Assessment of some image quality tests on a 128 slice computed tomography scanner using a Catphan700 phantom

Sir,

Routine quality control (QC) procedures in computed tomography (CT) centers in most African countries are not given much attention due to lack of access to newer technology and no/limited certified professional medical physicists trained to carry out this task. This has rendered the services of medical physicist generally limited especially in West Africa than the rest of the world.[1] The objective of this letter is to adequately provide information on some image quality tests on CT systems to medical physicist/radiographers, in order for them to perform QC tests with good confidence. This letter describes some essential image QC procedures performed at CT diagnostic facilities using Catphan700 phantom. The need for this is pronounced due to the increase in design capabilities and extended applications of CT scanners[2] and the increasing number of CT facilities coupled with a shortage of qualified professionals in West Africa.

These advancements in CT technology have raised many concerns about the differences in the quality of images produced by these scanners. An image that contains all the information needed for correct diagnosis of a patient disease condition is said to be a quality image. The quality of an image is affected by composite factors such as contrast, spatial resolution, noise, blur, artifacts, and distortion.[3,4]

Quality assurance for single slice CT (SSCT) and multi-slice CT (MSCT) scanners usually consists of some basic required elements of testing such as contrast scale, CT number, high-contrast resolution, low contrast resolution, image noise, uniformity, and artifacts; and other tests such as laser light alignment and accuracy, slice thickness and image noise, uniformity, and artifacts; and other tests such as spatial linearity, pixel size, CT number, spatial resolution, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR).

The initial test carried out was to verify the accuracy of distance measurement and pixel size on the image. The aim of the distance measurement is to ensure that the displayed image represents the true phantom image. The CTP682 module of the phantom was used to evaluate the accuracy of distance measurement by measuring the horizontal (x) and the vertical (y) dimensions using the distance tool in the DICOM viewer. Furthermore, the pixel size was evaluated to verify whether the image pixel size agrees with the nominal value. The number of pixels on the image display was determined by counting the pixels along both horizontal and vertical measured lines. By knowing the distance and the number of pixels along the distance, the pixel size was calculated using Equation 1.

\[
\text{Pixel size} = \frac{\text{Measured distance (mm)}}{\text{#pixels}}
\]  

(1)

The nominal value of the phantom dimensions in the horizontal (x) and vertical (y) direction is 150.5 mm. The x and y value for the acquired image of the CT system was measured to be 150.2 mm each. This presents an error percentage of 0.19 from the nominal value. It can be concluded that the displayed image properly represents the phantom dimension with insignificant variation observed. Furthermore, the expected pixel size is estimated to be 0.49 mm, while the measured pixel size value calculated on the image display from the study was found to be 0.44 mm ± 0.1 mm (variation range: 0.08 and 0.12 mm).

The second test was on CT number accuracy. The CT number measurement accuracy was obtained from the image of module CTP682 for the different sensimetry targets located in the phantom. These targets include Teflon, bone 50%, Delrin, bone 20%, acrylic, polystyrene, low-density polyethylene, polymethylpentene, lung foam #7112, and air. A 1 cm² region of interest (ROI) was selected on each target using DICOM viewer and the mean CT number value determined on each of the targets. The mean CT number of each material was then compared to the actual CT number range from the point of view of maximum performance.[9]

The scanner investigated is an Aquilion 128 slice CT scanner manufactured by Toshiba Company (Toshiba Aquilion 128 CXL Edition, manufactured in the city of Otawara-shi, located in Tochigi state in the country of Japan). In this letter, some parameters that characterize a system’s image quality performance have been assessed and their effects on image quality discussed. These include spatial linearity, pixel size, CT number, spatial resolution, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR).

