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Diagnostic reference levels for specific clinical indications of computed tomography scans

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Abstract – Diagnostic reference levels (DRLs) are relevant tools for radiation dose optimization. This study performed a regional survey to evaluate dose values based on specific clinical indications (CIs) for adult Computed Tomography (CT) examinations in Northwestern Nigeria. Ten groups of CIs for diagnostic CT in adult patients were considered based on frequency. Data was collected for CT examinations covering the head, chest, and abdomenopelvic regions performed between 2019 and 2020, per center and CIs. Distributions of Volume CT Dose Index ($CTDI_{vol}$) and examination Dose-Length Product (DLP) were assessed for each CI and gender. 993 single acquisition examinations were analyzed. Median $CTDI_{vol}$ values were closely gabbed in both genders for all examinations whereas median DLP values were higher for male compared to female patients for head and chest examinations, however, higher in female for abdominopelvic examinations. Median DLP difference in head CIs range from 0.7% in head trauma (1277 vs 1267 mG.cm) to 14% in dementia (1188 vs 1022 mG.cm), 17% in lung tumor (352 vs 292 mG.cm) to 20% in chest lesion with CKD (314 vs 251 mG.cm), and 8.4% in kidney stone (424 vs 463 mG.cm) to 18% in urothelial malignancy (423 vs 517 mG.cm) in abdominopelvic examinations. Analysis revealed no significant difference in median dose values among both genders, male and female for all CIs, $F(2, 27) = 3.354$, $p = .997$ for $CTDI_{vol}$ and $F(2, 27) = 3.354$, $p = .998$ for DLP. This study provides clinical indication-based dose reference values useful for optimizing clinical CT examinations.

Keywords: Computed tomography / radiation dose / dosimetry / optimization

1 Introduction

Computed Tomography (CT) technology evolved rapidly in the past few decades, enabling enormous diagnostic imaging possibilities, faster and more accurate diagnosis than conventional plain radiography (Hsieh and Flohr, 2021; Jin *et al.*, 2021). Multi-slice CT revolutionized CT allowing increased scan coverage and ability to perform whole-body scans in milliseconds. Besides, automatic modulation of radiation exposure to compensate for attenuation (AEC), dual-energy capability that allows investigation of materials with different attenuation characteristics at different energies, and improved detector and algorithm technology enhanced CT image quality and expanded its diagnostic potential (Lell and Kachelrieß, 2023).

However, radiation protection experts are concerned about radiation dose (cumulative and collective) and patient safety with its growing usage (Karavas *et al.*, 2022). Radiation-induced cancer is a health risk associated with medical CT exposures (Bernier *et al.*, 2019; Bahadori *et al.*, 2015). Therefore, dose optimization and adequate patient radiation protection measures became even more relevant (Inoue, 2023).

Diagnostic reference levels (DRLs) are essential and reliable tools for radiation dose optimization (Damilakis and Vassileva, 2021). As per the International Commission on

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Table 1. Description of clinical practice showing CIs, included number of scanners (scanner type and characteristics)/examinations/acquisitions, and contrast media use (for single acquisition).

Body region	Clinical indications (CIs)	N sc	N single acqs	%	N seq	Contrast usage	N exam per scanner (%)			
							a	b	c	d
Head	Head Trauma	4	319	34.0	1-2	yes	70(22.0)	65(20.3)	63(19.7)	121(38)
	Stroke/CVA	4	201	22.6	1-2	yes	63(31.3)	27(13.4)	30(15.0)	81(40.3)
	Brain Tumor	4	133	6.9	1-2	Yes	79(59.3)	11(8.2)	10(7.5)	33(25.0)
	Dementia	2	75	8.0	1	No	36(48.0)	–	–	39(52.0)
Chest	Chest lesion with CKD	3	26	2.8	1	No	5(19.2)	10(38.5)	11(42.3)	–
	Pulmonary embolism	3	21	2.2	2	Yes	8(38.1)	9(42.9)	4(19.0)	–
	Lung Tumor	3	37	3.9	2	Yes	13(35.1)	15(40.5)	9(24.3)	–
Abdomen	Abdominopelvic lesion	3	71	7.6	2	Yes	23(32.4)	24(33.8)	24(33.8)	–
	Kidney stones	3	46	5.1	1	No	16(34.8)	14(30.4)	16(34.8)	–
	Urothelial malignancy	3	64	6.8	1-3	Yes	27(42.2)	20(31.2)	17(26.6)	–

N; number, exam; examination, Acq; acquisition, A; BrightSpeed 4 Slice CT (ASIR), b; BrightSpeed 16 Slice CT (ASIR), c; Philips Brillance 16 Slice CT (IR), Toshiba Alexion 32 Slice CT (IR).

