RESEARCH ARTICLE

Comprehensive Quality Control Evaluation of a 128-Slice Computed Tomography Scanner Using Standard Phantom-Based Performance Tests: A Prospective Observational Study

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ABSTRACT

Introduction: Quality assurance (QA) and quality control (QC) programs are essential components of computed tomography (CT) imaging to ensure optimal image quality, patient safety, and compliance with international performance standards. Routine QC testing enables early detection of equipment deviations that may adversely affect diagnostic accuracy and radiation dose.

Aim: To evaluate the performance of a Philips Ingenuity Core 128-slice CT scanner using routine phantom-based quality control tests and determine its compliance with the recommended acceptance criteria.

Materials and Methods: This prospective observational study was conducted at the Department of Radiology, Maharishi Markandeshwar Institute of Medical Sciences and Research, Mullana, Haryana, India, between November 2018 and April 2019. A Philips Ingenuity Core 128-slice CT scanner was evaluated using a standard CT image quality phantom. The Performance parameters assessed included CT number accuracy, CT number uniformity, image noise, low-contrast resolution, high-contrast spatial resolution, gantry tilt accuracy, couch travel accuracy, slice thickness accuracy, CT number linearity and Computed Tomography Dose Index (CTDI). The measured values were compared with the manufacturer specifications and internationally accepted quality assurance standards.

Results:The measured CT number for water was 0 Hounsfield Units (HU), indicating excellent calibration accuracy. The CT number uniformity was 0.55 HU, whereas the image noise remained within acceptable limits. The CT number linearity for water, polyethylene, nylon, acrylic, Lexan, and Teflon inserts demonstrated acceptable agreement with the reference values. The low-contrast resolution was 3 mm, and high-contrast spatial resolution was approximately 2.4 line pairs/mm.The gantry tilt and couch travel accuracy tests showed negligible deviations. The measured CTDI_{vol} was 38.59 mGy, compared with the console-displayed value of 39.70 mGy, which represents a minimal variation.

Conclusion:The evaluated 128-slice CT scanner demonstrated satisfactory performance across all assessed quality control parameters and complied with the recommended acceptance criteria. Routine implementation of comprehensive quality assurance programs is essential to maintain diagnostic image quality, optimize radiation dose and ensure reliable clinical performance.

Keywords: Computed Tomography, Quality Assurance, Quality Control, CT Phantom, CTDI, Image Quality, Radiation Dose, Phantom Study.

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INTRODUCTION

Computed tomography (CT) has become one of the most important diagnostic imaging modalities because of its ability to provide rapid, high-resolution cross-sectional images for a wide range of clinical applications [1,12]. The continuous advancement of multidetector CT technology has significantly improved spatial resolution, image acquisition speed, and diagnostic accuracy, resulting in increased utilization across emergency medicine, oncology, neurology, cardiovascular imaging, and trauma care. Despite these technological improvements, maintaining consistent image quality while minimizing patient radiation exposure remains a fundamental challenge in clinical practice [2].

CT is a non-invasive imaging technique that utilizes rotating X-ray beams and sophisticated computer algorithms to generate detailed tomographic images of the human body. Unlike conventional radiography, which produces two-dimensional projection images, CT provides three-dimensional volumetric datasets with superior anatomical visualization by eliminating the superimposition of overlying structures[18]. Modern multidetector computed tomography (MDCT) scanners are equipped with multiple rows of detector elements that enable rapid volumetric data acquisition, thin-slice imaging, and high-quality multiplanar and three-dimensional image reconstruction. These technological advancements have substantially improved the detection, characterization, and localization of pathological lesions while reducing scan time and motion-related artifacts[23].

Recent innovations, including iterative reconstruction algorithms, automatic tube current modulation, dual-energy CT, spectral imaging, and artificial intelligence-assisted image reconstruction, have further enhanced image quality while optimizing radiation dose. These advances have expanded the clinical utility of CT in complex diagnostic and interventional procedures, including CT angiography, perfusion imaging, virtual endoscopy, oncological staging, preoperative planning, and image-guided interventions[20]. Consequently, CT has become an indispensable imaging modality for accurate diagnosis, disease monitoring, treatment planning, and emergency patient management[28].

