Determination of Computed Tomography Diagnostic Reference Levels in North-Central Nigeria.

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ABSTRACT

The aim of this study is to estimate dose levels for common CT examinations in North-Central Nigeria. Dose and scan parameters for the most commonly performed CT examinations (head, chest, and abdomen) were surveyed during a four month period in 4 CT centers with multi-slice scanning capabilities. Data on CT dose index ($CTDI_{vol}$) and dose length product (DLP) displayed on scanner console was recorded for a minimum of 10 averaged-sized patients for each facility to estimate the DRLs. Data for 226 patients was collected for the study. CT dosimetry software ImPACT CT patient dosimetry calculator, version 1.0.4 with National Radiation Protection Board SR250 data set was used to validate and compare scanner generated dose values.

Estimated regional DRLs for $CTDI_{vol}$ and DLP were 60 mGy and 1024 mGy.cm for head scans, 10 mGy and 407 mGy.cm for chest scans, and 15 mGy and 757 mGy.cm for abdominal scans, respectively. Mean effective dose values were 1.7 mSv, 5 mSv and 11.9 mSv for head, chest, and abdominal scans, respectively. A wide variation of mean doses was observed across the centers; however, DRL estimates were lower than studies from the European Commission and higher than a United Kingdom study. Validation result show unity (<10% overall variation) between scanner generated and software calculated dose values. A potential means by which CT practice in this part of Nigeria can be compared is produced.

(Keywords: computed tomography, CT, diagnostic reference levels, radiological examinations, dose)

INTRODUCTION

Optimizing the protection of patients and maintaining appropriate good practice is a priority for all diagnostic radiological examinations including computed tomography (CT) examination. This is because they involve the use of ionizing radiation which is known to have harmful effect on human body unless recommended safety and radiation protection measures are strictly adhered to. In CT imaging, an optimized protocol is one that produces the required image information with the lowest possible radiation dose to the patient.

X-ray Computed Tomography (CT) was introduced into clinical use in 1973, which over time has successfully enacted itself as a primary diagnostic modality. Mettler et al[1], have reported increased utilization of computed tomography examination for clinical diagnosis worldwide. Fast scanning speed, isotropic spatial resolution, non-invasive, affordability compared to other modalities such as magnetic resonance imaging, applications in staging, treatment planning, and follow up of cancer treatment are some of its unique advantages[2].

Although CT imparts high radiation dose to patients, its benefits can far outweigh the risk if all equipment, personnel, and the technical knowhow guiding the proper use of the equipment are well adopted. New advancements in CT such as multi-slice which gives higher doses to the patient have also been reported to have led to further increase in the collective dose of CT examinations[3]. As much as 1.5 – 2% of cancer may eventually be caused by the radiation currently used in CT[4].

Diagnostic reference levels (DRLs) are the recommended optimization tools used as special type of dose constraints (to identify abnormal high dose levels) above which doses must be reviewed[5] and considered above acceptable levels, especially if acceptable image quality can be achieved at lower doses. This will ensure that dose to each patient is kept as low as reasonably achievable for the clinical purpose of the radiologic examination (i.e., image of good diagnostic quality).

This study adopts the European Commission (EC)[6], American College of Radiology (ACR, resolution-47, 2013)[7] in collaboration with American Association of Physicist in Medicine (AAPM)[8], International Atomic Energy Agency (BSS)[9], and the International Commission on Radiological Protection (ICRP)[10]; recommended guidelines to determine DRLs in radio-diagnostics. This guideline states that; weighted CT dose index (CTDIw) now replaced by volume weighted CT dose index ($CTDI_{vol}$) and dose length product (DLP) are the appropriate dose quantities for the establishment of DRLs for optimizing patient exposure in CT. The measurement is normally referenced to 16 cm head and 32 cm body acrylic phantom. Literatures have also suggested that every country including Nigeria should have its own DRL values. This is because of the differences in practice and technological advancement such as iterative reconstruction, from country to country and the fact that Nigeria is yet to have a guideline for CT examinations[13]. Previous surveys have shown variation in doses and lack of standardization of practice among centers hence there is a need for optimization.

This study aims at assessing CT doses received by patients undergoing common CT procedures in North-Central Nigeria in order to provide a means by which practice in this region can be compared to CT practices elsewhere. Data from the study would also serve as reference when required in order to establish a guideline of optimized CT protocols for clinical usage in Nigeria.

