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ENHANCING RADIATION SAFETY AND JUSTIFICATION OF IMAGING IN PEDIATRIC CHEST RADIOGRAPHY: INSIGHTS FROM A TERTIARY HOSPITAL IN TANZANIA

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ABSTRACT

Objectives: This study focuses on the critical "Justification and Optimization" principles of radiation protection during pediatric chest X-ray (CXR) examinations, the most common radiographic procedure, to reduce unnecessary ionizing radiation exposure and enhance safety protocols. Given that children are particularly vulnerable to the long-term biological effects of ionizing radiation, such as cancer and hereditary conditions, this research evaluates the application of these principles at a tertiary hospital in Tanzania.

Methods: A hospital-based, cross-sectional study was conducted on 320 pediatric patients who underwent AP/PA CXR examinations over six months. The "justification" of CXR requests was assessed by comparing them with the "European Radiology and Nuclear Medicine Pediatric Imaging Referral Guideline." The "optimization" of radiation protection was evaluated using six radiographic criteria: X-ray beam projection, collimation, rotation, console exposure parameters, repeated examinations, and the use of thyroid and abdominopelvic shielding. The study used frequencies, percentages, measures of central tendencies, Pearson Chi-square test, logistic regression, t-tests, and ANOVA for data analysis, with significance set at $p<0.05$, all conducted using SPSS version 29.0.

Results: Among the 320 participants, 57.2% were male, with the majority aged 1-5 years (41.9%), and a mean age of 3.2 years ± 1.6. Clinically unjustified CXR requests accounted for 36.6%, predominantly from outpatient departments (82.9%). Optimization failures were observed in AP projection (79.7%), collimation (69.7%), and rotation (63.8%) of the exams, particularly in children under five years old. Additionally, 11.6% of the CXR exams were unnecessarily repeated, and 36.9% did not meet optimal console exposure settings. No thyroid or abdominopelvic shielding was used in any examination.

Conclusion: The findings reveal that approximately one-third of pediatric CXR exams were unjustified, and many were conducted using suboptimal techniques, highlighting the urgent need to strengthen the implementation of justification and optimization principles in pediatric radiography.

الخلاصة

الأهداف: تركز هذه الدراسة على مبادئ "التبرير والتحسين" الأساسية لحماية الأطفال من الإشعاع أثناء فحوصات الأشعة السينية للصدر، والتي تُعد أكثر الإجراءات الإشعاعية شيوعًا، بهدف تقليل التعرض غير الضروري للإشعاع المؤين وتعزيز بروتوكولات السلامة. نظرًا لأن الأطفال معرضون بشكل خاص للآثار البيولوجية طويلة الأمد للإشعاع المؤين، مثل السرطان والاضطرابات الوراثية، فإن هذا البحث يقيّم تطبيق هذه المبادئ في مستشفى تخصصي في تنزانيا.

الطرق: تم إجراء دراسة مقطعية في المستشفى على 320 مريضًا من الأطفال الذين خضعوا لفحوصات الأشعة السينية الأمامية والخلفية للصدر على مدى ستة أشهر. تم تقييم "مبرر" طلبات الأشعة السينية بمقارنتها بإرشادات "التصوير الطبي للأطفال من قبل قسم الأشعة والطب النووي الأوروبي". كما تم تقييم "تحسين" الحماية من الإشعاع باستخدام ستة معايير إشعاعية: نوع إسقاط الأشعة السينية، توجيه الحزمة، الانحراف، إعدادات تعرض الكونسول، تكرار الفحوصات، واستخدام واقيات الغدة الدرقية ومنطقة الحوض والبطن. استخدمت الدراسة التكرارات والنسب المئوية وقياسات النزعة المركزية واختبار كاي-تربيع بيرسون والانحدار اللوجستي واختبارات t وتحليل التباين (ANOVA)لتحليل البيانات، مع تحديد مستوى الدلالة عند$p<0.05$ ، وتم إجراء التحليل باستخدام برنامج SPSS الإصدار 29.0.

