Image Quality and Radiation Dose Assessment for the Clinical Applied 16 Slice CT Scanner using PMMA phantom and Quality Assurance phantom

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Abstract

When compared to other radiological examinations, computed tomography has a significantly higher radiation exposure and employs ionizing radiation to make an image of a slice or cut of tissue and to learn about the patient's sickness. The current studies' objectives were to determine image quality and radiation dose from the 16-slice Philips CT scanner in order to identify the radiation dose delivered accuracy and the acceptable image quality parameter of CT scanner. The current investigation was carried out using quality assurance CT phantom, Image software, CT dosimeters PMMA phantom coupled with a 100mm pencil chamber. The image quality performance parameters that were tested were image noise, uniformity, CT number accuracy, and resolution. The radiation dose performance parameters that were evaluated were volume computed tomography dose index (CTDIvol), weighed computed tomography dose index (CTDIw), and dose length product (DLP). The results of the present study were measured CTDIvol was 10.01mGy, and the displayed was CTDIvol was 10.2mGy for the head scan technique, 5.8mGy, and 6.1 mGy for the body scan technique respectively. The image quality parameters were 4.4HU, 2.3HU, and 10 8HU for uniformity, contrast to noise ratio, and CT number accuracy for PMMA Quality assurance phantom respectively. The image quality parameter tests were accepted because they were within the tolerance values and the CT radiation dose parameters were not accepted within the international dose reference level. All CT scanners must pass the CT quality control test with respect to image quality and radiation dose for their performance to be improved.

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Introduction

Computed tomography is the most crucial imaging method used today by radiologists to find diseases inside the human body (1). Multi-slice CT scanners in clinical practice from 2, 16, 32, 64, and 120-slice scanners are a recent technological development that produces better image quality but delivers a higher radiation dose than single-slice scanners (14,15). Dosimeter testing and image quality testing are two crucial components of evaluating the functionality of a CT scanner after installation and maintenance. The CT scanner quality assurance with respect to image quality and radiation dose means the planned and systematic action that will produce a consistently high-quality image with minimal exposure of the patient and worker. The quality assurance program included a careful selection of CT scanner technical parameters that control patient exposure; measurement of physical CT dose parameters; and image quality parameters (2). Phantoms are conventional human shapes or test objects of a specific shape, size, and structure that are used for CT scanner performance calibration and evaluation. Rarely do quality assurance phantoms enable the European Commission to examine all image quality parameters and to check for pass/fail criteria of the CT scanner (6). It is specified by the manufacturer and measured during the acceptance testing process to meet regulatory requirements for radiation safety (12). To measure the parameters of CT radiation dose and CT image quality the study was conducted using a multi-slice CT scanner, a 100mm pencil ionization chamber, PMMA head and body phantoms, a quality assurance phantom, and image J software. The problem of this study is that the radiation dose received by the patient from the multi-slice CT scanner is much greater than any other diagnostic X-ray modality. The purpose of the present work is to test image quality parameters and radiation dose for a 16-slice (Big Bore CT scanner) using a PMMA standardized phantom. The quality assurance phantom was acceptable to test CT number accuracy for bone value in this investigation compared to the literature (4).

Material and Methods

CT scanner

A multi-detector CT scanner (16-slice Philips Big Bore) installed at the Radiotherapy department of the S. Chiara Hospital, Trento, Italy was used in this study.

PMMA Phantom.

PMMA phantom has been designed to examine CT dose index parameters such as volume computed tomography dose index (CTDIvol), and dose length product (DLP). It consists of solid acrylic material made of polymethylmethacrylate (PMMA) with a 16cm diameter head and a 32cm diameter body phantom, 100mm pencil ionization chambers, and dosimeter read-out systems in **Fig 1**.

Fig 1. *Set up for CTDI and DLP determination*

Dose Measurement

Dosimeter tests for CT scanners are performed in terms of the CT Dose Index (CTDI) and dose length product (DLP). It is measured in mGy, which is a standardized measure of the radiation dose output of a CT scanner (16). The AAPM report No. 96 formalism was used to estimate the dosimetric technique for the measurement of CTDIvol and DLP. The radiation dose of a CT scanner can be measured using PMMA head and body phantom by a particular imaging protocol described by CTDIvol and influenced by many technical factors, including tube potential (kvp), tube current (mA), exposure time, x-ray beam collimation and pitch. Weighted computed tomography dose index (CTDIw) was used to measure the CT dose index at the center and at the periphery of a PMMA head and body phantom (8).

$$\mathrm{CTDI}_w = \frac{1}{3}\,\mathrm{CTDI}_c + \frac{2}{3}\,\mathrm{CTDI}_p \qquad (1)$$

Where

CTDIc= CTDI at the central position of the PMMA phantom

CTDIp= the CTDI averaged over the four peripheral positions of the PMMA phantom.

