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ARTICLE

Establishment of diagnostic reference level for routine CT scan examination in Sokoto state, Nigeria

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Abstract – Diagnostic Reference Levels (DRLs) are embedded into the optimization procedure to regulate CT dose and diagnostic quality. The purpose of this research was to establish the local DRLs and radiation dose exposure for CT scans at the Sokoto State Advanced Medical Diagnostic Center, Nigeria. 190 patients who had CT head, chest, and abdomen-pelvis scans were collected and evaluated for this study. It was established that the DRLs for $CTDI_{vol}$ for the head, thorax, and abdomen-pelvis were 48.2, 9.44, and 8.02, respectively with DLP DRLs in mGy.cm were 1044, 372, and 646. When comparing head CTs, our $CTDI_{vol}$ DRL is lower than many international standards, yet our DLP DRL is also below those of other nations. The chest CT DRL from Sokoto state is comparable to the DLP standards of some nations, although its $CTDI_{vol}$ is higher. The abdomen-pelvis $CTDI_{vol}$ DRLs are lower than those of the UK and US, thus necessitating the implementation of a controlled and optimized protocol in order to guarantee patient safety while maintaining image quality.

Keywords: computed tomography / dosimetry / diagnostic imaging / radiation medical / optimisation

1 Introduction

Godfrey Hounsfield's introduction of CT scanner in 1972 was a game-changer for diagnostic medicine and radiology. This type of scanning machine uses X-ray images to generate high-contrast images of the human anatomy. This process has enabled the precise identification and treatment of numerous patients, thus making it possible for surgeons to perform operations that were thought to be almost impossible. Nevertheless, worries have been expressed about the well-being of patients, who might be subjected to hazardous levels of ionizing radiation during CT scans (Albahiti *et al.*, 2022). Due to lack of optimization in delivery practices, CT scans have been previously linked to severe deterministic and stochastic effects (Kang *et al.*, 2021; Karim *et al.*, 2016b).

Over the past three to five years, the use of CT has increased worldwide, necessitating extensive research on optimization via DRLs especially in Nigeria. A quantitative cross-sectional study by Abdulkadir *et al.* evaluated the knowledge of diagnostic reference levels (DRLs) among computed tomography (CT) radiographers in northern Nigeria, which revealed a lack of understanding of DRLs (Abdulkadir *et al.*, 2021). In order to optimize the use of diagnostic radiology and nuclear medicine exposure in Nigeria, a national survey was conducted to establish DRLs (Buhari and Buhari, 2021; Jibiri and Olowookere, 2016a). Previously, Dambele *et al.* conducted a retrospective, cross-sectional study to determine the preliminary local DRLs for radionuclide bone tomography in a tertiary hospital in southwest Nigeria (Dambele *et al.*, 2021).

DRLs are an optimization technique in radiology that ensure patients get the right radiation doses without affecting the image quality (AlNaemi *et al.*, 2020). In Nigeria, numerous studies have been conducted to evaluate the use of DRLs in medical imaging. Jibiri *et al.* (2016) evaluated the dose-area product of common radiographic examinations in order to establish an preliminary diagnostic reference level (PDRL) in Southwestern Nigeria (Jibiri and Olowookere, 2016b). According to their findings, a more comprehensive national dose survey is required to establish a national reference dose. Buhari and Buhari (2021) conducted a review to establish a

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DRL for abdomen and thorax CT scan examinations in northern Nigeria, utilizing research for this region and comparing to global values. The results for the chest DRLs are 17.25 mGy for $CTDI_{vol}$ and 735 mGy cm for DLP, while the results for the abdomen are 19.25 mGy for $CTDI_{vol}$ and 1670.75 mGy cm for DLP.

