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Citation: Kafwimbi, S., Sichone, J. M., Munsanje, F., Sutherland, O., Bwanga, O., Ohene-Botwe, B. & Munsaka, S. M. (2025). Adult national diagnostic reference levels for common computed tomography examinations in Zambia: A preliminary study with findings from public hospitals. *Radiography*, 31(3), 102925. doi: 10.1016/j.radi.2025.102925

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Permanent repository link: <https://city-ref-test.eprints-hosting.org/id/eprint/35076/>

Link to published version: <https://doi.org/10.1016/j.radi.2025.102925>

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Adult national diagnostic reference levels for common computed tomography examinations in Zambia: a preliminary study with findings from public hospitals

Abstract

Introduction: While many European and American countries have established national diagnostic reference levels (NDRLs), few African countries have. Therefore, this study aimed to propose adult NDRLs for common computed tomography (CT) examinations in Zambia.

Methods: 1360 CT patient data for the brain, chest, abdomen and pelvis were collected from 10 public CT facilities. The CT images were assessed for acceptable image quality and patient anthropometry was done, with patients' anteroposterior diameter used as the patient parameter. NDRLs were set at the 75th percentile of the distribution of volume-based CT dose index (CTDI_{vol}) and dose length product (DLP) and were compared to countries' NDRLs.

Results: NDRLs for CTDI_{vol} in mGy were calculated as follows; non-contrast brain 70.5, contrast brain 56.74, non-contrast chest 20.24, contrast chest 20, non-contrast abdomen/pelvis, 21.3, contrast abdomen/pelvic 21.3, non-contrast chest/abdomen/pelvis 20 and contrast chest/abdomen/pelvis 19.1. The corresponding NDRLs for DLP in mGy.cm are 1455, 1206, 745.8, DLP 666.7, 1103, 1103, 1237 and 1141. Variations in DLP values between facilities were statistically significant ($p < 0.0001$). NDRLs for the brain and chest were higher than those from other countries but lower for the abdomen/pelvis and chest/abdomen/pelvis. Correlations between the CT scanner's number of detector rows and CTDI_{vol} were ($r = 0.08285$, $p < 0.0022$) and ($r = 0.5038$, $p < 0.0001$) between patients' AP diameter and CTDI_{vol}.

Conclusion: The proposed NDRLs confirmed the need to optimise CT scan parameters and protocols in Zambia. Therefore, extensive training of all CT radiographers in optimising CT image acquisition parameters and regular dose audits is recommended.

Implication of practice: NDRLs will likely provide a benchmarking mechanism for dose optimisation practices among CT radiographers in Zambia and beyond.

Keywords: Computed Tomography, Diagnostic Reference Level, Volume-weighted Computed Tomography Dose Index, Dose Length Product, Zambia.

Introduction

Computed tomography (CT) has earned a well-deserved role in diagnostic imaging. Its ability to produce cross-sectional and three-dimensional (3D) images which permit enhanced diagnosis, coupled with the speed, versatility, accuracy, and non-invasiveness have resulted in a rapid increase in its use.¹ The increase in the number of examinations has made CT one of the largest sources of medical exposure to radiation.^{1,2} This has raised concerns about possible cancer risks, particularly in children.³ Cohort studies of individuals who underwent medical imaging have suggested that radiation doses in the medical imaging range of 10-100 millisieverts (mSv) result in radiation-induced malignancy.⁴ While a high radiation dose to the patient may pose a significant lifetime risk of cancer, a low radiation dose can result in degraded CT images, potentially leading to misdiagnosis.⁵ This highlights the need for optimization of radiation exposure in CT imaging

In the USA, more than 74 million CT examinations were performed in 2017.⁶ Countries like Japan, the USA and Australia lead the world in the number of CT scanners per head, with 64, 26 and 18 scanners per million citizens respectively.⁷ There is a scarcity of information on the availability of both CT equipment and services in Africa in general. South Africa reported an availability rate of 5 scanners per million people. An audit of CT services revealed that Zambia had 23 CT scanners in both public and private healthcare facilities in 2021, serving a population of over 18 million people.⁹ Since this last audit, a few more CT scanners have been purchased and installed across the country.

