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Diagnostic Reference Level of Computed Tomography Examinations and Need for Dose Optimization in Ondo State, Nigeria

Oluwakayode Samuel Oyedokun[1]*, Adeseye Muyiwa Arogunjo[1, 2], Joseph Irewole Fatukasi[2], Adedeji Ayoola Egberongbe[3]

1. Department of Physics, Federal University of Technology, Akure, Ondo State, Nigeria
2. Department of Radiology, Trauma Center, University of Medical Sciences, Ondo, Ondo State, Nigeria
3. Department of Radiology, Federal Medical Center, Owo, Ondo State, Nigeria

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ABSTRACT

Introduction: The present study was conducted to obtain State diagnostic reference levels (DRLs) of five routine computed tomography (CT) examinations from two CT centers in Ondo State and to identify factors responsible for dose variation and escalation in these CT centers.

Material and Methods: Acquisition parameters and CT dose indices were collected from the storage drives of the two CT centers namely Federal Medical Centre, Owo and Trauma Center, Ondo, Ondo State, Nigeria, for six months on electronic spreadsheets for cranial, sinus, chest, abdomen and pelvis examinations. In addition, dose indices for multiphase examinations were collected to analyze chest and abdominal doses. Wilcoxon rank-sum test was used to assess variations in dose distributions of the two health institutions.

Results: The following diagnostic reference levels (DRLs) were obtained at 91 mGy; 1943 mGy.cm, 69 mGy; 1159 mGy.cm, 45 mGy; 1064 mGy.cm, 50 mGy; 2545 mGy.cm and 26 mGy; 622 mGy.cm in cranial, sinus, chest, abdomen and pelvis examinations respectively.

Conclusion: Estimated State DRLs exceed national and other DRLs indicating that there is a need to improve the quality of CT-examination for a better benefit to risk ratio. However, benchmarking DRLs to median dose levels (Achievable dose levels) instead of the upper quartile will be a good starting point in achieving the optimal dose level.

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Introduction

International Commission on Radiation Protection (ICRP) recommends regular monitoring of patient dose in diagnostic examinations to reduce population collective effective dose. Since international practice may not capture the clinical peculiarities of some regions, dose survey should be carried out at local and regional levels, based on acceptable practices. It was suggested by ICRP that all diagnostic centers should have a benchmark for their routine examinations[1]. In 1999, European Commission conducted a dose survey on computed tomography (CT) examination with a follow-up survey in 2004. Moreover, UK dose surveys are being reviewed every 5 years [2–5]. Dose surveys are not restricted to European communities, several countries around the world have incorporated CT dose monitoring into their radiation protection policies[6–9].

Early surveys on patient dose indicated the need for dose optimization. These led to some of the dose optimization strategies that are now in use which include automatic exposure control (AEC), reconstruction algorithms, and patient centering [10–14]. In addition to the new advancements in CT technology, diagnostic centers are also encouraged to set a benchmark for routine examinations. However, different dose benchmarks have been published for routine examination of the head, chest, abdomen, and pelvis at local and national levels. Factors that have contributed to making a difference in diagnostic reference level (DRL) are CT model, use of the manufacturer's default setting, and scanner acquisition setting [10, 15, 16]. Dose variations within and across CT centers have also been reported in several studies [17].

In Nigeria, dose escalation of CT procedures is generally reported in most local surveys due to, lack of guidance levels for routine examinations [18, 19]. The first national survey which was conducted in year 2017 necessitated conducting local surveys in Ondo State based on ICRP recommendations. Considering that local diagnostic reference level (LDRL) should be benchmarked against national DRL and also to

**Corresponding Author:* Tel: +2348062067344; E-mail: osoyedokun@futa.edu.ng

identify reasons for dose variations among CT centers. It is believed that DRL as a tool for optimization is not dose limits or a measure of competence of examining physician or performance level of the machine but a guide to good practice. It is on this ground that we decided to evaluate 25th, 50th, and 75th percentile dose levels of dose distributions of the participating centers. To the best of the researchers' knowledge, the present study was the first local survey to obtain the State reference levels and compared the DRLs to the national reference levels in Nigeria and those of other countries.