The growing dependence on CT imaging has also resulted in a substantial increase in the number of examinations performed worldwide, making CT one of the largest contributors to the collective radiation dose from medical imaging. Because CT employs ionizing radiation, optimizing image quality while maintaining radiation exposure within recommended safety limits is of paramount importance[30]. Achieving this balance requires not only advanced imaging technology but also continuous monitoring of scanner performance to ensure that diagnostic-quality images are consistently produced without unnecessary radiation exposure. Therefore, routine quality assurance and quality control programs have become essential components of modern CT practice, ensuring reliable system performance, patient safety, and compliance with national and international standards[24]. A comprehensive QA program encompasses systematic monitoring of equipment performance, standardized operating procedures, preventive maintenance, and routine quality control (QC) testing[3]. Quality control represents the technical component of QA and involves the periodic evaluation of imaging system performance using standardized protocols and phantoms. These assessments help identify equipment deterioration before it affects the clinical image quality or patient safety[4,16].

Several professional organizations, including the American College of Radiology (ACR), International Atomic Energy Agency (IAEA) and American Association of Physicists in Medicine (AAPM), recommend routine quality control testing of CT scanners to ensure optimal performance[5,13]. The important performance parameters include CT number accuracy, CT number uniformity, image noise, spatial resolution, low-contrast detectability, slice thickness accuracy, radiation dose measurements, and mechanical accuracy of gantry and patient table movement. Monitoring these parameters enables the early identification of technical deviations and supports timely corrective maintenance of the equipment[6,15].

Phantom-based quality control testing provides an objective and reproducible method for evaluating the performance of CT system under standardized conditions. Image quality phantoms simulate tissue-equivalent materials and allow a quantitative assessment of scanner performance independent of patient-related variables[7,14]. Therefore, regular phantom evaluation is essential for maintaining diagnostic confidence and ensuring compliance with national and international quality standards.

Although manufacturers provide acceptance testing during equipment installation, periodic independent quality control assessments are necessary throughout the operational life of a CT scanner[9,10]. Published studies have shown that gradual deterioration of detector performance, X-ray tube output, calibration stability, and mechanical alignment may adversely influence image quality and radiation dose if not detected through routine QC program[8,11].

MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted at the Department of Radiodiagnosis, Maharishi Markandeshwar Institute of Medical Sciences and Research (MMIMSR), Mullana, Ambala, Haryana, India, between November 2018 and April 2019. This study evaluated the performance of a Philips Ingenuity Core 128-slice Computed Tomography (CT) scanner using standardized quality control (QC) procedures.

Ethical Approval

The study was conducted after obtaining approval from the Institutional Ethics Committee of the Maharishi Markandeshwar Institute of Medical Sciences and Research. As the investigation involved phantom-based equipment quality assurance without direct patient intervention, the patient-related risks were minimal. Institutional permission was obtained prior to the commencement of the study.

Study Equipment

Quality control evaluation was performed using a Philips Ingenuity Core 128-slice Multidetector Computed Tomography (MDCT) scanner equipped with a 128-slice acquisition system, 80 kW X-ray generator, iterative reconstruction (iDose^4), automatic exposure control, and dose optimization technologies. The scanner had a 70-cm gantry aperture with a detector configuration suitable for high-resolution volumetric imaging.

Phantom

Image quality assessment was performed using the manufacturer-recommended CT quality assurance phantom consisting of dedicated modules for the evaluation of:

- CT number accuracy
- CT number linearity
- Image noise
- CT number uniformity
- High-contrast spatial resolution
- Low-contrast detectability
- Slice thickness
- Mechanical alignment

A separate CTDI head phantom (16 cm diameter) was used for radiation dose measurements.

QUALITY CONTROL PROTOCOL

Routine quality control procedures were performed according to the manufacturer's recommendations and internationally accepted QA guidelines.

The following performance parameters were evaluated:

1. EQUIPMENT WARM-UP

The CT system underwent routine tube warm-up and detector calibration before image acquisition to ensure a stable scanner performance.

2. MECHANICAL INSPECTION

Mechanical performance evaluation included

- Gantry laser alignment
- Patient couch movement
- Gantry tilt accuracy
- Visual inspection
- Safety indicators
- Intercom functionality
- Table positioning accuracy

3. CT NUMBER ACCURACY

A circular region of interest (ROI) was positioned at the center of the water phantom.

The measured CT number was compared with the acceptable reference value of 0 ± 4 HU.

4. CT NUMBER LINEARITY

The phantom contained multiple inserts of known attenuation values including

- Water
- Acrylic
- Lexan
- Nylon
- Polyethylene
- Teflon

Measured Hounsfield Unit (HU) values were compared with the manufacturer reference values.