The principles of justification, dose optimisation and dose limitation govern the protection of humans from the harmful effects of radiation in CT.¹⁰ The principle of dose optimisation is critical to radiation dose and image quality, implying that while the radiation dose is kept as low as possible, the image quality should not be compromised.¹¹ To avoid inhibiting the potential benefits of exposure, the International Commission on Radiological Protection (ICRP) introduced the concept of diagnostic reference levels (DRLs) in the 1990s as a dose optimisation tool.¹² By definition, the national diagnostic reference levels (NDRLs) correspond to the 75th percentile or the 3rd quartile of the observed dose distribution based on national surveys of typical radiation doses across various healthcare facilities¹³ These reference levels are not dose

limits but serve as guidance to ensure that radiation exposure is kept as low as reasonably achievable (ALARA) while maintaining adequate image quality for diagnosis.¹² For CT examinations, DRLs are defined in terms of two established dose quantities: volume-based computed tomography dose index (CTDI_{vol}) and dose length product (DLP). CTDI_{vol} represents the average radiation dose delivered to a volume of tissue during a CT scan and can be interpreted as the average dose per slice.¹⁴ In contrast, the Dose Length Product (DLP) reflects the total energy absorbed along the entire scan length and is calculated as the product of CTDI_{vol} and the scan length.¹⁴

When setting up a DRL, several principles must be considered. Key among them is the size of patients that should be included in the survey which plays a significant role in determining the amount of radiation required to achieve adequate image quality.¹⁵ With a reduced range in patient size, variation in the value of DRL quantities is substantially reduced. The choice is to use either patient weight or anthropological measurements as patient parameters in determining the size of patients, and CTDI_{vol} and DLP as dosimetric quantities.¹³ While most surveys have used the CTDI_{vol} and DLP as dosimetric quantities, variations have been observed as to which patient parameters are used in establishing NDRLs. A systematic review aimed at establishing commonly used approaches to establishing NDRLs for CT discovered that 70% of the studies reviewed used patient size, age and weight while 30% used clinical indication as patient parameters.¹⁶ Additionally, other studies have revealed that the AP diameter of the patient has shown a greater correlation with radiation dose than body weight and can be used in dose optimisation strategies and the establishment of DRLs.^{17, 13}

DRLs are accepted as the standard dose optimisation tool in CT intended to monitor radiation dose for specific procedures, set the bar for good clinical practice, identify outliers with unacceptably high radiation doses, allow comparison of equipment and protocols, and provide a mechanism for fine-tuning absorbed doses.¹⁸ It is generally accepted that each country requires NDRLs to guide the practice of radiography concerning dose optimisation as a prerequisite to sound radiation protection practice.¹⁹ Whereas there is widespread use of DRLs in European and American countries, very few African countries, including Zambia, have done so.²⁰ This study, therefore, seeks to establish NDRL for common CT examinations in a Zambian setting.

Methods

Study design

This study was a retrospective cross-sectional analytical survey that included public hospitals with CT scanners in Zambia. A two-stage approach was employed, which involved first identifying public hospitals with scanners and then assessing and selecting CT image files for inclusion in the study. Public hospitals were chosen for ease of access due to a centralised permission system through the Ministry of Health.

