Evaluation of some computed tomography quality control parameters in Kaduna, Nigeria

Original Article

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ABSTRACT

Background: Quality control (QC) tests for computed tomography (CT) are primarily concerned with the maintenance of CT scanners at the optimal operating conditions for providing the required diagnostic information at the least possible exposure to ionizing radiation. Routine QC procedures should be observed in every facility. However, an empirical review search shows no evidence of routine QC procedures being carried out in Kaduna State.

Objective: This study was aimed at evaluating some computed tomography quality control parameters in Kaduna

Methods: The study design was prospective and cross-sectional. Two scanners labeled Scanner I and II were included in the study. CT numbers for water, field uniformity, image noise, and high and low contrast resolution were tested using the head CT phantom

Result: CT scanners I and II passed the water and field uniformity tests (2.87 and -1.9). Both scanners failed the noise test (4.36 and 3.2). The scanner I failed the high contrast resolution test (30.55) but passed the low contrast resolution test (123.53)

Conclusion: Both scanners passed the tests for the CT number for water and field uniformity but revealed a significant failure in noise tests. The scanner passed the low contrast resolution test but failed the high contrast resolution tests. Both scanners measure tissue density reliably but excessive noise and scanner one's poor edge definition will limit diagnostic accuracy.

Keywords: Computed tomography, Quality Control, Image Noise.

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Introduction

Computed tomography (CT) is a medical x-ray imaging modality that transmits numerous X-ray beams through the human body to obtain images for disease diagnosis, evaluation of clinical treatment, and assessment of patient wellness [1]. The x-ray-based CT scanner was invented in 1972 by the British engineer Godfrey N. Hounsfield [2]. The formation of CT images by a CT scanner involves the collection of x-ray transmission measurements from the patient by electronic detectors which are sent to the computer for processing [3].

The CT scanner overcomes limitations in detail and clarity by using the mathematical construct of image reconstruction from projections to produce sharp and clear images of cross-sectional anatomy. [3]. The drawbacks and limitations of CT are notably the exposure of patients to high dose of ionizing radiation, high cost, and also the potential for misdiagnosis of certain diseases [4,5]. Today CT accounts for up to 40% of the resultant collective dose from diagnostic radiology [6]. The complexity of this technology continues to increase as does its potential to deliver substantial doses to patients, consequently; the need for routine quality control (QC) tests [7].

Quality control are systematic and procedural checks, tests and measurement done to a system to ensure standardization or conformance to a known standard [1]. Routine QC can help ensure the equipment is operating appropriately in order to ensure high quality diagnostic images are produced with the least exposure to ionizing radiation [1,6]. Quality of CT images can be assessed by qualitative and quantitative measurements of physical parameters such as CT number for water, field uniformity, image noise, high contrast resolution (HCR) and low contrast resolution (LCR) using suitable test phantom [7]. The CT number for water, field uniformity, image noise and artifacts evaluation are daily QC tests that are within the limits of the radiographer [7,8]. Meanwhile, high contrast resolution (HCR) and low contrast resolution (LCR) tests are done on post-installation and on monthly basis [7].

The CT number for water is defined as the density assigned to a voxel CT scan on an arbitrary scale on which the value is set at zero. The CT water number ensures that the calibration of CT numbers relative to water remains within acceptable limits [7, 8]. A range of 0 ± 3 at the centre of image and 0 ± 5 Hounsfield unit (HU) at the peripheral locations is acceptable [7]. Image noise is the random component of image non uniformity, which can be expressed in terms of standard deviation of the CT numbers in Hounsfield Units (HU). The tolerance limit for this test is 0 ± 3 HU [9]. High contrast resolution characterizes the scanner’s ability to distinguish between two very small objects placed closely together. Spatial resolution measurements are performed with objects which have a high contrast (contrast difference of 12% or greater) from uniform background. The standard deviation (SD) for a region of interest (ROI) within the normal bar pattern should equal 37 ± 4 for high contrast resolution test [9].

Low contrast resolution can be defined as the CT-scanner’s ability to distinguish relatively large objects which differ only slightly in density from background with an acceptance limit of 120 ± 12. The uniformity test describes how uniform the image of a homogenous material appears. This uniformity measurements are important to ensure that cupping and beam hardening artifacts are avoided [10]. The standard for field uniformity centre ROI measured $<$ 3 HU and the four ROIs in the periphery measured within the $<\pm 5$ HU of centre measurement are acceptable [7]. Artifact evaluation is conducted to identify and correct artifacts in images of a uniform test phantom before they become apparent in patient images. A set of QC phantom images are reviewed to identify image artifacts scanner [8, 11].

