

ORIGINAL RESEARCH



The Development of Local Diagnostic Reference Levels for Common Adult Computed Tomography Examinations at Mzuzu Central Hospital, Malawi

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Abstract

Background

Diagnostic reference level (DRL) is an important tool used to identify abnormally high radiation doses, aid dose audits, and trigger investigations in diagnostic radiological imaging. This study aimed to develop local DRLs for the adult head, chest, and abdomen computed tomography (CT) examinations without contrast material at Mzuzu Central Hospital (MCH).

Methodology

This retrospective study was conducted at MCH radiology department using a NeuViz 16-slice Essence CT scanner from September 2023 to March 2024. The consecutive sampling method was used to extract data from patients' head, chest, and abdominal images from advanced visualization workspace (AVW) and Picture Archiving and Communication Systems (PACS) using a checklist. All images were anonymized, and the data was kept in password-locked folders. Data was exported into SPSS version 26.0 software for analysis. Continuous variables were expressed as means and medians. Categorical variables were presented in form of tables as frequencies. The local DRLs were obtained by calculating the median radiation dose values by anatomical region.

Results

Out of 802 patients enrolled in this study, 361 (45%) had head CT examinations, 187 (23%) had chest CT examinations, and 254 (32%) had abdomen CT examinations without contrast. Local DRLs obtained by calculating the median of volume CT dose index (CTDIvol) and dose length product (DLP) for the head, chest, and abdomen CT examinations were 31 mGy, 5 mGy, 7 mGy, and 699 mGy.cm, 227 mGy.cm, and 331 mGy.cm, respectively.

Conclusion

Local DRLs for the head, chest, and abdomen have been developed for a NeuViz 16 Essence multi-detector CT scanner at MCH. The CTDIvol and DLP median values were lower or comparable to other single-facility, regional, and international values. This study should serve as a baseline for developing national adult CT DRLs for Malawi.

Keywords: Computed Tomography, Diagnostic Reference Levels, Volume-weighted Computed Tomography Dose Index, Dose Length Product, Radiation dose

Introduction

Computed Tomography (CT) is a specialized diagnostic radiological imaging modality that uses high radiation to produce cross-sectional images of the body to support disease screening, diagnosis, treatment, and management¹⁻⁴. However, patients, staff, and the general public may be at risk for cancer because of its high radiation dosages^{2,3}. Radiation dose from CT examinations accounts for 34% of the total dose from medical exposures⁵. Although radiation exposure from CT is associated with potential carcinogenic risks, its use in healthcare settings is justified where the patient's benefit outweighs the risk^{1,6}. Such potential risks prompted the International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) to recommend appropriate management of medical radiation exposures with an emphasis on strict adherence to radiation protection key principles of justification and

optimization while maintaining diagnostic image quality^{7,8}. The organizations further recommend adherence to the as low as reasonably achievable (ALARA) principle to reduce the risk of potential radiation effects⁸⁻¹⁰.

The concept of diagnostic reference levels (DRLs) was first introduced by ICRP in their 73rd publication in 1996 as an essential tool for optimization in radiological imaging and encouraged using it in imaging modalities utilizing ionizing radiation, including CT^{6,11}. DRLs have been proven to be an effective tool that aids in the optimization of protection in the medical exposure of patients for diagnostic and interventional procedures¹¹. Similarly, DRLs are used to detect abnormally high or low radiation doses for a specific examination under routine conditions, but they are neither maximum permitted patient doses nor patient dose estimations^{1,8,11}. If it turns out that DRLs are routinely being exceeded, a multidisciplinary team consisting of radiographers, medical physicists, and

clinicians is mandated to review imaging protocols and radiation protection measures^{1,11}.

The setting of DRL values from radiological procedures can either be patient-based (real clinical situation) or phantom-based, but the former is preferred because patient and technical characteristics are included¹². According to ICRP publication 135, the development and establishment of local, national, or regional DRL values require surveys or registries of patients across the country or region coordinated by national or regional organisations¹¹. For a single facility, typical DRL values can be developed by the department and are defined as the median of the distribution observed at the facility, while local, national, or regional DRL values are set at the 75th percentile of the medians of DRL quantity distributions observed at healthcare institutions^{4,11}.

