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Paper

Prospective dose monitoring using a manual dose management system: experience in brain computed tomography from a tertiary hospital in Nigeria

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Abstract

A manual radiation dose management system was developed to track the radiation dose and scan parameters of patients for brain computed tomography (CT). Radiation dose in volume computed tomography dose index (CTDIvol) and dose length product (DLP) were monitored to identify procedures that may require optimisation using notification values. The data were analysed and compared with national and international diagnostic reference levels (DRLs). A total of 596 brain CTs were monitored and grouped as <1: 36, 1–<5: 38, 5–<10: 25, 10–<15: 31 and adult: 466. The CTDIvol notification value identified the following number of examinations having high CTDIvol in <1 y: 1, 1–<5: 1, 5–<10: 0, 10–<15: 0 and adult (>15): 11. Furthermore, the DLP notification values identified the following examinations with high DLP in <1 y: 1, 1–<5:1, 5–<10:1, 10–<15: 1 and adults (>15): 18. The established local paediatric DLP DRLs were 2–3 times higher than the international paediatric DLP DRLs. This calls for a total protocol review and optimisation considering the local CT practices for paediatric imaging.

Introduction

Computed tomography (CT) is an invaluable imaging modality used to diagnose and manage disease[1]. However, the CT procedure is associated with radiation exposure that has the potential to cause serious radiation injuries that could potentially include cancer induction in the exposed individuals[2]. Brain CT is the most commonly performed procedure, especially in the emergency departments[3]. Compared with chest and abdominal examinations, brain CT has a lower effective dose; however, the cumulative exposure from brain CT is high because ∼39% of patients undergo repeated follow-up scans[3]. This calls for continuous dose justification and optimisation of brain CT exposure following the principle of as low as reasonably achievable (ALARA).

The radiation dose associated with CT has made the implementation of a dose management strategy more important. Thus, in 2019, a working group was launched by EuroSafe Imaging for the implementation of a dose management system in clinical practice[4]. The European Union Council Directive recommends that the radiation dose information forms part of the radiologist's report to facilitate dose justification and optimisation where possible [5].

A patient radiation dose management system (RDMS) is an organised and coordinated platform that allows patient radiation dose exposure to be tracked and managed for dose optimisation[6, 7]. The primary roles of a RDMS include radiation dose optimisation through the establishment and monitoring of local and national DRLs, quality assurance, identification of wide exposure variations and record-keeping of radiation doses[4].

Several electronic RDMS software, such as Radimetrics (Buyers), DoseWatch (GE Healthcare), DoseWise (Philips) and Teamplay (Siemens) have been developed and are currently being used to manage patient radiation doses[2, 8–11]. However, despite the large volume of CT scan examinations performed in the Nigerian study centre, there is a lack of electronic platforms to support the management of the scan parameters and radiation dose data. This is similar for CT scan

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examinations in many of the low- and middle-income countries (LMICs)[12]. In place of electronic RDMS, the study therefore developed and tested a manual RDMS template that allows prospective monitoring and management of the scan parameters and dose information by radiographers, radiologists, medical physicists and referring physicians to enhance dose optimisation.

Method

This was a cross-sectional, prospective study conducted on patients that presented for brain CT procedures at a tertiary institution, located in the northwest region of Nigeria, from 1 August to 31 December 2022. Ethics approvals were obtained from the relevant research ethics committees with reference numbers CPUT/HW-REC 2022/H1 and NHREC/28/01/2020/AKTH/EC/3186, respectively. The informed consent process allowed participants to agree or otherwise before being included in the study. Only those participants who consented were included. The consent was requested from the participants to allow age, weight and gender to be collected in addition to the dosimetric information from CT scans requested as part of their medical management.

Quality control on the CT scanner

The CT scanner radiation dose output in CTDIvol and DLP was validated using Impact CT patient dosimetric calculator version 1.0.4. The scan parameters were entered in the system, and the resultant doses in CTDIvol and DLP were noted not to differ significantly from the displayed CTDIvol and DLP on the scanner monitor. Furthermore, a tube warm-up is performed daily by the radiographer to ensure consistent optimal image quality. Image quality assessment is also performed daily using an image quality phantom, and the result was noted to be within the acceptable limit as recommended by the CT scanner manufacturer.