Garayoa and Castro[8] performed a study to evaluate the image quality on a cone beam CT scanner by determining various physical parameters that characterize a system’s performance, using Catphan phantom. Catphan700 phantom is a diagnostic imaging tool specially designed for comprehensive evaluation of axial, spiral, multi-slice, cone beam, and volume CT scanners from the point of view of maximum performance.[9]

Carayoa and Castro[8] performed a study to evaluate the image quality on a cone beam CT scanner by determining various physical parameters that characterize a system’s performance, using Catphan phantom. Catphan700 phantom is a diagnostic imaging tool specially designed for comprehensive evaluation of axial, spiral, multi-slice, cone beam, and volume CT scanners from the point of view of maximum performance.[9]
The measured CT numbers in the study for the various targets were all within the minimum and maximum range as specified by the manufacturer except for the Delrin and bone 20% which were found to be slightly outside the range. The deviations may be due to the variation in the density and composition of the materials, the type of scanner as well as the scanning parameters used. On average, the estimated CT values for all the other targets are within the range of phantom specification as shown in Table 1.

To establish a constancy of contrast scale over the range of CT numbers which is of clinical interest, the CT linearity was verified. This was performed by checking whether the CT numbers measured vary in a linear fashion with their linear attenuation coefficient values. Clinically, CT number relevant linearity was observed with \( r^2 = 0.973 \) close to unity, despite the slight deviation of CT mean number values from the line of best fit, especially as observed with bone 50% in Figure 1.

The third test was on measurement of spatial resolution using modulation transfer function (MTF). There are several methods that have been described to calculate the MTF of imaging systems, based on the slit, edge, or bar pattern images. In this letter, the MTF was calculated based on the method described in the Catphan700 manual. By obtaining the pixel values surrounding the image of a 0.18 mm tungsten carbide bead in the CTP682 module, the line spread function (LSF) along the x- and y-axes were determined by measuring the average pixel values of point spread function in the horizontal and vertical directions respectively, for four routine scanning protocols. The MTF curve was then computed by taking the Fourier transform of the LSF data using Matrix Laboratory (MATLAB) software (MATLAB software version R2012b, RadiAnt DICOM Viewer, Poznan, Poland).

The 10% MTF results of the study in Table 2 reflect the characteristics of the manufacturer specifications (6.5 ± 0.68) of CT system. The CNR clearly depends on both the SNR and MTF. An increase in SNR results in an increase in CNR and spatial resolution. In addition, since the MTF increases with an increase in the type of filter from FC8 to FC23, it can be concluded from the study that, the spatial resolution of CT images can be increased through further enhancement of reconstructed images by filtering. The spatial resolutions as expressed in terms of MTF for the four scan protocols are within the specifications set by the manufacturer.

The fourth test was SNR calculated from reconstructed images of module CTP712 of the Catphan700 phantom.

### Table 1: Measured computed tomography numbers of various materials and their computed tomography number range as specified by the manufacturer

| Material     | Measured CT number | \( \mu \) (cm\(^{-1}\)) | Expected CT number range | Error |
|--------------|--------------------|---------------------------|--------------------------|-------|
|              |                    |                           | Minimum                  | Maximum| Minimum | Maximum |
| Air          | −992.76            | 1.89E-04                  | −1046                    | −986   | 0.05    | −0.01   |
| PMP          | −202.32            | 1.36E-01                  | −220                     | −172   | 0.08    | −0.18   |
| Lung         | −806               | 2.87E-02                  | −925                     | −810   | 0.13    | 0.00    |
| Delrin       | 306                | 2.19E-01                  | 344                      | 387    | 0.11    | 0.21    |
| Polystyrene  | −54.46             | 1.59E-01                  | −65                      | −29    | 0.16    | 2.88    |
| Teflon       | 950                | 3.05E-01                  | 941                      | 1060   | −0.01   | 0.10    |
| Bone 20%     | 177.41             | 1.78E-01                  | 211                      | 263    | 0.16    | 0.33    |
| LDPE         | −110.89            | 1.51E-01                  | −121                     | −87    | 0.08    | −0.27   |
| Bone 50%     | 680.53             | 2.25E-01                  | 667                      | 783    | −0.02   | 0.130   |
| Acrylic      | 104.58             | 1.84E-01                  | 92                       | 137    | −0.14   | 0.24    |