5. IMAGE NOISE

Image noise was assessed using repeated scans of a uniform water phantom.

Noise was expressed as the standard deviation of CT numbers within a centrally placed ROI.

6. CT NUMBER UNIFORMITY

Uniformity was determined by comparing the CT numbers measured at the center and four peripheral regions of the water phantom.

Uniformity was calculated as the standard deviation of the measurements.

7. LOW-CONTRAST RESOLUTION

Low-contrast detectability was evaluated using a dedicated phantom insert containing objects of varying diameters.

The smallest visible object was then recorded.

8. HIGH-CONTRAST SPATIAL RESOLUTION

The spatial resolution was evaluated using the line-pair module of the phantom.

Resolution was expressed in line pairs per millimeter (lp/mm).

9. SLICE THICKNESS ACCURACY

The slice thickness was measured using an inclined aluminum ramp incorporated within the phantom.

The measured slice thickness was compared with the nominal slice thickness.

10. RADIATION DOSE ASSESSMENT

Radiation dose evaluation was performed using a standard 16-cm CTDI head phantom together with a calibrated pencil ionization chamber.

The following dosimetric parameters were recorded:

$CTDI_{100}$

- Weighted CTDI (CTDIw)
- Volume CTDI (CTDIvol)
- Dose Length Product (DLP)

The measured values were compared with the console-displayed values and manufacturer specifications.

OUTCOME MEASURES

The primary outcome was the assessment of the compliance of the CT scanner with the established quality control acceptance limits.

Secondary outcome measures included evaluation of

- Image quality
- Mechanical accuracy
- Radiation dose consistency
- Overall scanner performance

STATISTICAL ANALYSIS

Data were entered into Microsoft Excel 2016 and analyzed using descriptive statistical methods.

Continuous variables were expressed as

- Mean
- Standard deviation (SD)
- Percentage deviation from reference values

The measured QC parameters were compared with the manufacturer-recommended tolerance limits and internationally accepted quality assurance criteria.

An this investigation primarily involved equipment performance evaluation rather than hypothesis testing, inferential statistical analyses were not performed.

Table 1: Technical specifications of the evaluated CT scanner

Parameter	Specification
Scanner	Philips Ingenuity Core
Detector configuration	128 Slice
Tube voltage	80–140 kVp
Generator power	80 kW
Detector type	Solid-state GOS detector
Reconstruction	$iDose^4$ Iterative Reconstruction
Maximum FOV	50 cm
Maximum gantry tilt	±30°

Table 2: Quality control parameters evaluated

Parameter	Acceptance Criterion
CT number (Water)	0 ±4 HU
Uniformity	Within ±5 HU
Image Noise	Manufacturer specification
CT Number Linearity	Within tolerance
Low Contrast Resolution	Phantom specification
Spatial Resolution	Manufacturer specification
Slice Thickness	Nominal value
CTDI	Within tolerance

RESULTS

During the study period, comprehensive quality control testing of the Philips Ingenuity Core 128-slice CT scanner was successfully completed. The scanner demonstrated satisfactory performance across all evaluated mechanical, image quality, and dosimetric parameters. All measured values were within the manufacturer-recommended tolerance limits, indicating a stable system performance throughout the study period.

CT Number Accuracy and Linearity

The measured CT number for water was 0 HU, which was consistent with the recommended acceptance criterion (0±4 HU). The evaluation of the phantom inserts demonstrated satisfactory linearity of the CT number across all tested materials. The water, nylon, polyethylene, acrylic, Lexan, and Teflon inserts showed only minor deviations from the reference values, with all measurements remaining within acceptable limits.

Table 3: CT Number Linearity Measurements

Phantom Material	Measured CT Number (HU)	Reference Range	Performance
Water	0	0 ± 4	Acceptable
Nylon	102	+100 ± 19	Acceptable
Polyethylene	-75	-75 ± 19	Acceptable
Acrylic	168	+140 ± 15	Slightly higher*
Lexan	123	+116 ± 15	Acceptable
Teflon	1008	+1017 ± 51	Acceptable

Although acrylic demonstrated a small positive deviation, the overall scanner performance remained clinically acceptable according to the study observations.