Materials and Methods

Ethical approval was obtained from the institutional review board of the Federal Medical Center (FMC) Owo, Nigeria. In addition a waiver was allowed based on the recommendation at Trauma Center (TC) of the University of Medical Sciences, Ondo, Nigeria. The former is owned by the Federal government of Nigeria while the latter is the State government owning the facility. At the time of this survey, the FMC operated brilliance 16 big core and TC had two General Electric Optima ™ 660 CT scanners with only one in full operation. Information about the scanners is available in table 1. Two types of data were collected from the centers' archives, namely the technical and exposure parameters. The first set of parameters included tube potential and current, pitch, gantry rotation time, reconstruction slice thickness, scanning mode, phantom reference (16/32cm), and scan length. The other set were the volume computed tomography dose index and dose length product of cranial, sinus, chest, abdomen and pelvis examinations. The number of sampled data collected per examination from the two centers can be found in figures 1 and 2.

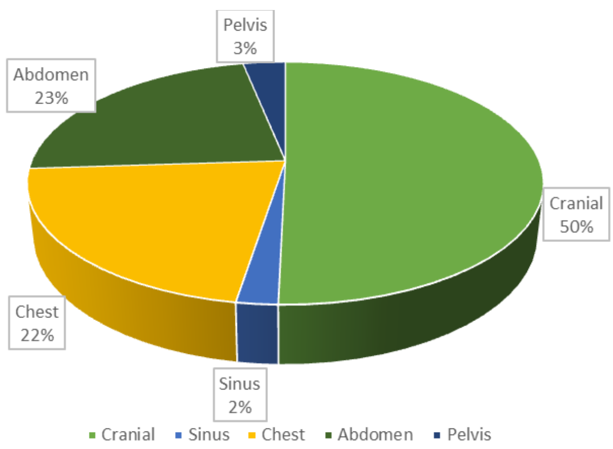

Figure 1. Percentage distribution of all routine computed tomography scans at Trauma Centre

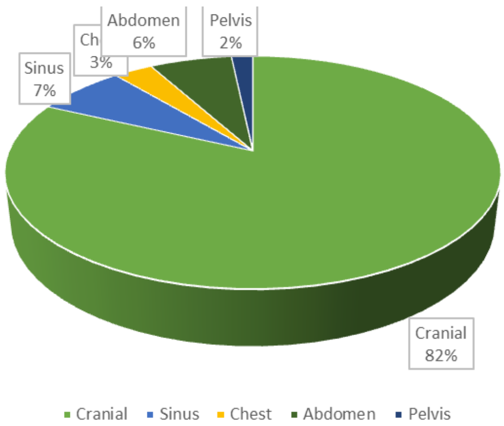

Figure 2. Percentage distribution of all routine computed tomography scans at Federal Medical Centre

The technical parameter distributions were grouped into mode and range. The mode represents the frequently used value while the range gives the min and max values. On the other hand, exposure data were classified into the lower, middle and upper quartiles also referred to as the 25th, 50th, and 75th percentiles, respectively. The 25th percentile is regarded as the dose level below which acquired image does not provide sufficient information relevant for diagnosis. The 50th percentile represents the optimal dose level for any given examination also referred to as the achievable dose level (AD) while the 75th percentile is meant to be the investigational level that should not be exceeded in standard examinations, this percentile is also known as the DRL. These percentiles were estimated using the dose distribution from each institution to obtain its current level of CT usage. Test for differences in dose distributions was performed using the Wilcoxon rank-sum test at a 95% confidence interval. For the five examinations, the State DRL and achievable dose level (AD i.e. 50th percentile) were estimated from pooled dose distributions of the two centers.

In terms of image quality, only images reported on by resident radiologists were kept for record purposes while low-quality images and images that did not provide information on patient illness were discarded immediately after the scan to save storage space. Therefore, it is logical to declare that images and the corresponding dose data obtained from these centers' archives were relevant for the current survey.