When developing DRL values, patient size, CT scan parameters, and CT dose characteristics are evaluated^{9,11}. For the patient size, a specified reference group of patients defined within a certain range of patient parameters (height and weight) is used, where patients with very heavy and very light weights are excluded¹³. Height and weight are used to calculate body mass index (BMI), which helps to determine the amount of dose the patient gets in a specific procedure to achieve optimum image quality^{12,14,15}. Similarly, CT scan parameters (tube voltage in kilovoltage peak [kVp], tube current time product in milliamperere-seconds [mAs], tube current [mA], helical pitch, slice thickness, and beam collimation filter), which have a direct influence on the amount of dose produced, are also evaluated¹⁶. Dose parameters (volume-weighted CT dose index [CTDI_{vol}] measured in milligray [mGy] and dose-length product [DLP] measured in milligray-centimeter [mGy.cm]) are assessed in patient surveys performed to set DRL values^{11,17}.

Even if ICRP recommends state legislation to be clear on organizations' responsibilities when setting up DRLs, there are no guidelines on health and radiation safety at all levels of radiology service delivery in Malawi at the moment, according to national radiology policy¹⁸. However, the commission stated that a group of radiology departments or a single facility can develop local DRLs by defining the median distribution of the DRL quantity¹¹. To keep the DRL values up to date, ICRP recommends 3-5 years of regular revision of national and regional DRLs to align the levels with technological advancements in imaging^{4,6,19,20}. Countries like the United States (US), Canada, Japan, the United Kingdom (UK), France, and Ethiopia have developed and revised their national DRLs for common CT examinations in response to ICRP's recommendation¹⁴. In the UK and France, for example, data have been collected approximately every 5 years, and DRL values have been determined since the mid-1980s¹¹.

At the time of this publication, DRLs do not exist in Malawi, as there is no traceable documentation about the development or establishment of either local or national DRLs to our knowledge. This is the first study in the country that will act as a baseline to develop and establish national DRLs. MCH, like other major hospitals and private clinics in Malawi, has a functional multidetector CT machine, but no study to develop and establish local DRL values for common adult CT examinations has been conducted. Therefore, the purpose of this study was to develop local DRLs for adult head, chest, and abdomen CT examinations at Mzuzu Central Hospital (MCH).

Methodology

Study design and setting

A retrospective study was conducted at Mzuzu Central Hospital from September 2023 to March 2024.

Study population and sample size

The study targeted records of patients aged 18 years old and above who had CT scans of the head, chest, and abdomen without the use of contrast material at MCH. All images that met quality departmental standards in terms of contrast limit and spatial resolution were captured. CT examinations with multiple CT images and images with artifacts and noise were not included. The data was extracted from Advanced Visualization Workspace (AVW) and Picture Archiving and Communication Systems (PACS). The study used a consecutive method to enrol patients' CT images of the head, chest, and abdomen with the aid of a well-designed checklist (Annex A).

In this study, a total of 802 patients' images (361 for CT head, 187 for CT chest, and 254 for CT abdomen) were included. The sample size was determined based on ICRP recommendations, which state that at least 30 standard-sized patients can be considered for DRL surveys if data collection is done manually¹¹. The size of the study participants based on weight ranged from 40 kilograms (kg) to 90 kg, with a calculated average weight of 60 kg.

Image acquisition

CT Head protocol

For all CT head examinations without contrast, the patient was allowed to remove all metallic objects, including earrings, necklaces, and metallic removable dental prosthetics. Thereafter, the patient was positioned supine on the CT couch with their head first, arms by their sides and acquisition average field of view (FOV) set at 250 mm. CT parameters selected for image acquisition were 100 to 120 kV, 200 to 380 mA, 200 to 350 mAs, 5 mm slice thickness, and helical pitch of 0.44 to 1.5. Craniocaudal scan direction was used, covering from cervical vertebra number 2 to the vertex for lateral scanogram and helical axial CT images. Post-processing techniques like iterative reconstruction (IR) and multiplanar reconstruction (MPR) and image reconstruction at 1-1.25 mm slice thickness for axial, coronal, and sagittal planes with brain and bone windows were used to improve diagnostic image quality and easy viewing.