For helical CT examinations, the parameter estimating the dose in a patient slice is the CTDIvol (9). It is defined as

$$\mathrm{CTDI}_{vol} = \frac{CTDIw}{p_f} \qquad (2)$$

Where

p_f = is the pitch factor (7,8).

CIDTvol =is the volume computed tomography dose index

$$DLP = CTDIvol * L \qquad (3)$$

Where

L=is the total scan length

Quality Assurance Phantom

The American Association of Physics in Medicine recommends using a specific phantom for quality control and to evaluate the operation of the CT scanner. Quality assurance phantom consists of an independent part which can measure the required image quality parameter. It has been designed to examine a wide range of scanner parameters; these include CT number accuracy, uniformity, noise, image slice thickness, and resolution in **Fig 2.**

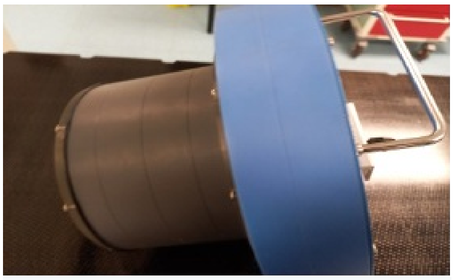

Fig 2. *Set up of CT image quality measurement*

CT number accuracy

There are cylinders of various materials, including acrylic, air, bone, water, and polyethylene, to measure the accuracy of the CT number. The primary CT number accuracy for each material allows you to choose a region of interest (ROI) location in **Fig 3**.

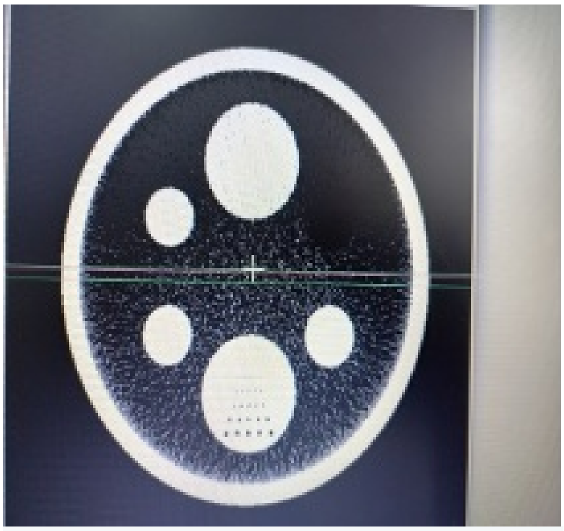

Fig 3. The measured CT number of different materials in the Quality Assurance phantom brain axial protocol.

Uniformity

The uniformity was calculated from the standard deviation of the five different regions of interest (ROI) in the phantom image in **Fig 3**. It is the mean value for every ROI divided by the mean value of the area covering the whole phantom image. The CT number for all five ROIs must be within this range ±5HU of the center ROI mean value (4).

Nose

It is one of the CT scanner performance parameters and is inversely proportional to the square root of the dose and to the slice thickness (13). The contrast-to-noise ratio (C/N) was employed to evaluate the signal level in the presence of noise in fig (4), and it is computed by dividing the average gray scales of a region of interest (ROI) minus the background region of interest (ROI) by the background region of interest (ROI) (10).

$$CNR = \frac{x_{s-} x_{bg}}{\sigma_{bg}} \qquad (4)$$

Where

CNR=is the contrast-to-noise ratio.

Xs= the average gray scale of the interested region of interest.

Xbg=the region of interest in the background

σbg=is the standard deviation of the background.

Fig 4. *The Contrast to noise ratio (CRN) is measured in the selected region of interest (ROI).*

Resolution

At low contrast and high contrast (high contrast resolution) (low contrast resolution). Low contrast resolution is significantly impacted by the accompanying image noise, while high contrast resolution establishes the minimum size of detail that can be seen in the plane of the slice with a contrast of more than or equal to 10 dose.

Result and Discussion

In this result, the CT radiation dose parameter was measured using an axial scan of the head and body PMMA phantom. The measured volume computed tomography dose index (CTDIvol) was 10.01mGy and DLP was 22.02mGy*cm for the head scan technique, whereas the volume computed tomography dose index (CTDIvol) in the body scan technique was calculated at 6.1mGy and DLP at 12.7mGy*cm respectively. The radiation dose delivered by the multi-slice computed tomography (CT) scanner matched the relevant console in **Table 1** with good accuracy and to the computed tomography dose index (CTDIvol) measurement was higher than the internationally accepted levels (3). The volume computed tomography dose index (CTDIvol) for adult head dose reference levels is 75mGy and for adult abdomen is 25mGy respectively (3).

Table1. CTDIvol and DLP test result for head and body PMMA phantom at 120kv and 100mAs.