Routine QC procedures should be observed in every facility in order to ensure acquisition of images with optimal diagnostic quality and smooth operation of the equipment [12]. However, empirical review search shows no evidence of routine QC procedures being carried out in Kaduna State.

Absence of routine QC procedures may lead to non-recognition of subtle changes in the equipment operation as well as images produced, which may lead to increase in false positive and false negative diagnosis. The findings of this study are expected to serve as a baseline for making recommendations to the relevant authorities about the status of the CT scanners in Kaduna State. This will also guide the management in formulating relevant policies needed to ensure continuation and smooth operation of the scanners. This will in turn lead to justification of practice. The study aims at evaluating some computed tomography quality control parameters in Kaduna.

Materials and Methods

The study was prospective and cross-sectional in design and primary source of data was used. The study was conducted at the Radiology Department of Barau Dikko Teaching Hospital, Kaduna and the National Ear Care Centre~~,~~ Kaduna from June 2022 to April 2023. Ethical clearance to conduct the study was obtained from the Research and Ethics Committee of the respective hospitals. Non-functional CT scanners and facilities not willing to participate in the study were excluded from the study. The CT water phantom provided by the manufacturer of each CT scanner at the time of installation for the purposes of QC tests was used for data collection.

There were six installed CT scanners in the study area but only two were functional during the study period and thus included in the study. These were tagged CT scanner I and II. CT scanner I was a 16 slice GE Medical System installed in 2019 while CT scanner II was a 160 slice Toshiba Aquilion. There were no available information of previous QC test records conducted during installation of the equipment and the subsequent routine QC tests conducted on both scanners. The CT number for water, field uniformity, image noise, HCR and low contrast resolution were tested using the head CT phantoms. The manufacturer's guidelines provided in the manual for QC tests was followed.

The phantom was placed on the couch using the phantom holder and placed centrally to achieve proper alignment in the axial, sagittal and coronal planes. Brain protocol was used in scanning the phantoms at both centres included in the study. On the monitor, about 2cm equal-sized circular ROI was placed at the centre and at 12, 3, 6 and 9 o'clock positions respectively, over uniform sections of the phantom image. CT number for water and image noise was determined by taking the mean CT number at the central ROI and SD of each ROI, respectively. The mean pixel values for the four peripheral ROIs were noted as the field uniformity in each phantom. The standard for field uniformity centre ROI measured < 3 HU and the four ROIs in the periphery measured within the $<\pm 5$ HU of centre measurement are acceptable.

Six sets of bar patterns in high contrast resolution module were examined to determine the limiting resolution. Then, using the standard algorithm, the SD of the pixel values of the multiple bar pattern was determined which validated the subjective assessment of the HCR. The SD for a ROI within the normal bar pattern should equal 37 ± 4 for standard algorithm. For low contrast resolution, the difference in the mean CT number between the water and water plus plastic in the low contrast section was recorded, with an acceptance limit of 120 ± 12. The images from each center was also inspected for the presence any artifacts. All information obtained was entered into a data capture sheet. Phantom used for scanner II was a pure water phantom and thus high and low contrast resolution tests were not conducted.

RESULT

Both scanners showed reliable performance in measuring tissue density and field consistency, with acceptable readings at the center and edges (Table 1). However, a notable issue emerged: both systems struggled with excessive noise in their images (Table 1). Scanner I had an additional problem, it couldn't clearly distinguish fine details and sharp edges (Figure IV). On the positive side, Scanner I did manage to differentiate between soft tissues reasonably well (Table 1), suggesting the core imaging capability remains intact despite these quality concerns.