Population and sampling

In 2021, there were 13 CT scanners in public hospitals across the country at the start of this study⁹. All 13 were earmarked to be included in this study. However, it was impossible to retrieve patient image files in 3 of the hospitals, so all the remaining 10 hospitals were selected. The population of the study included CT image files for brain, chest, abdomen and pelvis CT scans that were done with and without contrast following standard protocols and without repeat scans. The CT images included in this study were assessed using a defined set of diagnostic image criteria, which refers to characteristic features of imaged anatomical structures that are defined in the region of examination and have a specific degree of visibility. For example, assessment of a brain CT scan requires that the whole cerebrum, cerebellum, teca cranii, osseous basis and vessels after contrast media injection are visualised while the entire thoracic wall, thoracic aorta and vena cava, heart, lung parenchyma and vessels after contrast media injection in the chest CT scan should be visualised.²¹ Due to the limited number of CT image files in these hospitals, all the images that met the diagnostic image criteria were included using a census approach. A total of 1360 CT doses and patient dimensions data were collected from electronic files of individual patients who underwent CT examinations of the brain, chest, abdomen, and pelvis.

Data collection tool and pilot study

A data collection tool was developed based on the technical and patient details that needed to be captured to establish DRL based on the literature.¹⁵ The data collection tool was designed to collect data on CT equipment specifications, technical and patient parameters.¹³ The developed

tool was piloted on 10 patient CT files to establish if it could work and adjustments were made accordingly.

Data collection

Data was collected from CT image files in digital imaging and communication in medicine (DICOM) format and were analysed for diagnostic image quality using a defined set of diagnostic image criteria. Those that met the quality criteria were retrieved from each of the 10 CT scanners and were stored and secured on an external hard drive. In a systematic review aimed at establishing commonly used approaches to establishing NDRLs for CT, we discovered that 95% of the studies used CTDI_{vol} and DLP as dose quantities while 70% used patient size, age and weight and 30% used clinical indication as patient parameters.¹⁶ Based on these findings, the CT dose quantities, CTDI_{vol} and DLP were used in this study and were recorded from the CT scan image files. The AP diameter of the patient was measured at the widest point in the volume of the scan as a patient parameter indicating the size of the patient for each CT image using electronic calipers present on the scanner. This is because previous studies have acknowledged that patient dimensions (AP diameter) have shown the strongest correlation with CTDI_{vol} and DLP in abdominal and chest CT examinations.^{15, 17}

Technical specifications of the individual CT scanners were obtained which included the brand name and model of the unit, number of detector rows and the year of installation. All the data were entered into a Microsoft Excel spreadsheet in readiness for analysis. The ICRP recommends that to establish DRLs, the number of patient dose data to be included per anatomical region should be at least 20-30 if paper-based data collection is used, but this should not be a concern if the collection process is automated.¹³ In most hospitals, more than 20 CT dose and patient parameter data were collected per anatomical region used in this study.

Data analysis plan

CT dose and technical parameter data as well as patient anthropological measurements were exported onto Stata version 18 and GraphPad Prism version 8 for analysis. Data for both dose indices and patient anthropological measurements were tested for normality using the Shapiro-Wilk normality test and were found not to be normally distributed. Baseline characteristics were summarised as means for numerical variables that were normally distributed and median with interquartile range for numerical variables not normally distributed. To establish the NDRLs

three variables namely, CTDI_{vol}, DLP and patients' AP diameter, as an indicator of patient size, were considered. The median values for CTDI_{vol} and DLP were established and the NDRLs were then set as the 75th percentile of the median values of the dose quantities (CTDI_{vol}, and DLP) per anatomical region as prescribed by the ICRP.²² Spearman's correlations were done to examine any associations between dose indices, patient anthropological measurements and equipment configurations. To examine variations in the distribution of radiation doses among the participating hospitals, a Kruskal Wallis test and a one-way ANOVA test were done. The established NDRLs were compared with those from Egypt, Uganda, South Korea and Australia as a benchmarking mechanism.

Validity and reliability

To ensure the validity and reliability of findings, CT dose indices were collected from CT image files mostly done on days when there was documented evidence of radiographers having carried out daily, weekly and monthly dose calibrations. This was because quality control data and/or records were scanty in most public CT facilities. Additionally, it was also ensured that all the scanners had authorization as well as annual enforcement and compliance certificates from the regulator. Before data collection, the data collection tool was piloted and adjustments were made accordingly. The collected data was verified and checked to remove all entries that had outliers.