Table 1. Information about the CT machines used in TC and FMC, Ondo State, Nigeria

Information	TC	FMC
Manufacturer	GE Medical Healthcare	Philips
CT Model Type	Optima 660 Bright speed	Brilliance 16
Year of Installation	2015	2012
Capacity (slice number)	64-slice	16-slice
Country	Japan	Netherlands

Table 2. Technical parameters for computed tomography scans in TC

Examination	kV		mA		Pitch		Rotation time		Slice thickness (mm)	
	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range
Cranial	120	120	280	78-380	0.531	0.531-1.0	1.0	1.0-3.75	2.5	1.25-2.5
Sinus	120	120	80	80-89	0.531	0.531-1.0	0.6	0.6-1.0	3	1-3
Chest	120	120	169	63-338	1.375	1-1.375	0.6	0.6-0.8	3.75	3.75
Abdomen	120		280	50-400	1.375	1-1.375	0.6	0.6	3.75	3.75
Pelvis	120	120-140	127	50-362	1.375	1-1.375	-	-	-	-

Table 3. Technical parameters for computed tomography scans in FMC

Examination	kV		mA		Pitch		Rotation time		Slice thickness (mm)	
	Mode	Range	Mode	Range	Mode	Range	Mode	Range	Mode	Range
Cranial	120	120	600	600	0.625	0.30-1.87	1.5	0.75-23.96	3	0.75-3
Sinus	120	120	250	150-250	0.35	0.25-0.78	0.75	0.75-17.98	3	1-3
Chest	120	120	200	200-250	1.375	0.65-1.375	6.53	5.8-11.77	3	1.5-3
Abdomen	120	120-140	250	180-300	0.4	0.235-0.975	21.88	6.3-22.88	3	2-5
Pelvis	140	120-140	300	250-300	1	0.5-1.375	11.55	9.2-18.09	3	3