النتائج: من بين 320 مشاركًا، كانت نسبة الذكور 57.2%، وكان معظمهم تتراوح أعمارهم بين 1-5 سنوات (41.9%)، بمتوسط عمر 3.2 سنوات ± 1.6. شكلت الطلبات غير المبررة سريريًا للأشعة السينية نسبة 36.6%، معظمها من أقسام العيادات الخارجية (82.9%). لوحظت إخفاقات في التحسين في إسقاط الأشعة الأمامية (79.7%)، وتوجيه الحزمة (69.7%)، والانحراف (63.8%) من الفحوصات، خاصةً بين الأطفال دون سن الخامسة. بالإضافة إلى ذلك، تم تكرار 11.6% من فحوصات الأشعة السينية دون ضرورة، ولم تلتزم 36.9% من الفحوصات بمستويات التعرض المثلى. لم يتم استخدام واقيات الغدة الدرقية أو منطقة الحوض والبطن في أي من الفحوصات.

الاستنتاج: تكشف النتائج أن حوالي ثلث فحوصات الأشعة السينية للأطفال كانت غير مبررة، وتم تنفيذ العديد منها باستخدام تقنيات دون المستوى المطلوب، مما يبرز الحاجة الملحة لتعزيز تنفيذ مبادئ التبرير والتحسين في التصوير الإشعاعي للأطفال.

Keywords: Justification, Optimization, Ionizing, Radiation, Chest, X-Ray, Pediatric, Tanzania.

1. INTRODUCTION

Pediatric imaging modalities that use ionizing radiation, which includes chest X-ray (CXR), are crucial for diagnosis, therapy monitoring, and treatment planning. However, ionizing radiation causes two main effects, one stochastic effect, with no threshold, damaging cell's deoxyribonucleic acid (DNA), increasing mutation and cancer risk, hereditary effects and reduced immunity, probabilistically with dose. Two is deterministic effects, which have a threshold, once exceeded causing direct tissue damage and non-cancer diseases (examples skin erythema, cataracts etc.) For a given dose of X-ray radiation, children are at a higher risk of adverse effects compared to adults due to their increased lifetime vulnerability to exposure [1, 2].

In Tanzania and other similar settings, the practice of X-ray imaging often lacks standardized protocols and quality assurance programs, leading to a higher incidence of unnecessary or sub-optimal imaging procedures. This context underscores the importance of applying the principles of justification and optimization to raise awareness about unnecessary X-ray imaging and sub-optimal techniques during imaging, which is vital for developing protective measures to minimize radiation-related health impacts, especially for children [3, 4].

The justification principle asserts that any use of ionizing radiation must be medically warranted, with the procedure's benefits clearly outweighing the potential risks to the patient, ensuring that the procedure's necessity aligns with its diagnostic mission. This can be achieved by using standardized imaging referral guidelines [5]. The optimization principle emphasizes that imaging procedures should be conducted using proper design, equipment selection, installation, and daily radiographic techniques, ensuring that radiation doses are kept as low as reasonably achievable (ALARA) while meeting diagnostic requirements [6]. Optimal use of radiographic techniques includes setting appropriate operating console parameters [kilovoltage peak (kVp), tube current (mA), exposure time (ms), and current-time product (mAs)] [6, 7]. According to international standard criteria, for pediatric chest radiographs, the patient should be positioned either upright or supine, with a suggested radiographic voltage range of 60 - 80 kV (100 - 150 kV with a grid for older children), automatic exposure control set to lateral (preferably none in infants and young children), a tube current of 320-400mA, and an exposure time of less than 10ms. Additionally, it is critical to avoid patient rotation, ensure proper patient positioning, and apply adequate beam collimation and protective shielding of radiosensitive organs, such as thyroid and abdominopelvic shields, during CXR imaging [5, 8].

