Assessment of CT number accuracy, image uniformity and Noise of different Computed Tomography imaging machines.

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ABSTRACT

Regular and recommended quality control process is essential for quality images to avoid repeated examinations. Since the dose reduction technique is important for radiation protection of patients and repeated examination should be minimized in computed tomography scan. For this reason, quality control tests for image quality based on CT number accuracy, image uniformity and image noise were done regularly. The study was to determine whether Hounsfield of water varies across the images and whether the standard deviation of the HU for a large region of interest at the centre of a reconstructed image is within tolerance as part of the QC process of varried CT machines. Additionally, the QC test is also to determine whether the CT number or the HU varies across different materials or tissues other than water.The design methodology used for this study was based on IAEA harmonized diagnostic radiology quality control programme for diagnostic radiology. These were done with two Toshiba 128 and 640 slice CT machine, two 64 slice Philip CT equipment and two 16 slice General Electric CT machine in Accra, which were all installed between 2016 and 2022. Comprehensive cross-sectional quality control procedures were performed using two phantoms, including, manufacturers CT water phantom and ACR CATPHAN. A software analysis was used to estimate CT number accuracy, image uniformity and image noise, CT numbers of different materials and the recommended levels. The ROI was drawn in both the centre of the image and four ROIs at the periphery of the image. The mean and standard deviation were recorded, the mean values of the CT number and standard deviation were then used to estimate CT number uniformity and image noise. Additionally, CT numbers of different materials using the CATPHAN which contain different materials were analysed using the ROI technique. The study results shows that the measured HU for water were between 0.24-2.21, -0.59-1.85 and -2.31-0.84 for Center A, B and C respectively. Additionally, the results of the various measured uniformity tests were 0.07, 0.9 and 0.76 at center A, B and C respectively. This is within the accepted recommendations by both the IAEA harmonized CT protocol for diagnostic radiology and the manufacturers recommendation of +/-5. The study also shows that the maximum standard deviation between the center ROI and the peripheral ROI were greater than +/-5 HU. Therefore, both the two 64 slice Philips scanners and the 16 Slice GE scanner passed the noise test. These were done with two Toshiba 128 and 640 slice CT machine, two 64 slice Philip CT equipment and two 16 slice General Electric CT machine passed CT number of water and `image uniformity. However, they failed image noise tests because the values were outside the manufacturer's recommendation and acceptable limit by the IAEA harmonized CT protocol for diagnostic radiology for Africa.

Keywords: CT Image, CT Number, Image Uniformity, Image Noise, Hounsfield Unit

1.0. INTRODUCTION

Despite the current significant benefits of CT scanners in diagnostic, interventional and therapeutic decision-making process in its clinical application, lack of recommended quality control process may lead to higher patients' radiation dose and safety concerns. To optimize the use of CT equipment is to perform regular quality control tests on the CT scanners. This will help to keep the CT scanner at the optimized usable situation for providing the necessary diagnostic information before and during its usage. Additionally, the performance of QC process in the use of CT equipment has several benefits including monitoring the safe and effective use of the equipment without causing damage to the patient.

The purpose for performing these QC procedures is to specifically assess the quality of images produce by the equipment and more importantly to detect abnormalities in the image for corrective action. However, this must be done with the medical physicist, who is trained with the technical know-how to perform the QC procedure and to interpretate the results of the procedure meaningfully. To this end manufactures has several specific QC procedures that they recommend to be done within a specific time interval including daily weekly, quarterly and annual, depending on the purpose for performing this procedure. Some of such QC procedures recommended by the manufacture is the daily quality control procedure of assessing the CT number of water or the hounsfield (HU), image uniformity, image noise, and differentiation of ct number of different materials (De González et al., 2009; Goldoost et al., 2018). This is to ensure that the equipment are performing optimally, for diagnostic accuracy with noise level. Hence, manufacturers, professional bodies and regulatory authorities recommend regular QC for efficient equipment performance. To achieve these various manufacturers are to ensure that upon sale and supply of their equipment, manufacturers water phantom is supplied alongside this equipment. The manufacturers CT water phantom containing water, which form bases for CT image quality procedure. This is to ensure that the CT number of the scanner are measured accurately before clinical application. Where necessary accurate calibrations are done to ensure that the water-based CT numbers are within acceptable limits for clinical use.