CT radiation dose management

The CT radiation dose of individual patients was monitored and managed using a prospective manual RDMS template. The RDMS template was developed based on the findings of the systematic literature review conducted prior to the study[13]. The RDMS template has the following sections: demographic information; examination information; scan parameters; scan and image reconstruction details; examination dose information; notification values; cumulative dose in DLP for the previous CT procedure; justification if above the notification value, referring physicians' section and space for the radiologist to report. The provision of age groups was made to allow age classifications in paediatrics. The age was classified as <1, 1–<5, 5–<10, 10–<15 and adult categories. The age classification is based on the recommendation of the International Commission on Radiological Protection (ICRP) for establishing diagnostic reference levels (DRLs). According to ICRP[14], the age classification is the most commonly used internationally, and it was adopted in this study to allow local DRLs to compare with the established DRLs from other relevant studies[15, 16]. The authors are aware of the European age classification for brain CT DRLs; however, it is at variance with the recommended ICRP age classification[17]. For this study, the developed RDMS template was designed for application to all patients undergoing brain CT who consented. In future studies, this template could be used for other body regions. A sample of the developed adult RDMS template is presented in Figure 1.

Validity and reliability of RDMS

The face and content validity of the RDMS were established by a group of experts, which included two diagnostic radiographers and a radiologist. These experts scrutinised the template to ensure that appropriate information for dose management was provided. Thereafter, the RDMS template was pilot-tested in a selected group of consented patients who presented for brain CT.

Radiation dose management using RDMS

The validated RDMS template provides a system for managing the patient scan and dose information prospectively, which can be added to the radiology archive and patient hospital folder. During the study period, for each consented patient that presented for a brain CT, the demographic and clinical information of the patient, as provided on the patient request form, were transferred onto the RDMS template by the radiographer. In addition, once the patient was positioned and the protocol selected, the scan parameters, including the estimated dose in CTDIvol and DLP, were evaluated and recorded on the RDMS.

Use of notification value

The notification value was used to trigger when the displayed dose in CTDIvol and DLP exceeded the configured dose for a single scan[18]. Using RDMS, for every patient, the radiographer looked at the displayed CTDIvol and DLP to see whether they fell within the preset notification value or otherwise before a scan commenced. If the estimated dose was within the notification values in CTDIvol and DLP, the scan was authorised. Where the estimated dose was above the configured notification value, the scan parameters were optimised by the radiographer. If the scan parameters could not be optimised, for instance, due to clinical

CT EXAMS REPORT SHEET

Patient & Dose Information

Name:				Age:			Clinic:		ADULT
Gender:				Weight (Kg):			Hosp. No.:		
Examination information		**Scan parameters**		**Indicate scan mode and image reconstruction used.**	**Examination Dose information**		**Notification values specific to this CT scanner**	**Cumulative dose in DLP for the previous CT**	**(Justify if above the notification values)**
Procedure:	Routine Brain CT	kV		Wide volume	CTDIvol (mGy)		CTDIvol: 46		
Indication:		mAs		Helical:	Total DLP (mGy*cm)				
		Slice thickness		IR	Scan length (mm):		Total DLP: 1562		
		No. of slices		FBP	No. of series:				
Note: This exposure is equivalent to 100 chest X-rays and 10 months of exposure to natural background radiation For further clarification, kindly contact the following number: +2348034532750									

Name of Radiographer **Sign & date**

Radiologist report

Name of Radiologist **Sign & date**

Figure 1. RDMS template

requirements, a justifiable reason was provided and documented on the same RDMS.

The ICRP recommends that DRLs should not be used as a notification value, as DRLs are used for the optimisation of the protocol of a group of patients and not for individual patients[14]. Furthermore, DRLs may trigger frequently and make the radiographers ignore high dose indices. Therefore, it is recommended that the notification value be set at a value above the institutional diagnostic range values[14]. Therefore, the notification values for this study were set as the highest 5% value of the dose distribution in each age group. The American Association of Physicists in Medicine (AAPM) recommends the use of CTDIvol or DLP[19], as notification values, and therefore, in this study, both parameters were used for robust dose monitoring as presented in Table 1.

Table 1. Notification values for brain CT established as the highest 5% value of the dose distribution.

Age groups	CTDIvol (mGy)	DLP (mGy∗cm)
Adult (>15 y)	46	1562
<1 y	32	1392
1–<5 y	48	1724
5–<10 y	52	2202
10–<15 y	52	2108

In Figure 1, the space for the cumulative dose in DLP, which was meant for patients who come for a

repeated procedure, was never entered because, during the period of study, there was no case of a patient attending for a follow-up examination. In addition, the alert value was also not provided in the developed RDMS in this study, as the AAPM recommended the alert value for brain CT is 1000 mGy[19], and for a routine brain CT procedure in our centre, this value may not be attained; however, the alert value could be relevant for brain CT angiography or interventional procedures.