Radiological Protection (ICRP) definition and recommendation of DRL, they are defined or applicable for local, regional, national, and international levels of practice (ICRP, 2017). However, lately, the Eurosafe Imaging and ICRP Report 135 recommend and advocate creating DRLs for specific medical imaging procedures, *i.e.*, DRLs defined for a specific clinical indication (CIs) (ICRP, 2017; Damilakis *et al.*, 2023). Previously, a single CT protocol is set for examination of several CIs and clinical conditions affecting the same body region. However, modifications of technique for optimal image acquisition may vary with CIs. For instance, chest COPD, a CI of chest examinations requires lower image quality requirement; lower dose indices due to natural inherent contrast of the lung parenchyma compared to other CIs of the chest requiring higher image quality; higher dose indices. States, regions and local practices are highly encouraged to develop DRLs for radiological practices. In Nigeria, majority of available CT DRLs are based on surveys of local and regional estimates for various anatomical body regions (Abdulkadir *et al.*, 2021).

In line with increasing global trend of CT usage (Power *et al.*, 2016), previous CT practice surveys in Nigeria showed a consistent increase in CT scanners and examinations; the number of CT scanners rose to about 209 in 2022 (Adejoh *et al.*, 2022). Consequently, the average yearly collective dosage from CT is therefore predicted to rise significantly, which highlights the necessity to promote the use of dose optimization concepts in this population through DRLs. Consequently, the primary objective of this study was to survey, evaluate and estimate DRLs on a regional basis for specific CIs of CT examinations.

2 Materials and methods

2.1 Study design and setting

This study involved a multi-center retrospective survey conducted on patients aged ≥ 18 yr who underwent CT examinations in tertiary hospitals and referral healthcare centers housing radiology departments with functional CT scanners located in Northwestern region of Nigeria between 2020 and 2022. The multi-slice CT scanners were installed between 2010 and 2014.

According to previous surveys in decreasing order of frequency, CT scans of the head, abdominopelvic and chest regions were the most frequently performed adult diagnostic CT examinations in Nigeria (Kabeer *et al.*, 2024; Adejoh *et al.*, 2022; Abdulkadir *et al.*, 2021). However, a list of clinical indications for these anatomical regions has not been defined yet. Consequently, examinations of a particular CI of up to or exceeding 20 within the study period were considered while CI of less than 20 examinations were excluded. This is in keeping with the ICRP guideline for setting DRLs. Eventually, ten CIs covering the head, chest, and abdominopelvic regions were considered (Tab. 1).

Data were retrospectively collected manually *via* the institution's radiological information systems or their medical records/archives. For each scanner, at least 10 examinations per CIs was targeted for collection. Data were recorded in preformatted Excel sheets. Patients identifying details were anonymized in line with the confidentiality principle. Therefore, informed consent of the patients was not required. Complete examination data was collected from patients' CT dose reports. Data collected includes patient demographic information; age, gender, clinical indications (CIs), CT scanner characteristics; image reconstruction algorithm type *i.e.*, filtered back projection (FBP) or iterative reconstruction (IR), scan acquisition parameters; (tube voltage (kV), tube current (mAs), scan time, scan length, scan phase, automatic exposure control (AEC) usage, and field of view (FOV), contrast media usage and dose indices data; (volume weighted CT dose index ($CTDI_{vol}$) in mGy, dose length product (DLP) in mGy.cm

For the CIs of the head scans, the $CTDI_{vol}$ (mGy) and DLP (mGy.cm) values are given for the 16 cm diameter and 32cm diameter reference phantoms for the CIs of the body regions. We assumed that $CTDI_{vol}$ values agreed with the CT quality criteria (within ± 20% deviation) checked annually and after tube replacement. The DRLs study aims to optimize dose by ensuring image quality, therefore, only CT scan examinations accepted and reported by radiologists were included in this study. Single acquisition parameters for CIs were compared in relation to body region.