Global organizations like the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP) provide general guidelines and recommendations to help ensure the appropriate use of radiation. However, overall radiation exposure from medical imaging remains relatively unregulated, especially when compared to radiation exposure in occupational settings [9–11]. In some developed countries, there are well-established specific guidelines and quality assurance programs in place to minimize unjustified or sub-optimal radiation exposure. These regions often have advanced healthcare infrastructure and regulatory bodies overseeing medical imaging practices [11]. In contrast, developing countries, including those in Sub-Saharan Africa like Tanzania, often lack comprehensive data on the practice of justification and optimization principles, resulting in unnecessary procedures or additional radiation exposure.

There is broad consensus that the risks associated with radiation exposure, particularly in pediatric populations, must be carefully evaluated and regulated to ensure that the medical necessity justifies the exposure. Therefore, unjustified imaging requests and sub-optimal radiographic techniques should be discouraged, especially during CXR examinations, which are among the most common imaging procedures. This study aims to address these gaps by investigating the application of justification and optimization principles in pediatric chest radiography at a tertiary hospital in Tanzania, providing essential insights that could inform better practices and policies in similar contexts.

2. MATERIALS AND METHOD

This prospective, hospital-based cross-sectional study, enrolled pediatric participants under 15 years who underwent CXR exams at Muhimbili National Hospital from July to December 2022. The sample size of 320 was determined based on the Kish Leslie formula, using a prevalence estimate of 25% for unnecessary radiation exposures [12], with a 5% error margin at 95% confidence interval (CI). This sample size was chosen to ensure sufficient power to detect significant associations, assuming a moderate effect size. Data was extracted from the hospital's Digital Imaging and Communications in Medicine (DICOM) system. A structured data collection tool was used to record demographic data, clinical information from CXR imaging requests, as well as radiographic parameters from raw (unprocessed) digital CXR images of each participant.

For the 'justification principle,' CXR requests were deemed 'justified' if the clinical information provided by clinicians matched the standardized "referral guideline for imaging in pediatrics" from European Radiology and the UK Royal College of Radiologists [13]. The use of European guidelines was justified due to the lack of locally developed standards in Tanzania, making these widely recognized international guidelines the most appropriate benchmark available. Requests lacking sufficient clinical information or not meeting guideline criteria were categorized as 'unjustified.'

For the 'optimization principle,' six CXR radiographic parameters were reviewed and compared to established international standards, as summarized in (Table 1). To ensure consistency and reliability of data collection, all data collectors underwent training and calibration sessions prior to the study, where they were instructed on the use of the data collection tools and criteria for evaluation. This was done to minimize inter-observer variability and ensure that all data were collected uniformly.

The study excluded participants with lateral CXR exams, as these are rarely performed. Combined chest-abdomen X-rays, thoracic deformities, and patients requiring cervical spine or trachea evaluations were also excluded to ensure consistency and accuracy in the findings.

Data analysis was conducted using SPSS version 29.0 after ensuring data quality. Socio-demographic characteristics, the proportion of unjustified CXR requests, and the proportion of suboptimal radiographic techniques were summarized using frequencies, percentages, and measures of central tendencies. Associations were assessed using Pearson Chi-square, logistic regression, and two-independent samples test (Mann-Whitney U Test). Statistical test for normality of data (Shapiro-Wilk test) was done before proceeding with two-independent samples test. The logistic regression model predicted the probability of "unjustified imaging requests" based on department, age group, and gender, assuming linearity of the log-odds, independence of observations, no multicollinearity, and no influential outliers. Statistical significance was set at $p < 0.05$, with odds ratios and 95% CI calculated where applicable.

Table 1 Data Collection Methods for Assessing the Optimization of Radiation Protection in Pediatric CXR Imaging.

