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REVIEW ARTICLE

Paediatric computed tomography diagnostic reference levels in Africa: A systematic review

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Abstract

Introduction: Improvements in computed tomography (CT) technology in terms of image quality and reduction in absorbed dose have increased its applications in medical imaging. Diagnostic reference levels (DRLs) help to identify high radiation doses that are unusually delivered to patients undergoing exposure to ionising radiation. The aim of this review was to provide an overview of published studies by African researchers towards establishing paediatric CT DRLs in Africa. **Methods:** The search for articles was conducted using some relevant literature search engines including PubMed, Scopus, Science Direct, Google Scholar and Web of Science. Two reviewers were involved in the article selection process which involved a three-stage screening process of identifying; article titles, abstracts and full-test reading. **Results:** One hundred and seventy-four articles were identified from the database, PubMed (30), Scopus (21), Google Scholar (53), Web of Science (25) and Science Direct (45). Fifty duplicated articles were excluded before screening. Twelve peer-reviewed articles were included in this study based on the inclusion criteria. DRL values in terms of computed tomography dose index volume of head for the age groupings 0–1, 1–5, 5–10 and 10–15 were 27, 36.6, 39.5 and 47.5 mGy while the dose length product values were 461.6, 664, 872 and 978 mGy.cm respectively. The DRLs were calculated as 75th percentile of the local DRLs reported by the 12 articles included in this review. **Conclusion:** This review has shown that only few of the African countries (19%) have published studies on paediatric CT DRLs. There were variations in the DRLs published by the various authors which indicate that harmonisation and standardisation of paediatric CT protocols is essential for the optimisation of paediatric doses.

Introduction

Computed tomography (CT) is a powerful tool for the accurate and effective diagnosis and treatment of a wide range of conditions because it enables the rapid acquisition of high-resolution and three-dimensional medical images. The improvement in CT technology in terms of image quality and reduction in absorbed dose have increased its applications in medical imaging.[1] According to Al-Rammah, CT accounts for about 24% of the total radiation exposure and 49% of the total medical imaging examinations worldwide.[2] Paediatric CT examinations account for about 11% of all CT examinations worldwide.[3] Exposure to ionising radiation is associated with risks of developing cancers. The radiation risks from CT are about 67%, the highest when compared to other medical imaging modalities.[2] A study on the relationship between paediatric head CT and increased risk of developing leukaemia and brain cancer by Pearce et al. indicated that paediatric CT examinations resulting in cumulative doses of

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approximately 50 mGy could triple the risk of leukaemia while doses of about 60 mGy could triple the risk of brain cancer.[4] These risks are higher in paediatric population as compared to the adult population due to rapid cell division and longevity of growing children. As radiation has potential long-term stochastic effects, the potential and critical risks should be considered when exposing children to radiation.[5,6] To minimise, radiation risks in medical imaging, the International Commission for Radiological Protection (ICRP) recommended diagnostic reference levels (DRLs) in 1996 as an important tool to optimise techniques and procedures of radiological examinations.[7] CT DRLs are set at 75th percentiles of CT patients or anthropomorphic phantom dose from a large cohort study.[8] DRLs help to identify unusual high radiation delivered to patients undergoing routine examinations involving ionising radiation. The DRLs can also be used to compare radiation dose variations from different facilities or between different scanners within the same diagnostic centre.

In CT examinations, volume $CTDI_{vol}$, [mGy] and dose length product (DLP) [mGy.cm] are the dosimetric quantities used for the development of DRLs that have been reported by many studies.[9–12] $CTDI_{vol}$ is relevant for patient dose burden per slice while DLP is relevant for the patient dose burden for the complete CT procedure. Both quantities together allow the estimation of patient dose. In modern CT, $CTDI_{vol}$ and DLP values are available from the console and can be measured in real time. The DRLs could be set as local, national or international depending on whether the survey is at the level of a single or multiple medical imaging centre(s), the national level or the international level respectively. For national DRLs, a national authority helps to encourage, collect and collate data together with local facilities to set up the DRLs.[11] DRLs help in maintaining awareness of radiation protection at the local levels and identify unusually high paediatric doses. Establishing paediatric DRLs and comparing same with national or international values can help improve paediatric dose optimisation.[12] Paediatric CT DRLs are a good tool for monitoring patient radiation dose, modifying improper scanning methods, reducing patient dose and achieving the purpose of radiation protection optimisation.