MATERIALS AND METHODS

Four multi-slice CT scanners that display dose description parameters ($CTDI_{vol}$ and DLP) were selected randomly from 3 states in north-central region of Nigeria, these include two General Electric (GE) scanners (4 and 64-slices), a 16-slice Philips scanner and a 6-slice Siemens Electronic scanner. Most commonly performed CT examination; head, chest, and abdominal CT scan were selected. Selection of examination type surveyed was based on existing literature from survey of the most commonly performed CT scan in the country. Individual patient's CT machine generated dose data ($CTDI_{vol}$ in mGy and DLP in mGycm) and scan parameter data (kV, mA, scan time, pitch, and slice thickness) were recorded for at least ten patients in each type of examinations from each center. Patient weight was taken using a mobile weighing scale in order to ensure that only standard size adult patients (70±10kg) were surveyed.

The local center DRLs for each center presented in this study is based on the rounded 75th percentiles from the mean of the dose values ($CTDI_{vol}$ and DLP) and for the region by compiling results from all the centers surveyed. Statistical analysis was performed using Microsoft Excel 2010 version. The analysis of results employed the use of descriptive and inferential methods of data analysis. Quantitative variables were expressed by descriptive analysis to summarize and show variability of the data from the study in mean, range and standard deviation.

A CT dosimetry software ImPACT CT patient dosimetry calculator, version 1.0.4, (ImPACT, London, England) was used to validate and compare the dose values generated by the various CT scanners surveyed in order to ascertain the reliability of machine generated dose values. The ImPACT scan dose evaluator with National Radiological Protection Board SR250 Monte Carlo data set is a system that models the conditions of exposure on a mathematical phantom for a range of common makes of CT scanners. The software package provides values of CT dose index; these include CT dose index in air, weighted CT dose index, $CTDI_{vol}$, and the corresponding value of DLP when scanner specific information and scan parameter information are entered. The software also calculate effective dose using the National Radiation Protection Board (NRPB) organ dose coefficients with International Commission on Radiological Protection (ICRP) 103 organ weighing factors.

RESULTS

A total of 226 patient's data was collected, out of which 69.1% were male and 30.9% were female, they had a mean weight of 69.8 kg. Eighty-eight brain scans (38.9% of data), 60 chest scans (26.5% of data) and 78 abdominal scans (34.5% of data) were surveyed from the 4 participating centers (one private and three public hospitals).

All the centers were able to survey the minimum recommended number (at least 10) of patients recommended for each examination within a four month data collection period, though most centers reported more than 10 for majority of the examinations. Patient's age ranged from 16–90 years, since hospital age classification in Nigeria considered sixteen years of age as an adult[14]. This study presents estimated dose values for sequential scan mode for its brain CT scan. Summary of statistical distribution of the study data is presented in Table 1.

Diagnostic Reference Levels for North-Central Nigeria

Dose estimates in $CTDI_{vol}$ and DLP for CT centers understudy are presented in Figure 1 and Figure 2, respectively. The centers are denoted by alphabets A, B, C, and D. As shown center B presents with the highest dose values in terms of $CTDI_{vol}$ while center C reports the lowest dose values in terms of DLP.

The effective dose estimates which were calculated using the adult normalized values of effective dose per dose-length product (DLP) over various body regions is shown in Figure 3.

Comparison of estimated DRLs in terms of dose quantities $CTDI_{vol}$ and DLP from this study to that from United Kingdom[15] and European Commission[6] is presented in Table 3. The UK study surveyed only multi-slice CT scanners and the European Commission (EC) study surveyed mainly single slice CT scanners. As shown, diagnostic reference levels in North-Central Nigeria is less than EC 1999 DRLs but higher than the more recent UK diagnostic reference levels for head and abdominal CT scan.

Table 4 compares the estimated CTDI and DLP from this study and two other Nigerian studies.

Table 5 also gives the mean effective doses from this study compared to average and range of effective dose values for CT examinations compiled from reported literatures.

Table 1: Statistical Distribution of the Study Data.