CT chest protocol

The patient changed into a hospital gown, positioned supine on the CT couch with the chest in the middle of the gantry, and had both arms raised for every CT chest examination without contrast. Craniocaudal scan direction was used, covering from the lung apices to the level of the diaphragm for anteroposterior (AP) scanogram and helical axial CT images acquired at 5 mm slice thickness. Scanning was done during single breath-hold inspiration using a CT machine with pre-recorded instructions in a local language with an average of 300 mm FOV. CT parameters used ranged from 100 to 120 kV, 31 to 355 mA, 21 to 260 mAs, and a helical pitch of 0.71 to 1.9. Post-processing techniques like IR and MPR and image reconstruction at 1-1.25 mm slice thickness for axial, coronal, and sagittal planes with mediastinal and lung windows were used to improve diagnostic image quality and easy viewing.

CT abdomen protocol

The patient changed into a hospital gown and was positioned supine on the CT couch with the abdomen centered within the gantry and both arms raised for every CT abdomen examination without contrast. Craniocaudal scan direction was used, covering from the level of the diaphragm to the lesser trochanter for AP scanogram and symphysis pubis for helical axial CT images. Scanning was done during single breath-hold inspiration using CT machine pre-recorded instructions in a local language with an average of 350 mm FOV. CT parameters used ranged 100 to 120 kVp, 31 to 348 mA, 16.4 to 250 mAs, 5 mm slice thickness, and helical pitch of 0.77 to 1.5. IR and MPR at 1-1.25 mm slice thickness for axial, coronal, and sagittal planes were used to improve diagnostic image quality and easy viewing.

Data Collection and management

Three research assistants extracted demographic characteristics (age, gender, weight, and height), dose parameters (DLP and CTDIvol), and CT parameters (kVp, mAs, mA, slice thickness, and helical pitch) from CT images stored in the AVW workstation and PACS. All images were anonymized. These officers were trained in all research protocols when dealing with human subjects according to the Helsinki Declaration in 1964 with the latest amendment in 2013²¹ before data collection commences. The captured data was transferred into an Excel sheet. Two experienced image readers, blinded from each other, reviewed all the images for diagnostic image quality. Images that did not meet departmental quality standards, either due to patient body habitus, poor resolution, or artifacts, were not analysed. After the study, the data will be kept safely in password-locked folders by the corresponding author and made available when the need arises.

Data analysis

Data was exported into SPSS version 26.0 software for analysis. Baseline demographic, CT, and dose characteristics were summarized using means $\pm$ standard deviation (SD) for numerical variables that were normally distributed and frequencies for numerical variables that were not normally distributed. Frequencies for categorical variables were presented in the form of tables. CT scan and dose variables were compared for each of the examinations by comparing their means and medians depending on the type of variables and presented in the form of tables.

To determine the local DRLs, CTDIvol and DLP were considered. The reference levels were set by calculating the median value of the radiation doses by anatomical region. The Kruskal-Wallis test was used for comparison of non-normal data between groups, and the Mann-Whitney U test was used for the difference between each two groups. The description of the data distribution was expressed in terms of mean, median, maximum, minimum, and quartiles. A p-value of < 0.05 was considered statistically significant.

Ethical considerations

Ethical clearance was obtained from the Mzuzu University Research Ethics Committee (MZUNIREC) Ref No: MZUNIREC/DOR/24/137 in line with the Helsinki Declaration in 1964, with the latest amendment done in 2013 on studies involving humans. We obtained authorization to conduct a study and a waiver from the MCH research committee on informed consent for individual patients due to the retrospective nature of the study.

Quality control

CT examinations were done using the NeuViz 16 Essence 16-Slice CT Scanner System, independently developed and produced by Neusoft Medical. The machine is certified by relevant regulatory bodies, ensuring the capacity to produce quality diagnostic images. An advanced modeled IR algorithm was used to reduce image noise and improve image quality. Radiographers performing the examinations have good on-the-job training to operate CT scans by Chinese experts under the China-Africa skills development exchange visits. The CT logbook showed documented evidence of routine weekly calibrations according to the manufacturer's recommendation, ensuring capability of optimum performance. Experienced radiologists reviewed and certified that images meet departmental diagnostic quality standards.