Approximately 43% of the radiation dose from all radiological imaging procedures done in radiation medicine globally that have the potential to damage healthy tissues comes from Computed Tomography (CT) imaging. Regular and recommended quality control process is essential for quality images to avoid repeated examinations (Mutic et al., 2003; New Jersey Department of Environmental Protection, 2017). Since the dose reduction technique is important for radiation protection of patients, repeated examination should be minimized in computed tomography examination. It's important to note that, even though CT images have varied applications of its cross-sectional images with superior contrast that provide clear anatomical structures than those from other imaging modalities the images are generally used for diagnosis when anatomical details are the primary objective for the procedure. Additionally, CT scanners have high diagnostic benefits, unfortunately these benefits come with possible high doses which is relatively higher than conventional radiography (IAEA, 2023). In addition to diagnostic applications, CT scanners are also used in radiotherapy treatment planning purposes

Furthermore, both qualitative and quantitative assessment of the CT images are recommended to ensure that the test results with the recommended output reference values. The daily QC procedure such as image uniformity and CT number tests are recommended to be done by the physicist or his assignee, the results of which must be analysed for appropriate decision making (5). To determine the accuracy of the acquired and reconstructed image, the image uniformity test is performed by evaluating the CT number for water and uniformity of the CT numbers obtained by scanning a uniform water phantom. Where these tests failed to meet the recommended reference values, recalibration of the equipment are required and may require urgent attention by the medical physicist or biomedical engineer (Cody et al., 2012).

In addition, the level of noise in the image is also an important parameter that are used to assess the quality of images produce. This is done by assessing the percentage of image contrast (contrast to noise ratio) or the level of signal strength in the image (signal to noise ratio) in the CT image. Additionally, any fluctuations in the CT numbers around its average value in a uniform medium express the noise. However, factors such as: detectable photons, matrix size, slice thickness, scattered radiation, electronic noise, object size, and reconstruction algorithm can contribute significantly to image noise. Clinically, image noise has higher potential of hiding clinical pathology or anatomy structures, if it is similar to the surrounding tissues (Cody et al., 2012).

The aim of this study is to determine the hounsfield unit (HU) of water, image uniform, image noise and the CT number of different materials in selected diagnostic facilities and compare with the manufacturers recommended values using the IAEA harmonized protocol on CT quality Control programme for diagnostic procedure.

2.0. METHODS AND MATERIALS

2.1. Materials/Equipment

The materials used for the study include manufacturers water phantom and ACR CATPHAN. The most commonly technique factors used were 120 KVp and 442 mA and ImageJ was used for analysis of the images. Generally, the ACR CATPHAN is used to determine the total performance of the CT scanner. This involves scanning the whole phantom to enable the measurement of the following:

- CT number accuracy
- CT number uniformity
- Image noise

Measurement of CT number of water using the water phantom, image uniform, image noise and CT

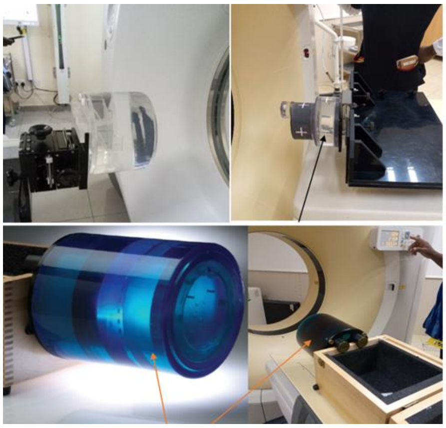

Figure 1: Manufacturer's water phantom and ACR CATPHAN

number of different materials were done as follows.

CT number for water

Method

1. Air calibration was done to normalise the detectors signals
2. The manufacturer's water phantom was placed on its holder as shown on *figure 1* and scan
3. The Hounsfield Unit (HU) of water was then confirm as 0 (within 5 HU) and the standard deviation less than 10 HU as shown on figure 3.
4. The image was then reconstructed and check for any artifacts
5. This was repeated at all the facilities

CT number Uniformity

Method

1. The water phantom was aligned as shown in *figure 1*
2. The CT number test for commonly used technique factors and average size patient (mAs and KVp setting) were performed.
3. On reconstructed images, five regions of interest (ROIs) of ~ 200mm^2 (center, 12:00 o'clock, 3:00 o'clock, 6:00 o'clock and 9:00 o'clock) was drawn to measure the HU of water. This was repeated at all the three facilities.