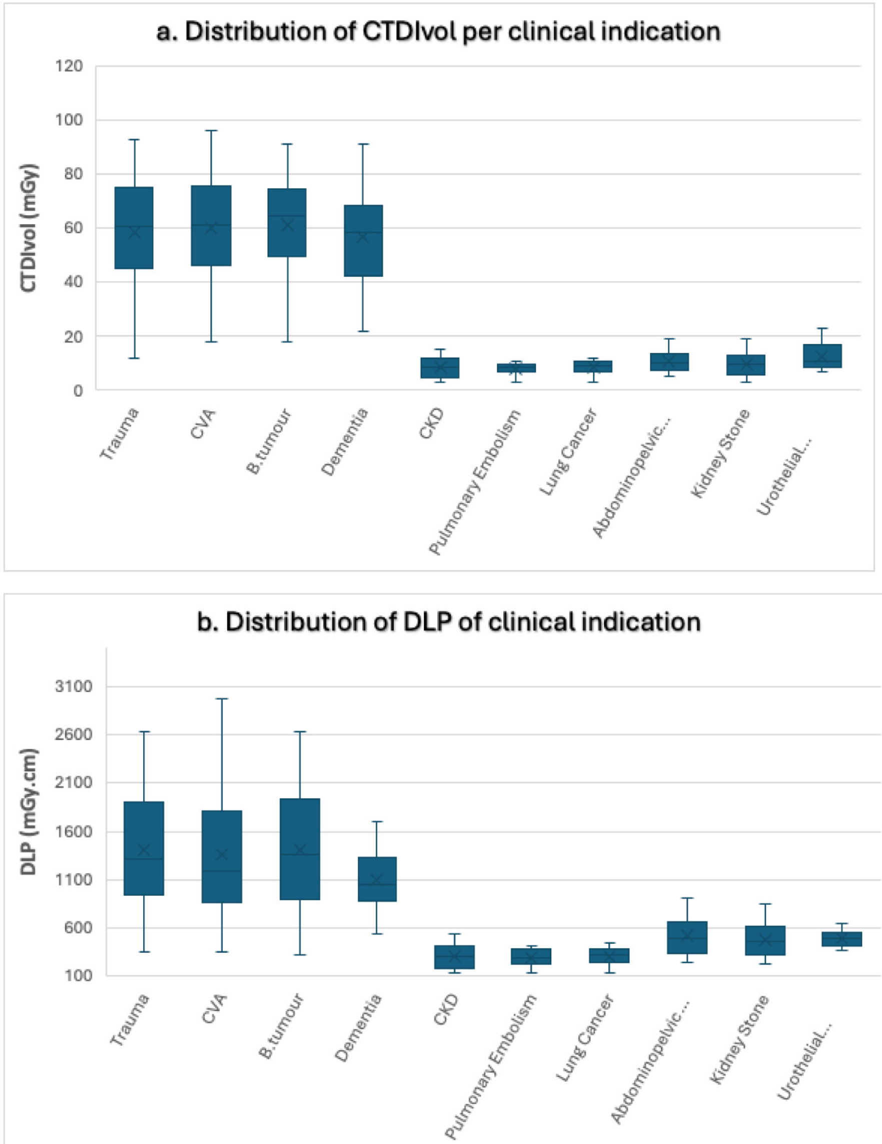

Fig. 1. Box plot graphs showing the distributions and comparison of dose $CTDI_{vol}$ (a) and DLP (b) according to clinical indication. The median, maximum value, minimum value, and interquartile range are shown. The cross shows the mean value.

2.2 Statistical analysis

Data was analyzed using Statistical Package for Social Sciences (SPSS) software version 23 (SPSS Inc., Chicago, IL, USA), with descriptive statistics used to show proportions and spread. Regional DRLs were defined using the ICRP 135 suggestion, with medians estimated for each center and 75th percentiles for every CI (ICRP, 2017). Furthermore, the DRLs values were again estimated based on the distribution of pooled data for all centers. Data of reference dose indices were found to be normally distributed, hence differences between median values were evaluated using a parametric test (One way ANOVA) with the significant level set at 0.05. One way ANOVA was conducted to examine the difference in median dose values among gender (all gender, male, female) and difference in dose values among CIs of same body region.