Radiographic Criteria	Method of Data Collection
Type of Beam Projection	Determined by assessing whether the CXR image was labeled as AP or PA. PA was recorded as "optimal" and AP as "sub-optimal."
Operating Console Exposure Parameters	Each parameter (tube voltage, tube current, exposure time, and time-current product) was compared to European diagnostic reference levels for pediatric CXR imaging [14].
X-ray Beam Collimation (with Adequate Coverage)	Evaluated using the Minimum Field Size (MinFS) as per the European Guidelines for AP/PA chest X-rays [15].
No Rotation	Assessed by ensuring equal distances between the spine and both sternoclavicular joints on the CXR image, as outlined in European guidelines [15].
Shielding of Radiosensitive Organs	Determined by checking for the use of thyroid and abdominal shielding tools during the CXR.
Repeat CXR Examinations	Recorded by reviewing patient records to identify repeat examinations due to previous sub-optimal techniques.

3. RESULTS

3.1 Baseline and Demographic Characteristics of Study Participants

The study sample included 137 (42.8%) female and 183 (57.2%) male participants, totaling 320 children (Figure 2). The age range was from 1 day to 14 years, with a mean age of 3.2 years (SD=1.5 years). Most participants, 134 (41.9%), were in the 1-5 years age group, followed by the <1 year age group with 113 (35.3%). The 6-10 years and 11-15 years age groups comprised 42 (13.4%) and 31 (9.4%) participants, respectively. Out of the total participants referred to the radiology department for CXR examinations, 221 (69.1%) were from the outpatient department (OPD) and 99 (30.9%) were from the inpatient department (IPD).

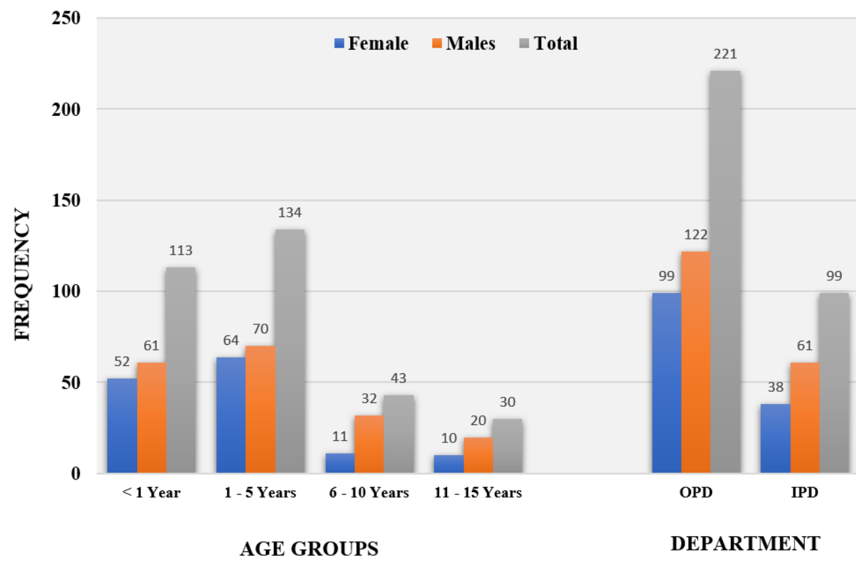


Figure 1 Frequency Distribution by Gender, Age, and Referring Department Among Children Undergoing CXR Exams at MNN, July-December 2022.

3.2 Justification of Imaging Requests

As shown in (Table 2), out of 320 CXR examinations, 203 (63.4%) were justified based on the imaging referral guidelines, while 117 (36.6%) were unjustified. Among the unjustified requests, 60 (51.3%) lacked sufficient clinical information, and 57 (48.7%) did not align with the specific referral guidelines for pediatric CXR imaging. The odds of an unjustified request originating from OPD were three times higher than from IPD (OR=3.1, 95% CI: 1.8 - 5.4, p<0.001). Differences in justification across age groups and genders were observed but were not statistically significant.

Table 2 Justification of CXR Imaging Requests and Its Association with Demographic Data Among Children at MNH, July-December 2022.