CT Image Noise

Method

1. The water phantom was aligned as shown in *figure 5*
2. The CT number test for commonly used technique factors and average size patient (mAs and KVp setting) were performed.
3. On the reconstructed images, a large ROI (~ 75%) was drawn at the centre of the images (~ 5 cm diameter). This was repeated at all the three facilities.

CT Number Accuracy of different Materials

Method

1. The ACR CATPHAN was aligned as shown in *figure 4*

2. The CT number accuracy test for commonly used technique factors and average size patient (mAs and KVp setting) were performed.
3. On the reconstructed image, ROIs was drawn on each of the inserts of the different materials as indicated on figure 7. This was repeated at all the three facilities

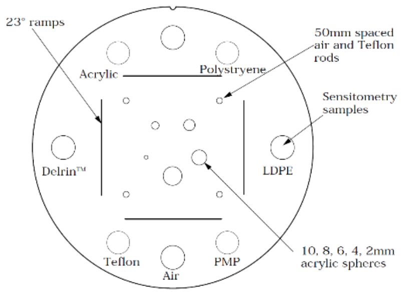

Figure 4: CATPHAN 600, CTP 404 module of different materials inserts.

3.0. RESULTS

CT Number Accuracy

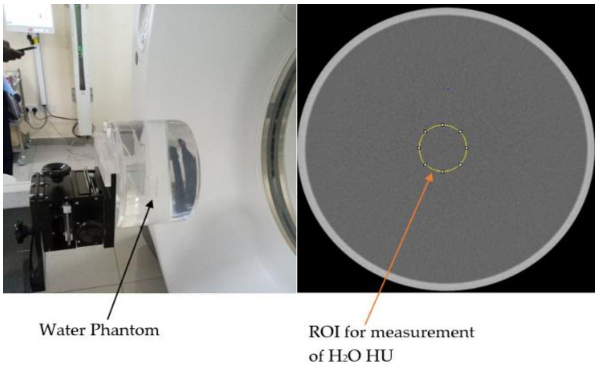

Figure 3: Image of Philips CT water phantom

Figure 2 shows a measured CT Number using the water phantom. While table 1 and 2 shows the results of the measured CT number

Table 1: Verified Hounsfield Units (HU) for water

Measurements	HU	SD	SNR
1	1.377	2.034	5.169
2	2.478	2.141	6.266
3	1.233	1.551	5.795
4	1.152	1.435	7.613
5	1.089	1.234	6.343
6	1.292	1.447	7.413

CT image uniformity

Figure 6 show the measurement of CT number with five ROIs CT number and image uniformity assessment

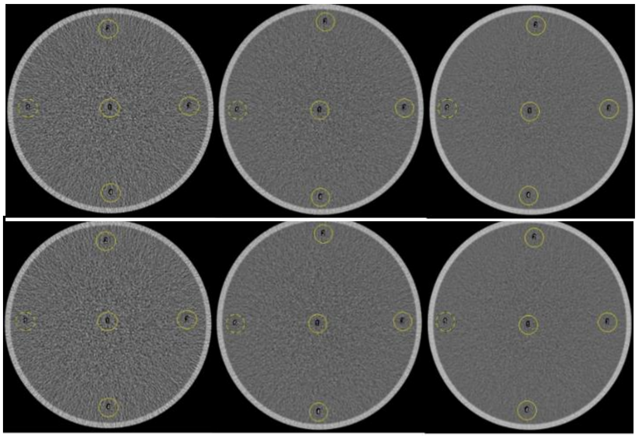

Figure 6: Measurement of CT number with five ROIs

Uniformity Analysis

Table 6: Uniformity analysis at 6 Center

ROI	**HU_A**	HU_B		**HU_C**	**HU_D**		**HU_E**	**HU_F**
1	0.355	0.414		0.590	0.277		2.328	0.767
2	1.334	0.335		1.676	1.93		0.864	0.625
3	0.239	0.311		0.044	1.81		0.663	1.18
4	0.871	0.347		1.611	1.87		0.838	1.19
5	2.206	0.342		1.850	1.97		0.794	1.39
Mean HU	1.001	0.3498		1.29525	1.895		1.0974	1.0304
Tolerance	**±5**			**±5**			**±5**	
Remarks	**Pass**			**Pass**			**Pass**	

CT Image Noise

Figure 7 show measured of CT images noise at the three facilities.

