology, particularly the development of multi-slice CT (MSCT) systems, has significantly improved diagnostic imaging through enhanced spatial resolution, shorter acquisition times, and wider clinical applications. Despite these advantages, CT examinations contribute a substantial proportion of the collective radiation dose from medical imaging and therefore require careful dosimetric monitoring to ensure patient safety and diagnostic optimization [1]. Accurate estimation of radiation dose is particularly important because CT-related exposure has been associated with increased stochastic risk, emphasizing the need for continuous quality assurance and dose verification programs [2].

According to the fundamental dosimetry guidelines established by authoritative bodies such as the American Association of Physicists in Medicine (AAPM) and the International Atomic Energy Agency (IAEA), several dose indices are standardly utilized in CT dosimetry [3], [4]. The Computed Tomography Dose Index measured over a 100-mm integration length (CTDI100) represents the foundational physical quantity for characterizing x-ray tube radiation output. To estimate the average dose within the scanned volume, the weighted CTDI (CTDIw) is calculated by combining central and peripheral dose measurements obtained using standard polymethyl methacrylate (PMMA) phantoms. Furthermore, the volumetric CTDI (CTDIvol) incorporates the effect of the scan pitch, serving as the primary indicator of scanner radiation output during clinical examinations. Finally, the Dose Length Product (DLP), calculated as the product of CTDIvol and the total scan length, provides a reliable estimate of the total radiation energy imparted for a specific examination.

Modern CT scanners automatically display CTDIvol and DLP values on the operator console. However, these displayed values are derived from reference measurements and computational models rather than direct measurements during each examination. Consequently, differences may exist between scanner-displayed dose indices and independently measured radiation output due to factors such as x-ray tube aging, detector performance variations, calibration drift, and long-term equipment usage [5]. Periodic verification of scanner-displayed dose values is therefore necessary to ensure compliance with quality assurance requirements and radiation protection standards.

In Indonesia, radiation output verification is regulated by the Nuclear Energy Regulatory Agency (BAPETEN) through Regulation No. 2 of 2022, which requires periodic performance testing and specifies that CT dose output deviations should remain within acceptable tolerance limits of ±20% [6]. Although CTDI-based quality

control procedures are routinely recommended, published data regarding the agreement between independently measured CTDI values and scanner-displayed dose indices in Indonesian clinical settings remain limited, particularly for modern 128-slice CT scanners. Furthermore, few studies have reported CTDI100-, CTDIw-, and CTDIvol-based verification using standard PMMA head and body phantoms under local operational conditions.

This lack of local verification data constitutes a critical research gap, as variations in long-term equipment performance and local operational settings may significantly influence the accuracy of the console-displayed dose indices, thereby compromising patient dose optimization efforts. *To address this gap, the specific research question of this study is: How accurate are the console-displayed CTDIvol and DLP values compared to independent ion-chamber measurements on a 128-slice CT scanner using standard PMMA phantoms, and do the output deviations comply with the national regulatory tolerance of ±20%?*

To answer this question, this study aimed to empirically verify the radiation dose output of a 128-slice CT scanner at RS Jiwa Menur Surabaya. Measurements of CTDI100, CTDIw, and CTDIvol were conducted using a 100-mm pencil ionization chamber inserted into standard PMMA head and body phantoms. The findings are expected to provide robust, evidence-based support for ongoing CT quality assurance programs and clinical radiation dose optimization.

2. Methods

The measurement of radiation parameters and the stability of the X-ray tube are critical factors in maintaining the performance of diagnostic modalities [7]. This research was conducted at the Radiology Installation of RS Jiwa Menur Surabaya, utilizing a 128-slice CT scanner. The methodology adhered to the standardized quality control procedures prescribed by the International Atomic Energy Agency (IAEA) TRS 457 [8] to evaluate radiation output consistency.

The primary dosimetry equipment utilized was a calibrated 100 mm Pencil Ion Chamber RTI Brand and Calibrated in SWEDEN with Factor Calibration 1,1 and connected to a digital electrometer/multimeter. Measurements were performed using standard standard polymethyl methacrylate (PMMA) dosimetry phantoms: a 16 cm diameter phantom simulating an adult head and a 32 cm diameter phantom simulating an adult body.

