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Assessment of radiation doses, associated factors, and indications for pediatric head CT scans at Kilimanjaro Christian Medical Center, Tanzania

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ABSTRACT

Objective: To evaluate ionizing radiation doses, associated factors, and clinical indications for pediatric head computed tomography (CT) scans performed at Kilimanjaro Christian Medical Centre (KCMC), Tanzania.

Materials and Methods: A retrospective analysis of 495 pediatric head CT scans performed between 2020 and 2023 at Kilimanjaro Christian Medical Centre was conducted. Data included CTDIvol, DLP, estimated effective dose, patient demographics, scan protocols, and clinical indications. Multivariate regression identified predictors of dose variation. International diagnostic reference levels (DRLs) served as benchmarks.

Results: Infants (<1 year) received the highest effective dose (6.5 mSv), while adolescents (11–15 years) had the lowest (2.4 mSv). Contrast use, younger age, and indications such as hydrocephalus and trauma were significantly associated with elevated ionizing radiation exposure. Trauma (35.8%), hydrocephalus (18.4%), and tumors (15.2%) were the most frequent indications. While CTDvol and DLP values were generally within international DRLs, effective doses in younger children exceeded global benchmarks.

Conclusion: Pediatric head CT scans at KCMC demonstrate age-dependent dose variability, with infants receiving disproportionately higher effective doses. Optimizing scan protocols and increasing awareness of alternative imaging modalities are essential to minimize ionizing radiation risks in pediatric populations.

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Pediatric CT; ionizing radiation; diagnostic reference levels; KCMC; Tanzania

Introduction

Computed tomography (CT) is a cornerstone of pediatric neuroimaging, offering rapid and detailed visualization of intracranial pathology. However, its reliance on ionizing radiation raises concerns, particularly in children whose tissues are more radiosensitive and who have longer lifespans during which ionizing radiation-induced effects may manifest [1]. Epidemiological studies suggest that head CT in young children may increase lifetime cancer risk, though estimates vary depending on dose and modeling assumptions [2]. Consequently, global initiatives such as the Image Gently campaign advocate for dose optimization using the ALARA principle [3]. By evaluating ionizing radiation doses, associated factors, and clinical indications for pediatric head CT scans, this study contributes to international dose-reduction initiatives (such as Image Gently, ALARA) by providing locally relevant data from a low-resource setting.

Despite international efforts to standardize pediatric CT protocols, significant variability persists, especially in low-resource settings [4]. There is limited published data from Tanzania and sub-Saharan Africa, leaving a gap in regional benchmarks and practice evaluation [5]. This study aims to assess ionizing radiation dose metrics, identify associated factors, and evaluate clinical indications for pediatric head CT scans at KCMC, a major referral center in northern Tanzania.

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Materials and Methods

Study design and population

A retrospective cross-sectional study was conducted at KCMC, reviewing head CT scans performed on pediatric patients aged 0–15 years between January 2020 and December 2023.

Scan protocol

All pediatric head CT scans were performed using a Siemens SOMATOM Definition AS 128-slice CT scanner. Tube voltage ranged from 80 to 100kVp, and tube current was modulated using CARE Dose 4D, Siemens' automatic exposure control system. Rotation time was set between 0.5 and 0.75 seconds, with a pitch of 0.8 to 1.2 depending on patient size. Slice thickness was maintained between 2.5 and 5 mm, and images were reconstructed using soft tissue (H30s) and bone (H60s) kernels. Scan range from the skull base to the vertex. CARE kV was enabled to optimize tube voltage selection. Contrast-enhanced scans were included only when clinically indicated.

Data collection

Data were extracted from the radiology information system and included CTDvol, DLP, estimated effective dose, patient demographics, scan protocols, and clinical indications. The effective dose was calculated using age-specific conversion factors [6].

Inclusion/exclusion criteria

All pediatric patients aged 0-15 years who have undergone at least one head CT scan at KCMC within the study period, with complete medical records and CT scan data, including ionizing radiation dose measurements, were included. Exclusions were made for Head CT scans performed as part of interventional radiology procedures and repeat scans within the same admission or clinical episode, unless they are necessary for evaluating changes in ionizing radiation dose or clinical indications.