Examination	Number of Participants (N)	Dose Parameter	Mean	Range	75th Percentile
Head	88	$CTDI_{vol}$(mGy)	52.2 (±10)	25 - 69	60
		DLP (mGy.cm)	841.5 (±324)	320 - 1968	1024
Chest	60	$CTDI_{vol}$(mGy)	8.8 (±4)	2 - 23	10
		DLP (mGy.cm)	333 (±173)	72 - 1048	407
Abdomen	78	$CTDI_{vol}$(mGy)	12 (±5)	4 - 23	15
		DLP (mGy.cm)	590 (±260)	218 - 1148	757

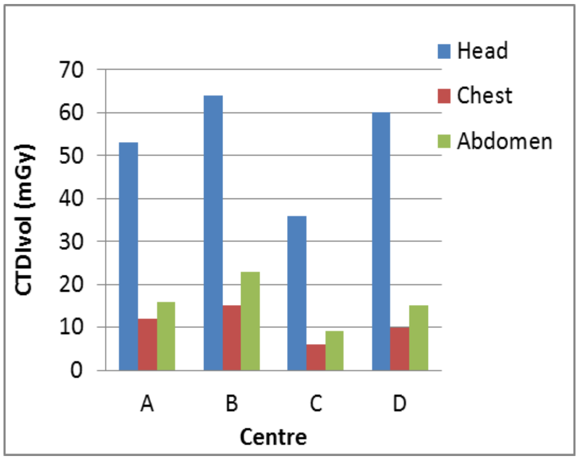

Figure 1: $CTDI_{vol}$ (DRLs) for CT Centers Surveyed.

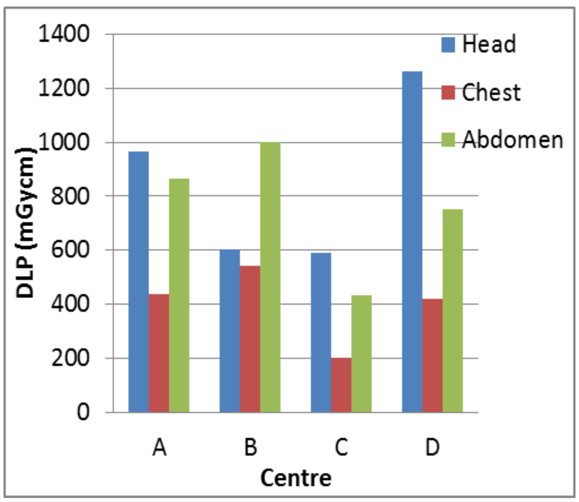

Figure 2: DLP for CT Centers Surveyed.

Table 2: Estimated Regional Diagnostic Reference Levels for Head, Chest, and Abdominal CT.

Diagnostic reference levels	Examination		
	Head	Chest	Abdomen
CTDIvol (mGy)	60	10	15
DLP (mGy.cm)	1024	407	757

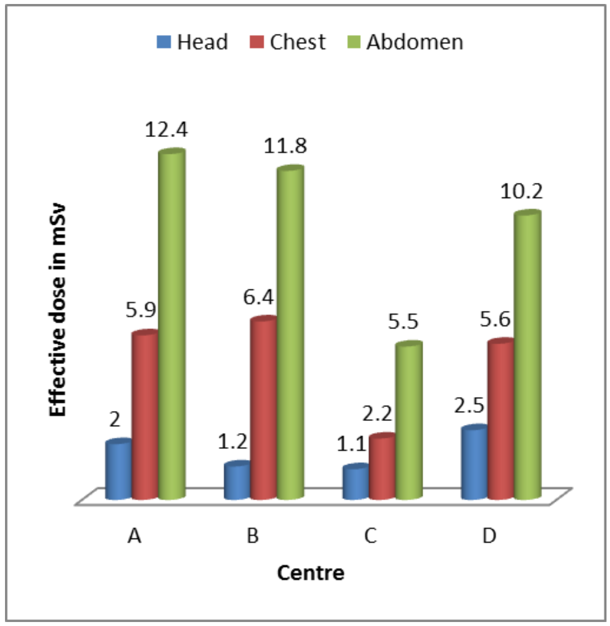

Figure 3: Estimated Mean Effective Dose across Centers for Head, Chest, and Abdominal CT Scan.