3 Result

We reviewed 993 single acquisition examinations collected from four centers, one scanner per center. This included 73.4% head, 8.4% chest and 18.2% abdominopelvic CT examinations. The examinations were of adult patients aged between 18 and 98 yr. Table 1 shows the distribution of examinations collected by CT scanners. The CT scanners manufacturers included General Electric Healthcare (2), Philips (1) and Toshiba Medicals (1). The distribution of the 10 CIs, number of scanners per CI is also presented in Table 1. Of the ten CIs reviewed, the highest percentage (34.0%) were head trauma scans, while the lowest (2.2%) were PE scans (Tab. 1). Figure 1 shows the distribution of $CTDI_{vol}$ and DLP for all evaluated CIs.

Acquisition characteristics are quite similar for each of the three body regions examined. Iterative reconstruction (IR) algorithm and automatic exposure control (AEC) were used in

Table 2. Distribution of reference dose and Acquisition parameters for single acquisitions examinations of all CIs based on the distribution of pooled data for all centers/scanners.

Clinical indication	Mean Pt Age (years)	Dose index percentiles 50th (25th – 75th)		Acquisition parameters (mean/sd)				
		$CTDI_{vol}$(mGy)	DLP (mGy.cm)	kVp	mAs	P (mm)	ST (mm)	SL
Trauma/RTA	39 ± 18	61(56-69)	1273(1133-1657)	126 ± 10	252 ± 114	1.4 ± 0.2	3.8 ± 1.3	23
Stroke/CVA	52 ± 19	61(56-69)	1166(1023-1426)	123 ± 7	316 ± 138	1.5 ± 0.1	2.4 ± 1.2	20
Brain tumor	44 ± 18	66(60-69)	1326(1098-1690)	125 ± 10	254 ± 118	1.5 ± 0.2	2.4 ± 1.7	23
Dementia	70 ± 11	61(50-61)	1023(995-1201)	121 ± 5	336 ± 83	1.5 ± 0.0	2.3 ± 0.6	20
Chest lesion with CKD	51 ± 18	8(5-11)	313(193-375)	115 ± 9	144 ± 105	1.3 ± 0.3	3.6 ± 1.8	39
Pulmonary embolism	45 ± 16	9(8-9)	289(261-366)	120 ± 9	172 ± 65	1.4 ± 0.2	3.8 ± 1.7	37
Lung tumor	52 ± 19	9(8-10)	311(281-359)	118 ± 10	170 ± 83	1.5 ± 0.0	3.8 ± 1.6	40
Abdominopelvic lesion	50 ± 18	10(8-12)	491(369-580)	120 ± 7	155 ± 82	1.4 ± 0.2	3.6 ± 1.8	49
Kidney stones	49 ± 17	9(7-11)	453(349-542)	120 ± 10	163 ± 105	1.1 ± 0.4	3.1 ± 1.8	50
Urothelial malignancy	33 ± 11	10(9-14)	494(423-517)	123 ± 8	156 ± 76	1.3 ± 0.4	4.3 ± 1.6	47

Clinical indication; CI, Number; N, examination; exams Tube voltage; kVp, Tube loading; mAs, Pitch; P, Slice thickness; ST, Scan length; SL.

all the examinations. For the CIs of the head region, dominant mean kV used ranged from 121-126 kV, 115-120 kV for CIs of the chest and 120-123 kV for abdominopelvic region CIs. The results of the one-way ANOVA revealed no significant difference in dose values ($CTDI_{vol}$ and DLP) among CIs of same body region, F (3, 24) = 3.008, p =.994, n2= 0.0032; $CTDI_{vol}$ and F (3, 24) = 3.008, p =.859, n2 = 0.030; DLP. And therefore, there was no need to perform a post hoc test since the ANOVA was not significant. The difference between dose estimate based on the distribution of median values per center/scanner and the distribution of pooled data for all centers/scanners (Tab. 2) was below 10% and 20% for $CTDI_{vol}$ and DLP respectively.

There was minimal unevenness in the distribution of examination between the genders (56% males and 44% female). The median $CTDI_{vol}$ value between genders were similar across CIs whereas median DLP values were higher in male patients for head and chest CIs, however, higher in women for abdominopelvic CIs. Median DLP difference in head CIs range from 0.7% in head trauma to 14% in dementia, 17% in lung tumor to 20% in chest lesion with CKD, and 8.4% in kidney stone to 18% in urothelial malignancy. Analysis revealed no significant difference in median dose values among both genders, male and female for all CIs, F(2, 27) = 3.354, p =.997 for $CTDI_{vol}$ and F(2, 27) = 3.354, p =.998 for DLP.