The ion chamber was placed sequentially in the central axis hole and the four peripheral holes (located at 12, 3, 6, and 9 o'clock positions, 1 cm from the phantom surface). Scanning was performed using a standardized axial protocol with exposure parameters set at 120 kVp,200 mAs,Pitch:1,Rotation Time: 1 second,Slice Thickness :

0,6 mm,Reconstruction in 64 image. Each measurement was repeated twice (Trial 1 and Trial 2) to assess measurement repeatability and Type A uncertainty.

Data obtained from the electrometer as an integrated dose-length reading (mGy.cm) was converted to CTDI100 (expressed in mGy). This conversion incorporated the electrometer's calibration factor (Nk = 1.1) and the temperature-pressure correction factor (k_TP), which accounts for air density variations. The k_{TP} is calculated using the formula k_TP = (273,2+T)/(273,2+T_0) X P_0/P where T and P are the ambient temperature and pressure during measurement, and T_0and P_0 are the reference conditions. The CTDI100 was then computed by dividing the corrected integrated dose by the nominal beam collimation (N X T). The uncertainty budget was established by combining Type A uncertainty (derived from measurement repeatability) and Type B uncertainty (derived from the instrument's calibration certificate tolerances).

To evaluate the average dose delivered to a single slice, the weighted CTDI (〖CTDI〗_(ω))was calculated using the following established equation:

$$CTDI_{\omega} = \frac{1}{3} CTDI_{100,center} + \frac{2}{3} CTDI_{100,peripheral}$$

$$CTDI_{100} = \frac{k\ x\ E\ x\ L}{N\ x\ T} \quad (1)$$

Where $CTDI_{100,peripheral}$ is the average of the four peripheral measurements.

Subsequently, the Volumetric CTDI 〖(CTDI〗_V) which represents the dose over the entire scanned volume, was calculated based on the pitch factor (assuming a pitch of 1 for standard axial calibration):

$$CTDI_V = \frac{CTDI_{\omega}}{Pitch} \quad (2)$$

Finally, a deviation analysis was performed by comparing the measured $CTDI_{vol}$ with the predicted $CTDI_{vol}$ displayed on the CT console. The percentage error was calculated using:

$$Deviation\ (\%) = \left| \frac{CTDI_{V,Measured} - CTDI_{V,Displayed}}{CTDI_{V,Displayed}} \right| x\ 100\% \quad (3)$$

Measurement repeatability was statistically evaluated using the Coefficient of Variation (CV%), formulated as the standard deviation divided by the mean of the trials.

3.Results and Discussion

This section presents the empirical findings derived from the dosimetry measurements conducted at the Radiology Installation of RS Jiwa Menur Surabaya. The primary focus of this analysis is to quantify the radiation output of the 128-slice CT scanner and evaluate its consistency across different anatomical simulations using standardized phantoms. The results are categorized into head and body

phantom evaluations to illustrate the influence of object geometry and material attenuation on the dose index. Following the presentation of the raw data, a comprehensive discussion is provided to interpret these findings in the context of national safety standards and clinical optimization principles

3.1 Presenting the Results

The radiation dose measurements for both head and body phantom configurations were successfully obtained at a standardized setting of 120 kV and 200 mA. Tabel 1 and Tabel 2 summarize the 〖CTDI〗_100 values for each position. Note: Data values reflect dose indices in mGy, corrected from integrated dose-length formats for direct CTDI calculation.

Tabel 1. $CTDI_{100}$ Measurement Results for Head Phantom (16 cm)

No	Position	Properties				
		Trial 1 (mGy)	Trial 2 (mGy)	Mean CTDI_100(mGy)	SD(mGy)	CV(%)
1	Center	14.110	14.104	14.107	0.004	0.03
2	12 o'clock	15.319	15.329	15.324	0.007	0.05
3	3 o'clock	14.758	14.627	14.693	0.093	0.63
4	6 o'clock	14.384	14.320	14.352	0.045	0.31
5	9 o'clock	14.351	14.310	14.331	0.029	0.20

Tabel 2. $CTDI_{100}$ Measurement Results for Body Phantom (32 cm)

No	Position	Properties				
		Trial 1 (mGy)	Trial 2 (mGy)	Mean CTDI_100(mGy)	SD (mGy)	CV (%)
1	Center	42.41	42.11	42.26	0.212	0.50
2	12 o'clock	81.21	80.92	81.07	0.205	0.25
3	3 o'clock	81.78	81.03	81.40	0.530	0.65
4	6 o'clock	83.99	83.11	83.55	0.622	0.74
5	9 o'clock	82.89	82.02	82.45	0.615	0.75

Based on the equations provided in the methodology, the $CTDI_w$ and $CTDI_{vol}$ (assuming Pitch = 1) were computed and compared to the console display values to determine accuracy.