The filled RDMS template was passed from the radiographer's desk to the reporting radiologist, who wrote the report on the same RDMS template, having access to all the scan and dose information as provided by the radiographer. The same RDMS template was designed on the computer where the radiologist report is typed. The typed report, which was based on the information provided by the radiographer and the radiologist, was printed, signed and submitted to the referring physician who apart from the radiological findings also had access to information about the radiation dose the patient had incurred in the course of the procedure. The same process was repeated for all consenting patients who were referred for brain CT during the data collection period.

Protocol for brain CT at the study site

The scan was performed on a 160-slice Toshiba CT scanner, which was manufactured in 2013 and installed in 2015. Following the AAPM protocol for brain CT[20]. The patients were positioned supine on the scanner table, and two scanograms were acquired in the front-occipital (FO) and lateral (Lat) projections. Thereafter, the scan was planned on the scan monitor using the positioning box, and the images were acquired from the vertex to the base of the skull. However, in some trauma cases, due to the suspected cervical spine injury, the protocol was modified to include the cervical spine. This group of patients was excluded from the study as the scan length is expected to be longer, which affects DLP for comparison purposes. All patients scanned had contrast and non-contrast series scans, except those with acute bleeds due to trauma or cerebrovascular disease (CVD) who were scanned using a single series acquisition.

The adult patients were scanned using the wide volume (WV) protocol. The WV protocol allows the scanner table to move into the gantry incrementally[21]. Meanwhile, the paediatric patients were scanned using the helical mode. The helical mode allows continuous movement of the scanner table into the gantry[1]. The helical mode is faster compared with WV, thus reducing the possibility of motion blur in children[1].

Data collection

For each patient scanned, the following information was collected: patient demographic information (age, weight and gender); examination information (indication); scan parameter details (kV, mAs, slice thickness (ST) and number of slices (NS)) and scan and image reconstruction details (scan mode and type of reconstruction software). In addition, radiation dose in CTDIvol and DLP, including scan length and number of scan series, were collected. The CTDIvol and DLP recorded were based on the 16 cm phantom size as per the recommendation for the brain procedure[22]. Notification values in CTDIvol and DLP and reason for justification where the dose exceeded the notification value were also collected.

Data cleansing

The collected data were cleaned for any erroneous data entry, such as providing adult information in place of paediatric, or where vital information, such as radiation dose data, was not provided.

Data analysis

The analysis was performed using the Statistical Package for Social Sciences (SPSS) version 20. The data were checked for normality and noted to be normally distributed based on the Shapiro–Wilk test results. The data were described using the mean and standard deviation.

Patients having high doses were identified using the established notification values presented in Table 1. To establish local DRLs, CTDIvol and DLP were calculated in median values as recommended by the ICRP[14]. Furthermore, the established median values were compared with the national and international DRLs. Although most of the scans were acquired using multiple acquisitions, whereby the patient had both non-contrast and contrast series, a single DLP was calculated for comparison with the national DRL, which reported the DLP based on a single series scan. Total DLP, as recommended by ICRP, was equally calculated to allow comparison with the international DRLs.

Results

A total of 596 patients referred for brain CT were included in the study. The paediatric group of 130 (22%) represents the <1: 36 (6%), 1–<5: 38 (7%), 5–<10: 25 (4%) and 10–<15: 31 (5%) age groups. Meanwhile, the adults (>15 y) represent 466 (78%).

The demographic data of the patients are presented in Table 2. The majority of the patients were adults. In all the groups, there were more male participants

Table 2. Demography and clinical indications based on age groups.