The practice of the principles of optimisation is well established in the developed countries. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) code of practice for radiation protection in the medical applications of ionising radiation published in 2008 mandates the development and application of diagnostic reference levels.[10] Some African countries have successfully established or currently developing national DRLs[13–16]; however, these are for adult CT examination only. Although there are no established DRLs for paediatrics, individual countries may have published DRLs. The aim of this review was to provide an overview of published studies by African researchers towards establishing paediatric CT DRLs in Africa.

Materials and Methods

This systematic review on CT paediatric DRLs in Africa was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) model. It involves literature search, article selection and data extraction and synthesis. The question to be answered from this review is, what is the level of research in paediatric CT DRLs in Africa?

Literature Search

The search for articles was conducted using literature search engines including PubMed, Scopus, Science Direct, Google Scholar and Web of Science which stored large quantity of published articles. The search for articles was done from February 2023 to July 2023. Search statement used for the identification of articles was ('paediatric OR padiatric') AND ('computed tomography') AND ('diagnostic reference levels') AND ('in Africa OR country's name'). All the names of the African countries were placed in the search statement one after the other in order not to exclude a study that used the country's name.

Article Selection

Two reviewers with 10 years of working experience in diagnostic medical imaging and radiation protection were involved in the article selection process. The details of the process are shown in Figure 1. It involved a three-stage screening process of identifying; article titles, abstract and full-test reading taking into consideration the inclusion and exclusion criteria. Peer-reviewed original articles published in the English language from 2012 to 2023 with the sole objective of developing paediatric CT DRLs in Africa were included in this study. Non-peer-reviewed, opinions, commentaries, perspectives, editorials and literature reviews were not included. The reasons for excluding these articles were the use of secondary information, incomplete study information and the potential of unsubstantiated information from these sources could affect the reliability of this review study.

Data Extraction and Synthesis

Data collection form was developed based on a recent systematic literature review on paediatric CT DRL[8] as

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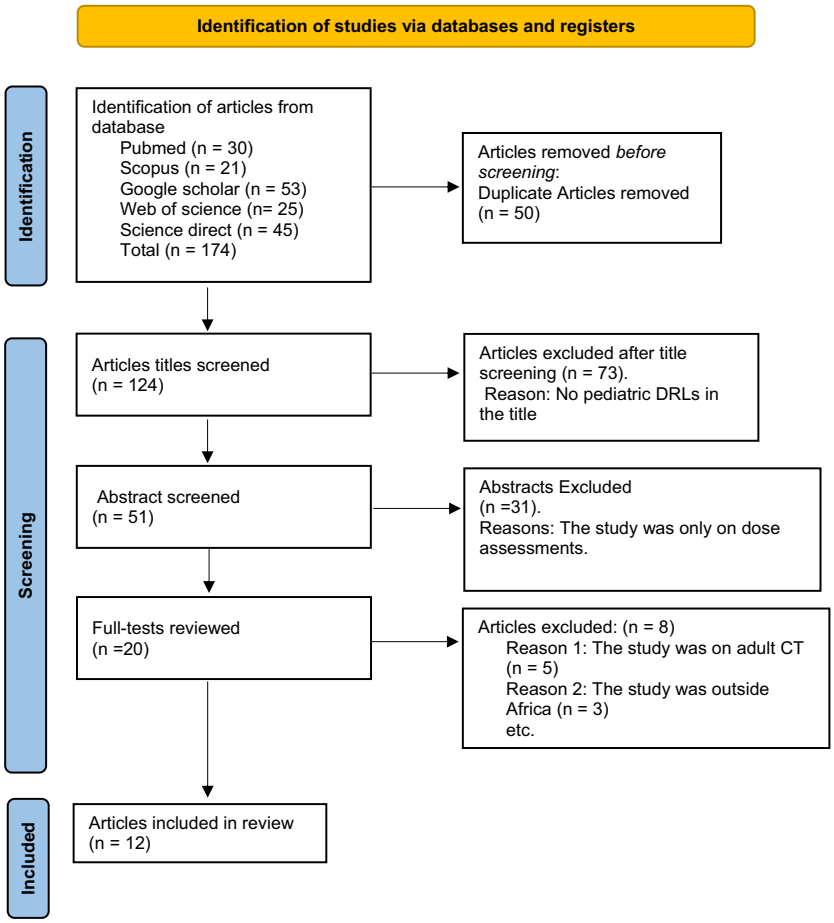

Figure 1. PRISMA diagram for systematic review on paediatric CT DRLs in Africa.

shown in Table 1. The table includes the authors, the country of origin, the methodology, the anatomical region examined, sampling size, the number of hospitals, type of DRLs and the approach.