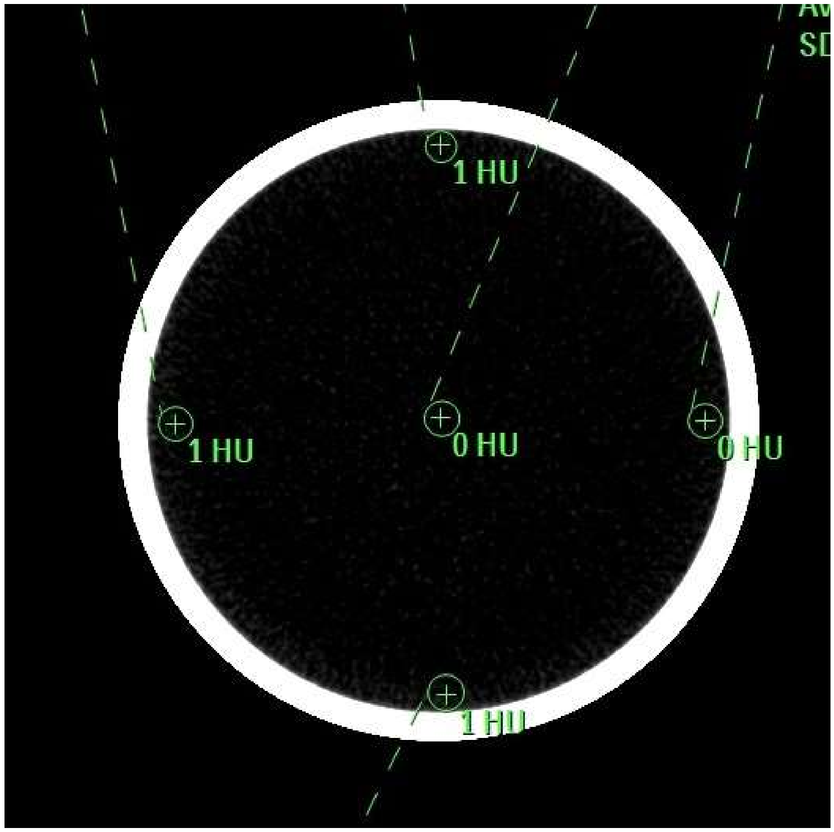


Figure 1: CT number uniformity

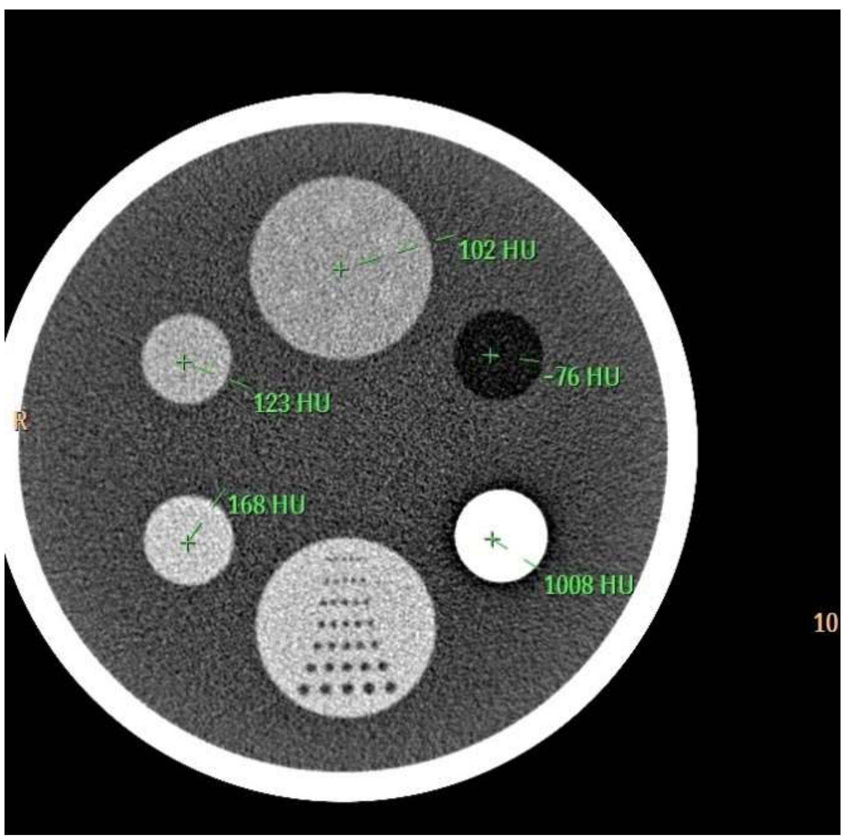


Figure 2: CT Number Linearity

Low-Contrast Resolution

The phantom-based low-contrast detectability test demonstrated the visualization of structures measuring 3 mm, indicating adequate low-contrast resolution for routine diagnostic imaging.