Demographic/indication		<1 y ($n = 36$)	1–<5 y ($n = 38$)	5–<10 y ($n = 25$)	10–<15 y ($n = 31$)	Adult:>15 y ($n = 466$)
Gender	Male:Female	19:17	19:20	19:6	20:11	293:173
Age (y)	Mean ± SD	0.3 ± 0.3	2.4 ± 0.9	7 ± 1.2	11.5 ± 1.3	48.6 ± 20.4
	Range	0.01–0.9	1–4	5–9	10–14	15–112
Weight (kg)	Mean ± SD	5.3 ± 2.4	9.8 ± 4.1	20.0 ± 5.1	32.6 ± 16.0	63.3 ± 16.9
	Range	2–10	2–19	12–30	4–79	25–120
CVD			1 (0)			132 (50)
Trauma		2 (1)	7 (1)	5 (1)	8 (2)	49 (51)
Headache			1 (0)		4 (0)	28 (4)
ICSOL			2 (0)	3 (0)	2 (0)	18 (0)
Seizures disorder			3 (0)	1 (0)	1 (0)	10 (4)
Convulsion		1 (0)		1 (0)	2 (0)	9 (1)
Hydrocephalus		21 (0)	7 (0)	3 (0)		NIL
Others such as optic nerve atrophy, brain mass, slurred speech, retinoblastoma		11 (0)	17 (0)	11 (0)	11 (0)	96 (14)

Contrast and non-contrast series (only non-contrast series); CVD, cerebro-vascular disease; ICSOL, intracranial space-occupying lesion.

Table 3. Scan parameters for the included patients.

Scan parameters		<1 y ($n = 36$)	1–<5 y ($n = 38$)	5–<10 y ($n = 25$)	10–<15 y ($n = 31$)	Adult:>15 y ($n = 466$)
kV	100	35	22	NIL	2	NIL
	120	1	16	25	29	466
mAs	125	1	13	3	NIL	NIL
	135	35	22	NIL	NIL	NIL
	150	NIL	2	21	19	NIL
	225	NIL	1	1	12	466
Pitch		0.625	0.625	0.625	0.625	0.637
Scan length (mm)		141.4 ± 26.7	147.9 ± 20.5	159.7 ± 13.9	159.5 ± 4	154.6 ± 15.5
		90–222	90–195	135–185	141–200	150–298.5
Number of slices		29 ± 5	31 ± 4	33 ± 3	32 ± 3	31.6 ± 2.5
		20–48	19–40	28–44	29–49	31–60
Slice thickness (mm)		5	5	5	5	5
Number of scan series	One	1	1	1	116	
	Two	35	37	24	350	
Scan mode	Helical	36	37	24	9	
	WV	NIL	1	1	457	
Image reconstruction algorithm		AIDR 3D	AIDR 3D	AIDR 3D	AIDR 3D	AIDR 3D

AIDR 3D, adaptive iterative dose reduction 3-dimensional; WV, wide volume.

than females, except for age group 1–<5. Clinical indications based on age groups are also presented in Table 2. CVD was the most common indication (182) followed by trauma (100) in the adult group. Meanwhile, in 1–<5, 5–<10 and 10–<15, trauma was the common indication, and hydrocephalus was the common indication in <1.

Table 3 presents the scan parameters used for brain CT in the study area. Of the 466 adult patients, 457 were scanned using the WV protocol and the remaining nine (9) were scanned using the helical protocol. Meanwhile, most of the paediatric patients were scanned using the helical protocol. In all the groups, the scan was performed based on one (1) or two (2) series acquisitions. All the adult patients were scanned using 120 kV and 225 mAs. Meanwhile, paediatric patients were scanned using a range of kV and mAs.

In terms of CTDIvol, the following number of examinations in each group adult: 11, <1 y: 1, 1–<5 y: 1, 5–<10 y: 0 and 10–<15 y: 0 were identified as having CTDIvol readings above the set notification values (Figure 2). Also, in terms of DLP, the following number of examinations in each group adult: 18, <1 y: 1, 1–<5: 1, 5–<10: 1 and 10–<15: 1 were identified as having DLPs above the notification values (Figure 3).

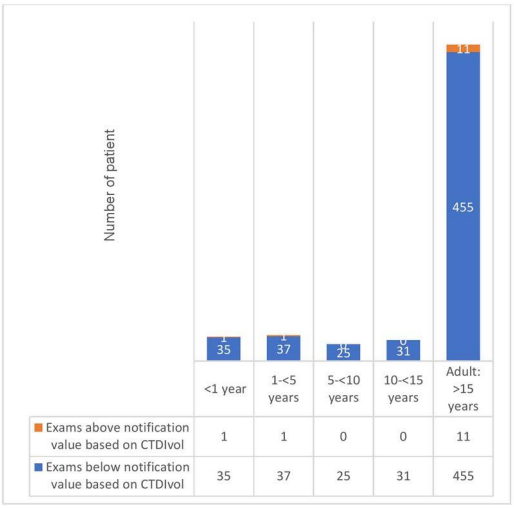

Figure 2. Number of examinations above and below the notification value based on CTDIvol