4 Discussion

In this study, $CTDI_{vol}$ and DLP regional distributions were assessed on 10 CIs of head, chest and abdomen in adult patients. Slight variations in dose across centers observed are common findings in DRLs studies usually linked to differences in scanner manufacturer, model, software, tube current modulation (TCM), and scan acquisition characteristics (Paulo *et al.*, 2020; Foley *et al.*, 2012; Smith-Bindman *et al.*, 2019). For all body region, $CTDI_{vol}$ values were generally closely gabbed for both genders across CIs. In examinations of the head, DLP values were higher in men compared to women patients for the same type of CI examination (Tab. 2). This is probably because men's heads are bigger and denser than women's, particularly since most of the scans used automatically modulated tube current (AEC). Similarly, for chest CIs, DLP values were higher in men than women except for PE (Tab. 2), this suggests that men have broader chests than women, Previous studies also noted this (Greyes *et al.*, 2019). On the contrary, for the CIs of abdominopelvic, DLP values for women were higher than for men except for the CI abdominopelvic lesions suggestive of larger abdomen size in women. This may also be related to the size of the lesion detected, altering the patient morphology and size of the abdomen. Nevertheless, our findings corroborate the concept that dose estimates are highly dependent on patient morphology.

When comparing different CIs within the same body region, the study found that brain tumor and head trauma examinations had slightly higher dose values, evidenced by higher tube voltage usage due to high image quality (contrast) requirements for this CIs. Other examinations, such as stroke and dementia, had slightly lower dose values but higher tube current (mAs) usage to compensate for the image noise resulting from the usually smaller slice thickness needed to resolve tissues or small vessels in the brain in this type examinations. The $CTDI_{vol}$ indices were similar across head CIs, but a gap was observed for brain tumor scans due to highest mean tube voltage (125 kV) usage. The study showed gabs in DLP values, reflecting the impact of differences in mean scan length values and usage across head CI examinations, but overall, homogeneous practice was observed.

The study found that chest CT examinations have similar dose values across different CI examinations due to similar exposure factors. However, optimal PE scans may be achieved using lower scan protocol values due to lower image quality requirement of this CI compared to high resolution required to detect minute nodules in the lung tumor scans (Geryes *et al.*, 2019). Besides, lower acquisition values (mean: 115 kV, 144 mAs) (Tab. 2) were used for CKD and often without contrast enhancement due to the high natural contrast of the lung tissue and denser metastatic pulmonary calcifications that

Table 3. Comparison reference dose values with NDRLs.

DRLs	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)
	CVA/stroke		**Trauma/RTA**		**Brain tumor/SOL**	
This study	69***	1426* 1413**	69* 63**	1657* 1352**	69***	1690* 1374**
Botwe *et al.*	77	1313	77	1596	82	1390
Geryes *et al.*	44	850	43	870	44	790
Tan *et al.*	42.1	692	41.2	677	41.3	669
Foley *et al.*,	38.8	626	39	908	38.7	–
EU DRLs	48	807	–	–	45	–
UKHSA	46	804	–	–	–	–
HIQA, (IR)	–	970	–	908	–	–
Widmark *et al.*	–	–	60	950		
	Pulmonary embolism		**Lung tumor**		**Chest lesion with CKD**	
This study	9***	366* 344**	10* 9**	359* 324**	11***	375* 330**
Botwe *et al.*	14	491	12	467	13	467
Geryes *et al.*	8	310	5	200	–	=
England, UK	10	337	9	328	–	–
UKHSA	13	440	12	610	–	–
Aberle *et al*	8	300	–	–	–	–
Lee *et al*.	–	–	10	390	–	–
	Abdominopelvic lesion		**kidney stones**		**Urothelial malignancy**	
This study	12* 10**	580* 523**	11* 10**	542* 519**	14* 12**	517* 496**
Botwe *et al.*	17	694	14	731	11	336
Geryes *et al.*	12	620	8	870	=	790
England, UK	9	725	7	338	–	–
Widmark *et al.*	11	800	–	–	13	1300
Aberle *et al*	11	540	6	338	–	–

Lee *et al*=Austria, Geryes *et al.*=France, Botwe *et al.*=Ghana, Widmark *et al.*=Norway, Aberle *et al*=Australia, Foley *et al.*=Ireland, HIQA=Ireland, UKHSA=UK, EU=European Union, HIQA= Health Information and Quality Authority, Ireland, UKHSA=UK Health Security Agency. * Values derived from the distribution of pooled data for all centers, ** values derived from 75th percentile of all medians (Table 2), *** values of * and ** are the same.

characterize this type of examination. The abdominopelvic region showed slightly lower dose values for kidney stone CI scans compared to other CIs, possibly due to high natural contrast between kidney stones and tissues, resulting in lower kV scans (mean 120 kV) (Tab. 2).