In addition, DRLs for specific radiological examinations are established through studies. (Dambele *et al.*, 2021) established DRLs for bone scintigraphy, whereas (Salama *et al.*, 2017) conducted a research to establish a national diagnostic reference levels (DRLs) for computed tomography in Egypt. Comparing the Egypt DRL to a study in the UK, in their study, it was noted that the $CTDI_{vol}$ values for brain were approximately half that of the UK study. In conclusion, optimizing medical imaging is crucial for improving patient outcomes and preventing unnecessary radiation exposure (Karim *et al.*, 2016a; Muhammad *et al.*, 2022). Nigeria still requires extensive nationwide dose surveys in order to establish a national reference dose that will be followed in the future to ensure that patients receive the optimal radiation dose while maintaining image quality in medical imaging. One notable example of monitoring the DRL of computed tomography is evident in France, as well as in other countries (Benamar *et al.*, 2023; Habib Geryes *et al.*, 2019; Hakme *et al.*, 2023). Good regulatory guidelines, additional training, and constant encouragement from the healthcare system to its personnel are required to increase the use of DRLs in Nigeria.

1.1 CT scan services in Sokoto state, Nigeria

To address the requirements of its population of over five million, the Sokoto State Government has established an Advanced Medical Diagnostics Centre to provide medical diagnostic services. The ancient city of Sokoto, situated in northern Nigeria, has two CT scan machines, one of which is situated at Usmanu Danfodiyo University Teaching Hospital (UDUTH) and the other at the Sokoto State Advanced Medical Diagnostic Center (SSAMDC). Unfortunately, the scanning machine in UDUTH is currently not functioning due to maintenance. Therefore, both public and private healthcare facilities in the state are heavily dependent on SSAMDC for CT scans.

2 Methodology

The SSAMDC Research Ethics Committee approved this retrospective study, with the ethical number SSREC/ID-0091-22, and no consent was required. All data was taken from the Picture Archiving and Communication System (PACS) system of 16 multi-slice CT scan (CT Revolution, GE Healthcare, USA). The scanner able to reconstruct 16 slices, each measuring either 0.63 mm or 1.25 mm in rotation. Regarded as state-of-the-art in Nigeria, the upgraded version of GE's Light Speed CT series produces high-resolution 3D images which are better than other single slice CT scans. The data was collected from June 2021 to June 2023. This research observed and evaluated the results of 190 patients.

2.1 CT dosimetry

CTDI (measured in mGy) is a standard measure used to compare the radiation dose output of different CT scanners. It is important to note that the CTDI value does not represent the actual dose to the patient, as they are neither cylindrical nor made of plastic. Two useful types of CTDI are $CTDI_w$ and $CTDI_{vol}$. $CTDI_w$ is the weighted average of $CTDI_{100}$ measurements taken at two locations in a given phantom, one central and one peripheral, and mathematically expressed as

$$CTDI_w = \frac{1}{3}CTDI_c + \frac{2}{3}CTDI_p.$$

$CTDI_{vol}$ is a measure of the dose for a scan protocol that takes into account the radiation dose profile from successive rotations of the X-ray source, including any gaps and overlaps. Mathematically, it is expressed as:

$$CTDI_{vol} = \frac{CTDI_W}{\text{pitch}}.$$

The dose-length product (DLP) is ultimately determined and provided by the console, taking into account the duration of the scan to calculate the total dose output. The DLP represents the entire dose absorbed by a phantom over the course of a scan. DLP, measured in milligray-centimeter (mGy cm), is advantageous for evaluating exam dose if the scan lengths are equal. This is mathematically expressed as:

$$DLP = CTDI_{vol} \times \text{Scan length}.$$

2.2 Data collection

We collected data from 190 cases to conduct our research, which included essential parameters such as effective tube current (mAs), tube voltage (kVp), exposure time (s), table feed (TF), pitch factor, scan range, and slice thickness. To acquire this information, we accessed the Digital Imaging and Communications in Medicine (DICOM) system of the hospital and obtained data regarding $CTDI_{vol}$ and DLP from the Picture Archiving Communication System (PACS) console, specifically for CT brain, CT thorax, and CT abdominal-pelvis examinations.