Table 1: CT quality control parameters for scanner I and II

CT SCANNER	CT QUALITY CONTROL PARAMETERS							
	CT no. for water	Field Uniformity				IN	HCR	LCR
	R1	R2	R3	R4	R5			
I	2.87	3.23	4.59	4.71	3.96	4.36	30.55	123.53
II	-1.9	-0.8	-2.1	-0.9	-0.9	3.2	-	-

R: Region of interest, IN: Image noise, HCR: High contrast resolution, LCR: Low contrast resolution, CT: Computed tomography

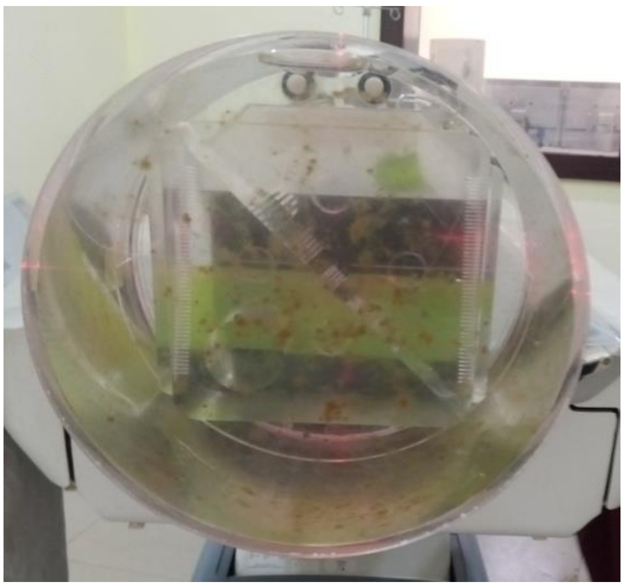
Figure I: Phantom image for Scanner I


Figure II: Phantom image for scanner II

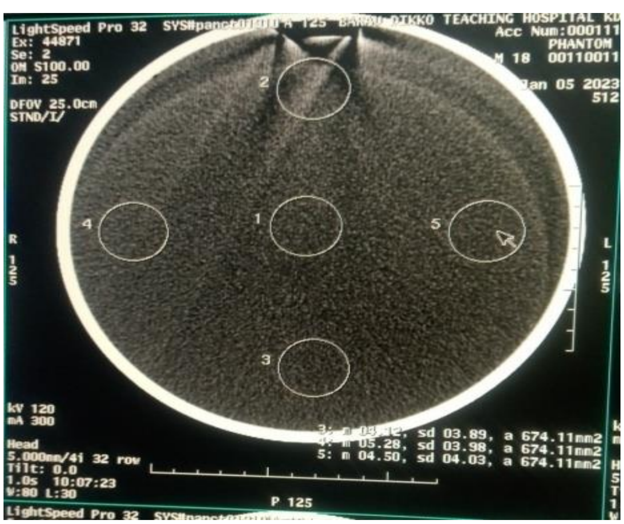

Figure III: Scanner I CT QC image for: 1 (Mean values for water and image noise), 2-5 (field uniformity)

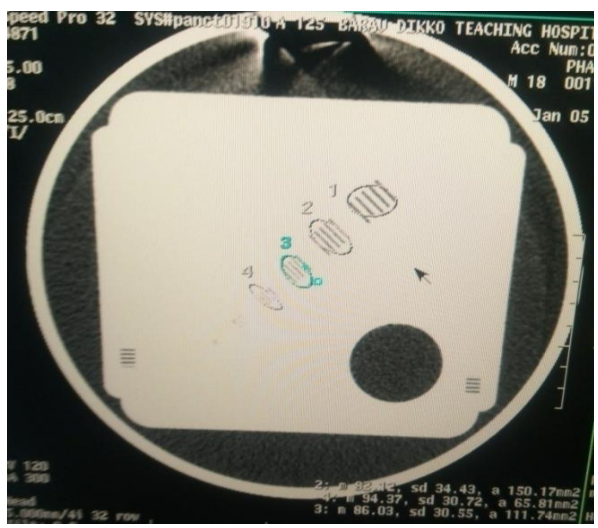

Figure IV: Scanner I CT QC image for high contrast resolution

Figure V: Scanner I CT QC image for low contrast resolution

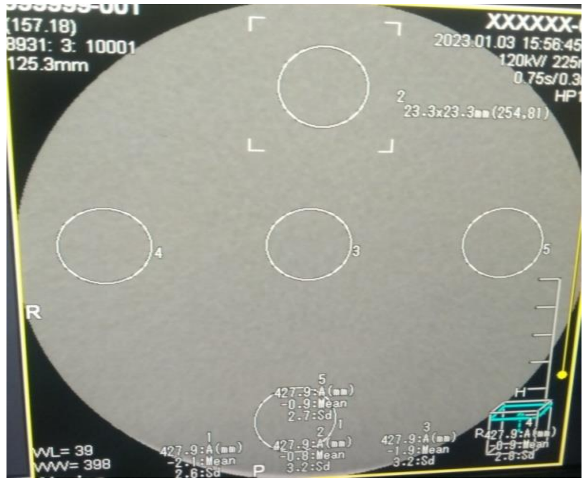

Figure VI: Scanner II CT QC image for; CT number, field uniformity and image noise