Ethical considerations

Ethical approval to conduct this study was obtained at 3 levels, the University of Zambia Biomedical Research Committee (UNZABREC Ref: 3022-2022), the Zambia National Health Research Authority (NHRA0000012/12/09/2022) and the individual hospital sites as per the requirement to conduct health-related research in Zambia. Confidentiality about medical information that was collected was achieved by the use of password-protected personal computers to restrict access to data. In conducting this research, the researchers also adhered to the Data Protection Act of Zambia (2021) and guidelines issued by the National Health Research Authority of Zambia.^{23, 24}

Results

This study aimed to propose adult national diagnostic reference levels for common computed tomography examinations in Zambia. A total of 1360 CT dose and patient dimensions data from individual patients who underwent computed tomography examinations of the brain, chest, abdomen and pelvis were collected from 10 public CT facilities in Zambia as shown in table 1.

Characteristics of CT examinations and equipment

Data for this study was collected from the ten public hospitals with CT scanners across the country. Table 1 provides details about CT images and anatomical regions, the scanners, their specifications, models, and brand names used in the study.

Table 1: The table below shows the characteristics of CT images and equipment in the public hospitals included in this study.

HOSPITAL AND EQUIPMENT DETAILS					REGIONS AND NUMBER OF EXAMINATIONS							
Hospitals	Brand of Machine	No. of Detector rows	Model	Year of installation	Non-Contrast Brain	Contrast Brain	Non-contrast Chest	Contrast Chest	Non-contrast Abd/pelvis	Contrast Abd/pelvis	Non-contrast Chest/Abd/pelvis	Contrast Chest/Abd/pelvis
1	Toshiba	128	Acquilion CXL	2017	71	12	13	8	12	10	10	11
2	Siemens	24	Somatom	2008	58	21	14	10	12	17	16	13
3	Nuesoft	128	NeuViz 128	2011	24	10	11	3	10	11	15	10
4	Philips	64	Brilliance	2011	48	16	13	10	25	20	13	11
5	Nuesoft	64	NeuViz 64	2014	66	20	10	9	20	20	11	11
6	GE	16	Revolution Act	2023	31	21	11	10	23	20	12	18
7	Nuesoft	16	NeuViz 16	2016	64	12	10	10	10	10	20	14
8	Nuesoft	16	NeuViz 16	2016	14	11	10	10	14	12	10	11
9	Nuesoft	16	NeuViz 16	2017	46	15	11	2	12	11	12	11
10	Siemens	32	Somatom	2020	17	15	18	6	29	19	12	11
TOTALS					439	153	121	78	167	150	131	121

Patient parameters used

The AP diameters for the anatomical regions chosen were the patient parameters used in establishing these NDRLs. The range of the AP diameters per region is shown in Figure 1.