2.3 Statistical analysis

All the data related to scans, patient details and dose reports, was taken from the console and organized in a Microsoft Excel spreadsheet for further analysis. Boxplots were generated to visually display the median and third quartile of the $CTDI_{vol}$ and DLP values, which had been categorized according to anatomical regions and protocols, in order to assess the data and gain a clear understanding of the central tendency and distribution of the dataset. Furthermore, a student's t-test was conducted to compare the means between groups and determine any statistically significant differences.

Table 1. Demography and descriptive analysis of CTDI and DLP of this study.

Region		mean ± SD		
		Brain	Thorax	Abd-pelvis
Patient characteristics	*n*	92	30	68
	Age (y/o)	43.3 ± 20.0	32.5 ± 12.3	45.5 ±16.8
	Weight (kg)	65.9±19.1	68.4±16.4	69.2±16.9
	Height (m)	1.57±0.19	1.605 ± 0.1	1.61 ± 0.1
	BMI (kg/m^2)	25.6 ± 6.7	26.1 ± 7.5	26.6 ± 6.4
	kV	120 ± 0	120 ± 0	120± 0
Acquisition parameter and dose	mAs	126.6 ± 33.7	121.5 ± 47.9	118.4 ± 49.7
	Scan range (cm)	24.61 ± 13.51	35.93 ± 9.30	82.8 ± 15.2
	$CTDI_{vol}$ (mGy)	42.7±10.35	9.84 ± 2.63	13.10 ± 1.99
	DLP (mGy.cm)	973.2 ± 336.30	364.1 ± 107.06	681.6 ± 197.1
	E (mSv)	2.04 ± 0.71	5.1 ± 1.5	10.22 ± 2.96

Table 2. Statistical analysis on dose and region of examinations.

Region	Brain		Thorax		Abdomen-pelvis	
	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
1st quartile	45.9	857.4	8.4	349.1	11.4	519.1
Median	48.2	1057.0	9.4	372.0	12.3	646.7
3rd quartile	50.2	1156.9	12.2	436.1	14.7	786.7
Maximum	51.9	1982.2	13.1	560.8	17.0	1372.6

This comprehensive approach enabled us to make informed interpretations and draw valid inferences regarding our research objectives.

3 Results and discussion

Table 1 tabulate the characteristics of the patients, with 92 brain CT exams, 30 chest CT exams, and 68 abdominal-pelvis CT exams. On average, those who had brain CT scans were 43 years old, chest CT scans were 32 years old, and abdominal-pelvis CT scans were 45.5 years old. Additionally, the mean weights for brain, thorax, and abdominal-pelvis CT scans were 65.9, 68, and 69 respectively. In addition, the mean BMI was 26.1 for chest CT and 26.6 for abdominal-pelvis CT. Table 2 presents the mean mAs values for all examinations, which varied from 49 to 126 mAs, as well as the kVp values, which were set at 120 for all CT scans. Furthermore, the table displays the average scan range values for each CT scan region, along with the mean $CTDI_{vol}$, $CTDI_w$, and DLP values, which encompass all 190 cases included in the study.

Table 2 illustrate the distribution of radiation exposure of CT dosimetry in brain, thorax, and abdomen-pelvis regions, which are measured in terms of $CTDI_{vol}$ and DLP. As observed the $CTDI_{vol}$ and DLP values for the brain, thorax, and abdomen-pelvis regions reveals that the radiation exposure in the brain region ranges from 45.9 mGy to 51.9 mGy, with a median $CTDI_{vol}$ of 48.2 mGy and a median DLP of 1057.0 mGy · cm. In comparison, the Thorax region has a narrower spread of $CTDI_{vol}$ values, ranging from 8.4 mGy to 13.1 mGy, and a median $CTDI_{vol}$ of 9.4 mGy and median DLP of 372.0 mGy · cm. It is noteworthy, the abdomen-pelvis region has $CTDI_{vol}$ values between 11.4 mGy and 17.0 mGy, and a median $CTDI_{vol}$ of 12.3 mGy and median DLP of 646.7 mGy · cm, indicating higher radiation exposure compared to the brain and thorax regions.