Variables	Justification Of CXR Requests n (%) Unjustified Requests	Justified Requests	p-value	OR	95%CI
Department					
OPD	97 (43.9%)	124 (56.1%)	< 0.001	3.1	1.8 - 5.4
IPD	20 (20.2%)	79 (79.8%)			
Total	117 (36.6%)	203 (63.4%)			
Age group					
< 1 year	43 (38.1%)	70 (61.9%)	0.688		
1-5 years	48 (35.8%)	86 (64.2%)			
6-10 years	12 (28.6%)	30 (71.4%)			
11-15 years	14 (45.2%)	17 (54.8%)			
Total	117 (36.6%)	203 (63.4%)			
Gender					
Female	47 (34.3%)	90 (65.7%)	0.272		
Male	70 (38.3%)	113 (61.7%)			
Total	117 (36.6%)	203 (63.4%)			
Optimization of Radiographic Techniques					

a. Type of CXR Beam Projection

(Table 3) shows that the majority of CXR examinations (255; 79.7%) were performed using the anteroposterior (AP) projection, particularly among participants under five years old. A smaller proportion (65; 20.3%) used the posteroanterior (PA) projection. The AP projection was significantly more common across all age groups, with younger children more likely to receive an AP projection (mean age= two years, SE=0.19) compared to those receiving a PA projection (mean age=7.6 years, SE=0.50) (p<0.001).

Radiographic Technical Criteria (N=320)	Frequency n (%)	Age (Years) Mean (SE)	Mann-Whitney U-Test β p-value
Type of beam projection			
AP	255 (79.7%)	2.0 (0.2)	< 0.001
PA	65 (20.3%)	7.6 (0.5)	
Rotation (N=320)			
Yes	204 (63.8%)	1.8 (0.2)	< 0.001
No	116 (36.2%)	5.5 (0.4)	
X-ray beam collimation			
Optimal	97 (30.3%)	5.8 (0.4)	< 0.001
Sub-optimal	223 (69.7%)	2.1 (0.2)	
Application of radiation shielding tools			
Applied	0 (0.0%)	0	NA*
Not applied	320 (100%)	3.2 (0.2)	
Repeat CXR examinations			
Repeat	37 (11.6%)	1.6 (0.5)	0.005
No repeat	283(88.4%)	3.4 (0.2)	
Console exposure parameters (kVp, mA & ms)			
Optimal	202 (63.1%)	1.6 (0.2)	< 0.001
Sub-optimal	118 (36.9%)	5.8 (0.5)	

Table 3 Distribution of Radiographic Technique Optimization and Its Association with Age Among Children Undergoing CXR Imaging at MNH, July-December 2022.

β The Mann-Whitney U Test was applied after the Shapiro-Wilk test for normality indicated that data didn't follow a normal distribution.
*Due to the consistent lack of shielding, no statistical analysis was computed for this variable.

b. Rotation

Rotation was observed in 204 (63.8%) of CXR images, while 116 (36.2%) images showed no rotation. As depicted in (Table 3) and (Figure 2), patients with rotation were significantly younger (mean age=1.8 years, SE=0.21) than those without rotation (mean age = 5.5 years, SE=0.41) (p<0.001).