Ethical approval:

This study was approved by the KCMC Institutional Review Board (Approval No. PG90/2024). Informed consent was waived due to the retrospective design. Patient confidentiality was maintained.

Statistical analysis

Descriptive statistics summarized demographic and dose data. To identify factors associated with increased ionizing radiation dose, multivariate linear regression models were constructed. Covariates included age group, sex, body weight, use of contrast media, and clinical indication. Variable selection was based on clinical relevance, prior literature, and a univariate screening threshold of $p < 0.20$. Each regression model used the 11–15 year age group as the reference category, given its physiological maturity and relatively stable imaging parameters. This allowed meaningful comparisons across younger, more radiosensitive groups. Sex with females as the reference; and contrast use with non-contrast studies as the reference. Comparisons were made against international DRLs such as European Commission (EC), American Association of Physicists in Medicine (AAPM), and International Atomic Energy Agency (IAEA) guidelines [7]. Statistical significance was set at $p < 0.05$. For the tertiary objective, the common clinical indications for ordering head CT scans in pediatric patients were evaluated and compared against ACR appropriateness criteria guidelines and expert consensus from two radiologists.

Results

Demographics

A total of 495 pediatric patients underwent head CT examinations at Kilimanjaro Christian Medical Centre (KCMC). The age distribution revealed that the largest proportion of patients were between 1 and 5 years (44.24%, ***n*** = 219), followed by those aged 6–10 years (26.06%, ***n*** = 129), infants under 1 year (24.24%, ***n*** = 120), and adolescents aged 11–15 years (5.45%, ***n*** = 27). The cohort comprised slightly more males (54.34%, ***n*** = 269) than females (45.66%, ***n*** = 226).

The mean weight across the study population was 15.8 ± 8.6kg, with age-specific averages ranging from 6.5kg in infants (<1 year) to 34.2kg in adolescents (11–15 years). Most CT scans were performed without contrast enhancement (63.4%, ***n*** = 314), while 36.6% (***n*** = 181) involved contrast administration. Regarding imaging alternatives, 38% (***n*** = 188) of the cases had potential access to modalities with lower or no ionizing radiation, whereas 62% (***n*** = 307) did not. These characteristics are summarized in Table 1.

Radiation dose metrics

Radiation dose metrics demonstrate distinct age-related variations. The mean volume CT dose index

Table 1. Demographic characteristics of pediatric patients undergoing head CT (*N* = 495).

Characteristics	Frequency (*n*)	Percent (%)
Age		
<1	120	24.24
1–5	219	44.24
6–10	129	26.06
11–15	27	5.45
Sex		
Female	226	45.66
Male	269	54.34
Weight		
Age	Average Weight (Kg)	
<1yr	6.5	
11–15yrs	34.2	
1–5yrs	13.6	
6–10yrs	24.4	
Mean ± SD	15.8 ± 8.6	
Use of contrast	Frequency	Percent
No	314	63.4%
Yes	181	36.6%
Was this Indication having alternative imaging modality with less or no ionizing radiation?		
No	307	62%
Yes	188	38%

SD = standard deviation.

Table 2. Radiation dose metrics by pediatric age group.

	Mean values				
Variable	**<1**	**1–5**	**6–10**	**11–15**	***p* value**
CTDIVol (mGy)	29.63	38.08	39.15	44.92	<0.001
DLP (mGy.cm)	593.48	870.87	1005.08	1120.7	<0.001
Estimated Effective Dose (mSv)	6.49	3.48	3.22	4.08	0.003

CTDIvol = Computed Tomography Dose Index volume; DLP = Dose-Length Product.

(CTDIvol) increased progressively with age, ranging from 29.63mGy in infants to 44.92mGy in adolescents, a difference that was statistically significant ($p < 0.001$). Similarly, the dose–length product (DLP) showed an upward trend with age, reaching its highest value in the 11–15-year age group (1120.7mGy·cm. In contrast, the estimated effective dose exhibited an inverse pattern, with the highest mean value observed in infants (6.49mSv) and the lowest in children aged 6–10 years (3.22mSv). These differences in effective dose across age categories were also statistically significant ($p = 0.003$). These findings are demonstrated in Table 2.

