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Research Paper

Measurement of Computed Tomography Dose Quantities at Some Radiological Units of Abuja Hospitals

Joseph Teryima Iortile [1,✉], Taofeeq Abdallah Ige [2]

1. Department of Radiology, Benue State University Teaching Hospital Makurdi, Nigeria.
2. Department of Medical Physics, National Hospital, Abuja, Nigeria.

✉ Corresponding author: Dr. Joseph Teryima Iortile, Department of Radiology, Benue State University Teaching Hospital Makurdi, Nigeria; E-mail: iortileter@gmail.com

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Abstract

Computed Tomography (CT) is a valuable diagnostic modality used for treatment of patients but has become a potential threat due to cancer risk. To address this concern, measurement of computed tomography dose quantities at five radiological units at Abuja hospitals were investigated using polymethyl methacrylate phantom (PMMA), ion chamber and integrated electrometer labeled A, B, C, D and E respectively. The results obtained for the body phantom for computed tomography dose index (CTDIvol) range from 6.30±0.01 mGy to 10.8±0.004 mGy and its estimated dose index ($CTDI_w$) range from 4.68±0.01 mGy to 20.02±0.01 mGy. While the CTDIvol for head phantom range from 19.18±0.004 mGy to 70.0±0.90 mGy and its estimated dose index ($CTDI_w$) range from 10.38±0.004 mGy to 37.32±0.90 mGy. The dose ratio for the body phantom range from 0.31±0.01 mGy to 1.56± 0.01 mGy, while that of head phantom range from 1.39±0.03 mGy to 1.88± 0.90 mGy. The dose length product (DLP) for body phantom range from 152.08± 0.01 mGy.cm to 677.40±0.01 mGy.cm and that of head phantom range from 230.14±0.004 mGy.cm to 1075.00±0.90 mGy.cm. The results indicate that the body phantom labeled A- C was within the acceptable limits of 10-40 mGy. While that of head phantom was also within the acceptable limits of 40-60 mGy from centres A-D except centre E (70 mGy) that had values above the accepted limits. Similarly, the dose length product (DLP) at centres A, B, C was within the European Diagnostic Reference Levels for body (650mGy.cm) and head (1050mGy.cm) phantoms. Except centres D and E that was above the European Diagnostic Reference Levels for body and head Phantoms respectively. The differences in the results of the study imply a need for optimization of some computed tomography examinations protocol and quality control measures.

Keywords: Phantom; Radiation dose; Computed Tomography; Quality Control; Scanning parameters.

Introduction

Computed tomography (CT) scan has emerged as a powerful tool for effective radiological diagnosis of patients ailments since it produces high-resolution three-dimensional patient images to be acquired in a short period of time [1]. It can generate images in different planes of the human anatomy by reconstructing X-ray attenuation through the tissues into pixels and volume elements [2]. The rapid development of computed tomography (CT) technology and the resulting sudden increase in new clinical applications, combined with the significance of CT dose levels, have created a compelling need to utilize detailed information regarding computed tomography dose. As a result, the numbers of examinations are increasing; to the extent that CT has made a substantial impact on not only patients care but also patients and population exposure to medical X-rays [3]. In Nigeria, for instance, there is inadequate research work on the subject matter relating to CT procedures and is generally not reported in most local surveys. There is need therefore to expediently employ special measures to ensure optimization of performance in CT and of patients' protection [4-6]. CT is therefore considered as a potential source of increased cancer risk. This is a source of major concern since the dose delivered to the patient in CT scan procedure is considered as high as compared to other imaging modalities [6]. Therefore, the use of CT requires strict adherence to the tenets of radiation protection, justification and optimization to ensure that the risk to patients does not outweigh the benefit gained from the technique [7-8]. Several parameters have been employed in this study to explain CT dose over a region, specifically volume CT dose index (CTDI), weighted CT dose index and Dose Length Product (DLP). The above parameters are mainly due to scanner type, model, operator parameters, and body size [9]. The study therefore aims to measure the computed tomography dose at some radiological units of Abuja hospitals.

Material and Methods

Description of computed tomography type and equipment used

The standard dosimetry phantoms for head and body are made of a transparent (PMMA) with lightweight for easy mobility and density of 1.19 g/cm^3 with a thickness of 3 mm each at the right circular cylinder with diameters of 16cm and 32cm for head and body phantoms with phantoms holes at a depth of 1 cm (center to phantom edge) from the outer surface, at the 90^0, 180^0, 270^0 and 0^0 normal positions referred to as the peripheral sites and along the cylinder axis were used for the study. The computed tomography dose phantoms employed models 76-414 (head), 76-415 (body) phantoms respectively. Each part contains five probe holes, one in the center and four around the perimeter, 90° apart and 1 cm from the edge. Each part includes five acrylic rods for plugging all the holes in the phantom. The CT dose phantoms were designed in accordance with the Food and Drug Administration's performance standard for diagnostic X-ray systems [10-11].