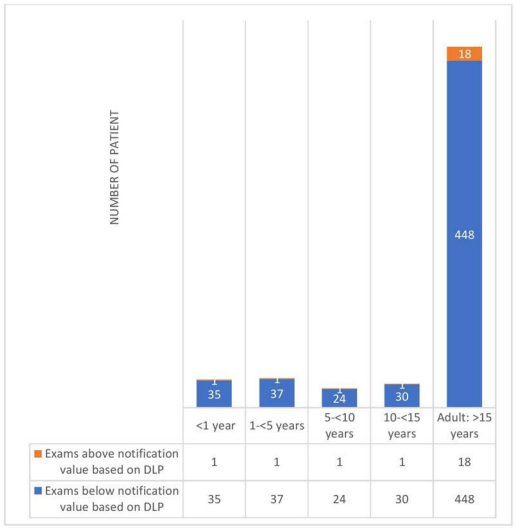

Figure 3. Number of examinations above and below the notification value based on DLP

Table 4 shows descriptive statistics of patient doses in CTDIvol and DLP. Mean, standard deviation and range values were calculated for each group. Similarly, the median values (second quartile) of CTDIvol and DLP for each group were calculated to allow for establishing local DRLs and also for comparison with DRL values from other studies.

Figure 4 presents the established local DRLs in median CTDIvol and DLP. The median CTDIvol for 5–<10 and 10–<15 were the same and higher than the adult DRLs. Similarly, the median CTDIvol for <1 and 1–<5 were the same and lower than that of 5–<10, 10–<15 and adult values.

Figure 5 shows the established local brain DRLs in the median DLP. The adult median DLP was statistically significantly ($p = 0.001$) lower than the DLP of 5–<10, who had the highest DLP, followed by 10–<15. The <1 and 1–<5 had the lowest DLP, but this was not a statistically significant ($p = 0.159$) difference.

Figure 6 shows the established median CTDIvol in comparison with the national and international values. Although there are no data available for the international adult brain DRLs, the established median adult CTDIvol was lower than the national DRLs. The established median CTDIvol for the paediatric brain was slightly lower than the national and international established DRLs except for <1 y, which was higher. The international DRLs presented as green bars were established based on the data collected across the globe[16].

Figure 7 shows a DLP comparison to the national DRLs. The national DRLs were established based on a single-series scan. To compare with the national DRLs, the present study calculated DLP DRLs for a single scan, and this resulted in a lower comparative value to the national DRLs across all the age groups.

The DLP DRLs of the present study were calculated and established based on a total DLP to allow comparison with the DLP DRLs of the international study (Figure 8). The values obtained were compared higher to the international DLP DRLs by 2- to 3-fold (Figure 8). There were no international adult DRLs available for comparison with the local DRLs.

Discussion

The focus of this study was on the use of a prospective RDMS template for monitoring patient radiation dose information during brain CT scans, which could be managed to promote dose optimisation from procedures with high radiation exposure. The use of the RMDS template has provided a source of patient scan parameters and dosimetric records added to the radiologist's report, as presented in Tables 3 and 4. This is the first known study that provides scan and dose information on the radiologist's report in Nigeria for CT practice. The provision of such information, along with the radiologists' report, proves useful in promoting radiation dose monitoring and optimisation[23]. In the same vein, one of the EU recommendations to member states in the management of patient doses in CT is the provision of dose information on the radiologist's report[5].

It was noted that the majority (78%) of the patients scanned were adults, and most were referred on

Table 4. Dose parameters for the included patients.

Scan parameters		<1 y ($n = 36$)	1–<5 y ($n = 38$)	5–<10 y ($n = 25$)	10–<15 y ($n = 31$)	Adult:>15 y ($n = 466$)
CTDIvol (mGy)	Mean	30.4	35.7	47.7	45.7	42.7
	SD	2.1	6.9	3.8	4.5	3.6
	Range	27.5–39.6	27–52.3	39.6–52.3	30.9–52.3	41–68.7
	1st Q	30.2	30.9	47.3	41.4	41.4
	2nd Q	30.9	30.9	47.6	47.5	41.4
	3rd Q	30.9	43.6	52	47.6	41.7
Total	Mean total	978.2	1174.4	1722.4	1548.4	1170
DLP (mGy∗cm)	SD	177.1	367.5	294.2	373.8	390.8
	Range	481.4–1429	528–2198	807–2246	625–2279	624–4314.1
	1st Q	870	934	1644.6	1249	781
	2nd Q	975.6	1072	1756.2	1661	1250
	3rd Q	1088	1446	1893.5	1837	1255
Single	1st Q	481	528	807	625	625
DLP (mGy∗cm)	2nd Q	481	543	807	686	625
	3rd Q	481	559	807	1258	686