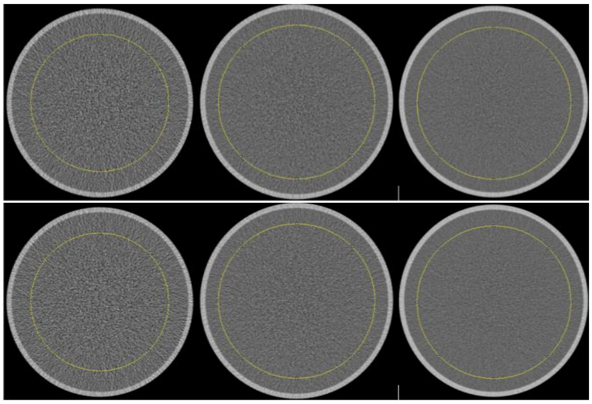

Figure 7: CT images obtained at the facilities.

ROIs covering more than 75 % of the images were used to obtain results.

Image Noise Quantitative Analysis

Table 10: Noise measurement analysis

Facilities	Noise/SD	Tolerance SD	Remarks
Center A	3.67	5	Pass
Center B	2.41	5	Pass
Center C	4.87	5	Pass
Center D	1.43	5	Pass
Center E	2.67	5	Pass
Center F	3.02	5	Pass

CT Number Accuracy of other Materials

CT number accuracy for each kV setting was performed, by using average size patient mAs on the reconstructed image, draw ROIs over the inserts of the different materials.

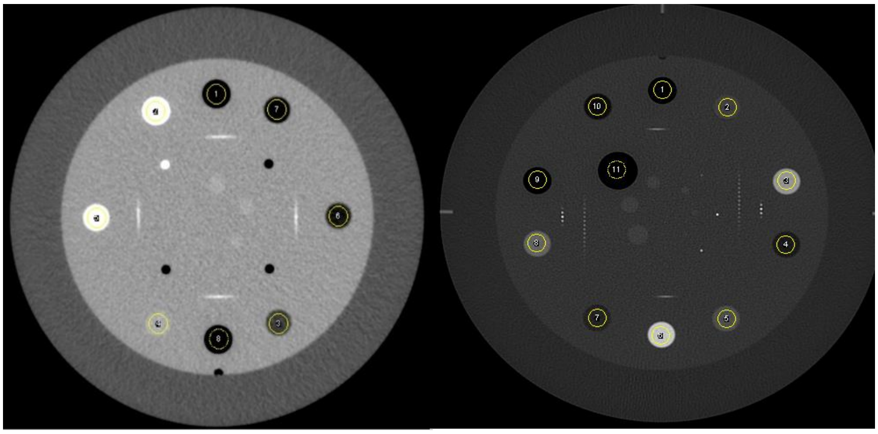

Figure 8: CT CATPHAN image

Analysis

Table 11: Analysis of HUs measured for different materials

Material	**ROI**	**Area**	**$HU_{measured}$**	**HU_{actual}**	**HU Range**	**Tol**	**Remarks**
Air	1	65.686	-974.291	-1000	-970 to -1005	±20	Pass
Teflon	2	65.686	916.887	990	850 to 970	±20	Pass
Polystryrene	3	65.686	-32.53	-35	-65 to -29	±20	Pass
Acrylic	4	65.686	123.673	120	110 to 135	±20	Pass
Delrin	5	65.686	339.384	340	344 to 387	±20	Pass
LDPE	6	65.686	-90.196	-100	-107 to -84	±20	Pass
PMP	7	65.686	-177.131	-200	-220 to -172	±20	Pass
Air	8	65.686	-974.176	-1000	-970 to 1005	±20	Pass

Tolerances: ±5 HU (water), ±20 HU (other materials) compared with phantom manufacturer recommendations and baseline values established during system commissioning. Assessment of the 8 different materials in CATPHAN passed the CT number test. Since there were all within the accepted recommendations by both the IAEA harmonised protocol and the manufacturers recommendations.

Table 12: Relative electron density (specific gravity) of different CATPHAN materials

Material	**Relative Electron density**	**$HU_{measured}$**
Air	0.00	-974.291
Teflon	2.16	916.887
Polystyrene	1.05	-32.53
Acrylic	1.18	123.673
Delrin	1.41	339.384
LDPE	0.92	-90.196
PMP	0.83	-177.131