Results

Out of 802 patients enrolled in this study, 414 (52%) were males and 388 (48%) were females. The patients had a weight range of 40 kg to 90 kg with a calculated average weight of 60 kg. These patients were divided into commonly performed CT examinations of the head 361 (45%), chest 187 (23%), and abdomen 254 (32%). The patients were further divided into three groups based on their BMI in these examinations. Group one patients had a BMI $< 18.5 \text{ kg/m}^2$, group two patients had $18.5 \text{ kg/m}^2 \leq \text{BMI} < 24 \text{ kg/m}^2$, and group three patients had a BMI $\geq 24 \text{ kg/m}^2$. Demographic characteristics (age, gender, weight, and height), CT parameters (kV, mAs, mA, pitch, and slice thickness), and dose parameters (CTDIvol and DLP) were analysed using means in specific CT examinations (Tables 1-3). Dose parameters (CTDIvol and DLP) were further analysed against head, chest, and abdomen examinations to get the median and third quartile values to aid in the development of the local DRL values (Table 4). The developed local DRL values (Table 6) were compared with DRL values established in other countries (Table 7).

CT Head without contrast

Out of 361 patients who had CT head without contrast, 198 (55%) were males and 163 (45%) were females. The study found 23 (6%) patients with BMI $< 18.5 \text{ kg/m}^2$, 165 (46%) patients with $18.5 \text{ kg/m}^2 \leq \text{BMI} < 24 \text{ kg/m}^2$ and 173 (48%) patients with BMI $\geq 24 \text{ kg/m}^2$ which were considered groups one, two, and three, respectively. On dose parameters, patients had mean values of 31 mGy, 35 mGy, and 35 mGy ($P = 0.005$) and 660 mGy.cm, 793 mGy.cm, and 771 mGy.cm ($P = 0.017$) for CTDIvol and DLP in groups one, two, and three respectively. The dose parameters significantly correlated with patients' BMI (Table 1).

CT Chest without contrast

Out of 187 patients who had CT chest without contrast, 80 (43%) were males and 107 (57%) were females. The study found that 25 (13%) patients had a BMI $< 18.5 \text{ kg/m}^2$, 89 (48%) patients had $18.5 \text{ kg/m}^2 \leq \text{BMI} < 24 \text{ kg/m}^2$, and 73 (39%) patients had a BMI $\leq 24 \text{ kg/m}^2$. There was a positive correlation between patients' BMI and CTDIvol and DLP mean values with ($P < 0.001^*$) and ($P = 0.002^*$) statistical significance, respectively (Table 2).

CT Abdomen without contrast

Out of 254 patients who had CT abdomen without contrast, 136 (54%) were males and 118 (46%) were females.

Table 1. Multiple comparison of parameters between different BMI groups according to CT head without contrast

	BMI < 18.5 (n = 23)	18.5 ≤ BMI < 24 (n = 165)	24 ≤ BMI (n = 173)	$\chi^2/H^{\#}$	P
Age (year)	45.56 ± 19.38	45.54 ± 18.33	51.12 ± 17.84	19.40	< 0.001*
Gender (M/F)	14/9	107/58	77/96	24.75	0.26
Weight (kg)	47.18 ± 4.97	57.53 ± 6.65	68.89 ± 10.41	137.84	< 0.001*
Height (cm)	165.39 ± 6.90	164.12 ± 8.90	154.77 ± 12.79	55.65	< 0.001*
CTDIvol (mGy)	31.06 ± 2.25	34.74 ± 5.47	34.92 ± 6.21	10.71	0.005*
DLP (mGy.cm)	659.73 ± 88.52	793.24 ± 199.45	770.63 ± 203.01	8.10	0.017*
KV	120	120	120	-	-
mAs	265.41 ± 20.62	248.13 ± 37.52	203.01 ± 12.96	-	-
mA	256.21 ± 31.47	287.62 ± 22.62	323.69 ± 14.97	-	-
Pitch (mm)	1.00-1.30	0.44-1.5	0.48-1.2	-	-
Slice Thickness (mm)	5	5	5	-	-

[#]H: Kruskal-Wallis test. *p < 0.05 indicates statistical significance.

Table 2. Multiple comparisons of parameters between different BMI groups according to CT Chest without contrast