Discussion

The findings of the study show that CT scanner I and II passed CT number for water and field uniformity tests because the HU at the centre and peripheral ROI were within the acceptable limits (±3 and ±5 respectively) as shown in Table 1. This is an indication that the reconstruction algorithm that computes the CT numbers of the images was in appropriate working condition. Therefore, good quality diagnostic images with optimal radiation dose are expected from these scanners [13]. These findings are in accordance with the findings of several previous studies [1,7,10,11], where CT number for water and field uniformity tests were within acceptable limits for all the scanners studied.

Both scanners in this study failed the noise test, because the standard deviation value of the central ROI was above the acceptable limit of ±3 as shown in Table 1. The possible causes of noise in CT images are algorithm, scattered radiation, number of detected photons, slice thickness, electronic noise and object size. The implication of this is that the noise reduces contrast resolution and might hide pathology with density similar to that of the surrounding tissues. Most pathologies imaged in CT are seen in soft tissue such as liver, brain, kidneys and lungs, and this can lead to misinterpretation of the CT images. These findings are in accordance with the findings in previous studies [7, 11, 12], but contrary to the study conducted by Oliveira et al. [8], where all scanners included in the study passed the noise test. The possible agreement between this findings and others [7,11] might be because both studies were all conducted in the same geo-political regions in Nigeria. Hence, the attitude or manner of handling the equipment by the radiographers and management might be similar. Whereas, study by Oliveira et al. [9] was conducted in Asia where they probably ensured good quality management of the equipment.

Results from this study showed that CT scanner I failed the HCR test because the standard deviation of the pixel values of multiple bar patterns was below the acceptable limit of 37±4 as shown in figure IV The possible cause of HCR failure could include; enlarged x-ray tube focal spot, excessive mechanical wear in gantry motion, and misalignment of electromechanical components or detector failures. The implication of failed HCR test is that the images produced may fail to clearly demonstrate the edges of structures, margins of tumors, small foreign bodies and small bony structures, and thus resulting in misdiagnosis. This finding is in accordance with the findings of the studies conducted by Sidi et al. [7] and Njiki et al. [10], but contrary to the findings of the study conducted by Oliveira et al. [9], where all scanners included in the study (20) passed the high contrast resolution test.

Based on the findings of this study, CT scanner I passed the LCR test because the difference in the mean CT number between the water and water plus plastic was within the acceptable limit of 120±12. Thus images produced will allow clear visualization of pathologic tissue changes, especially soft tissue low-density tumors, which are mostly found within the brain, kidney and liver. This finding is contrary to the findings of the studies conducted by Sidi et al. [7] and Njiki et al. [10] but in accordance with the findings conducted by Oliveira et al. [9] where 16 out of the 20 scanners included in the study passed the low contrast resolution test.

Phantom images obtained with CT scanner I demonstrate some evidence of streak artefacts as shown in Figures III – V. Streak artefacts are caused by multiple mechanisms, including beam hardening, scatter, Poisson's noise, motion, and edge effects in the scanned objects, including hair pins, clips, and metals inside the patient. Metals, such as gold-implanted objects within a human body absorb the x-ray beam almost completely, thus producing "radiation shadows" which generate pronounced dark and bright streak artifacts over the entire reconstructed image. This can only be avoided via a gantry tilt that excludes the disturbing metallic objects from the slice plane [2].

Limitation of the study: The major limitation of the study was the downtime of several CT scanners in the study area thereby narrowing the sample size to two. -

Conclusion: Both scanners passed the tests for the CT number for water and field uniformity but revealed a significant failure in noise tests. Scanner I passed the low contrast resolution test but failed the high contrast resolution tests. While both scanners can reliably measures tissue density and soft tissue contrast, the elevated noise levels combined with scanner I's poor high contrast resolution significantly limit diagnostic accuracy. Clinicians should be cautious when diagnosing conditions requiring precise edge definition or when looking for subtle abnormalities that can be mask by noise.

Recommendation: The authors recommend that at regular intervals, CT engineers should be invited to take measures about the failed QC test. Furthermore, each facility should ensure full implementation of QC programme and all information relevant to QC should be appropriately kept for future use.

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Conflict of interest: nil

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