Results

Twelve peer-reviewed articles were included in this study based on the inclusion criteria. All the articles established DRLs based on the age groupings and the approach was either retrospective or prospective. Dosimetric quantities used for the establishment of DRLs were $CTDI_{vol}$ and DLP. Six authors published local DRLs while four published on national DRLs. However, two authors did not indicate the type of DRLs established. Table 2 shows the results of all the DRLs established by the various authors.

The review indicated that DRLs published using $CTDI_{vol}$ ranges from 2.30 to 8.0 mGy, 2.30 to 10 mGy, 3.10 to 12 mGy and 6.97 to 64.1 mGy for age groups of >1, 1–5, 5–10 and 10–15 respectively for chest CT. For head CT, the highest $CTDI_{vol}$ of 51.00 mGy was reported by Bouaoun et al.[27] with the corresponding DLP of 978.00 mGy. cm for the age group of 10–15 years while Abdou et al.[24] reported the lowest $CTDI_{vol}$ of 23 mGy with DLP of 345 mGy. cm in the age group of less than 1 year. Abdou et al.[24] established the DRLs in a dedicated paediatric centre with harmonised protocols in all the centres that could account for the lower values recorded. Sulieman[19] proposed DRLs for the age group of 5–10 years using only the DLP for head, chest and abdomen. Mustafa et al.[28] also proposed DRLs using only DLP for abdomen and pelvis. We have proposed regional DRLs for Africa by calculating the 75th percentile of the local DRLs reported by the 12 articles included in this review (Table 3).

The African DRL values from this review were compared with some international studies from the United States and China as shown in Table 3.

Discussions

The aim of this review was to provide an overview of published studies by African researchers towards

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Table 1. Summary of characteristics of included articles.

Author (s)	Country of origin	Methodology	Type of DRLs	No. of Hospital Involved	Sampling size	Approach	Anatomical region examined
Van der Merwe et al.[17]	South Africa	Retrospective study	Local DRLs	2	1031	Age-based	Cervical spine, Chest, Abdomen, Brain, Temporal Bone, Paranasal sinuses
Vawda et al.[18]	South Africa	Retrospective study	Local DRLs	1	30	Age-based	Head
Sulieman[19]	Sudan	–	Local DRLs	8	296	Age-based	Head, Abdomen, Chest
Eddy et al.[20]	Cameroon	Retrospective study	National DRLs	15	1269	Aged-based	Head
Eddy et al.[21]	Cameroon	Retrospective study	Local DRLs	3	320	Age-based	CT Brain
Benmessaout et al.[22]	Morocco	Retrospective study	–	3	1007	Age-based	Head
Ayugi et al.[23]	Uganda	–	–	5	683	Age-based	Head, Chest, Abdomen
Abdou et al.[24]	Egypt	Prospective Study	National DRLs	7	1680	Age- and weight-based	Head, Chest, Abdominal- Pelvis
Kamdem et al.[25]	Cameroon	Retrospective Study	Local DRLs	2	199	Age-based	Brain
Benmessaout et al.[26]	Morocco	Retrospective Study	Local DRLs	2	630	Age-based	Abdominal-Pelvis, chest–abdominal–pelvis
Bouaoun et al.[27]	Tunisia	Retrospective study	National DRLs	7	916	Aged-based	Head, Chest, Abdomen
Mustafa et al.[28]	Sudan	Prospective Study	NDRLs	8	96	Age-based	Abdomen

This table shows the countries from which paediatric DRLs have been published, and whether the study was prospective or retrospective. It also shows the anatomical regions investigated, and the patients sample size for each examination.

establishing paediatric CT DRLs in Africa. This review indicated that in Africa, chest, head and abdomen are the most common examinations being investigated for the establishment of the paediatric DRLs. This conforms to the recommendations by the European Union (EU) that DRLs are set for the most frequently performed examinations as well as the least frequently performed examinations with high doses to patients.[11]