	BMI < 18.5 (n = 25)	18.5 ≤ BMI < 24 (n = 89)	24 ≤ BMI (n = 73)	$\chi^2/H^{\#}$	P
Age (year)	54.44 ± 16.11	52.68 ± 18.15	57.91 ± 17.10	3.44	0.179
Gender (M/F)	14/11	44/45	22/51	8.16	0.017*
Weight (kg)	46.96 ± 5.29	55.49 ± 7.31	65.33 ± 11.62	64.23	< 0.001*
Height (cm)	165.77 ± 9.20	162.02 ± 9.73	150.26 ± 13.80	40.48	< 0.001*
CTDIvol (mGy)	4.24 ± 1.41	5.20 ± 2.25	6.79 ± 2.95	21.07	< 0.001*
DLP (mGy.cm)	238.08 ± 125.79	286.10 ± 200.40	385.50 ± 242.5	12.99	0.002*
KV	120	120	120	-	-
mAs	64.80 ± 21.66	79.16 ± 34.08	103.24 ± 44.69	-	-
mA	110.32 ± 37.53	128.58 ± 46.85	159.32 ± 66.81	-	-
Pitch (mm)	0.9-1.2	0.9-1.4	0.9-1.4	-	-
Slice Thickness (mm)	5	5	5	-	-

[#]H: Kruskal-Wallis test. *p < 0.05 indicates statistical significance.

Table 3. Multiple comparisons of parameters between different BMI groups according to CT abdomen without contrast

	BMI < 18.5 (n = 40)	18.5 ≤ BMI < 24 (n = 125)	24 ≤ BMI (n = 89)	$\chi^2/H^{\#}$	P
Age (year)	41.80 ± 17.47	46.47 ± 16.74	47.38 ± 13.81	3.88	0.14
Gender(M/F)	23/17	67/58	46/43	0.38	0.83
Weight (kg)	46.10 ± 3.32	55.82 ± 7.35	70.27 ± 10.11	139.08	< 0.001*
Height (cm)	164.32 ± 6.33	160.86 ± 8.96	158.30 ± 12.37	8.54	0.014*
CTDIvol (mGy)	5.54 ± 1.92	6.78 ± 2.13	8.96 ± 2.80	72.58	< 0.001*
DLP (mGy.cm)	272.10 ± 109.31	337.64 ± 136.04	441.50 ± 154.97	56.99	< 0.001*
KV	120	120	120	-	-
mAs	80.21 ± 23.89	103.10 ± 30.76	133.73 ± 31.18	-	-
mA	107.55 ± 39.65	138.25 ± 49.70	181.01 ± 53.93	-	-
Pitch (mm)	0.9-1.00	0.9-1.4	0.9-1.4	-	-
Slice Thickness (mm)	5	5	5	-	-

[#]H: Kruskal-Wallis test. *p < 0.05 indicates statistical significance.

This study found that 40 (16%) patients had BMI < 18.5 kg/m², 125 (49%) patients had 18.5 kg/m² ≤ BMI < 24 kg/m², and 89 (35%) patients had BMI ≤ 24 kg/m². The CTDIvol and DLP mean values showed a significant association (P < 0.001*) with the patient's BMI (Table 3).

CT head, chest and abdomen without contrast

Out of 802 patients enrolled in this study, 361 (45%) had head CT examinations, 187 (23%) had chest CT examinations, and 254 (32%) had abdomen CT examinations. The study found that CTDIvol median values for CT head, chest, and abdomen were 31 mGy, 5 mGy, and 7 mGy, and DLP was 699 mGy.cm, 227 mGy.cm, and 331 mGy.cm, respectively. Similarly, CTDIvol third quartile values for head, chest, and abdomen CT examinations were 41 mGy, 7 mGy, and 9 mGy, and DLP was 893 mGy.cm, 448 mGy.cm, and 443 mGy.cm, respectively. There was a positive relationship between CTDIvol and DLP mean values and head, chest, and abdomen CT examinations with (P < 0.001*) statistical significance (Table 4).

Developed CT scanning parameters and local DRLs for MCH in 2024

The study developed CT parameters for the commonly done examinations of the head, chest, and abdomen without contrast, which produced high-quality images that satisfy departmental requirements. These standard parameters for the multi-detector NeuViz 16 Essence 16-Slice CT Scanner System were developed based on the patient's BMI (Table 5).

For each head, chest, and abdomen CT examination without contrast, the median of CTDIvol and DLP values were calculated and considered as local DRL. The developed CTDIvol DRL (typical values) for the head, chest, and abdomen were 31 mGy, 5 mGy, and 7 mGy, respectively. Similarly, DLP DRL values were 699 mGy.cm, 227 mGy.cm, and 331 mGy.cm for head, chest, and abdomen, respectively (Table 6).