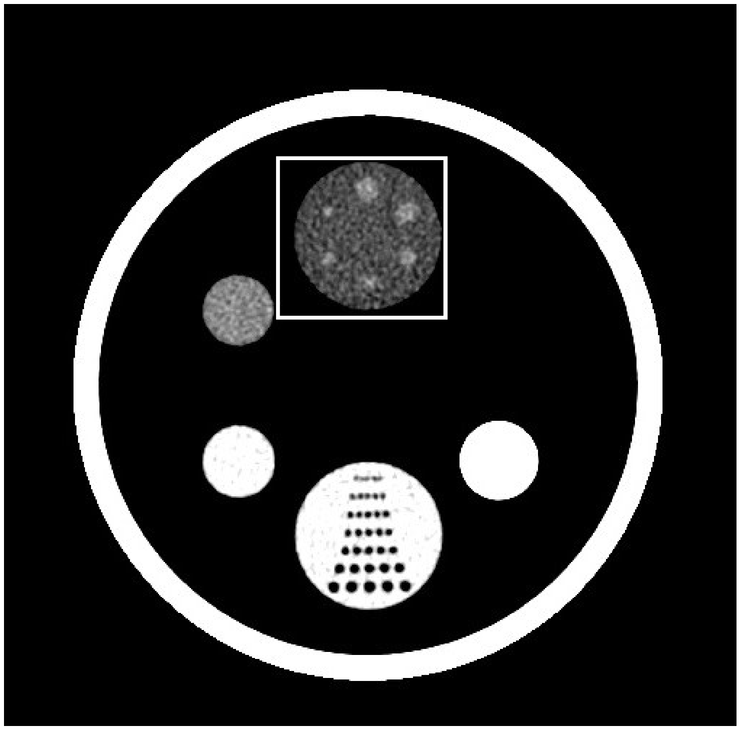


Figure 3: CT low contrast resolution

High-Contrast Spatial Resolution

The evaluation of the high-contrast resolution module showed that phantom rows corresponding to 1.25 mm objects with 2.5 mm spacing were clearly resolved, yielding an estimated spatial resolution of approximately 2.4 line pairs/mm.

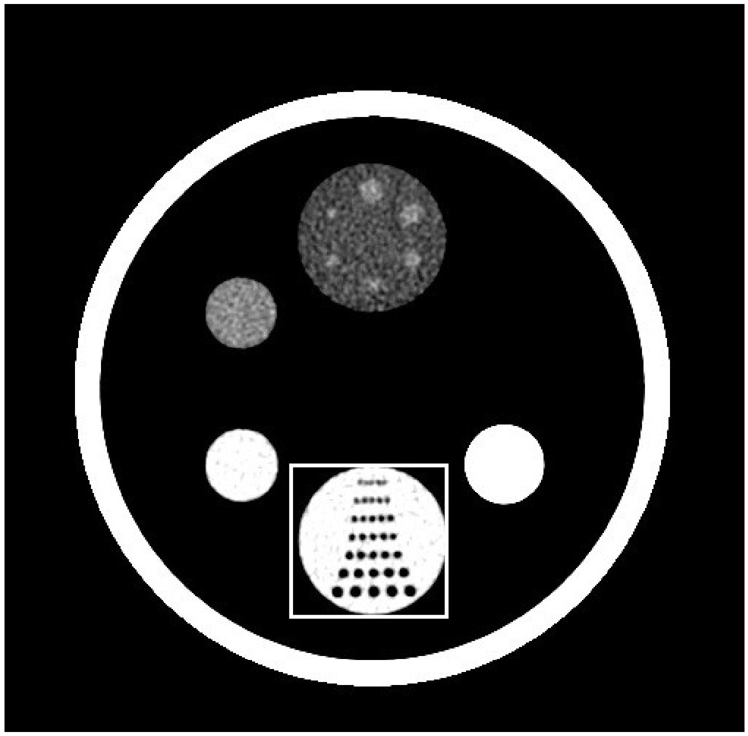


Figure 4: CT high contrast resolution

Image Noise

Repeated measurements performed using a uniform water phantom demonstrated a mean CT number of 0 HU with negligible variation among repeated acquisitions, indicating excellent calibration stability and low image noise.