Comparison of scan parameter (scan length in cm) for head, chest, and abdominal CT scans is shown in Figure 4. Mean scan length from this study were 15.7 cm, 36 cm and 46 cm, respectively, for head, chest, and abdomen scans. These lengths did not differ so much from the UK study which produced 12.7 cm, 39.3 cm and 41 cm, as scan lengths for head, chest, and abdomen.

Study from the National Radiological Protection Board also produced 14.6 cm, 25 cm, and 40 cm as scan lengths for head, chest and abdomen scans)[6]. Scan length used for head and abdominal CT scan in North-Central Nigeria are higher than scan length in the two comparing references except for chests CT scans.

Table 3: Comparison of Diagnostic Reference Levels (DRLs).

Examination		Mean value	75th percentile value	European DRL	U.K Study2003
Head					
	CTDIvol(mGy)	52	60	60	65
	DLP(mGy.cm)	841	1024	1050	930
Chest					
	CTDIvol(mGy)	8.8	10	30	14
	DLP(mGy.cm)	333	407	650	580
Abdomen					
	CTDIvol(mGy)	12	15	35	14
	DLP(mGy.cm)	590	754	780	560

Shrimptom et al., (2005), European commission,(1999)

Table 4: Comparison of Mean CTDI (mGy) and DLP (mGycm).

Examination	Dose	This Study	Garba (2014)	Ogbole and Obed (2014)
Head	$CTDI_{vol}$ (mGy)	60	76	73.5
	DLP (mGy.cm)	1024	789	1898
Chest	$CTDI_{vol}$ (mGy)	10	N/A	22.7
	DLP (mGy.cm)	407	N/A	1189
Abdomen	$CTDI_{vol}$ (mGy)	15	N/A	37.9
	DLP (mGy.cm)	757	N/A	1902

Table 5: Comparison of Mean Effective Doses.

Examination	Average Effective Dose (mSv)	Values Reported in the Literature (mSv)	Mean Effective Dose from this study (mSv)
Head	2	0.9 - 4.0	1.7
Chest	7	4.0 - 18.0	5.0
Abdomen	8	3.5 - 25	11.9

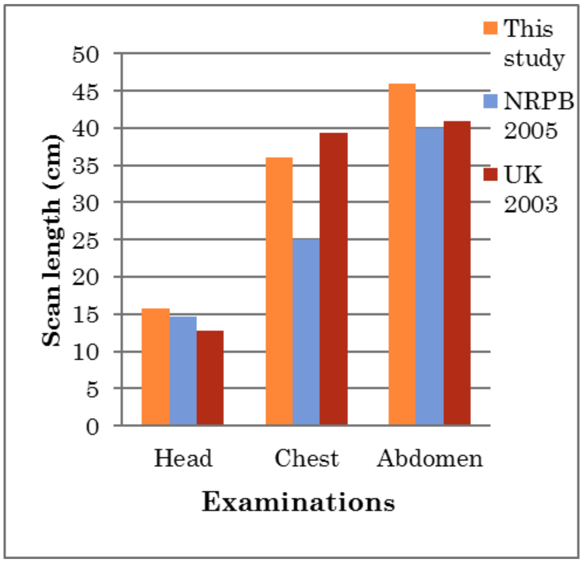

Figure 4: Comparison of Scan Length.

Validation Result

Table 6 (a, b, & c) shows a comparison of dose in $CTDI_{vol}$/DLP for head, chest, and abdominal examinations in percentage (%) coefficient of variation between scanner generated and dosimetry software package generated values across the study centers.

DISCUSSION

This study represents the collection of estimated local computed tomography DRLs in North-Central region of Nigeria and it revealed enormous variations between the different centers in reported local DRLs and individual patient doses. The reasons for these variations in line with many DRL studies[16, 17, 18] are mainly attributed to different exposure parameters and radiographic techniques. This shows a huge optimization potential among almost all the centers and standardization of practice is also lacking.

The UK (2003) study is a better means of comparing with this study because its values were obtained from a survey of multi-slice CT scanners. However, result of the comparison revealed a need for optimization of doses in North-Central Nigeria. This is because 75th percentile values in $CTDI_{vol}$ and DLP from this survey (60 mGy, 1024 mGy.cm: 10 mGy, 407 mGy.cm and 15 mGy, 754 mGy.cm) are higher for all the examinations except for chest scan compared to the UK DRLs (65 mGy, 930 mGy.cm: 14 mGy, 580 mGy.cm and 14 mGy, 560 mGy.cm) for head, chest, and abdominal CT scans, respectively.