The pencil ionization chamber is made of diameter of 10 mm, a sensitive length of 100 mm, and an active volume of 3 cm^3. The response is designed to be uniform along the entire length of the sensitive volume, with a conversion factor determined in the conventional manner. The ionization chamber that was used in this study is the Victoreen CT Probe, model 6000-100 designed to be used for standard CT dosimetry polymethyl methacrylate (PMMA) cylindrical acrylic head and body phantoms. Its specifications are listed in Table 2. The chamber was connected, through 0.9 m of low noise flexible cable terminated with a male BNC size triaxial connector. It is designed to be readout on the NERO™ or Model 400M$^+$ [12-13].

(A)

(B)

Figure 1. Image of CT ion chamber (A) and electrometer (B) (PTW chamber type 30009, Freiburg, Germany).

Table 1. Technical specifications of the CT machines used in the selected hospitals

Hospitals	Manufacturer name	Type model	Source strength	Model number
A	GE Model: light speed VCT64 Slice	GE light speed VCT64 Slice CT Scanner(D3162T)	120kVp 340mAs	2232785
B	Toshiba Scanner Alexion Japan	Toshiba Scanner Alexion TSX-034A	120kVp - 135kVp(Max) 260mA-300mA(Max)	3CC1532167
C	GE HANGWEI MEDICAL SYSTEMS CO.,LTD,BEIJING 100176 CHINA/OCTOBER 2019	Revolution ACT (GE Revolution 16 Slice)		5492001
D	Siemens Medical Systems Germany 2010	Siemens 6 Slice Somatom Emotion	415kVp(Max) 50mAs(Max)	
E	Toshiba Scanner Activion 16	TSX-031A	120kV 300mA 135kV 260mA	1CC11Z3354

Table 2. Specifications of the computed tomography phantoms

Weight	Body phantom: 14.5 kg Head phantom: 3.6 kg
Optional accessories	Carrying Case (Model 89-414) CT Head Dose Phantom with five plugs (Model 76-414) CT Body Dose Phantom with five plugs (Model 76-415)

Table 3. Specifications of Victoreen CT Probe, model 6000-100 CT Probe

Detector type	Vented air ionization chamber
Volume	3.2cm^3
Sensitive length	10.0 cm
Chamber	Material: Clear Acrylic Inside Diameter: 6.4 mm Wall Thickness: 54mg/cm^2
Electrode	Material: Aluminum. Diameter : 0.64 mm
Sensitivity	10 R cm/Nc
Factor Calibration	100 kVCP , 5.5 mm Al HVL
Energy Response	+5%, 1 mm Al to 10 mm Al HVL Uniformity along z axis: +3% over central 90% of active length
Beam Orientation	Normal to chamber axis
Phantom Adapter	Outside diameter: 1.27 ±0.04 cm

Table 4. Specifications of PTW DIA DOS E

Measured Quantities

Kilovoltage	Measured during the first 300 ms of exposure: • kVp average • kVp effective • kVp maximum Accuracy: ±3%
Time	Measured during entire exposure; reference to 75% rise/fall kV time. Accuracy: Within 2% or 2 ms, whichever is greater Range: 1ms to 10 sec
Exposure	Measured during entire exposure, kVp corrected. Accuracy: ±10% Range: 10 mR to 10 R

(A)

(B)

Figure 2. (A) Barometer (Pressure indicator D PI 800) and (B) Thermometer (Digital, China)

The electrometer that was used is a PTW DIA DOS E, it is a self-contained, non-invasive X-ray test device. In a single exposure, it can measure simultaneously: kVp, exposure rate or air kerma rate and time. It is calibrated for both tungsten anode (W/Al) and Molybdenum (Mo/Mo) anode X- ray tubes. Additionally, it has an external ion chamber port that accepts a variety of accessory ionization chambers for various applications, including pencil shaped ionization chambers for CT dosimetry. It can compute the tube potential with ±3% accuracy. Five separate, selectable filter pairs ensure optimum accuracy over the maximum range with minimum filtration dependence. A separate internal ionization chamber measures tube output [14].