Fig 5: Slice 1

Fig 6: Slice 2

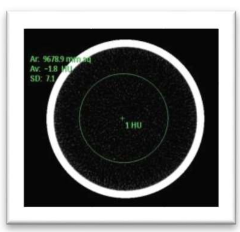


Fig 7: Slice 3

Fig 8: Slice 4

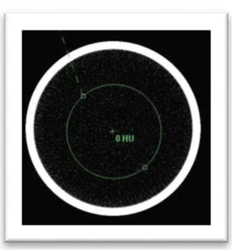


Fig 9: Slice 5

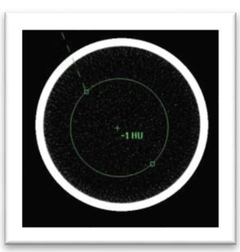


Fig 10: Slice 6

Fig 11: Slice 7

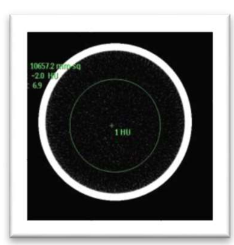


Fig 12: Slice 8

Fig 13:Slice 9 **Fig 14:Slice 1**

CT Number Uniformity

Five-region analysis of the water phantom demonstrated excellent CT number uniformity. The calculated standard deviation was 0.55 HU, which was substantially lower than the recommended acceptance threshold.

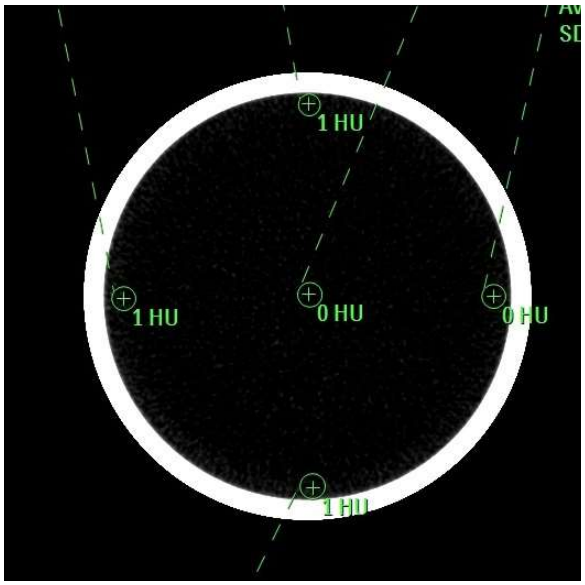


Figure 15: CT number uniformity

Mechanical Performance

Mechanical quality assurance tests confirmed the accuracy of the scanner operation. Laser alignment was satisfactory, gantry tilt demonstrated no measurable deviation from the displayed angle, and patient couch travel accuracy showed only minimal positional error (0.5 mm), which remained well within the acceptable tolerance limits.

Table 4: Mechanical Performance Assessment

Parameter	Measured Value	Acceptance	Status
Gantry laser alignment	Accurate	Pass	Pass
Gantry tilt	Correct	±1°	Pass
Couch travel error	0.5 mm	≤2 mm	Pass
Visual checklist	All items satisfactory	Pass	Pass

Slice Thickness Accuracy

The measured slice thickness was 0.7 mm compared with the nominal setting of 1.0 mm. The observed difference was considered acceptable for the acquisition protocol used and did not affect overall the scanner performance.