Factors associated with dose

Table 3 summarizes the multivariable regression analysis of factors associated with pediatric head CT ionizing radiation dose, expressed as CTDIvol, DLP, and effective dose. Compared with the reference group (11–15 years), infants (0–1 year) demonstrated a lower CTDIvol (β = –5.1, 95% CI –10.4 to 0.2, $p = 0.059$) and DLP (β = –90.2, 95% CI –290 to +110, $p = 0.378$), but a significantly higher effective dose (β = +6.3mSv, 95% CI +5.0 to +7.6, $p < 0.01$). Children aged 1–5 years showed no significant differences in CTDIvol or DLP but had a higher effective dose (β = +2.6mSv, 95% CI +1.8 to +3.4, $p < 0.01$). The 6–10-year group exhibited significantly

Table 3. Factors associated with pediatric head CT ionizing radiation dose.

Variable	CTDIvol (mGy) β	95% CI	*p*-value	DLP (mGy·cm) β	95% CI	*p*-value	Effective dose (mSv) β	95% CI	*p*-value
Age (Ref: 11–15 yrs)									
0–1 year	–5.1	–10.4–0.2	0.059	–90.2	–290–+110	0.378	**+6.3**	+5.0–+7.6	**<0.01**
1–5 years	–1.6	–5.9–+2.7	0.458	+58.5	–100–+217	0.482	**+2.6**	+1.8–+3.4	**<0.01**
6–10 years	+1.1	–1.9–+4.1	0.469	**+134.3**	+13–+255	**0.030**	**+2.1**	+1.3–+2.9	**<0.01**
Sex (Ref: Female)									
Male	+0.6	–0.6–+1.8	0.301	+31.1	–14–+76	0.179	–0.01	–0.2–+0.2	0.889
Weight (per kg)	+0.1	–0.2–+0.4	0.487	**+9.7**	+3.3–+16.1	**0.003**	**+0.04**	+0.02–+0.06	**0.001**
Contrast use (Ref: No)									
Yes	**+22.1**	+18.5–+25.7	**<0.01**	**+553.9**	+470–+638	**<0.01**	**+2.44**	+2.0–+2.9	**<0.01**
Clinical Indication									
Hydrocephalus	**+2.6**	+0.2–+5.0	**0.037**	**+199.1**	+120–+278	**<0.01**	**+0.7**	+0.3–+1.1	**0.001**
Trauma	+1.5	–0.4–+3.4	0.132	**+132.8**	+70–+196	**<0.01**	**+0.7**	+0.4–+1.0	**<0.01**
Tumor	+4.2	+2.1–+6.3		**+66.1**	–18–+150	**0.129**	**+0.3**	–0.05–+0.7	**0.092**
Congenital anomalies	+2.3	–0.8–+5.4	0.146	**+145.1**	+30–+260	**0.015**	**+0.9**	+0.5–+1.3	**0.001**
Visual/optic symptoms	–9.6	–12.8—6.4		–168.5	–345–+8	0.060	–0.4	–1.0–+0.2	0.252
VP shunt evaluation	–2.1	–7.9–+3.7	0.487	–29.9	–150–+90	0.796	+0.1	–0.4–+0.6	0.792

higher DLP (β = +134.3, 95% CI +13 to +255, p = 0.030) and effective dose (β = +2.1mSv, 95% CI +1.3 to +2.9, p < 0.01), with no significant change in CTDIvol.

Male patients did not differ significantly from females in CTDIvol, DLP, or effective dose (all p > 0.05).

Increasing patient weight was significantly associated with higher DLP (β = +9.7, 95% CI +3.3 to +16.1, p = 0.003) and effective dose (β = +0.04mSv, 95% CI +0.02 to +0.06, p = 0.001), but not CTDIvol (p = 0.487).

Examinations performed with contrast were strongly associated with higher ionizing radiation dose across all metrics: CTDIvol (β = +22.1, 95% CI +18.5 to +25.7, p < 0.01), DLP (β = +553.9, 95% CI +470 to +638, p < 0.01), and effective dose (β = +2.44mSv, 95% CI +2.0 to +2.9, p < 0.01).