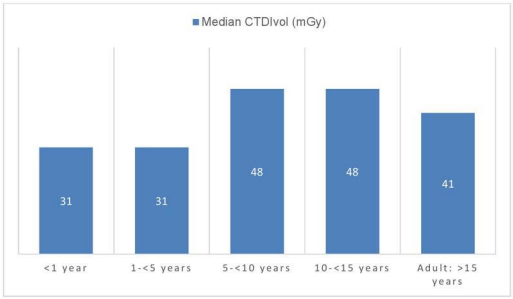

Figure 4. Median brain CTDIvol for different age groups

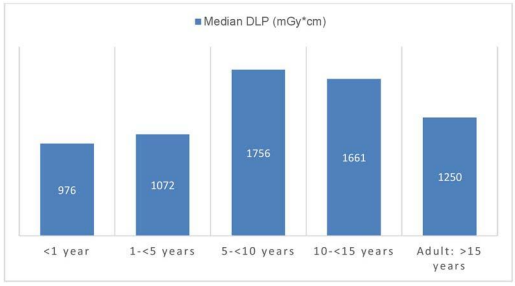

Figure 5. Median brain DLP for different age groups

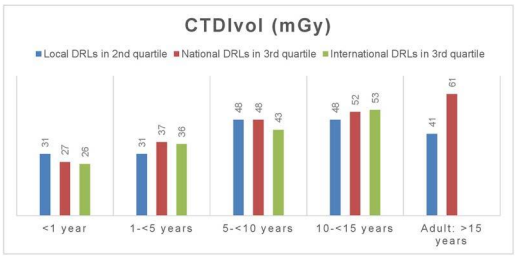

Figure 6. Local DRLs in comparison with the national and international values

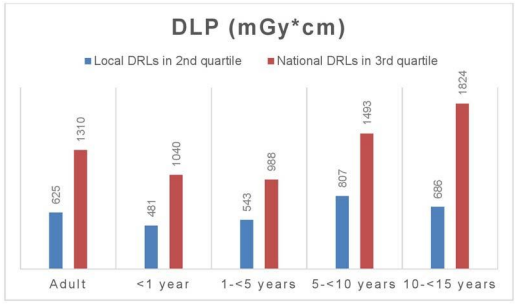

Figure 7. Established median DLPs compared with the national DRL values based on a single series

account of trauma and CVD (Table 2). Similar clinical indications were reported in a clinical indication DRLs and post-optimisation image quality study by Ukoha *et al.*[24]. As in the Ukoha *et al.*[24] study, there was no protocol variation in this study due to differences in clinical indications, thus the adult patient had the same CTDIvol. However, the CTDIvol value of the present study was marginally lower than the value reported by Ukoha *et al.*[24], who reported 43 mGy for both CVD and trauma compared with 42 mGy in the present study. Although 51% of the trauma patients had a single series scan, which reduced the radiation dose in DLP by 50%, there is a need to incorporate a strong justification principle to further reduce the rate of contrast series on account of trauma. In the study conducted by Mutch *et al.*[25] on imaging evaluation of acute traumatic brain injury, it was indicated that

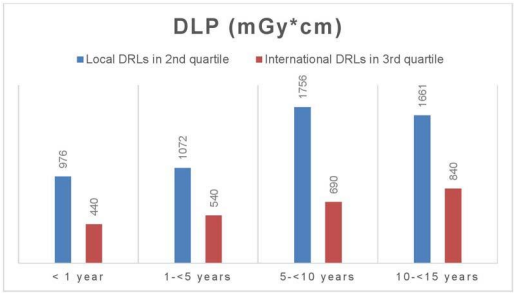

Figure 8. Established median DLPs compared with the international DRL values based on a total DLP

contrast series is not useful in head trauma unless vascular damage is suspected; otherwise, it only adds to the cumulative patient dose. The present study has shown that only 27% of CVD patients had a single series scan; thus, the majority could potentially receive high doses due to both non-contrast and contrast series acquisition. This is against the practice, as non-contrast CT is considered the first imaging method for all patients with suspected stroke[26]. Protocol review is therefore recommended for patients with suspected CVD to ensure dose justification and protocol optimisation.