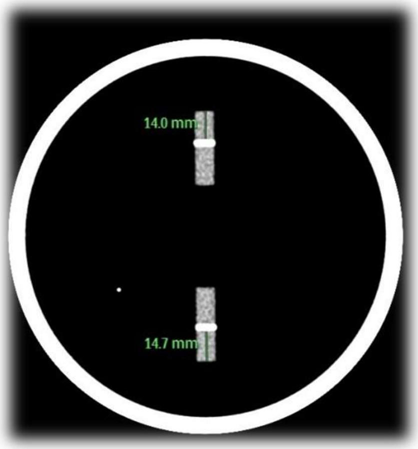


Fig 16: Image slice width

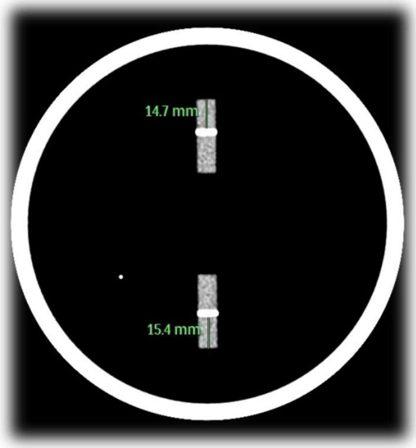


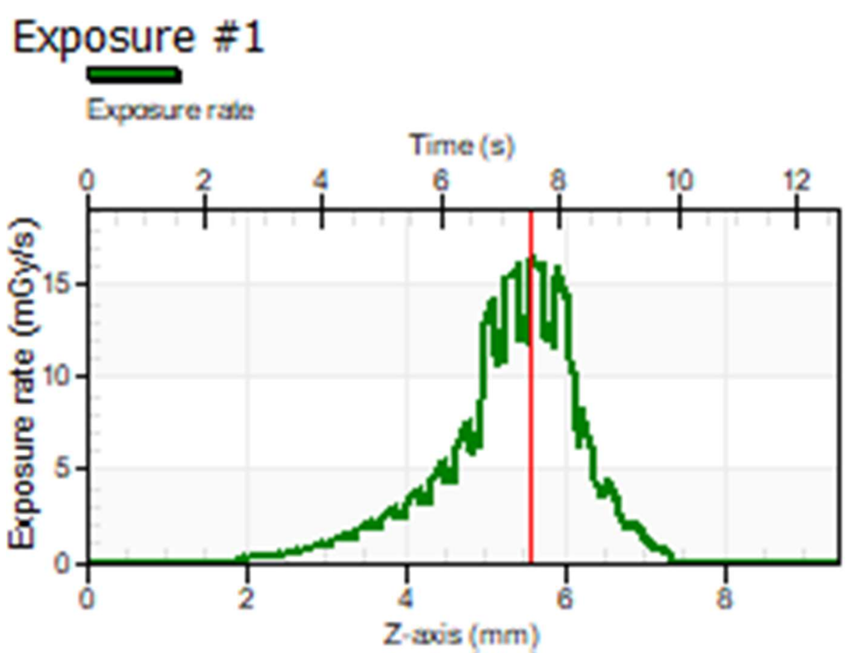
Fig 17: Imaged slice width

Radiation Dose Assessment

Radiation dose evaluation using the standard CTDI phantom demonstrated close agreement between the measured and console-displayed values. The measured CTDI_{vol} was 38.59 mGy, whereas the scanner console displayed 39.70 mGy, representing a difference of 1.11 mGy between the two values. This small variation indicates satisfactory dosimetric accuracy.

Table 5: CT Dose Measurements

Parameter	Measured Value
Tube Voltage	120 kVp
Tube Current	250 mAs
CTDI100	10.83 mGy
CTDIw	11.46 mGy
CTDIvol	38.59 mGy
Console CTDIvol	39.70 mGy
Difference	1.11 mGy
DLP	578.9 mGy·cm



Graph No 18: CTDI analysis

Image Quality Check

The automatic image quality (IQ) assessment could not be completed because of an air bubble within the phantom water compartment, which interrupted the automated quality assurance procedure. Therefore manual quality control assessments were used for performance evaluation.

Summary of Results

Overall, the evaluated CT scanner demonstrated stable mechanical performance, excellent image quality, accurate CT number calibration, satisfactory spatial and contrast resolutions and radiation dose measurements consistent with the manufacturer specifications. No clinically significant deviations that required corrective maintenance were identified during the study period.

DISCUSSION

The study comprehensively evaluated the quality control performance of a Philips Ingenuity Core 128-slice computed tomography (CT) scanner using standardized phantom-based quality assurance tests. The evaluated parameters included CT number accuracy, CT number linearity, image noise, CT number uniformity, spatial resolution, low-contrast detectability, mechanical accuracy, slice thickness and radiation dose measurements. Overall, the scanner demonstrated satisfactory performance, with all measured parameters remaining within the acceptable tolerance limits recommended by the manufacturer and international quality assurance guidelines. These findings indicate that routine quality control procedures are effective in maintaining diagnostic image quality and ensuring patient safety.

Accurate CT number calibration is fundamental for diagnostic confidence because quantitative attenuation measurements are increasingly used in lesion characterization, treatment planning and follow-up examinations. In the present study, the CT number of water was measured as 0 HU, which falls within the internationally accepted tolerance of 0±4 HU. Similarly, CT number linearity assessed using phantom inserts composed of water, polyethylene, nylon, acrylic, Lexan and Teflon demonstrated only minor deviations from the reference values, confirming stable detector calibration and reconstruction accuracy. These findings are comparable to those reported in previous phantom-based quality assurance studies, which have consistently shown that routine calibration minimizes systematic measurement errors and improves quantitative reliability.