Hydrocephalus was associated with significantly higher CTDIvol (β = +2.6, 95% CI +0.2 to +5.0, p = 0.037), DLP (β = +199.1, 95% CI +120 to +278, p < 0.01), and effective dose (β = +0.7mSv, 95% CI +0.3 to +1.1, p = 0.001). Trauma cases showed significantly higher DLP (β = +132.8, 95% CI +70 to +196, p < 0.01) and effective dose (β = +0.7mSv, 95% CI +0.4 to +1.0, p < 0.01), but not CTDIvol. Tumor indications were associated with higher CTDIvol (β = +4.2, 95% CI +2.1 to +6.3), though the increase in DLP and effective dose did not reach statistical significance. Congenital anomalies were linked to higher DLP (β = +145.1, 95% CI +30 to +260, p = 0.015) and effective dose (β = +0.9mSv, 95% CI +0.5 to +1.3, p = 0.001), but not CTDIvol. Visual/optic symptoms were associated with a markedly lower CTDIvol (β = –9.6, 95% CI –12.8 to –6.4), though differences in DLP and effective dose were not significant. VP shunt evaluations showed no significant associations with any dose metric.

Bold values indicate statistical significance at p < 0.05. CI = confidence interval; CTDIvol = volume CT dose index; DLP = dose-length product.

Table 3 presents multivariable linear regression coefficients (β) with 95% confidence intervals (CI) for factors associated with pediatric head CT radiation dose, expressed as CTDIvol, DLP, and effective dose. Age was modeled with 11–15 years as the reference category; sex with female as the reference; and contrast use with non-contrast studies as the reference. Clinical indications were compared against all other indications combined. Positive β coefficients indicate an increase in radiation dose relative to the reference group, while negative

coefficients indicate a reduction. Bold values denote statistical significance at $p < 0.05$.

Clinical indications

The most frequent clinical indication for head CT scanning was trauma, accounting for 35.76% (*n*=177) of cases, followed by hydrocephalus (18.38%, *n*=91) and suspected brain tumors (15.15%, *n*=75), as depicted in Table 4 and Figure 1.

Discussion

This study demonstrates that ionizing radiation dose in pediatric head CT imaging is influenced by multiple interacting factors, with clear age-related variability and strong effects from contrast use and clinical indication. Infants (<1 year) received significantly higher effective doses (+6.3 mSv, 95% CI: 5.0–7.6, $p < 0.001$) compared to adolescents, despite lower CTDIvol and DLP values. It is important to note that the effective dose is a population-based risk metric and should not be interpreted as an individual patient dose.

These results are consistent with prior studies, including those by Frush et al. and Brody et al., which highlighted that infants and younger children are more radiosensitive and often receive higher doses when scanning protocols are not properly adjusted for body size. This underscores the importance of age-specific protocol optimization [1,3].

Relative to international DRLs, CTDIvol and DLP values at KCMC were generally within acceptable ranges. However, effective doses in younger children exceeded benchmarks reported in countries such as Turkey and Switzerland [7]. A detailed comparison with other published studies is presented in Table 5.

This study identified several key factors influencing ionizing radiation dose during pediatric head CT scans, including patient age, clinical indication, body weight, and the use of contrast media. Age emerged as one of the most important determinants, with infants under 1 year receiving disproportionately higher effective doses. Clinical indications also contributed to dose escalation: hydrocephalus was associated with increased CTDIvol (+2.6mGy), DLP (+199.1mGy·cm), and effective dose (+0.7mSv), reflecting extended scan ranges and repeated imaging often required in these patients. Trauma similarly elevated DLP (+132.8mGy·cm) and effective dose (+0.7mSv), consistent with emergency imaging practices. Congenital anomalies contributed to higher DLP (+145.1mGy·cm) and effective dose (+0.9mSv), highlighting the reliance on CT in settings where MRI availability is limited. Tumors increased CTDIvol (+4.2mGy) but did not significantly affect effective dose after adjustment, suggesting that protocol tailoring may mitigate exposure in these cases.

Contrast use emerged as the strongest predictor of dose escalation across all metrics, increasing CTDIvol by +22.1mGy, DLP by +553.9mGy·cm, and effective dose by +2.44mSv (all $p < 0.001$). This emphasizes the need for judicious use of contrast, particularly in infants and young children, where cumulative exposure is most concerning. Weight was also positively correlated with dose, with each additional kilogram increasing DLP by +9.7mGy·cm and effective dose by +0.04mSv, supporting the rationale for weight-based protocol adjustments. These findings align with prior studies where age, weight, contrast use, scan protocol, and clinical indications were associated with ionizing radiation dose [5,8,9]

The predominance of trauma as an indication aligns with global trends, while the high frequency of hydrocephalus and congenital anomalies reflects local epidemiology and limited access to alternative imaging modalities such as MRI [5,10,11]

Practical strategies for dose reduction at KCMC include lowering kVp/mA for infants, using

Table 4. Clinical indications for pediatric patients undergoing head CT scans at KCMC.