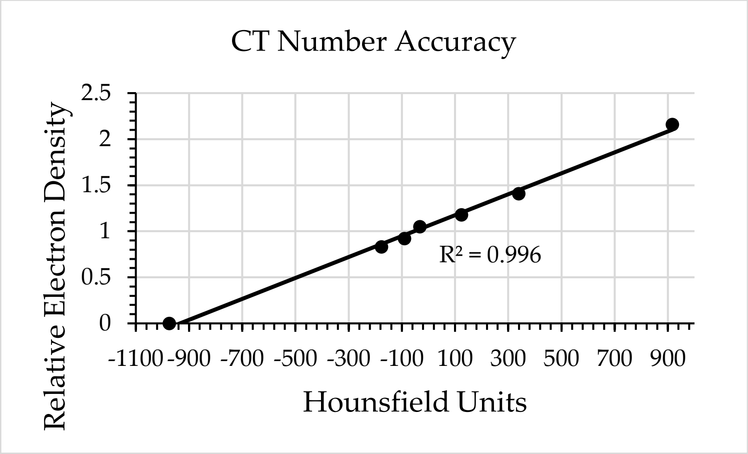

Figure 9: Relative electron density against measured Hounsfield Units or the Calibration Curve.

The plot of relative electron density against CT number is approximately linear with $R^2 = 0.996$. This implies that CT number accuracy passed the test.

4.0. DISCUSSIONS

The study results shows that the measured HU or CT numbers of water were between 0.24-2.21, -0.59-1.85 and -2.31-0.84 for Center A, B and C respectively. This shows that the assessed CT machine passed the HU of water assessment test based on the recommendation of ±5 by both the IAEA harmonized protocol and the manufacturers recommendation (Goldoost et al., 2018). Furthermore, based on the manufacturer's standard instructions of the various CT machines used, the CT number of water is equal to zero and the range of ±3 in the center of the reconstructed image and the range of ±5 in the peripheral regions are recommended. Therefore, the measured results are accepted for both the center and the peripheral at all the centres as shown in Table 4, 5 and 6 for Centre. Additionally, the results of the various measured uniformity tests at center were varied from 0.4 to 1.9 and are all below the recommended measured value of ±5 units. This is within the accepted recommendations by both the IAEA harmonized protocol and the manufacturers recommendation of ±5 (Goldoost et al., 2018). Furthermore, the recommendation of standard measured uniformity test is that the measured value at the center should be less than 3 HU and ±5 HU for the 4 selected ROI in the peripheral of the reconstructed image. The results of this study show that Philips 64 slices scanners in center A and B and 16 slices GE scanner in Center C passed CT number for water and uniformity tests because the measured values were within the recommended acceptable limit.

Furthermore, by the recommendations of the manufacturers the measured standard deviation or the noise on the image should be ±5. Additionally, the level of noise in the CT images can be expressed as a percentage of image contrast in CT numbers. The study shows that the maximum standard deviation between the center ROI and the peripheral ROI were greater than ±5 HU. Therefore, both the 64 slice Philips scanners and the 16 Slice GE scanner failed the noise test because the measured values were outside the acceptable limit. Furthermore, qualitative assessment of the real physical images and the quantitative measured values show poor image quality produced by the scanners, which is not good for efficient clinical used. This might lead to the wrong diagnosis with possible wrong clinical decision.

Finally, the assessment of the eight material inserts in the CATPHAN (Air, Teflon, Polystyrene, Acrylic, Delrin, LDPE, PMP) passed the CT number test. The quantitative measured values varied from -974 for Air to 917 for Teflon, which reflect the recommendation of the standard operating manual of the CATPHAN by the manufacturers.

In summary, the possible causes of these poor image quality due to high image noise may be due to one or more of the following features: in appropriate slice thickness, insufficient detectable photons due to inappropriate collimation, scattered radiation, improper reconstruction algorithm, matrix size or pixel size, detector electronics (electronic noise) and inappropriate technique factors, hence further investigation is required. The resultant effect of these is that the high image noise affect contrast resolution and may lead to detailed anatomy structure being hidden within the surrounding tissue. This is because most clinical pathologies in CT images are seen in soft tissues such as the spleen, kidney, lungs, brain and liver, which can lead to misdiagnoses of the clinical pathology.

5.0. CONCLUSION

In conclusion, CT scanners in the participated facilities passed the CT number for water and field uniformity tests, but all the scanners failed the noise test. There is the need for further assessment and possible recalibration of the technique factors of the three machines.

RECOMMENDATIONS

The following four recommendations are made after the study:

1. All quality control reports should be documented including images of the QC tests
2. A regular Qualily Control tests should be done based on harmonized IAEA Protocol on QC.
3. Procedure for solving identify QC problem should be documented with clear role of the responsible persons and a clear reporting line.

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