Comparing CI DRLs can be challenging because of non-uniformity of number of acquisitions reported by studies (Dalah *et al.*, 2022). This study compared 75th percentile single acquisition dose indices for CIs of adult CT with other NDRLS data (Tab. 3). Differences in dose values were observed, with the largest disparity in head examinations being 42% and 56% higher for $CTDI_{vol}$ and DLP compared to lowest NDRL values (Tab. 3). Indicating a need for CT dose/practice optimization, similar to findings in Hakme *et al.*, in their study (Hakme *et al.*, 2023). Higher dose values may be due to differences in practice and technological advancement. This study utilized less advanced CT scanners, primarily 4-32 slice MSCT, compared to modern models with advanced dose reduction options likely used by the NDRLs. Besides, CT Technology has been confirmed to enhance dose reduction in CT practice (Yadav *et al.*, 2021). Another reason may be the lack of professional medical physicist who would provide guidance for optimized scan protocols in several radiological centers due to relatively small work force of this professionals in the study population and country (Bezak *et al.*, 2023; Obed *et al.*, 2016). Moreover, Geryes *et al.*, opined that centers where medical physicist is involved in radiological practices tend to have low dose indices (Geryes *et al.*, 2019). Nigeria has not yet proposed a national framework for DRLs, which would facilitate the comparison and guidance of local and regional practices. Hence, prompting regulatory authorities to expedite the proposal. However, we suggest that a review of equipment settings and examination protocols according to image quality requirement of each CI could optimize current practice considering the observed differences with NDRLs. Dose evaluation and establishment of DRLs for either body region (morphology) or CIs in line with image quality requirements are relevant tools for radiological dose optimization and patient protection. Dose indices provided in this study (Tab. 2) are to encourage practitioners to periodically investigate and optimize their practices in line with the ALARA principle through dose surveys and comparisons using the 25th, 50th and 75th percentiles indices values. Depending on their capability and resources, size-based evaluations are encouraged, if not possible, age based, anatomic region based, body mass index (BMI) based, or clinical indication-based assessments can be performed.

The study's limitations include uneven distribution and representation of CIs, particularly in chest examinations, and inconsistencies in scanner contribution, particularly in chest and abdomen examinations. There are incidences of incomplete data due to manual data collection and lack of digital collection systems. Image quality was based on standard set by the facilities, and BMI was not estimated due to inadequately documented weight and height data. Although the study only examined data from four CT facilities, these referral centers can offer important insights into CT practice in the area.

5 Conclusion

This study performed a regional survey and evaluation of CT doses based on clinical indications. The results offer a tool for optimizing CT dose that is more aligned with clinical practices. Periodic dose monitoring and optimization strategies must be put in place to enhance patient safety while preserving image quality in CT practice. This study could encourage and serve as reference or guidance for CT clinicians on CT dose evaluation before a national reference is achieved.

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Conflicts of interest

The authors declare that they have no conflict of interest

Data availability statement

All relevant data are included in the study.

Author contribution statement

MK. Abdulkadir: Conceptualization, Methodology, Formal analysis, IY. Izge: Writing- Original draft preparation, Formal analysis, U. Ibrahim: Investigation, JD. Zira: Validation, SA. Audu: Investigation, U. Abubakar: Writing – review & Editing, D. Mohammed: Data curation, A. Mohammed: Investigation, Data curation, NM. Gunda: Visualization, Investigation

Ethics approval

The study received institutional ethical approval from the Health Research Ethics Committee of the Usmanu Danfodiyo University Teaching Hospital, Sokoto (UDUTH/HREC/2022/1137/2).

Informed consent

In this study, patients identifying details were anonymized in line with the confidentiality principle and there was no additional impact or risk to the patients involved. Therefore, informed consent of the patients was not required.

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