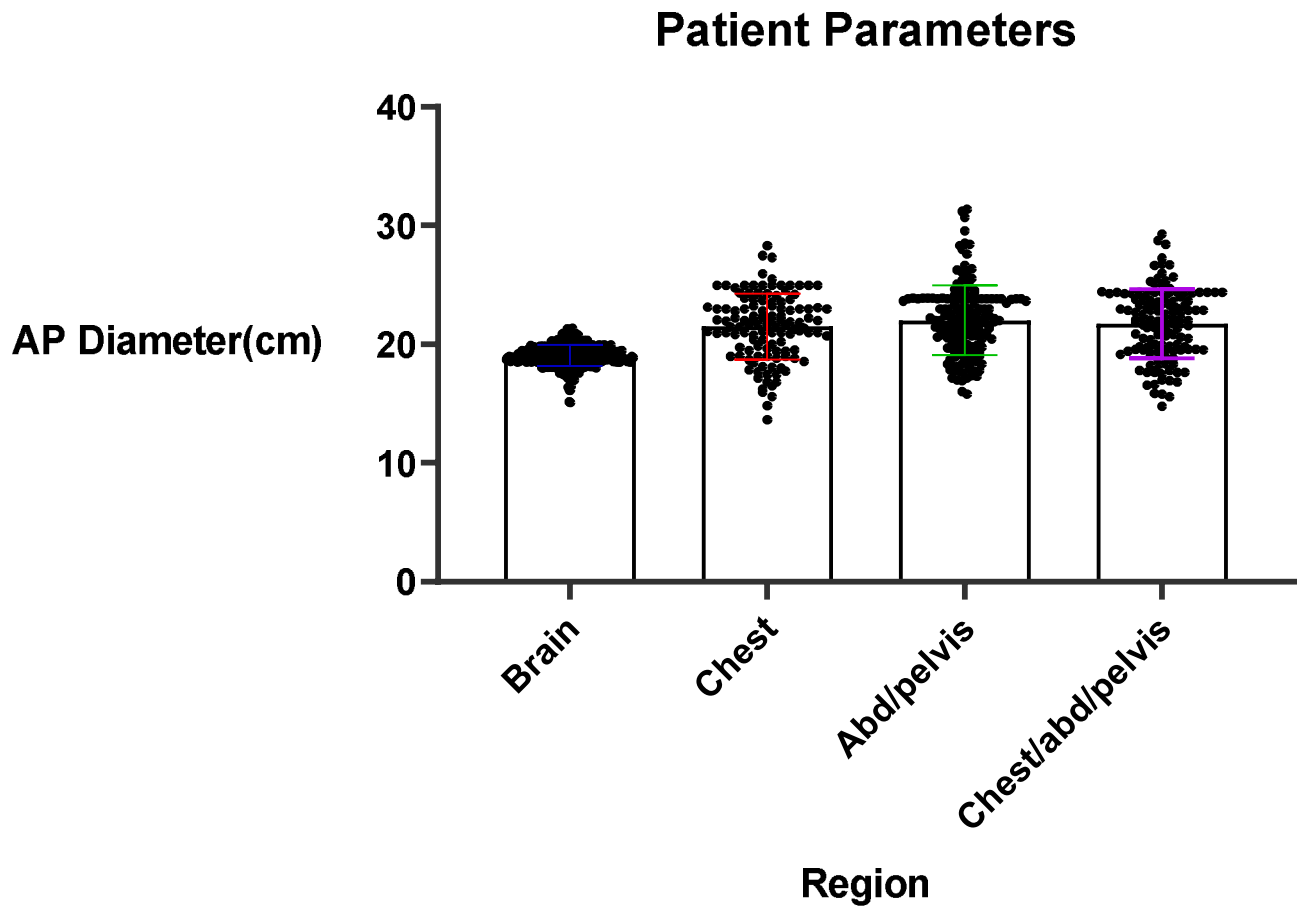


Figure 1: Median scores of the patient AP diameters at a 95% confidence interval.

NDRL values for common CT examinations in Zambia

The NDRLs proposed for Zambia were estimated at the 75th percentile of the median scores of the distribution of CTDI_{vol} and DLP quantities as shown in Table 2.

Table 2: Shows the proposed NDRL values for common CT examinations in Zambia.

NATIONAL DIAGNOSTIC REFERENCE LEVEL VALUES								
ANATOMICAL REGION	CTDI _{vol} mGy Per Sequence				DLP mGy.cm Per Examination			
	25%	50%	Median	75%	25%	50%	Median	75%
Non-contrast brain	43	49	55.5	70.5	838	1129	1163	1455
Contrast Brain	37.5	46	49.1	56.7	785.6	1022	1037	1206
Non contrast Chest	10.5	13.3	17	20.2	376	469.6	595.3	745.8
Contrast Chest	10.5	12	16	20	376	432.7	539.7	666.7
Non-contrast Abdomen/Pelvis	12.4	14	19.5	21	604.8	756.7	896.6	1103
Contrast Abdomen/Pelvis	12.4	14	19.6	21	604.8	756.7	918.1	1103
Non-contrast Chest/Abd/Pelvis	10.5	13.4	15.6	20	621.5	969.8	972.6	1237
Contrast Chest/Abd/Pelvis	11.1	13.4	15.4	19	647.3	921.6	929.6	1141

CTDI_{vol}: Volume-based computed tomography dose index: mGy: milligray: mGy.cm: milligray per centimetre

Associations between dose and anthropo-technical parameters

Spearman correlations were done to establish associations between dose, equipment specifications and patients' anthropological measurements. As indicated in Table 2, there was a statistically significant association among CT dose indices, technical parameters and patient parameters.