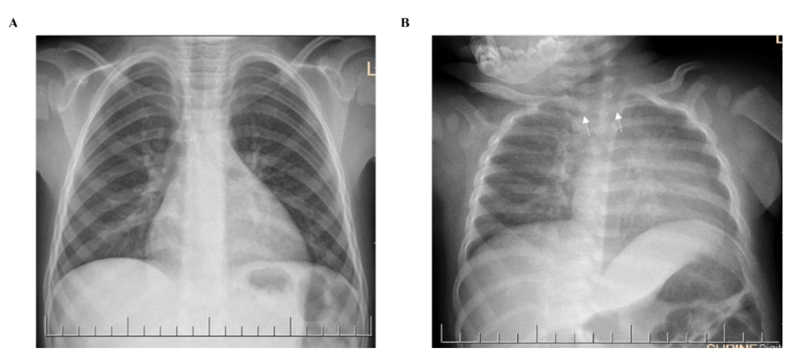
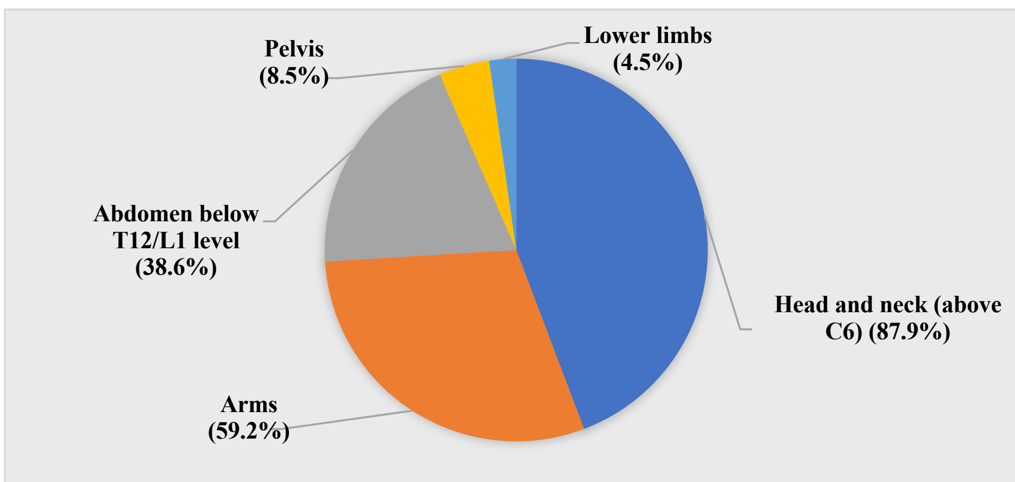


Figure 2

A PA CXR image of a 4-year-old boy showing no rotation, as indicated by equal distances between the medial ends of the clavicles and the spinous process. B AP CXR image of a 9-month-old baby displaying leftward rotation, evidenced by an increased distance between the medial end of the left clavicle and the spinous process compared to the right side (arrows).

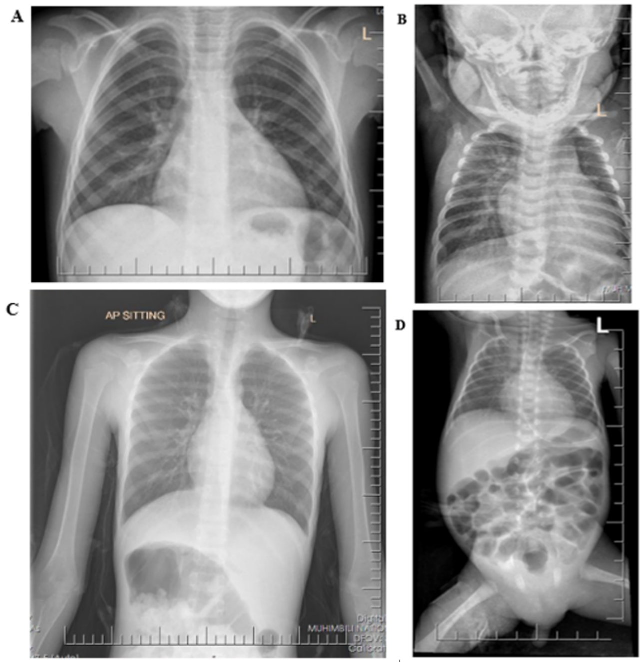
c. X-Ray Beam Collimation

As shown in (Table 3), optimal beam collimation was observed in 97 (30.3%) CXR examinations, while 223 (69.7%) showed sub-optimal collimation, particularly among children under five years old. Participants with optimal collimation were significantly older (mean age=5.8 years, SE=0.48) compared to those with sub-optimal collimation (mean age=2.1 years, SE=0.2) ($p<0.001$). Among the 223 radiographs with sub-optimal collimation, one or more body regions were unnecessarily exposed to radiation. The most frequently irradiated areas were the head and neck (87.9%), arms (59.2%), and abdomen below the T12/L1 level (38.6%) (Figure 3) and (Figure 4).



Distribution of Unnecessarily Exposed Body Parts in 223 Poorly Collimated Pediatric CXR Radiographs at MNH, July-December 2022. Note: Multiple body parts may be exposed in a single radiograph.