Body region	PC readings at different phantom locations (mGy)					CTDIvol (mGy)		DLP(mGy*cm)
	Center	3	6	9	12	Calculated	Displayed	
Head	2.29	2.48	2.31	2.46	2.60	10.01	10.2	22.02
Body	0.77	1.81	1.48	1.82	1.65	5.8	6.1	12.7

Image quality tests were conducted in terms of CT number accuracy, linearity, noise, and resolution using a quality assurance phantom to determine the parameter.

Table2. The measured CT number accuracy of different materials in quality assurance phantom axial brain protocol at 120kv and 500mAs.

Material	Actual (HU)	Measured CT number (HU)	SD (HU)	Result
Air	-1000	-66.7	3.5	Pass
Bone	900	936	7.3	Pass
Water	0	3.2	4	Pass
Acrylic	120	138	3.7	Pass
Polyethylene	-95	108	3.7	Pass

CT number accuracy

The CT number which defines the x-ray linear attenuation coefficient is the normalized value of a pixel in a CT image. It is 0 for pure water, -1000 for air and 900 for bone (11). The measured CT numbers of air, water, bone, polyethylene, and acrylic were in good agreement with the CT numbers in the actual values. We compared the measured and actual values of the CT number accuracy of these materials in the brain protocol at 120kv and 500mAs as shown in **Table2**. The mean CT number of a homogeneous object should differ by no more than 8HU between its peripheral and central regions (2). The image quality parameter was obtained for the CT number accuracy of bone value which was not accepted to the tolerance values for the ACR phantom (4). In these studies, the CT number accuracy of bone, air, water, Polyethylene, and Acrylic were accepted as the reference values for quality assurance phantoms.

Noise measurement

The contrast to noise ratio (CNR) was employed to evaluate the signal level in the presence of noise in **Fig 4.** It is computed by dividing the average gray scale of a region of interest (ROI) by the background region of interest (ROI) (5).

Using Eq.4 the CT number of gray scales of the selected region of interest is equal to 63.9HU, the CT number of the background region of interest is equal to 54.7HU, and the standard deviation (SD) of the background is equal to 4HU. Then the contrast to noise ratio of the image was equal to 2.30HU, so the noise measurement was accepted. For adult head, pediatric head, and adult abdomen protocols, the contrast to noise ratio (CNR) must be greater than one, and for pediatric abdomen protocol, the contrast to noise ratio (CNR) must be more than 0.5 HU (3,4).

Uniformity measurement

The uniformity is calculated as the mean value of the standard deviation (SD) of a peripheral and a central region of interest (ROI). The SD in the peripheral and central areas were 3.7HU, 3.5HU, 7.3HU, 3.7HU, and 4 HU, respectively. The mean values of these five regions of interest were 4.4HU, so the measured uniformity was accepted.

Table 3. Comparison of the present study CT image quality parameter with other studies

	In this study	Other studies
CT number accuracy of PMMA phantom material	108	-91
Contrast-to-noise ratio (CNR)	2.3HU	1.8HU
Uniformity	4.4HU	3HU

The importance of estimating the image quality and radiation dose of any medical imaging machine is to maintain the safety of the machine after installation and maintenance. Two methods were used to test the safety of CT machines. The first one was dosimetric evaluation, and the second one was image quality evaluation. The image quality parameters were obtained for the noise, uniformity, and CT number accuracy of a material were accepted to the tolerance values for quality assurance CT phantom and to the measured CT dose index parameter also obtained volume computed tomography dose index (CTDIvol), and dose length product (DLP) were not accepted to the standard limits. Computed tomography quality control can help ensure the equipment is operating appropriately.

Conclusion

After installation and maintenance, a computed tomography (CT) scanner must pass a radiation dosimeter test to ensure that the image quality and radiation dose parameters were approved by the two standard phantoms and the test was crucial to the acceptance of any CT scanner. The multi-slice CT scanner, a 100mm pencil ionization chamber, PMMA head and body phantoms, a quality assurance phantom, and image J software were used to carry out this investigation. If the images generated accurately reflect the attenuation values of the x-ray beam caused by the body tissue as shown on the CT scanner that is a sign of good image quality. The measured CT radiation dose for a 16-slice CT scanner was higher than the international accepted dose reference level. We then reduced the dose delivered to the head and body scan technique by adjusting the scan parameter. We advise that testing image quality parameters and radiation dose for CT scanners plays a crucial role in getting the optimal performance of the CT system and also helps each radiological department build a quality control and quality assurance program.

List of Abbreviations

CT: Computed Tomography; PMMA: polymetaylelenmetaAcrylate; CTDI: Computed Tomography Dose Index; SD: standard deviation; ROI: region of interest; CNR: contrast to noise; ACR stands for American College of Radiology; DLP stands for dose length product; and AAPM stands for American Association of Physics in Medicine.

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Conflict of interest

The authors declare that there is no conflict of interest.

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