Characteristics	Frequency (*n*)	Percent (%)
Reason for CT scan	***N* = 495**	
Seizure/Neurological Events	72	14.55
Visual/ Optic Symptoms	9	1.82
Infection	24	4.85
Hydrocephalus	91	18.38
Headache	16	3.23
Tumor	75	15.15
Trauma (Injury)	177	35.76
Congenital anomalies	26	5.25
VP shunt evaluation	5	1.01

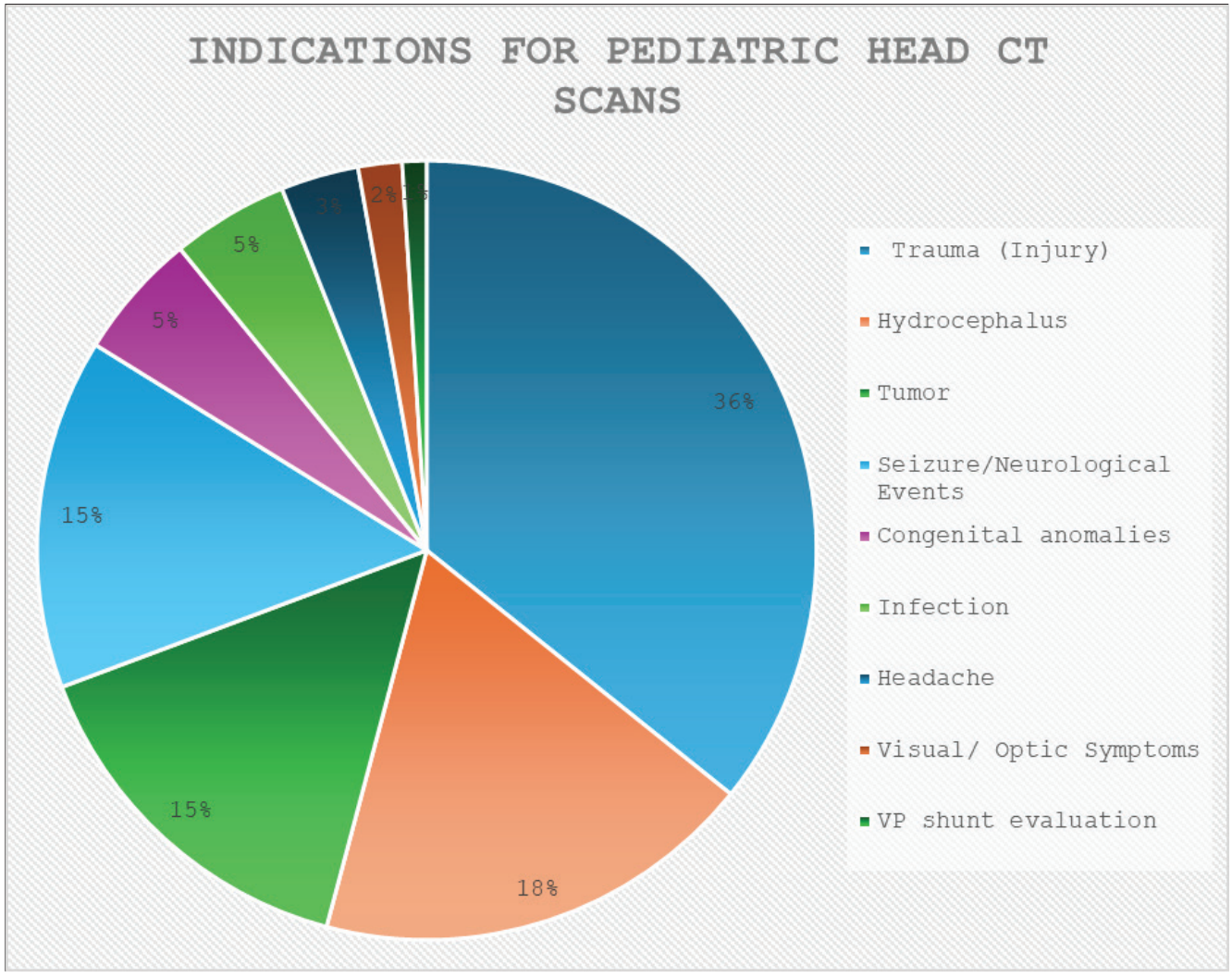


Figure 1. Distribution of clinical indications for pediatric head CT scans at KCMC (N = 495). Percentages represent the proportion of total examinations.