Comparison of the CTDIvol and DLP DRLs for the head, chest and abdomen with other single facility, national, and international values

The CTDIvol and DLP median values from our study were compared with the median values of two single-site facilities (the Irish Neurological Centre of Excellence in Ireland and the Sokoto State Advanced Medical Diagnostic Centre in Nigeria), radiology organizations [the American College of Radiology (ACR), the American Association of Physicists in Medicine (AAPM), and the Society for Pediatric

Table 4. Multiple comparisons of CTDIvol and DLP between CT head, chest and abdomen without contrast

		Head (n = 361)	Chest (n = 187)	Abdomen (n = 254)	H [#]	P
CTDIvol (mGy)	Mean	34.60 ± 5.76	5.69 ± 2.62	7.35 ± 2.67	622.34	< 0.001*
	Median	30.60	4.90	6.70		
	Maximum	58.10	13.20	19.20		
	Minimum	15.00	2.00	3.00		
	1 st quartile	30.60	3.70	5.57		
	3 rd quartile	41.40	7.20	8.70		
DLP (mGy.cm)	Mean	773.64 ± 198.2	318.48 ± 337.3	363.7 ± 151.84	483.38	< 0.001*
	Median	699.30	227.10	331.25		
	Maximum	1625.50	1088.70	1094.10		
	Minimum	439.70	68.30	122.40		
	1 st quartile	622.70	146.10	262.80		
	3 rd quartile	892.60	448.40	443.12		
Weight (Kgs)		62.32 ± 10.92	58.19 ± 11.03	59.35 ± 11.8		-
	Maximum	90	90	90		-
	Minimum	40	40	40		-
KV		120	120	120		-
mA		302.91 ± 29.24	138.14 ± 57.20	148.40 ± 56.15		-
mAs		227.61 ± 36.37	86.64 ± 39.78	110.22 ± 38.0		-

[#]H: Kruskal-Wallis test. * p < 0.05 indicates statistical significance.

Table 5. Developed CT parameters for NeuViz multi-detector 16-slice Essence CT scanner based on BMI

Examinations	BMI (kg/m ²)	kVp	mA range	mAs range	Slice thickness
Head	< 18.5	120	167-270	203-300	5mm
	18.5 ≤ to < 24	120	270-320	200-381	5mm
	≥ 24	120	320-384	200-320	5mm
Chest	< 18.5	120	59-240	36-120	5mm
	18.5 ≤ to < 24	120	39-300	30-200	5mm
	≥ 24	120	58-355	38-200	5mm
Abdomen	< 18.5	120	66-313	35-202	5mm
	18.5 ≤ to < 24	120	33-320	46-200	5mm
	≥ 24	120	82-300	55-250	5mm

Radiology (SPR)], the European Society of Radiology, and other nations like Ethiopia, Australia, Japan, and the US.

For CT head, the CTDIvol median value was 31 mGy compared to 39 mGy in a study conducted at the Irish Neurological Centre of Excellence in Ireland, 48 mGy at the Sokoto State Advanced Medical Diagnostic Centre in Nigeria, 49 mGy in a study by ACR/AAPM/SPR, 48 mGy in a study by the European Society of Radiology, 43 mGy in Australia, 70 mGy in Japan, 47 mGy in the US, and 48 mGy in Ethiopia. Similarly, the DLP median value was 699 mGy.cm compared to 626 mGy.cm in a study conducted at the Irish Neurological Centre of Excellence in Ireland, 1057.48 mGy.cm at the Sokoto State Advanced Medical Diagnostic

Centre in Nigeria, 811 mGy.cm in a study by ACR/AAPM/SPR, 885 mGy.cm in a study by the European Society of Radiology, 770 mGy.cm in Australia, 1052 mGy.cm in Japan, 767 mGy in the US, and 1022 mGy.cm in Ethiopia.

For CT chest, the CTDIvol median value was 5 mGy compared to 9 mGy in a study done at Sokoto State Advanced Medical Diagnostic Centre in Nigeria, 9 mGy in a study by ACR/AAPM/SPR, 8 mGy in a study by the European Society of Radiology, 8 mGy in Australia, 10 mGy in Japan, 9 mGy in the US, 48 mGy in Ethiopia, and 8 mGy in Ethiopia. Similarly, the DLP median value was 227 mGy.cm compared to a study conducted at Sokoto State Advanced Medical Diagnostic Centre in Nigeria, 334 mGy.cm in a study by ACR/AAPM/SPR, 318 mGy.cm in a study by the European Society of Radiology, 372 mGy.cm and 300 mGy.cm in Australia, 409 mGy.cm in Japan, 334 mGy in the US, and 301 mGy.cm in Ethiopia.