The median $CTDI_{vol}$ values we identified in our brain CT scan study were found to be similar to the DRLs for brain $CTDI_{vol}$ in Malaysia and Australia. However, these values were notably different from those obtained in other countries, such as the UK, Canada, and the US, also there is a significant difference when compared with the practice in France as tabulated in Table 3. Japan had the highest $CTDI_{vol}$ value of 77.0 mGy in 2020, indicating a higher radiation exposure during brain CT scans compared to other regions. The $CTDI_{vol}$ for the United Kingdom was recorded as 60.0 mGy, whereas Australia reported the lowest at 52.0 mGy.

In chest CT scans, Malaysia recorded the highest dose at 19.9 mGy, compared to 15.4 mGy in the United States and 14.1 mGy in Canada. Australia reported the lowest value at 10.0 mGy, while our study reported a $CTDI_{vol}$ of 9.4 mGy. Conversely, there is no substantial difference between the median $CTDI_{vol}$ value for chest CT examinations in our study and the DRLs for chest CT $CTDI_{vol}$ in Australia and the UK. However, when compared to values from other countries such

Table 3. A comparison between DRLs of some countries and the median value of this study

Region/Country*	Brain		Chest		Abdomen-Pelvis		References
	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	
Japan, 2020	77.0	1350	13.0	510	18.0	880	(Abe *et al.*, 2020)
United Kingdom, 2019	60.0	970	12.0	350	15.0	745	(Salama *et al.*, 2017)
Canada, 2016	79.1	1302	14.1	521	18.1	874	(Wardlaw, 2016)
Australia, 2019	52.0	880	10.0	390	13.0	566	(Lee *et al.*, 2020)
United states, 2017	57.0	1011	15.4	566	19.4	998	(Damilakis and Vassileva, 2021)
France, 2019	38.1	753	5.8	203	6.5	333	(Habib Geryes *et al.*, 2019)
Malaysia, 2013	46.8	1050	19.9	600	14.5	637	(Karim *et al.*, 2016a)
Egypt,2017	30.0	1360	22.0	420	31.0	1325	(Salama *et al.*, 2017)
Nigeria, 2018	61.0	1310	17.0	735	20.0	1486	(Ekpo *et al.*, 2018)
Kenya, 2018	61.0	1612	19.0	895	20.0	1842	(Ekpo *et al.*, 2018)
India, 2014	32.0	925	12.0	456	16.0	482	(Saravanakumar *et al.*, 2014)
This study	48.2	1057	9.4	372	12.3	647	