Table 3: Spearman's correlation coefficients of the association between dose and anthropo-technical parameters.

	Dose Indices		Technical Parameters				Patient Parameters	
	CTDI _{vol}		kV		No. of Detector Rows		Patient AP Diameter	
CTDI _{vol}	r	<i>p-value</i>	r	<i>p-value</i>	r	<i>p-value</i>	r	<i>p-value</i>
	1.000		0.1734	<0.0001 ****	0.08285	0.0022 **	-0.5038	<0.0001 ****
DLP	0.6727	<0.0001 ****	0.3146	<0.0001 ****	0.1178	<0.0001 ****	-0.2200	<0.0001 ****

CTDI_{vol}: volume-based computed tomography dose index, kV: kilovoltage, AP: Antero-posterior

Variations in DLP values across hospitals

One-way ANOVA tests were done to establish differences in DLP values between the hospitals per anatomical region included in this study. Figure 2 below shows the differences in DLP values across the hospitals.

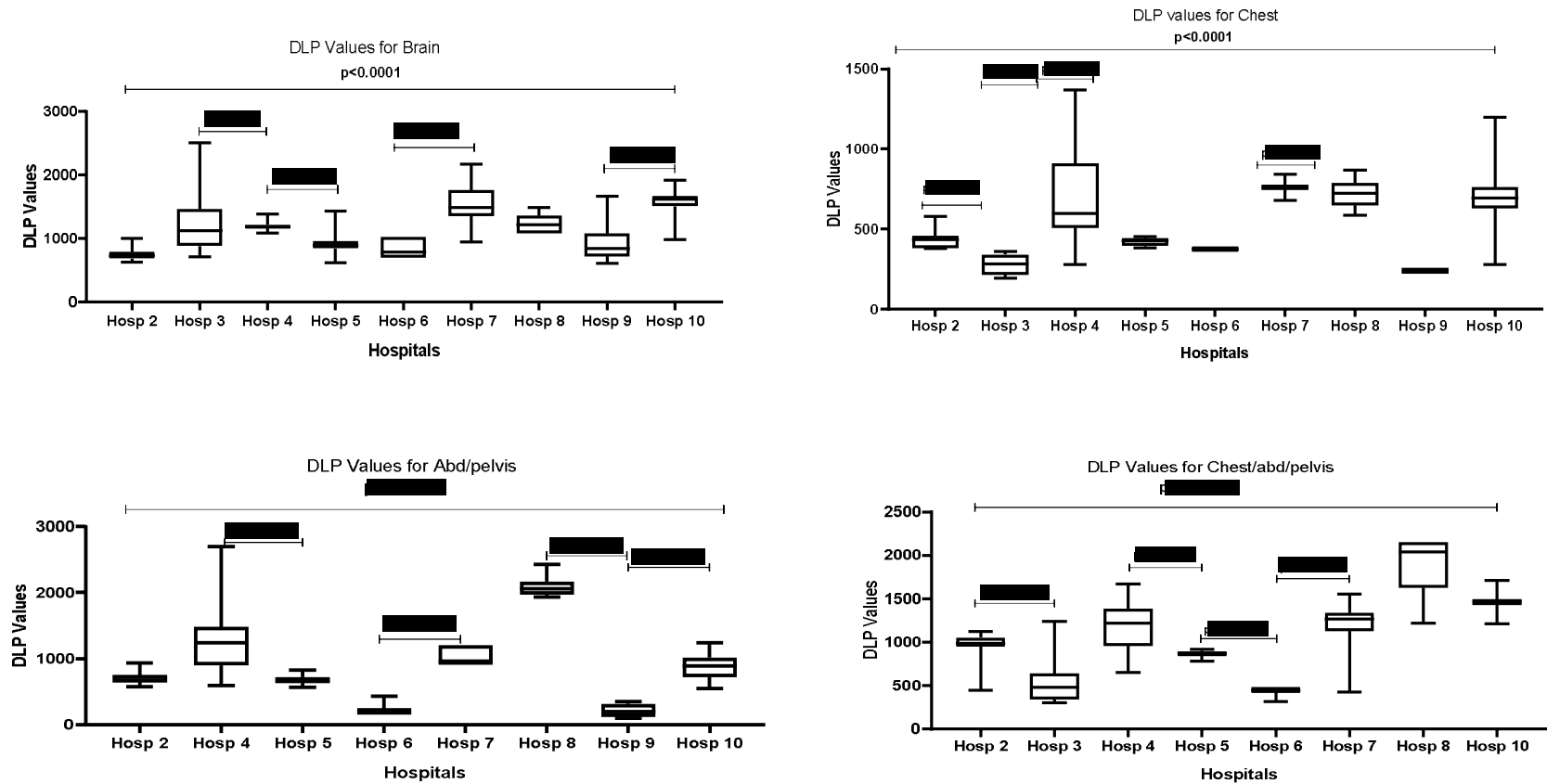


Figure 2: Shows variations in DLP values between hospitals for CT examinations

Comparison of Zambian NDRLs to those of other countries

Following the establishment of NDRLs for Zambia (Table 3), NDRL values established in other countries for some CT examinations were compared as a benchmark (Table 4).

Table 4: Comparison between the NDRLs established for common CT examinations in Zambia and those established for Egypt, Uganda, South Korea, and Australia.

COMPARISON OF ZAMBIAN NDRLs TO OTHER COUNTRIES'										
ANATOMICAL REGION	ZAMBIA(2024)		EGYPT(2017) [20]		UGANDA(2022) [26]		SOUTH KOREA(2019) [27]		AUSTRALIA(2013) [28]	
	CTDI _{vol}	DLP	CTDI _{vol}	DLP	CTDI _{vol}	DLP	CTDI _{vol}	DLP	CTDI _{vol}	DLP
Brain	70.5	1455	30.4	1358.6	56	1260	63.7	1119.4	60	1,000
Contrast Brain	56.7	1206								
Chest	20.2	745.8	22.3	420.8	7.8	377			15	450
Contrast Chest	20	666.7					7.3	297	15	700
Abdomen/Pelvis	21.3	1103	31	1323	12.5	1418.2	9.2	460.9		