For the CT abdomen, the CTDIvol median value was 7 mGy compared to 12 mGy in a study conducted at Sokoto State Advanced Medical Diagnostic Centre in Nigeria, 13 mGy in a study by ACR/AAPM/SPR, 9 mGy in a study by the European Society of Radiology, 10 mGy in Australia, 15 mGy in Japan, 13 mGy in the US, and 48 mGy in Ethiopia. Similarly, the DLP median value was 331 mGy.cm compared to a study conducted at Sokoto State Advanced Medical Diagnostic Centre in Nigeria, 639 mGy.cm in a study by ACR/AAPM/SPR, 1257 mGy.cm in a study by the European Society of Radiology, 480 mGy.cm in Australia, 667 mGy.cm in Japan, 639 mGy.cm in the US, and 546 mGy.cm in Ethiopia (Table 7).

Discussion

The developed DRL (CTDIvol and DLP) median values for CT head, chest, and abdomen from our study are lower compared to the values developed by Sokoto State Advanced Medical Diagnostic Centre in Nigeria, ACR/AAPM/SPR, European Society of Radiology, Ethiopia, Australia, Japan, and the US (Table 7). Possibly, this could be due to evaluation of CT examinations without contrast material only. Additionally, the use of standardized protocols and CT operation training by Chinese radiology experts who were present during the study period under a skills development exchange visit to MCH could be another reason for the lower DRL values. However, an exception is observed in the median CTDIvol value for the CT head without contrast developed by a Neurological Centre of Excellence in Ireland, which was lower compared to the value obtained from our study²².

In CT, like other radiation-producing modalities, radiation dose varies with patient size¹¹.

Table 6. Developed local (CTDIvol and DLP) DRL values for the head, chest and abdomen CT examinations without contrast material at MCH

Examination	CTDI _{vol} (mGy)		DLP (mGy.cm)	
	Median	3 rd quartile	Median	3 rd quartile
Head	31	41	699	893
Chest	5	7	227	448
Abdomen	7	9	331	443

The study found that CT head had the highest CTDI_{vol} and DLP mean values, followed by CT abdomen and CT chest, which had the lowest values with ($P < 0.001^*$) statistical significance. Similarly, CTDI_{vol} and DLP median values for CT head were the highest, followed by CT abdomen and chest with the lowest values. In the same vein, the third quartile CTDI_{vol} values were highest for CT head, followed by CT abdomen, with CT chest having the lowest.

Table 7. Comparison of the CTDIvol and DLP DRLs median values for the head, chest and abdomen with other single site facility, national and international

Country/organization	Head		Chest		Abdomen		References
	CTDI _{vol}	DLP	CTDI _{vol}	DLP	CTDI _{vol}	DLP	
This study	31	699	5	227	7	331	
Irish Neurological Centre of Excellence, 2023	39	626	-	-	-	-	22
Sokoto State Advanced Medical Diagnostic Center, Nigeria, 2024	48	1057	9	372	12	647	23
ACR/AAPM/SPR, 2023	49	811	9	334	13	639	24
European Society of Radiology, 2022	48	885	8	318	9	1257	25
Addis Ababa, Ethiopia, 2023	48	1022	8	301	10	546	4
Australian updated National DRLs, 2020	43	770	8	300	10	480	20
Japan, 2020	70	1052	10	409	15	667	26
US, 2017	47	767	9	334	13	639	27

Note: CTDI_{vol} is in mGy and DLP is in mGy.cm.

Our study results showed that for CT chest and abdomen, an increase in BMI had a corresponding increase in CT parameters (mA and mAs) and dose parameters (CTDI_{vol} and DLP). Surprisingly, for CT head, an increase in BMI did not consistently result in an increase in CT and dose parameters, and we did not manage to independently establish the reason behind this finding. On the other hand, helical pitch, tube voltage, and slice thickness did not show significant change with a rise in BMI in CT head, chest, and abdomen examinations, possibly because these were pre-selected by the operator while current is autogenerated by the machine²³. A separate study is recommended to relate demographic characteristics like age, gender, weight, and height to radiation dose on CT.