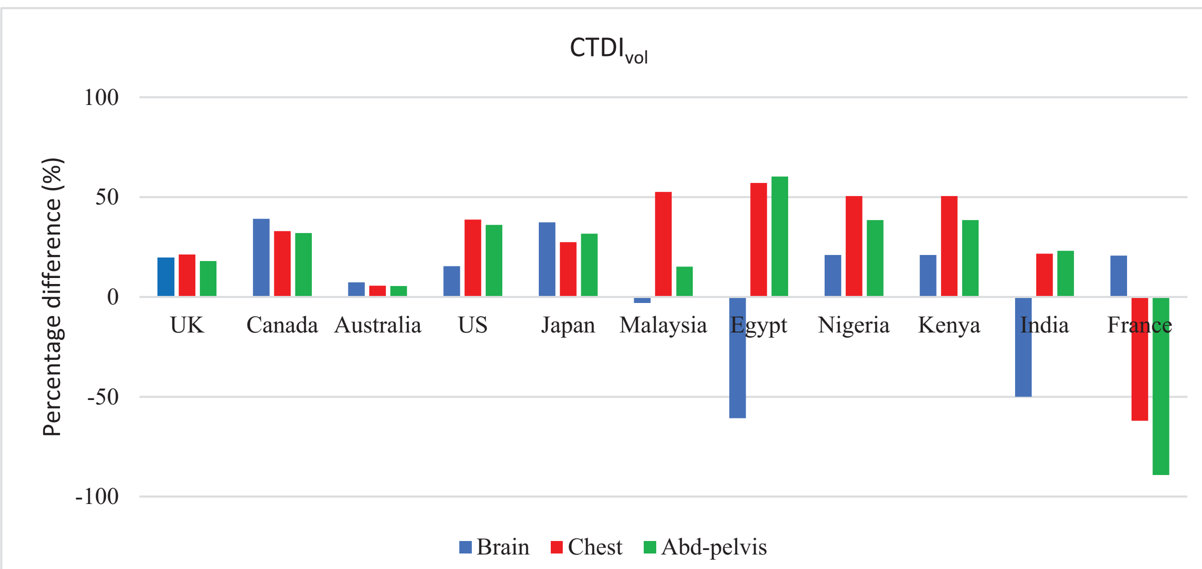

Fig. 1. A comparison percentage between $CTDI_{vol}$ DRLs of some countries with the current median.

as India, Kenya, Egypt, France and Nigeria, the disparities are considerably higher than those in our study, except for India.

Our study found that the median $CTDI_{vol}$ value in abdominal-pelvic CT examinations closely matched the Diagnostic Reference Level (DRL) established in Australia. Furthermore, Malaysia had the highest $CTDI_{vol}$ value for abdomen-pelvis scans at 14.5 mGy, while the United States reported a $CTDI_{vol}$ of 19.4 mGy and Canada had 18.1 mGy. Australia recorded the lowest $CTDI_{vol}$ value at 13.0 mGy, and our study reported a $CTDI_{vol}$ of 12.3 mGy. When compared to values from some countries such as Kenya, India, Egypt, and Nigeria as in Table 3, it is evident that the mean $CTDI_{vol}$ value differs significantly especially in France.

Analysis of the data presented in Figure 1 reveals noteworthy findings. The study reveals a minimal percentage difference in $CTDI_{vol}$ compared to Australia, suggesting a significant similarity in values. Moreover, the percentage variance in CTDIvol values in the UK is moderately low in comparison to several other countries. Notably, the UK, Canada, US, Japan, Nigeria, and Kenya exhibit an overall rise in $CTDI_{vol}$ across various CT scan types (brain, chest, abdomen-pelvis). Particularly, Canada demonstrates a substantial increase in brain CT scans (39.1%), while the US shows a significant rise in chest CT scans (38.7%). In contrast to France, there is an increase in $CTDI_{vol}$ for brain scans (20.7%), while chest scans show a significant decrease (–62%) and abdomen-pelvis scans exhibit a marked reduction (–89.2%). The substantial decrease, particularly in abdomen-pelvis scans, may suggest the adoption of intensive dose reduction approaches, potentially impacting image quality or reflecting the integration of advanced imaging technology.

In contrast, DLP appears to be heavily dependent on the scan range as shown Figure 2. France demonstrates the most significant decrease in DLP for brain CT scans, with a negative percentage difference of −40.3%, indicating a notable reduction compared to the baseline. Conversely, Nigeria and