For the measurement of the CT dose index, the chamber was positioned parallel to the rotation axis of the scanner inside a cylindrical phantom. For a single scan (except for a Multislice), the primary beam does not usually cover more than about 10% of the full length of the chamber. At the same time, the CT chamber detects the scattered radiation generated in the phantom by the primary beam, thereby allowing quantification of the total exposure of a patient. This unique use of the CT chamber requires that the response of the active volume be uniform along its entire axial length, a restriction that is not required of other cylindrical full immersion chambers [13]. They are usually calibrated in terms of air kerma by exposing the entire sensitive volume to a uniform X-ray field because the dose profile rapidly falls to zero away from the position of the CT slice, the pencil ionization chamber also measure CTDI to a very good approximation [14]. For measurement, the chamber is mounted in such a way that its length axis corresponds to the axis of rotation of the gantry and that its centre corresponds to the centre of the slice.

This a hand- held, light weight pressure test and measurement instrument ideally suited for use in the field for performing work such as calibration and repair, installation, maintenance, as well as in various manufacturing environments. The DPI 800 pressure indicator is available with a maximum of two internal pressure sensors. It has the following specifications: measuring range from 25 mbar to 700 bars, one or two internal sensors, transmitter calibration and switch test function.

Thermometer is a device that measures temperature or temperature gradient and used in technology and industry to monitor processes, in meteorology, medicine and in scientific research [15]. It has two important elements namely; (1) temperature sensor (example the bulb of a mercury in-glass thermometer or the pyrometric sensor in an infra red thermometer) in which some change occurs with a change in temperature; and (2) some means of converting this change into a numerical value (example the visible scale that is marked on a mercury-in-glass thermometer or digital readout on an infrared model).

Dose Measurements

In this study, dose measurements were performed by setting up the body and head phantoms in succession. The body phantom was first positioned on the CT couch and centered at the isocenter of the scanner with the long axis of the phantom aligned with the z-axis of the scanner. The PTW pencil ion chamber was connected to an electrometer with the cable placed in the central insert of the phantom. Two horizontal lasers in the CT room were adjusted to be visible on the mid-line of the ion chamber and a vertical laser was also set to be visible at the middle of the phantom. This was done to properly align the phantom and the chamber on the couch. A piece of masking tape was put along the probe, attaching it on to the phantom to ensure that the probe was not dislodged within the phantom during scanning. A topogram image of the phantom was taken and used to select the volume to be scanned by the entire hospitals investigated which has been a standard procedure operated at all the CT investigated in order to get accurate dose measurements. The CTDI quality assurance measurements was activated for the first scan at each centre with the standard protocol of body examination for three readings at each point (one in centre and four points on peripheral of a phantom) at 90^0, 180^0, 270^0 and 0^0 normal clock positions represented as P_1, P_2, P_3, P_4 and C and subsequently the head phantom respectively. Charges were measured and recorded in each scan. The charges measured and recorded from the electrometer in charge mode and the temperature and pressure corrections were used to estimate $CTDI_w$, DLP values and compared with CTDI and console displayed values on the CT machines using the following equations:

$$\mathbf{k_{TP}} = \frac{(273.2+T)P_0}{(273.2+T_0)P} \quad (1)$$

$$\mathbf{C_{PMMA,100,c}} = \frac{10}{NT}\mathbf{M_c N_{PKL,Q_o} k_Q k_{TP}} \quad (2)$$

$$\mathbf{C_{PMMA,100,P}} = \frac{10}{NT}\mathbf{M_P N_{PKL,Q_o} k_Q k_{TP}} \quad (3)$$

$$\mathbf{CTDI_w} = \frac{1}{3}(\mathbf{C_{PMMA,100,c}} + 2\mathbf{C_{PMMA,100,P}}) \quad (4)$$

$$DLP = CTDI_{vol} \times L \quad (5)$$

Results and Discussion

The results and discussion of the study carried out and calculations leading to CT dose index, temperature and pressure corrections and dose length product at Abuja hospitals are presented in Tables 4-8.

Table 5. The Scan parameters for the body phantom

Hospitals	kVp	mAs	ST(mm)	No. of slices
A	120	124.5	5	27
B	100	224	10	16
C	120	147	5	29
D	110	88	10	15
E	120	98	5	28

Table 6. The Scan parameters for the head phantom

Hospitals	kVp	mAs	ST(mm)	No. of slices
A	120	200	2.5	48
B	120	200	5	30
C	120	270	5	30
D	110	250	6	24
E	120	196	5	28

Table 7. Dosimetry phantom readings for the body at some hospitals in Abuja

Hospitals	CTDI(mGy)	$CTDI_w$ (mGy)	Dose (Gy)
A	10.05±0.01	7.18±0.01	1.39±0.01
B	10.8±0.004	7.9±0.004	1.37±0.004
C	9.57±0.01	18.59±0.01	0.51±0.01
D	7.30±0.01	4.68±0.01	1.56±0.01
E	6.3±0.01	20.02±0.01	0.31±0.01
			Mean Dose = 1.03±0.01