Contrast Abdomen/Pelvis	21.3	1103					9.7	471.6		
Chest/Abd/Pelvis	20	1237	32.8	1322					30	1200
Contrast Chest/Abd/Pelvis	19.1	1141								

Discussion

This study aimed to establish national diagnostic reference levels for common CT examinations in Zambia. Data on CT dose and patient dimensions were collected from 1,360 individual patients across ten public CT facilities. These patients had undergone CT examinations of the brain, chest, abdomen, and pelvis. The study established NDRLs at the 75th percentile of the median values of local DRLs using the CTDI_{vol} and DLP as dose quantities and the patients' AP diameter as the patient parameter. This approach complied with the principles prescribed by the ICRP for setting DRLs.^{13, 17} The proposed NDRL values especially for brain and chest are higher when compared to those already established in Egypt, Uganda, South Korea and Australia. However, for abdomen/pelvis and chest/abdomen/pelvis CT examinations, our NDRL values are lower than those for Egypt²⁰. Where CTDI_{vol} values are lower or comparable, our DLP values are still higher than those already established. Significant variations were observed in the DLP values for all CT examinations across facilities, with a p-value of <0.0001. These variations can be attributed to several factors, including differences in the technical specifications of CT scanners and the choice of technical parameters by CT radiographers. A recent publication revealed that several facilities with 64 or more detector row CT have consistently higher doses compared to those with lower detector row configurations²⁰, and recommended additional investigations in calibration and protocol setting, collaboration in dose optimisation activities between radiographers, radiologists, medical physicists and manufacturers in addressing these variations.