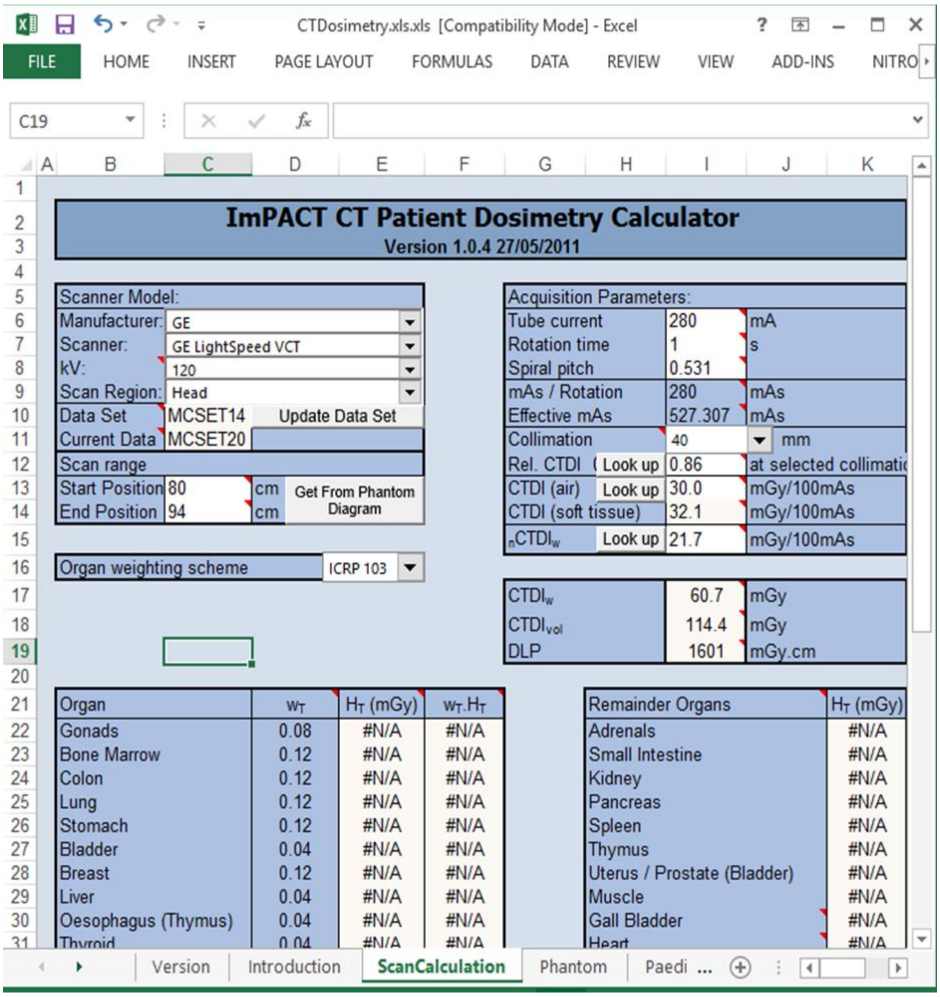

Figure 3. Image Performance Assessment of Computed Tomography Scanner (ImPACT), Computed tomography dosimetry calculators showing the dose length product and the scan range of the cranial scan

In addition, measuring patients' weight was not a routine practice in the State, owing to the severity of patients' condition at the time of hospital arrival. However, young adults and pediatric patients were excluded from the present study whose ages were below 18 years.

Finally, the console displayed dose length product (DLP) was verified using Image Performance Assessment of Computed Tomography (ImPACT) software (Medical Physics Department, Knightsbridge Wing, St George's Hospital, Tooting, London SW17 0QT) through user-defined technical parameters as shown in figure 3 [20]. In addition, the CT dose index (CTDIvol) was multiplied by the scan length to ensure the product yielded DLP value approximate to console displayed DLP before such data was used.

$$DLP = CTDIvol \times scanlength. \quad (1)$$

Results

CT scan of the head was predominant in the two centers. A total of 502 CT scans of the head out of 771 recorded examinations showed that CT scan of the head was the most commonly requested examination in Ondo State. Dividing into 207 and 295 head scans at Trauma Center and Federal Medical Center respectively. Other diagnostic examinations of interest among physicians were abdomen, chest, sinus and pelvis. The choice of technical parameters that made these examinations worth considering is illustrated in tables 2 and 3. The tube voltage and slice thickness adjustments were almost similar in the two centers. A tube potential of 120 kV was preferred in all examinations except in pelvis examination where 140 kV dominated FMC scanning voltage record, and also the slice thickness ranged from 0.75-3 mm with a mode value of 3 mm. Slice thickness of 2.5 mm was favored in the cranial examination and a slightly higher value in the abdomen and pelvis examinations at TC. Moreover, higher tube current and longer rotation time with relatively lower pitch values were common parameters employed at FMC and the opposite values at TC. The only few exceptions were tube current and selected pitch with mode values of 280 mA and 0.531 for the abdomen and cranial examinations respectively at TC, respectively.

Table 4 shows obtainable LDRL and other relevant dose levels of the two diagnostic institutions. The dose levels at 75th, 50th, and 25th percentiles were generally higher at FMC and relatively lower at TC. Some multiple-fold increases were observed in three examinations at FMC; about two-fold, more than two-fold, and about a three-fold increase in cranial, chest and pelvis, respectively. However, the 75th percentile was referred to as DRL and the 50th percentile referred to as the achievable dose level. The abovementioned percentiles were measured at 182 mGy and 38 mGy for cranial and sinus examinations at FMC and TC, respectively. Moreover, the dose levels for sinus and abdomen examinations were comparable, especially at the 50th and 25th percentile values. Accordingly, the Wilcoxon rank-sum test was used to reveal the differences in the dose distributions of the two centers in all the examinations with a 95% confidence interval as shown in table 5. Variation in dose distributions of the cranial and chest examinations was significant in each case ($P<0.05$). No significant difference was observed in the sinus, abdomen and pelvis with p-values 0.95, 0.83, and 0.091, respectively