Establishing DRLs for paediatric patients is more challenging as compared to establishing for adults. This is because image quality and radiation dose vary considerably with the size and age of a child.[31] For all body examinations and for DRLs based on prospective dose survey, weight should be used as the parameter for patient grouping in accordance with recommendations by the European Union and the ICRP publication (135).[11,32] However, for head examinations age is recommended as the grouping parameter. The recommendation is based on the fact that there is little variation in the head of paediatric as compared to the variations of chest, abdomen and pelvis and that weight is the most appropriate for those examinations. One author[24] followed the EU and ICRP recommendation using age-based grouping for head examinations while chest, abdomen and pelvis examinations were based on weight distribution. This was possible because the study was conducted prospectively. Bouaoun et al.[27] stated that the age-based was adopted due to the absence of information on the weight of paediatric patients in the hospital.

In this review, six authors proposed local diagnostic reference levels (LDRLs), while four of the authors proposed NDRLs as shown in Table 1. Additionally, two authors did not indicate either the study was LDRLs or NDRLs. None of the authors investigated image quality as part of proposing or establishing a DRLs programme. National diagnostic reference levels (NDRLs) should be established by a national competent authority such as national radiation protection body, health authorities or other specific institutions established and authorised by competent national authorities.[11] Abdou et al.[24] established paediatric DRLs in Egypt for head, chest and abdomen under the guidance of national steering committee established for the purpose of developing paediatric DRLs in collaboration with the Ministry of Health, management of the University hospitals and health professionals. The steering committee was made up of 1 medical physicist, 2 radiology consultants, 3 hospital managers, 14 radiographers and IAEA expert in medical

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Table 2. Paediatric diagnostic reference levels (DRLs) established in Africa (CTD_{vol} and DLP).

Author (s)/ Country	Anatomical region examined	Age grouping (Years)	$CTDI_{vol}$ (mGy)	DLP (mGy. cm)
Van der Merwer et al.[17] South Africa	Brain	0–1	20.3	311.3
		1–5	20.3	362.4
		5–10	22.3	457.2
		10–15	32.1	746.1
	Chest	0–1	5.66	153.5
		1–5	3.27	105.1
		5–10	4.73	136.4
		10–15	6.97	325.1
	Abdomen	0–1	6.17	191.5
		1–5	4.73	187.8
		5–10	4.73	203.3
		10–15	8.4	371.1
	Trunk	0–1	19.29	1362.2
		1–5	4.73	212.7
		5–10	6.51	238.8
		10–15	4.73	290.2
	Neck	0–1	7.85	195.4
		1–5	6.93	195.4
		5–10	7.85	215.2
		10–15	15.99	142.3
	Cervical spine	0–1	13.16	303.9
		1–5	6.44	186
		5–10	7.07	186.7
		10–15	8.50	227.9
	Temporal bone	0–1	–	–
		1–5	–	–
		5–10	41.78	305.8
		10–15	57.37	547.2
Vawda et al.[18] South Africa	Head	0–2	30.00	488
		2–5	31.00	508
		5–10	32.00	563
Sulieman[19] Sudan	Head	5–10	–	1053
	Chest	5–10	–	208
	Abdomen	5–10	–	574
Eddy et al.[20] Cameroon	Head	>1	34.20	710.1
		1–5	36.60	838.4
		5–10	39.50	964
		10–15	49.60	1177.2
Eddy et al.[21] Cameroon	Brain	<1	22.24	506.92
		1–4	28.92	622.77
		5–9	38.82	931.76
		10–14	48.26	1055.98
Benmessaoud et al.[22] Morocco	Head	>1	26.98	461.64
		1–5	28.88	540.06
		5–10	34	627.2
		10–15	38.2	705.98
Ayugi et al.[23] Uganda	Head	0–1	40.9	829
		1–5	43.1	908
		5–10	42.7	953
		10–15	47.5	997
	Chest	0–1	2.3	104
		1–5	2.3	171
		5–10	3.1	276
		10–15	64.1	480
	Abdomen	0–1	2.8	243
		1–5	2.3	171
		5–10	3.1	276
		10–15	4.1	480
Abdou et al.[24] Egypt	Head	<1	23	345
		>1–5	27	428
		>5–10	28	499
		>10–15	32	637
	Chest	<5–15 kg	4	67
		>15–30 kg	5	85
		>30–50 kg	6	145
		>50–80 kg	8	215
	Abdomen–pelvis	<5–15 kg	5	97
		>15–30 kg	6	135
		>30–50 kg	7	240
		>50–80 kg	9	320
Kamdem et al.[25] Cameroon	Brain	>1	24	381
		1–5	43	876
		5–10	46	940
		10–15	57	1222
Benmessaoud et al.[26] Morocco	Abdomen–pelvis	>1	6.9	198.5
		1–5	8.5	267.2
		5–10	8.5	331.2
		10–15	8.5	381.5
	Chest–abdomen–pelvis	>1	7.3	252.7
		1–5	7.3	321
		5–10	7.3	307.2
		10–15	10.3	443.2
Bouaoun et al.[27] Tunisia	Head	<1	26	384
		1–5	38	664
		5–10	51	873
		10–15	51	978
	Chest	<1	8	118
		1–5	10	330
		5–10	12	442
		10–15	15	526
	Abdomen	<1	9	353
		1–5	13	485
		5–10	19	592
		10–15	18	1072
Mustafa, et al.[28]	Abdomen	0–5	–	795
		6–10	–	1398
		11–16	–	926