Table 5. Comparison between our findings and other studies.

	Age group (Yrs)	CTDIVol (mGy)	DLP (mGy.cm)	Estimated Effective Dose(mSv)
CURRENT STUDY	<1	29.6	593	6.5
	1–5	38.1	871	3.5
	6–10	39.2	1005	3.22
	11–15	44.9	1121	2.35
DRL KENYA [5]	<1	32.2	605	4.18
	1–5	37.02	933.3	3.87
	6–10	37.5	1391	3.75
	11–15	38.72	1014	2.94
NDRL UK [6]	<1	25	350	
	1–5	40	650	
	6–10	60	860	
	11–15	60	860	

Continued

	Age group (Yrs)	CTDIVol (mGy)	DLP (mGy.cm)	Estimated Effective Dose(mSv)
IAEA [8]	<1	26	440	
	1–5	36	570	
	6–10	43	610	
	11–15	53	800	
NDRL KENYA [12]	<1	38	1005	6
	1–5	50	1395	5
	6–10			
	11–15	55	1608	4
NDRL TURKEY [13]	<1	31	288	1.9
	1–5	33.4	368	1.5
	6–10	40.3	267	1.3
	11–15	51.3	625	
DRL SOUTH AFRICA [14]	<1	30	488	
	1–5	31	508	
	6–10	32	563	
	11–15	32	563	
DRL AUSTRALIA [15]	<1	30	470	
	1–5	30	470	
	6–10	35	600	
	11–15	35	600	
NDRL THAILAND [16]	<1	25	400	
	1–5	30	570	
	6–10	40	610	
	11–15	45	800	
NDRL SWITZERLAND [17]	<1	20	270	
	1–5	30	420	
	6–10	40	560	
	11–15	60	1000	

automatic exposure control, limiting scan range, reducing unnecessary contrast use, enhancing staff training in pediatric dose optimization and appropriateness criteria, and promoting ultrasound or MRI for hydrocephalus follow-up.

Study strength and limitations

The study boasts several key strengths, including its large sample size, multivariate regression analyses, and comparisons with international DRLs ensure statistical reliability and contextual relevance. By focusing on pediatric patients, a particularly vulnerable population, the study addresses a critical gap in low-resource settings.

Study, however, is not without limitations; being retrospective in nature, it relies on the availability and quality of the secondary data. Single-center scope restricts the generalizability of the findings to broader settings within Tanzania or the region. Absence of long-term follow-up data limits the ability to evaluate potential radiation-induced health effects.

Conclusion

CTDIvol ranged 29.6–44.9mGy, DLP 593–1120mGy·cm, with effective doses highest in infants (6.5mSv) compared to adolescents (2.4mSv). Optimizing protocols through pediatric-specific parameter adjustments, expanding MRI/ultrasound access, and staff training are critical next steps for improving pediatric radiation safety at KCMC.

Recommendations

There is an urgent need to establish standardized pediatric CT protocols at KCMC, with adjustments based on age and weight to optimize radiation dose. Ongoing professional development and training for radiology staff in pediatric radiation safety and dose modulation techniques should be prioritized. Where resources allow, the adoption of advanced imaging technologies such as automated dose modulation and iterative reconstruction software is strongly recommended.

Clinician awareness and greater use of alternative modalities such as ultrasound or MRI should also be promoted, particularly for non-urgent neurological conditions, to minimize unnecessary radiation exposure. At the policy level, the development of national pediatric DRLs tailored to local imaging practices is essential to ensure safe and effective diagnostic imaging.

Finally, prospective multicenter studies with long-term follow-up are needed to better characterize radiation-related risks and guide best practices for pediatric CT imaging in Tanzania and other low-resource settings.

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