Image noise and CT number uniformity are important determinants of diagnostic image quality because excessive noise reduces lesion conspicuity, whereas poor uniformity may indicate detector instability or beam-hardening artifacts. In this study, repeated measurements demonstrated negligible image noise, whereas the CT number uniformity was measured at 0.55 HU, which is substantially below the recommended tolerance limits. These observations suggest excellent detector performance and stable image reconstruction throughout the evaluation period of the study. Similar results have been reported in quality assurance studies of multidetector CT scanners, where routine phantom testing was shown to maintain a consistent image quality and reduce variability in quantitative measurements.

High-contrast spatial resolution and low-contrast detectability are essential parameters for evaluating the ability of CT systems to visualize fine anatomical structures and a subtle pathological lesions. The present study demonstrated a high-contrast spatial resolution of approximately 2.4 line pairs/mm and low-contrast detectability of 3 mm, indicating satisfactory image quality for routine clinical imaging. These findings are consistent with the expected performance of contemporary 128-slice multidetector CT systems and support the continued clinical reliability of the evaluated scanner used in this study.

Mechanical quality assurance tests confirmed the satisfactory performance of the gantry alignment, patient couch movement and laser positioning systems. Accurate mechanical alignment is essential because errors in patient positioning or gantry angulation may result in image misregistration, inaccurate localization of lesions and unnecessary repeated examinations. The observed couch travel error of 0.5 mm was well below the accepted tolerance limit, demonstrating the excellent mechanical precision of the evaluated CT system.

Radiation dose optimization remains one of the principal objectives of CT quality assurance programs. The measured CTDI_{vol} of 38.59 mGy differed by only 1.11 mGy from the console-displayed value, indicating an excellent agreement between the measured and displayed radiation dose indices. This close correlation suggests appropriate calibration of the dosimetry system and supports the reliability of dose reporting during routine clinical examination. Maintaining accurate CTDI measurements is essential for adherence to the ALARA (As Low As Reasonably Achievable) principle and for optimizing patient radiation protection.

One limitation encountered during the study was the inability to complete the automated image quality assessment because of the presence of an air bubble in the quality assurance phantom. Nevertheless, comprehensive manual quality control tests were successfully completed, providing sufficient evidence to evaluate the scanner performance. This observation also emphasizes the importance of regular phantom maintenance, as physical defects within quality assurance phantoms may interfere with automated testing procedures without necessarily reflecting deficiencies in the scanner performance.

Overall, the findings of the present study support the implementation of structured quality assurance programs incorporating routine phantom-based evaluations. Such programs facilitate the early identification of equipment deterioration, reduce the likelihood of repeat examinations, optimize radiation dose, and improve diagnostic confidence. Therefore routine quality control should remain an integral component of CT imaging practice to ensure sustained equipment performance and patient safety.

Study Limitations

This study had several limitations. First, the quality control evaluation was performed on a single 128-slice CT scanner at a single institution, which may limit the generalizability of the findings to other CT systems and manufacturers. Second, the investigation primarily relied on descriptive performance assessments without long-term monitoring of scanner stability over multiple years. Third, automated image quality assessment could not be completed because of the presence of an air bubble within the phantom, although manual quality control testing adequately evaluated the scanner performance. Finally, advanced image quality metrics, such as the modulation transfer function (MTF), noise power spectrum (NPS), and task-based detectability index were not evaluated.

Clinical Implications

Routine phantom-based quality assurance testing enables the early detection of equipment malfunctions before deterioration affects clinical image quality. Regular monitoring of CT number accuracy, image noise, spatial resolution, and radiation dose contributes to improved diagnostic confidence while supporting the optimization of patient radiation exposure. The findings of the present study reinforce the importance of periodic quality control programs as recommended by international radiological organizations and demonstrate that consistent adherence to these protocols can maintain stable scanner performance in routine clinical practice.

CONCLUSION

The Philips Ingenuity Core 128-slice CT scanner demonstrated satisfactory performance across all evaluated quality control parameters, including CT number accuracy, CT number linearity, image noise, CT number uniformity, spatial resolution, low-contrast detectability, mechanical accuracy, slice thickness, and radiation dose measurements. All evaluated parameters remained within the recommended acceptance limits, indicating stable scanner performance and reliable diagnostic image quality. The routine implementation of comprehensive quality assurance programs is essential for maintaining equipment performance, ensuring patient safety, optimizing radiation dose, and supporting accurate clinical diagnosis.

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