Table 4. Different dose levels derived from each center's dose distribution

Examination	FMC		TC	
	CTDIvol (mGy)	DLP (mGy.cm)	CTDIvol (mGy)	DLP (mGy.cm)
Cranial				
75th percentile	182	2840	92	1876
50th percentile	182	2621	66	1468
25th percentile	91	2378	38	836
Sinus				
75th percentile	69	1159	38	888
50th percentile	39	993	38	773
25th percentile	34	579	34	766
Chest				
75th percentile	67	1068	23	918
50th percentile	52	981	18	669
25th percentile	35	777	12	496
Abdomen				
75th percentile	65	2811	35	2008
50th percentile	35	1625	27	1650
25th percentile	27	1042	18	1102
Pelvis				
75th percentile	41	1950	14	507
50th percentile	32	1343	9	424
25th percentile	29	832	6	238

FMC: Federal Medical Center
TC: Trauma Center
CTDIvol: Volume computed tomography dose index
DLP: Dose length product

Dose distributions of the two CT dose indices were pooled together to obtain the State DRL as shown in figures 4 and 5. In all the examination types, the 50th percentiles were lower than the 75th percentiles. The highest differences were detected in sinus and abdomen examinations in CTDIvol and DLP charts, respectively. Considerable differences in the CTDIvol and DLP graphs of chest and pelvis examinations were observed as well. While a noticeable change in the CTDIvol graph only was present for the abdomen.

No clear-cut difference in sinus examination's DLP benchmarks at 75th and 50th percentiles as illustrated in figure 5 while only a slight difference occurred in CTDIvol. benchmarks of cranial examination. However, the 75th percentile of the dose distributions of all the examinations were higher than the national and other countries' DRLs as presented in table 6.

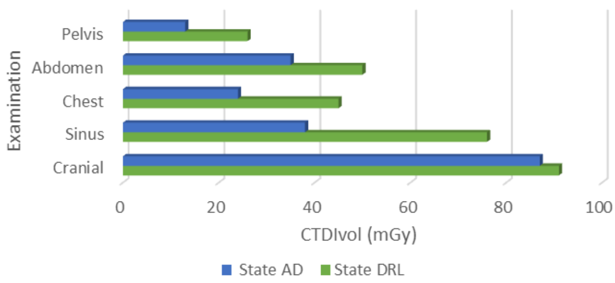

Figure 4. CTDIvol levels for all routine examinations in the State. State diagnostic reference level is the 75th percentile of pooled dose distributions and State achievable dose is the median of the pooled dose distributions

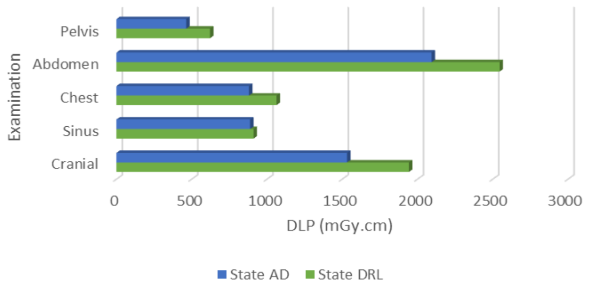

Figure 5. Dose length product levels for all routine examinations in the State. State diagnostic reference level is the 75th percentile of pooled dose distributions and State achievable dose is the median of the pooled dose distributions

Discussion

The DRLs were obtained from dose-related parameters namely the CTDIvol and DLP values, which were displayed on the CT scanner console. These exposure terms are dependent on technical parameters. The CTDIvol is a function of slice thickness, rotation time, tube current and voltage, and pitch, while DLP depends on a range of region of interest. The CTDIvol of all examinations at FMC was higher than its counterpart because of the acquisition parameters used by the radiographers. For instance, the optimal and the standard dose levels of cranial examination at FMC have the same value of 182 mGy owing to consistent use of default technical parameters especially the tube current. Other factors that influenced dose were, including slice thickness, tube potential, long acquisition, gantry rotation time and low pitch values. These factors aside, the mode of scanning also affected radiation outputs. Cranial and sinus examinations were mostly performed in axial scanning mode at FMC producing high exposure levels while TC employed the helical mode for the same examination types yielding low exposures. This observation is supported by a similar study carried out in Germany [21]. The dose distributions in helical and axial scanning modes varied significantly and became non-significant by appropriate selection of tube current as observed in cranial and sinus examinations, respectively. However, the aforementioned technical parameters are the major factors leading to high exposure in most surveys [22-27].