This table shows paediatric DRL values (CTDIvol and DLP) for most performed paediatric examinations in Africa. The authors did not report DRL values where there are dashes.

physics. This study was conducted in seven (7) dedicated paediatric centres in Egypt without including nondedicated paediatric centres that perform paediatric CT examinations. The DRLs are not for individual

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Table 3. Comparison of the proposed African diagnostic reference levels (DRLs) to other international studies.

CT examination	Age groupings (years)	This review		Kanal et al.[29] (United States)		Kang et al.[30] (China)	
		$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)
Head	0–1	27	461.6	23	344	36	488
	1–5	36.6	664	27	440	43	635
	5–10	39.5	872	31	518	49	723
	10–15	47.5	978	55	910	51	852
Chest	0–1	4.8	111	4.8	62	12.2	216
	1–5	4.1	171	5.8	116	12.8	272
	5–10	5.4	210.5	5.2	190	13.6	274
	10–15	11.5	402.6	15.8	544	19.2	586
Abdomen	0–1	6.0	243	4.8	120	21	502
	1–5	6.7	281.3	5.8	200	20.6	568
	5–10	8.9	357.1	5.2	340	22.8	706
	10–15	10.2	641.0	15.8	716	26	523

The African paediatric DRLs for frequently performed paediatric examinations compared with some international studies. For the head CT, the $CTDI_{vol}$ from the United States are lower than those from Africa except for the age group of 10–15 years.

patients and should not be used for legal and regulatory purposes but good tool for monitoring patient dose, identifying improper scanning methods and reducing patient dose. The DRLs therefore help to achieve the purpose of radiation protection optimisation.

Despite the recognised importance of DRLs, no African country has been able to establish a DRL programme for paediatric CT examinations. Egypt has made significant effort to establish NDRLs for head, chest and abdomen for paediatric CT examinations. As of 2023, only few of the African countries (19%) have published studies on paediatric CT DRLs but no African country has established paediatric NDRLs. In Africa, most of the paediatric CT examinations are performed in nonpaediatric centres due to lack of specialised paediatric diagnostic centres, which may have the potential to deliver higher radiation dose than necessary. Nabaweesi et al.[33] compared radiation dose of paediatric CT head examination from one dedicated paediatric trauma centre to 16 different nonpaediatric trauma centres. The study concluded that children received a double dose of radiation in CT scans at nonpaediatric hospitals in comparison with that received at dedicated paediatric centres. However, some studies have found that nonpaediatric centres can achieve similar radiation dose levels as compared to dedicated paediatric centres.[34,35] The studies suggested that radiation exposure to paediatric patients largely depends on effective standardisation and optimisation of CT examinations rather than the department being dedicated paediatric centre or not. However, in Africa published data on optimisation and standardisation of paediatric CT imaging procedures and techniques are lacking which is evident during the literature review of this study.