Tabel 3. $CTDI_V$ and Console Deviation Analysis

No	Phantom Type	Calculate $CTDI_V$ (mGy)	Console Display (mGy)	Deviation (%)	Tolerance	Status
1	Head (16 cm)	41.49	37,50	10,65 %	±20 %	Acceptable
2	Body (32 cm)	19.71	17.90	10,16%	±20 %	Acceptable

3.2 Discussion

The results demonstrated distinct dose distribution characteristics between the head and body PMMA phantoms. For the 16 cm head phantom, peripheral dose measurements were relatively close to the central dose, resulting in a CTDIvol of 41.49 mGy. This finding reflects a more uniform dose distribution, which can be attributed to the smaller phantom diameter and reduced attenuation path length. In contrast, the 32 cm body phantom exhibited substantially lower central dose values relative to the peripheral measurements, yielding a CTDIvol of 19.71 mGy. This behavior is consistent with the increased attenuation, scatter, and beam hardening effects that occur in larger phantom geometries, resulting in greater dose reduction toward the phantom center.

The observed dose distribution patterns are consistent with established CT dosimetry principles. Reports from the American Association of Physicists in Medicine (AAPM) and the International Atomic Energy Agency (IAEA) similarly describe higher attenuation and greater center-to-periphery dose differences in body phantoms compared with head phantoms. Furthermore, the calculated deviations of 10.65% (head) and 10.16% (body) align with previous national studies. For instance, investigations such as those by Ilham et al. [6] have reported comparable deviation ranges in multi-slice CT scanners. These typical deviations are generally attributed to scanner-specific computational models, variations in detector response characteristics, and inherent calibration tolerances rather than systemic hardware malfunction.

Measurement repeatability was excellent, with coefficients of variation below 1% for all measurement positions. The low variability indicates stable radiation output during repeated exposures and consistent performance of the pencil ionization chamber measurement system. Such repeatability is important for quality control programs because it reduces uncertainty in CTDI-based dose output assessments.

Comparison between independently measured CTDI values and scanner-displayed dose indices showed deviations of 10.65% for the head phantom and 10.16% for the body phantom. These deviations remain within the ±20% tolerance limit specified by BAPETEN Regulation No. 2 of 2022. Similar deviation ranges have been reported in previous CT quality control studies, where differences between measured and displayed CTDI values were attributed to calibration uncertainties, scanner-specific modeling assumptions, detector response characteristics, and measurement geometry.

Although the deviations remain within the ±20% tolerance limit specified by BAPETEN Regulation No. 2 of 2022, it is crucial to clearly distinguish between equipment output accuracy and clinical dose optimization. This study solely

validates that the scanner's hardware radiation output aligns accurately with its console display under static, standardized PMMA phantom conditions. It does not evaluate the appropriateness of the dose for specific clinical indications or varying patient anatomies.

Consequently, clinical protocol optimization represents a distinct and necessary step beyond basic dose output verification. While accurate CTDI measurements provide confidence in the displayed console indices, true patient dose optimization requires adjusting scanning parameters—such as tube current modulation, pitch, and iterative reconstruction—to individual patient sizes while strictly adhering to national Diagnostic Reference Levels (DRLs)

This study has several limitations. First, measurements were performed using standard PMMA head and body phantoms and therefore may not fully represent patient-specific attenuation conditions. Second, the investigation was conducted on a single 128-slice CT scanner at one institution, which limits the generalizability of the findings. Third, only selected exposure parameters were evaluated. Future studies should include multiple clinical protocols, additional scanner models, and comparisons with national diagnostic reference levels to provide a more comprehensive assessment of CT dosimetry performance.

Overall, the results indicate that the measured CTDI values and scanner-displayed dose indices are in agreement within the regulatory tolerance limits specifically under the tested standardized phantom conditions. These findings support the continued use of periodic CTDI-based verification as a foundational component of routine CT quality control programs.