A comparison of the proposed Zambian NDRL values to those established in other countries, especially for the brain and the chest, revealed that our NDRL values for the brain were higher than those for Egypt, Uganda, South Korea and Australia as shown in table 4. For the chest, our NDRLs are higher than those for Uganda and Egypt. We could not determine if these differences in NDRL values between the countries were statistically significant or not because statistical tests that compare two or more populations, such as the Mann-Whitney U test compare means²⁵, as opposed to the median and IQR scores which are used in setting up DRLs.

Conversely, some of our NDRL values are lower when compared to other countries for abdomen/pelvis and chest/abdomen/pelvis CT examinations. In some examinations, our CTDI_{vol} values were lower or comparable to Egypt and Australia, but our DLP values are still higher.

This could be attributed to the choice of scan parameters when carrying out CT examinations. Studies have acknowledged this consistent problem because in most studies DRLs for DLP do not correspond with DRL for $CTDI_{vol}$.^{20,22} These studies propose that improvements can be made in the selection of scan parameters for different examinations while taking into consideration the quality of the CT images with particular attention to facilities with consistently higher doses compared to DRLs.

This study used the patients' AP diameter as a patient parameter in determining the size of patients. For the anatomical regions used in this study, the AP diameters were within a narrow range with their median score calculated at a 95% confidence interval (Figure 1). There is evidence that with a reduced range in patient size, variation in the value of DRL quantities is substantially reduced.¹⁵ However, in this study, variations in DLP DRL values between facilities were observed and found to be statistically significant ($p < 0.0001$) despite having similar-sized patients as per AP diameter measurements as shown in Figure 2. Another study has indicated that AP diameter had a better correlation with $CTDI_{vol}$ and DLP than other patient parameters such as weight and transverse diameter which had no contribution to changes in $CTDI_{vol}$ and DLP.¹⁷ This study, however, has shown that an increase in AP diameter resulted in a moderate but statistically significant decrease in $CTDI_{vol}$ ($r -0.5038$, $p < 0.0001$) and DLP ($r -0.2200$, $p < 0.0001$). An increase in kV resulted in a moderate but statistically significant increase in $CTDI_{vol}$ ($r 0.1734$, $p < 0.0001$) and DLP ($r 0.3146$, $p < 0.0001$). This is in line with studies that observed that there was a linear relationship between scan acquisition parameters like kV and $CTDI_{vol}$ and DLP in CT.

Limitations of the study

This study's limitations centred mainly on its retrospective nature. In some hospitals, it was difficult to retrieve patients' CT data files, while in others, QA/QC data was scanty.

Conclusion and recommendations

The national diagnostic reference levels for common CT examinations in Zambia have been proposed as baseline dosimetric data by this study. The proposed NDRL values especially for the brain and chest are higher when compared to those already established in Egypt, Uganda, South Korea and Australia. However, for abdomen/pelvis and chest/abdomen/pelvis CT examinations, the NDRL values are lower than those for Egypt. Where CTDI_{vol} values are lower or comparable, the DLP values in this work are still higher than those already established. These findings confirm the need to optimise CT scan parameters and protocols in Zambia. To achieve this, extensive training of all CT radiographers in optimising CT image acquisition parameters, regular dose audits, **development of local DRLs** and continuous surveys to update these NDRLs is recommended. **The review of radiography curricular, continuous professional development programmes and strict enforcement of radiation protection regulations will be key in this regard.** The Ministry of Health (MOH) and the Radiation Protection Authority of Zambia can spearhead this radiation protection measure.

Conflict of interest

There is nothing to declare.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

See attached acknowledgement.

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