Research on adult CT DRLs in Africa is far ahead of the paediatric CT DRLs. Egypt and Algeria have established NDRLs for adult CT examinations,[36] while Ghana, Senegal, Namibi and Kenya are jointly working to establish regional adult CT DRLs for chest, head and abdomen.[13] Researchers in Africa have also published some studies on adult CT DRLs.[14,15,37–39] Comparison research in paediatric CT DRLs in Africa is difficult because of a lack of existing literature. Vawda et al.[18] and van de Merwe et al.[17] have reported that South Africa has no published national DRL data and that DRLs have not played a meaningful role in evaluating the quality and safety of South African radiological services. In Tunisia, Bouaoun et al.[26] observed that there is no documented evidence related to paediatric CT practice with respect to protocols and techniques. Kamdem et al.[25] and Eddy et al.[20] have reported that there are no established DRLs programmes in Cameroon.

The inability of countries to establish paediatric CT NDRLs in Africa could be attributed to limited human resources, insufficient awareness for radiation safety, lack of medical imaging facilities and opportunities for education and training.[35] The patient dose surveys required for setting up DRLs are resource-demanding and time-consuming. It is very expensive and time-consuming for collecting large amount of data required for establishing the NDRLs. The main methods of data collection largely depend on manual or semimanual due to a lack of automatic data management software. Data analysis has also become challenging because there is often a lack of standardisation in the specification for a given examination.

Another important observation from this review which makes the establishment of NDRLs or LDRLs important

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was the variations in patient radiation dose. There were variations within centres with different equipment, variations among different centres and variations among different studies. All the authors ($N = 12$) reported variations in their results when compared to other studies or when compared to different centres within the same studies. There were variations when the DRL values from the African authors were compared with studies from China and the United States as shown in Table 3. The average DRL values from this review are similar to the US study in terms of $CTDI_{vol}$ but DLP values are higher. The higher DLP values recorded in Africa were as a result of longer scan length, as DLP is the product of scan length and $CTDI_{vol}$.[22] The higher values of DLP can also be a result of scanning multiple series. Data from the European study on clinical diagnostic reference levels for x-ray imaging (European Commission project) revealed that CT DRLs vary between centres or countries mainly due to different number of scan phases or different scanning lengths. While some studies included all phases, others included only a single phase in the determination of the DRLs.[40] The China study reported higher CTDIvol and DLP values than all the studies. The authors reported that the overall high DRL values for head CT were due to fixed scanning protocols for all patients and therefore suggested personalised scanning techniques based on the size or weight of the paediatric patient.

Some of the authors reported DRLs (DLP and $CTDI_{vol}$) based on the 75th percentile values of the mean[18] while others reported based on the 75th percentile median values.[22] However, the difference between the 75th percentiles of median and mean values for nonsymmetrical data has been suggested to be within 15% according to a study by Vassileva et al.[41] and concluded that the 75th percentiles based on mean values are higher than those based on median values. Therefore, studies cannot be compared fairly with variations in the methodology of calculating the 75th percentiles. The variations in DRL values suggest that protocols are not being optimised but could also be due to variations in clinical presentations. Other contributing factors include difference in equipment, exposure protocols, lack of education on radiation protection and availability and utilisation of dose reduction software, patient sizes, lack of continuous education on radiation protection and dose reduction principles for radiologists, radiographers and lack of medical physicists in most of the diagnostic imaging departments.[18,20,22,24,27] A study conducted by Smith-Bindman et al. reported that CT variations among centres or countries were largely depended on technical parameters to produce the optimal CT images but not patient size, institutional characteristics, machine manufacturer or the model. The authors concluded that the largest driver of dose variations was how clinical staff chose to set the machine technical parameters, not the machine.[42]

Recommendations

This review recommends the following:

1. The regulatory bodies, the Ministry of health, health professionals and researchers in Africa should take a keen interest in the establishment of paediatric CT DRLs.
2. Education on radiation protection should be provided to the imaging professionals in Africa to appreciate the need to optimise paediatric medical exposures.
3. More medical physicists should be recruited into the diagnostic medical imaging departments to help the process of optimisation.

Conclusion

This review has shown that only few of the African countries (19%) have published studies on paediatric CT DRLs. Only one country (Egypt) has made a significant effort to establish national DRLs for head, chest and abdomen. It has been found that limited human resources, insufficient awareness for radiation safety, and insufficient facilities and opportunities for education and training are some major challenges hindering the establishment of NDRLs in Africa. There were variations in the DRLs published by the various authors which indicate that harmonisation and standardisation of paediatric CT protocols is very necessary for the purpose of optimisation of paediatric doses.

Conflict of Interest

The authors have no conflict of interest in this work.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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