4. Conclusion

This study successfully evaluated the radiation dose output of a 128-slice CT scanner at RS Jiwa Menur Surabaya using the Computed Tomography Dose Index (CTDI) method. The results quantitatively demonstrated how phantom geometry and mass attenuation influence dose distribution; the head phantom exhibited a higher dose profile 〖CTDI〗_V= 41.49 mGy), whereas the body phantom displayed a characteristic reduction in dose due to high photon attenuation (〖CTDI〗_V= 19.71 mGy).

Crucially, the measurement repeatability was excellent (CV < 1%), indicating highly stable x-ray output and low experimental uncertainty. The calculated deviations between the measured CTDIvol and the console's displayed values were 10.65% and 10.16% for the head and body phantoms, respectively. Because these deviations are under the ±20% regulatory limit established by BAPETEN Regulation No. 2 of 2022, the CT scanner's dose output performance satisfies the national acceptance criteria for equipment calibration under standardized phantom testing.

While this ensures the console accurately reflects the emitted dose, comprehensive patient radiation protection still requires the continuous optimization of clinical scanning protocols based on the ALARA principle.

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The author confirms that this independent research was conducted solely for academic purposes at the Radiology Installation of RS Jiwa Menur Surabaya, with all data collection, analysis, and manuscript preparation performed by the author under institutional supervision. This study did not involve human or animal subjects, as all measurements were carried out using standardized PMMA phantoms in compliance with national nuclear safety protocols. Furthermore, the author declares no conflicts of interest or competing financial interests that could have influenced the results or interpretations presented in this work.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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References

[1] S. S. Putri, S. H. Intifadhah, and E. R. Putri, "Estimation of Organ Dose , Effective Dose , and Cancer Risk in Abdominal CT Scan Patients," vol. 50, no. xxx, pp. 289–294, 2024.

[2] S. Agoes Hyperastuty, Y. Mukhammad, and B. Andayani, "Analisis Pengaturan Faktor Eksposi Dosis Serap Pasien Menggunakan Piranha 557," Med. Tek. J. Tek. Elektromedik Indones., vol. 4, no. 2, pp. 126–130, 2023.

[3] R. Filano, I. G. E. Dirgayussa and A. Alfarabi, "Advancements and Challenges of Deep Learning in Diagnostic Radiology : A Systematic Literature Review," Jurnal Fisikavol. 15, no. 2, pp. 38–50, 2025.

[4] N. M. Parwati, "Penyelenggaraan Layanan Kedokteran Nuklir Di Rumah Sakit Berdasarkan Peraturan Pemerintah Nomor 5 Tahun 2021 Tentang Perizinan Berusaha Berbasis Risiko Serta Aspek Pertanggungjawabannya" Jurnal P. Magister Hukum FH Unmas," vol. 02, no. 02, pp. 102–112, 2022,

[5] P. S. Horuoby, A. Agung, A. Diartama, I. K. Sukadana, and P. Shalry, "Analisis Nilai CTDI vol Dan DLP Pada Pemeriksaan CT Scan Brain Non Kontras Dewasa Untuk Periode Januari – Desember 2022 Di Instalasi Radiologi Rumah

Sakit X Jakarta Pusat Akademik Teknik Radiodiagnostik dan Radioterapoi Bali , Indonesia kepala , thorax , abdomen dan sebagainya . Pemeriksaan CT Scan yang sering dilakukan yaitu," Jurnal Rummpun Ilmu Kesehatan., vol. 3, no. 3, 2023.

[6] I. Ilham, S. Zelviani, J. Jumardin, and K. Bariah, "ANALISIS NILAI COMPUTED TOMOGRAPHY DOSE INDEX (CTDI) PADA PHANTOM KEPALA DI INSTALASI RADIOLOGI RUMAH SAKIT UMUM," Jurnal Fisikaa vol. 10, no. 1, pp. 55–61, 2024.

[7] A. Santika Hyperastuty, Y. Mukhammad, and S. Sugeng, "Journal of Health Science," J. Heal. Sci. (Jurnal Ilmu Kesehatan), vol. VI, no. I, pp. 19–26, 2021.

[8] International Atomic Energy Agency (IAEA), "Dosimetry in Diagnostic Radiology: An International Code of Practice," Technical Reports Series No. 457, Vienna, Austria, 2007.

[9] American Association of Physicists in Medicine (AAPM), "The Measurement, Reporting, and Management of Radiation Dose in CT," AAPM Report No. 96, Maryland, USA, 2008.