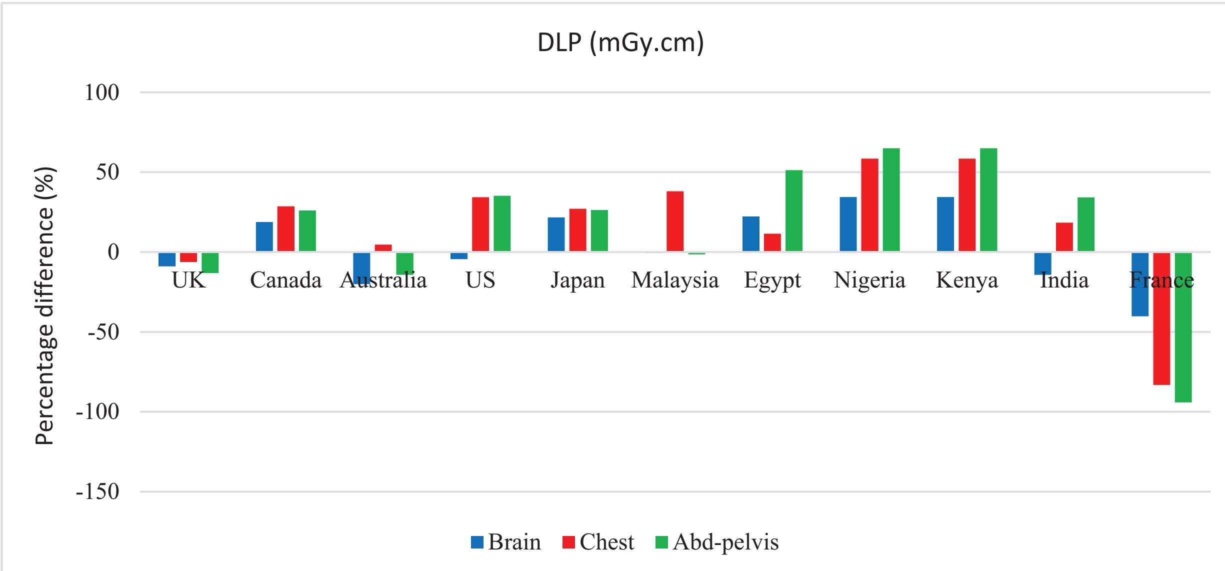

Fig. 2. A comparison percentage between DLP DRLs of some countries with the current median.

Kenya exhibit the highest positive percentage difference at 34.4%, suggesting elevated DLP levels. In the case of chest CT scans, France once again displays a substantial decrease in DLP, with a difference of −83.2%, while Nigeria and Kenya show a marked increase of 58.4%. The pattern persists for abdomen-pelvis CT scans, where France records the most substantial reduction in DLP at −94.2%, whereas Nigeria and Kenya demonstrate the largest increase at 64.9%. Negative values signify reduced radiation dose, enhancing patient safety if image quality is preserved. Conversely, positive values indicate higher radiation exposure to patients, potentially improving image quality.

This finding reveals that the median DLP value for brain CT examinations is approximately similar to those obtained in Malaysia and the US but significantly differs from values recorded in some countries such as India, Kenya Egypt and Nigeria (see Tab. 3). It was observed that a median value of DLP for chest CT, which is related to that of the UK, is also present. Notably, the mean scan range for brain CT scans is lower when compared to chest and abdominal-pelvis scans, yet the DLP for brain CT exceeds that of chest and abdominal-pelvis. When scrutinizing the DLP for chest CT, our study exhibits substantial differences compared to some countries. In the case of abdominal pelvis, the DLP values obtained in this study closely align with those of Australia and Malaysia but diverge significantly when contrasted with values from some Nigeria, Kenya Egypt, France, and India. These marked differences may be attributed to the relatively low scan range values documented in our study.

4 Conclusion

In this study, we analyzed $CTDI_{vol}$, and DLP, values from routine CT examinations at SSAMDC. When these values were compared with those from eleven nations – Canada, the UK, the US, Malaysia, Japan, France, Australia, Nigeria, India, Kenya, and Egypt, discrepancies were evident. Specifically, the values diverged from those of the UK, Canada, and the US, yet intriguingly mirrored the metrics from Australia and Malaysia. Recognizing that the dose values align closely with those of Australia and Malaysia, we advocate for subsequent studies to delve into the nexus between image quality as perceived by radiologists and technologists. Furthermore, it would be beneficial to examine the strategies for optimizing scan protocols.

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Conflicts of Interest

The authors disclose that they have no conflict of interests.

Data availability statement

All relevant data are included in the study.

Author contribution statement

The authors confirm contribution to the paper as follows: study conception and design: Conceptualization, MKAK; Formal analysis, SMK, SAA; Investigation, SMK, FKU; Project administration, MKAK and NAM; Resources, HHH; Supervision, MKAK and IK; Validation, MMAK and NAM; Visualization, MKAK; Writing – original draft, HM and SMK; Writing – review & editing, MKAK.

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