Table 6a: Center A with GE Light Speed VCT, 64 Slice CT Scanner.

Examination	Dose quantity	% Coefficient of variation	Overall average variation
Head	$CTDI_{vol}$	11	4.9
	DLP	1	
Chest	$CTDI_{vol}$	6	
	DLP	7	
Abdomen	$CTDI_{vol}$	0.5	
	DLP	4	

Table 6b: Center C with Siemens Emotion 6, 6 Slice CT Scanner.

Examination	Dose quantity	% Coefficient of variation	Overall average variation
Head	$CTDI_{vol}$	5	5.8
	DLP	7	
Chest	$CTDI_{vol}$	5	
	DLP	11	
Abdomen	$CTDI_{vol}$	2	
	DLP	5	

Table 6c: Center D with Philips Brilliance 16 Slice CT Scanner.

Examination	Dose quantity	% Coefficient of variation	Overall average variation
Head	$CTDI_{vol}$	1	6.5
	DLP	0.1	
Chest	$CTDI_{vol}$	11	
	DLP	9	
Abdomen	$CTDI_{vol}$	9	
	DLP	9	

Scan parameters; kV, mA, pitch factor, scan time, scan length and slice thickness have been observed to influence dose. The kV, mA and scan time have direct proportional relationship with absorbed dose. All the centers adopt different parameters (kV, mA, and scan time) for different examination types.

Amongst all the scanners/centers studied, center C (Siemens Electronics) optimized its practice the most, as it recorded the least $CTDI_{vol}$, DLP and mean effective dose values for all examination categories. This is because the scanner adopted or used tube current (mA) and scan length less than other scanners. This scanner also used the highest pitch value especially for abdominal CT scans, which implies that they avoided overlap of adjacent slices in helical scans and hence absorbed dose is reduced, this is in line with Chinnaiyan et al.[19] findings.

Scan length is the most compared exposure parameter in CT dose parameters comparison, because dose length product (DLP) which describes the dose delivered in a scan volume is directly depended on the length of the scanned body region. Image quality criteria, subjective request of varying scan lengths by radiologist, and lack of standardization of protocol may be the cause of variation in the selection or coverage of area scanned. However, a properly selected scan length should only include areas of diagnostic significance and exclude areas not indicated or of no diagnostic benefits[15].

Comparison of this study scan length with that of UK (2003) and NRPB (2005) shows that in all examination categories (head, chest & abdomen) surveyed, scan length can still be reduced by 12.3%, 14.4% and 11.5% for head, chest and abdomen, respectively without losing any area of diagnostic benefit. If these reductions in scan length are applied throughout the centers then a significant reduction in absorbed dose per patient volume scanned will be achieved. This study also reported that head scans are the most requested CT scans in line with Erondu et al.,[20] and Foley et al.,[21] findings.

Comparison of head, chest, and abdominal examination dose values generated by scanners and dosimetry software package as shown in Table 6 a, b, & c. With the exception of center B (GE, Bright speed Hct, 4 slice CT scanner) whose model was not found on the software, typical variation from the mean value according to the scanner generated and software calculated values per examination, per scanner as well as overall average were below 10%. The variations were least observed in the head scan dose values across all the scanners. This may be due to the fact that head scans were acquired using an axial scan and not helical scan that depend on a lot of complex but adjustable manufacturer depended parameters (pitch, filters) and various dose reduction software.

The unity observed between scanner generated and ImPACT software calculated dose values is in line with International Electrotechnical Commission[9] recommendation on the use of scanner generated parameters in the setting of diagnostic reference levels. Walter, Kent et al[22] have also shown that the ImPACT spread sheet or data package agree with other commercially available dosimetry software packages with only a variation of approximately 5%. Therefore, reliability in the use of scanner generated dose values and the use of ImPACT dosimetry software with NRPB data set is once again justified.

CONCLUSION

A means by which CT practice in this part of Nigeria can be compared is produced as Nigeria is yet to have an established national diagnostic reference levels for CT practice. The reliability of CT dosimetry software (imPACT scan) is once again confirmed especially in the absence of dosimetry apparatus to carry out practical dose measurements as it is the case in most third world countries.

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