CT: Computed tomography, LDPE: Low-density polyethylene, PMP: Polymethylpentene

### Table 2: Experimental results obtained from the study

| Scan technique | kV  | FOV | ST | Pitch | mAs | SNR | CNR | Mean deviation CNR | 10% MTF±0.68 | Reconstruction filter |
|----------------|-----|-----|----|-------|-----|-----|-----|---------------------|--------------|-----------------------|
| Head           | 120 | 150 | 7.0| 1.01  | 210 | 26.20| 2.3 | 1.5                 | 7.11         | FC23                  |
| Thorax         | 120 | 150 | 5.0| 1.45  | 40  | 15.00| 1.5 | 2.3                 | 5.86         | FC8                   |
| Abdomen        | 120 | 150 | 5.0| 1.34  | 50  | 15.14| 1.8 | 3.2                 | 6.28         | FC18                  |
| Pelvis         | 120 | 150 | 7.0| 1.35  | 100 | 23.20| 2.1 | 1.8                 | 6.76         | FC18                  |

SNR: Signal-to-noise ratio, CNR: Contrast-to-noise ratio, MTF: Modulation transfer function, FOV: Field of view

Figure 1: The measured computed tomography numbers of the target materials plotted against linear attenuation coefficients for energy of 120 kV
By selecting four different ROIs on each image, the SNR was calculated as the ratio of average pixel value, \( \text{ave}_p \), to the standard deviation of the pixel values, \( \sigma_p \), between the ROIs [Equation 2].

\[
\text{SNR} = \frac{\text{ave}_p}{\sigma_p}
\]

(2)

The SNR was calculated from reconstructed images using three different convolution filters. These filters which are used in smoothing or enhancing images of high frequencies are described as FC8 (sharp), FC18 (medium), and FC23 (smooth). Noise depends on the filter function F (and can be reduce with smooth filter kernel). It was found that, as the filter sharpness is increased from FC8 to FC23, the SNR increases. Increase in mAs decreases noise which increases the spatial resolution element as shown in Table 2. The high value of SNR as observed from analysis of the image obtained using the head scan protocol is due to the high mAs and smooth filter used. This is contrary to the thorax protocol with a low value of SNR due to low mAs and sharp filter. Although not obvious from the table, it may be added here that there would be excessive noise if size of the matrix and FOV used are not appropriate; also, noise varies with slice thickness (h) as \((h)^{-0.5}\). Further work is planned to determine the variation of range of values of noise with mAs, spatial resolution, and slice thickness.

The final test on the assessment was CNR. The CNR was determined from scan images of module CTP515 of the phantom. By taking the mean pixel values of ROIs on eight different contrast targets and backgrounds, the CNR was calculated from Equation 3 below;

\[
\text{CNR} = \frac{\text{ave}_T - \text{ave}_B}{\sigma_N}
\]

(3)

Where, \( \text{ave}_T \), \( \text{ave}_B \), and \( \sigma_N \) are mean pixel values of the contrast targets, mean pixel values of backgrounds and standard deviation of the noise, respectively. The results indicate the visibility of all the contrast targets relative to the background at 1% nominal contrast level. The thorax routine scan protocol demonstrated a low CNR with a mean deviation of ± 0.43 in comparison to the routine head, abdomen, and pelvis protocol. This difference may be attributed to the increase of noise produced at low mAs. However, it is difficult for one to tell exactly which parameters directly have an influence on the CNR. Results of CNR vary at different scan routine times with inconsistent values observed especially between the thorax and abdomen scan protocol. Despite the inconsistency, it was realized that the CNR increases with the reconstruction filter [Table 2]. On an average, all values of CNR calculated for the four scan protocols are within tolerance of ± 0.5 as specified by manufacturer.

In this study, some image quality parameters of a CT scanner have been analyzed from acquired images of Catphan700 phantom using four default scan techniques. The analysis was performed using DICOM and MATLAB software. In general, results of the CT images obtained from analysis reveal that the CT system is adequate for accurate diagnostic purposes. It must be noted that these are preliminary tests from image quality test only. For quality assurance which includes type approval and acceptance/constancy testing, more comprehensive tests are needed. It is planned to carry out further work and publish the complete results. The methods described in this study can be used for future routine image QC assessment of CT systems.

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**Conflicts of interest**

There are no conflicts of interest.

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