In the present study, hydrocephalus was the common indication in <1 y (Table 2). Beyond <1 y age, the next most common indication was trauma. Similar indications were reported in a clinical indication-based DRLs for paediatric brain CT study by Joseph Zira *et al.*[27]. Most paediatrics 125 (96%) had both non-contrast and contrast series acquisition, while only a few with trauma 5 (4%) had only the non-contrast series (Table 2). A study conducted in Nigeria by Abdulkadir *et al.*[28] on the evaluation of age-based radiation dose in paediatric head CT also reported the acquisition of multiple scan series in paediatric CT. However, a study by Nievelstein *et al.*[29] on multidetector CT related to the current concept and dose reduction strategies in children reported that multiple-phase CT should be avoided. They reported that the non-contrast series adds insignificant additional diagnostic information and should be abandoned. It is therefore recommended that multiple series acquisitions in paediatric patients only be considered with strong justification, due to the vulnerability of children to radiation injury.

The notification values in CTDIvol identified 11 (2.4%) procedures in the adult category, 1 (2.8%) in <1 y, 1 (2.6%) in the 1–<5 y, 0 (0%) in the 5–<10 y and 0 (0%) procedure in the 10–<15 y groups (Figure 2). Similarly, the notification values in DLP identified 18 (3.9%) procedures in the adult category, 1 (2.8%) in <1 y, 1 (2.6%) in 1–<5 y, 1 (4%) in 5–<10 y and 1 (3.2%) procedure in 10–<15 y (Figure 3). A similar study conducted by Osman *et al.*[2] on radiation dose management in CT imaging, though using GE software, identified procedures having high doses above the DLP notification value. In addition, a study by Cook *et al.*[30] using customisable interactive Radiance toolkits for CT dose management reported procedures that had higher and lower doses than the established limits. In addition, a study by Parakh *et al.*[6] on CT radiation dose management reported a gradual reduction, in many CT procedures identified as having high doses based on CTDIvol over the years, which shows the effectiveness of the dose optimisation strategy. The procedures identified in this study were those adult cases incidentally scanned with the mostly helical protocol. Also, the procedures had both non-contrast and contrast series and mostly had a long scan length in their respective groups. Long scan length has been reported as one of the reasons for having DLP above the notification value[8]. Other possible causes of high DLP include the scan mode and CTDIvol[1, 31]. This indicates the need for a critical review of every protocol selected to ensure that the dose is within the accepted levels to avoid unnecessary exposure to anatomical areas that could have been saved.

The notification values in CTDIvol and DLP for paediatrics were noted as being triggered frequently, which shows the protocols were incorrectly programmed and need review. A review of the protocol, considering the local CT practice in addition to the national DRLs protocol, is therefore recommended.

The AAPM[19] and ICRP[14] have recommended that the notification values could be set in CTDIvol or DLP. In this study, the two-dose parameters were considered as notification values. The CTDIvol determines the tube output, but it does not consider the extent of anatomy (scan length) exposed to radiation during the scan. The DLP is the product of CTDIvol and scan length; thus, it provides additional information on the anatomy exposed[1]. The AAPM proposed notification values were in CTDIvol, not in DLP. Thus, using the two parameters CTDIvol and DLP provided robust information that could not be achieved with a single parameter. In this study, using CTDIvol alone could have allowed higher exposures to be missed, especially in the adult category, which was identified based on DLP (Figure 3).

It has been shown through this study that the use of RDMS is impactful for identifying high-dose procedures that require dose optimisation and that could go unnoticed without the application of a RDMS. Similar to Heilmaier *et al.*[32], the CT radiographers in this study were trained on how to use the RDMS template. Thus, the radiation dose for every protocol was checked by the radiographer before the scan was authorised,

which could have increased their dose awareness. However, the number of examinations identified as having high CTDIvol and DLP is of concern and calls for the retraining of radiographers in dose optimisation.