Table 8. Dosimetry phantom readings for the head at some hospitals in Abuja

Hospitals	CTDI (mGy)	$CTDI_w$ (mGy)	Dose (Gy)
A	19.18±0.004	10.38±0.004	1.85±0.004
B	49.8±0.03	35.88±0.03	1.39±0.03
C	38.50±0.02	25.18±0.02	1.53±0.02
D	36.60±0.02	23.78±0.02	1.54±0.02
E	70.0±0.90	37.32±0.90	1.88±0.90
			Mean Dose = 1.64 ± 0.19

Table 9. Mean calculated DLP and readout on CT Scanners examined at Abuja Hospitals

Hospitals	CT Scanners	Body phantom (mGy.cm)	Head Phantom (mGy.cm)
A	GE light speed VCT 64 slice	159.49±0.01	230.14±0.004
B	Toshiba Scanner Alexion	195.20±0.004	817.70±0.03
C	GE Revolution 16 Slice	152.08±0.01	577.53±0.02
D	Siemens 6 Slice Somatom Emotion	677.40±0.01	527.06±0.02
E	Toshiba Scanner Activion 16	105.60±0.01	1075.00±0.90

The computed tomography dose index (CTDI) and the weighted computed tomography dose index (CTDIw) values range from 6.3±0.01 mGy to 10.8±0.004 mGy and 4.68 ±0.01 mGy to 20.02 ±0.01 mGy respectively for body phantom as shown in Table 7. However, Tables 5 and 6 revealed large differences in scan parameters for the same CT examination among different hospitals and these variations are due to different examination techniques and CT scanner models [6, 9]. There is an essential need for establishing a reference level of activity with the aims of comparing different techniques and protocols to find situations where examination procedures must be reviewed. Also, some of the CT machines have used smaller slice thickness for routine CT procedures to achieve better resolution [26]. Similarly, the computed tomography dose index (CTDI) and the weighted computed tomography dose index (CTDIw) values range from 19.18 ±0.004 mGy to 70.0 ± 0.90 mGy to 10.38 ±0.004 mGy to 37.32 ±0.90 mGy respectively for head phantom as shown in Table 8. The implications of the results shows that the head phantom used higher scan parameters which led to higher doses owing to the fact that the head had fewer radiosensitive organs which were irradiated giving rise to higher absorbed dose when estimated [20-21]. Also, it had greater energy deposition equivalent dose of more than 1 Gray [16-19]. Conversely, the results illustrate that the adult body phantom meets the American College of Radiology (ACR) CT accreditation requirement specified that the CTDI should be within the range of 10-40 mGy. While the head phantom for hospital E was above the recommended value of 40-60 mGy for the adult head protocol. In comparison of our results with other studies, it was found to be consistent with the reported values for CTDI by [22-24] as 49.6 mGy, 42.40 mGy, 40 mGy for head phantom and 27.8 mGy, 19.49 mGy and 12 mGy for body phantom respectively.

The mean calculated dose length product (DLP) and readout on CT scanners for body and head phantoms were in the range of 105.60 ±0.01 mGy.cm to 677.40 ± 0.01 mGy.cm and 230.14 ±0.004 mGy.cm to 1075.00 ±0.90 mGy.cm respectively as shown in Table 9. The values of the hospitals A, B, C and E for body phantoms were lower than the values of European Diagnostic Reference Levels of 650 mGy.cm. Except hospital D that had DLP value of 677.40±0.01 mGy.cm, which was above European Diagnostic Reference Levels. Equally, the DLP results obtained for head Phantom CT at various hospitals were lower than those of European Diagnostic Reference Levels (1050 mGy.cm). Except the DLP at hospital E which DLP value of 1075.00±0.90 mGy.cm was above European Diagnostic Reference Levels (Table 9). The higher DLP for body at hospital D and hospital E for head phantom in the study may be due to the differences in the number of slices used and the scan mode employed during the CT procedures at the various centres. Therefore, periodic quality control (QC) checks should be done on CT machines to ensure good scan practices [25-26].

Conclusions

The importance and significance of implementing and effectively determining patient CT dose and quality control parameters during computed tomography examinations cannot be over emphasized in radiation protection. The results obtained for body and head phantoms for most of the hospitals were within acceptable dose limits but some had abnormality. Therefore, periodical quality control should be done on the CT facilities and survey data on diagnostic reference levels (DRLs) values for CT head and body examination for dose optimization.

Abbreviations

CT: Computed tomography; PMMA: Polymethyl methacrylate phantom; CTDI: CT dose index; DLP: Dose length product; QC: Quality control; DRLs: Diagnostic reference levels.

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Author Contributions

All authors contributed to this study. All authors gave their final approval.

Competing Interests

We declare no competing interests.

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