Our findings are in line with a study done by Inoue et al. which found a positive correlation between BMI and CTDI_{vol} and DLP²⁴. The data reported here supports the concept that an increase in BMI requires a large FOV of the anatomical region, which yields higher CTDI_{vol} and DLP values²⁵. Published studies show that CT parameters (kVp, mA, mAs, pitch factor, and slice thickness) have an influence on the patient's dose values (CTDI_{vol} and DLP)²⁶.

CT head, chest and abdomen examinations

In this study, in commonly done CT examinations like head, chest, and abdomen; CTDI_{vol} and DLP were assessed for their mean, median, and third quartile values to develop local DRLs.

Surprisingly, DLP third quartile values took a slightly different trend, with CT head recording the highest, followed by CT chest, and CT abdomen with the lowest values.

Our findings are similar to a study conducted in Ethiopia—Addis Ababa on the establishment of local DRLs for common adult CT examinations, where CT head also recorded the highest CTDI_{vol} and DLP mean and median values, followed by CT abdomen and CT chest with the lowest values⁴. Unlike in our study, where CTDI_{vol} third quartile values were highest on CT head, followed by CT abdomen, with CT chest recording the lowest, and DLP third quartile values recording highest for CT head, followed by CT chest, and lowest in CT abdomen, CTDI_{vol} and DLP third quartile values in the Ethiopian study recorded highest in CT head, followed by CT abdomen, with CT chest recording the lowest values. The reason for this finding cannot be explained at the moment because the expectation is that tissues with high density should have higher values compared to tissues with lower density.

In general, our study results are in line with previously conducted studies, which also recorded the highest CTDI_{vol} and DLP mean, median, and third quartile values from CT head, followed by CT abdominal, with CT chest recording the lowest values^{4,16}. The observation was that CTDI_{vol} and DLP values in our study and previously conducted studies are high in the CT head, followed by the CT abdomen, with the CT chest recording the lowest values, most likely due to tissue compositions, with the head having high-density

bone tissues, the abdomen with more medium-density soft tissue, and the chest with lung tissue full of low-density air, which explains the reasons behind the discrepancies in their dose values. Nevertheless, the CTDIvol and DLP mean, median, and third quartile values from our study were lower or comparable to those from single-facility, national, and international values, most likely because standardized protocols were used during the study^{4,26,27}.

Comparison of MCH 2024 adult local CTDIvol DRLs and DLP DRLs for the head, chest and abdomen with single facility, national, and international values

Just like in other countries and organizations, a range of key CT parameters were established before the development of the local DRLs, which was done by calculating the median of CTDIvol and DLP for each CT examination of the head, chest, and abdomen⁴. The developed adult local DRLs from this study were lower or comparable to adult DRLs from other single facilities and national values with minor variations^{4,11}.

For CT head, chest, and examinations, our CTDIvol DRL values were lower than single facility, national, and international values. The DLP DRL value from our study was higher for CT head than the value obtained in a study at the Neurological Centre of Excellence in Ireland²². However, DLP values for CT head, chest, and abdomen examinations from other national and international studies were higher than the values from our study^{4,26,27} (Table 7).

ICRP recommends that despite wide variations between CT systems, CT DRL values of 8 mGy (CTDIvol) and 750 mGy cm (DLP) have been proposed for whole-body CT¹¹. Our developed adult local DRLs are within ICRP-recommended value ranges. Some variations in our developed local DRLs are suggested to be due to the single CT center study used compared to other studies where multiple centers with different CT brands were used, which might have variable manufacturer-specific protocol development, CT operators' expertise, and selection of CT parameters for a specific examination. However, this study would serve as a baseline for the development of national adult CT DRLs for Malawi.

Conclusions

The local DRLs for the head, chest, and abdomen have been developed for a NeuViz 16 Essence 16-Slice CT Scanner System at MCH. The CTDIvol and DLP DRLs were either lower or comparable to other single-facility, national, and international values. Therefore, these DRLs should be adopted at our facility to optimize patient radiation protection by using optimized scanning parameters without compromising image quality. This study should serve as a baseline for the development of national adult CT DRLs for Malawi.

Strengths

The study used original patient data with technical, patient, and CT-related factors well considered throughout the survey according to ICRP recommendations. Authorship consists of cadres recommended by ICRP when developing DRLs.

Limitations

The retrospective nature of the study is among the limiting factors because DRL (CTDIvol and DLP) values were assessed in patient CT and dose parameters that were not performed for the purpose of setting DRL values. This has

potential for bias and missing values.

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