Chest and abdomen examinations performed in a single run of non-contrast, contrast and delayed phase produced a higher exposure level than the examinations performed in a sequence of non-contrast, contrast and delayed phase. Moreover, the center that employed the latter approach also turned on automatic exposure control for chest and abdomen examinations which favored a reduction in patients' exposure level. The CT dose survey in Ireland reveals that chest and abdomen examinations performed using AEC diminishes the dose level by 40% and 23%, respectively [17]. Furthermore, although the LDRL is about three-fold higher at FMC, dose distributions of pelvis examination show no significant difference. The non-significant difference observed in the dose distributions is the result of small sample size.

Our State DRLs for cranial, sinus, chest, abdomen and pelvis examinations exceed the DRL of national level and that of the other countries(e.g., Kenya); however, the DRL obtained for cranial examination is comparable to that of Japan [5, 13, 16, 23, 26]. Dose levels at 50th percentile (achievable dose) are lower than dose levels at 75th percentile (DRL) (figures 4 and 5). Therefore, the former should be considered as a working benchmark. In support of this idea, a survey in Kenya by Korir et al. suggests that an appropriate level of the dose distribution should be set as a guidance level for CT practice in countries with no strict regulations on radiation protection [16]. Similarly, the achievable dose level (AD) of the current study provides an initial step to dose optimization.

Table 5. Wilcoxon rank-sum test for the assessment of differences in dose length products of the two centers

Examination	Cranial	Sinus	Chest	Abdomen	Pelvis
p-value	0.036	0.950	0.024	0.830	0.091

Table 6. Comparison of State diagnostic reference levels with diagnostic reference levels at the national level and that of the other countries

Examination	Present study		Nigeria[26]		Kenya [16]		Italy [13]		Turkey [22]		Japan [23]		UK [5]		EU [4]		Iran [28]	
	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP
Cranial	91	1943	61	1310	61	1612	69	1312	66	810	85	1929	70	787	60	045	50	1611
Sinus	69	1159	-	-	41	700		-	-	-	-	-	-	-	-	-	-	-
Chest	45	1064	17	735	19	895	15	569	11	289	15	580		786	10	649	-	-
Abdomen	50	2545	20	1486	20	1842	18	555	13	204	20	680		472	25	774	-	-
Pelvis	26	622	-	-	21	1928	18	920	19	421	20	350		534	-	566	-	-

CTDIvol: Volume computed tomography dose index (mGy)
DLP: Dose length product (mGy.cm)

Conclusion

The DRL is one way to ensure that radiation dependent equipment (e.g., CT scanner) is being used safely. The present study sets out the LDRL applicable to each facility and State DRL, as well as examined the implications of technical parameters on the DRL. The factors that caused dose variation in our centers were tube current and potential settings, slice thickness, pitch, rotation time, automatic exposure control, sequential or single run of non-contrast, and contrast and delayed phase during chest and abdomen examinations. Helical scanning mode yielded a lower LDRL than axial scanning mode in cranial and sinus examinations. Moreover, either axial or helical scanning mode did not cause significant variation in dose distribution when the tube current was adequately selected as observed in the sinus examination. In addition, the use of AEC reduced patient exposure to radiation in all examinations. Therefore, the State DRL values obtained from the current study showed that the optimization strategy needs to be pursued to avoid patient overexposure and the initial step is to benchmark State DRL to the 50th percentile of the dose distributions.

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