Figures 4 and 5 show local brain DRLs that were established in the median CTDIvol and DLP. Age groups 5–<10 and 10–<15 had higher CTDIvol and DLP than the adult. The reason could be due to the difference in the scan modes. The adults were scanned using the WV axial, while helical was used in the paediatric group. In all the three (3) groups, 120 kV was used, except for 2 out of 31 patients aged 10–<15 y, where the 100 kV was used (Table 2). However, the mAs for the adults were higher than the mean mAs for the 5–<10 and 10–<15 groups (Table 3). Thus, the reason for higher CTDIvol in paediatrics was determined to be the scan mode. A study conducted by Garba *et al.*[33] on the analysis of image quality and radiation dose between WV and helical has reported that the helical scan was associated with a significantly higher dose compared with the WV protocol. Similarly, in a study comparing WV and helical in children's brain CT by Jeon *et al.*[34], it was reported that WV reduced radiation dose compared with the helical scan mode. In addition, a study comparing WV and helical on paediatric chest CT by Ryu *et al.*[35] reported that WV decreases patient dose compared with the helical technique, though it may be associated with motion artefacts. Therefore, it is recommended to consider the WV protocol for children between the ages of 10–15 as they are more likely to cooperate, and there would be a corresponding lower radiation dose advantage. However, it is recommended that the helical protocol in the <1, 1–<5 and 5–<10 should be maintained but optimised to reduce the dose in line with the ALARA principle.

The median DLP DRLs in this study were compared and found to be lower than the national DRLs by 45–62% across all the age groups (Figure 7). Although the adult CTDIvol DRLs were compared as being lower by 33% to the national DRLs and similarly—<5 y and 10–<15 y by 16 and 8%, respectively,—the CTDIvol for the <1 y was comparably higher to the national DRLs (Figure 6). The reason for lower DLP in some age groups, despite having higher CTDIvol, could be related to the scan length used, as DLP is the product of CTDIvol and the scan length[1]. For example, the average scan length used in all the age groups ranges from 14 to 16 cm (Table 3). Meanwhile, in the national study, the average scan length for one of the age groups is 29 cm[15]. In this case, the scan length is longer than the recommended scan length, as reported in a study on dose metrics and patient age in CT by Huda and Tipnis[36]. They reported that the scan length could be increased from 15 cm in the <1 y to 20 cm in the adult. This shows that the values obtained in the current study could be considered to be within the recommended range. It, therefore, emphasises the need for collimating the beam to the requested region to avoid irradiation of an unnecessary anatomical area unless there is justification.

When compared with the international paediatric DRLs, the established local CTDIvol typical values were found to be higher except for 1–<5 y and 10–<15 y, which resulted in a lower comparative outcome (Figure 6). The CTDIvol typical values were higher than the international DRLs by 10–16% for the <1 to 5–<10, while the CTDIvol typical value was lower than the international in 1–<5 y and 10–<15 by 9–14%. Similarly, the median DLP DRLs were comparably higher than the international DLP DRLs by 2–3 times across the age groups (Figure 8). The reason for higher DLP in the present study could be protocol-related and therefore involving scan parameters. The DLP of the present and international studies was based on multiple scan acquisition. This aligns with ICRP 135, which reported that variation in patient dose due to body size in children is acceptable[14]. However, these authors continue to stress that variation in dose due to imaging protocol or clinical task is never appropriate and should be looked into for corrective actions[14]. In this one-centre study, it was found that the level of variation, especially in DLP, requires attention and possible optimisation of the imaging protocols.

Limitations of the study

The study is from a single centre; thus, while the findings can be used for comparison in other CT centres, they cannot be generalised nationally. The manual prospective dose management could be time-consuming and characterised by data entry errors. Thus, radiographers must exercise due diligence to ensure proper implementation of the dose management system.

Conclusion

The study has developed a manual RDMS that provides a prospective assessment of patient scan parameters and dosimetric information for brain CT. The CTDIvol and DLP notifications in RDMS have triggered the identification of procedures with radiation exposure above the notification values. Similarly, the dose record has shown that the paediatric DLP DRLs were 2–3 times higher than the international paediatric DLP DRLs. This calls for a review of CT protocol, considering local CT practice. The process increases radiographers' understanding of the scan protocol and its impact on dose and image quality. However,

the use of manual RDMS requires due diligence and proper scrutiny to minimise data entry errors. It is suggested that for those centres that do not have electronic RDMS, it is worthwhile to apply the manual system. To enable improved radiation protection, it is recommended that the developed RDMS template should be applied in this centre for other CT regions and in other centres across Nigeria to facilitate prospective dose monitoring, management and optimisation.

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