Figure 3



A PA CXR image of a 4-year-old boy demonstrating collimation within the recommended MinFS standards. B Poorly collimated AP CXR image of an 8-month-old baby with unnecessary exposure of the head. C CXR image of a 9-year-old showing unsatisfactory collimation, resulting in exposure of the chin, neck, arms, and abdomen. D Poorly collimated AP CXR image of an infant with unnecessary exposure of the chin, neck, abdomen, pelvis, gonads, and thighs.

Figure 4

d. Repeat CXR Examinations

Following previous imaging errors, 37 (11.6%) CXR examinations were repeated. Participants with repeated CXR examinations were significantly younger (mean age=1.6 years, SE=0.48) than those with no repeated examinations (mean age=3.4 years, SE=0.24) (p=0.005). The primary reason for repeating CXR exams was rotation errors (69.1%), followed by poor collimation (20.3%) and inadequate preparation (8.1%). These findings are illustrated in (Figure 5) and (Figure 6).

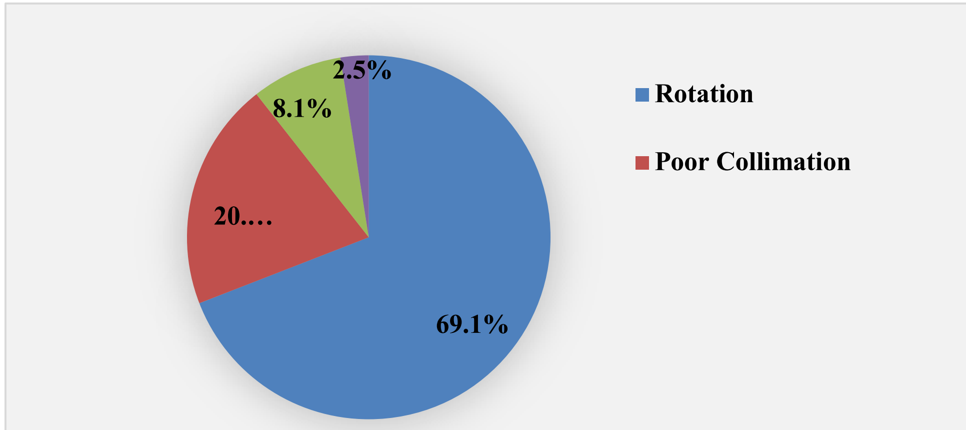
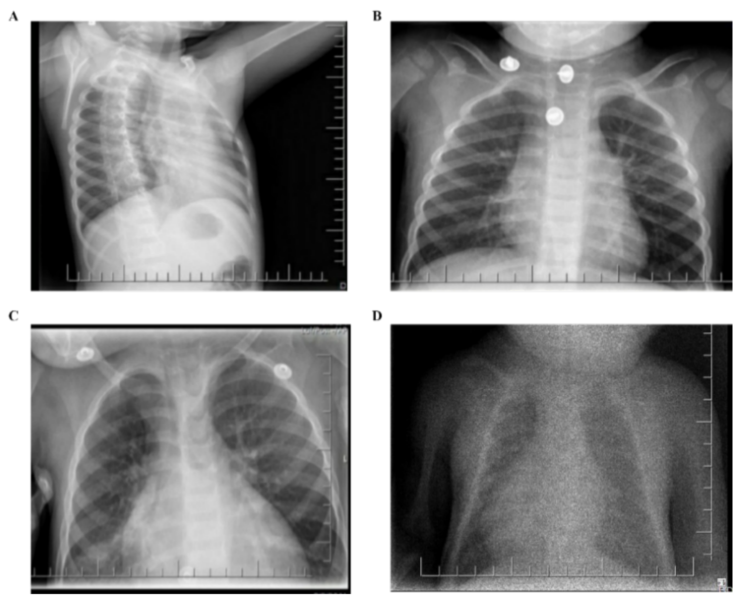


Figure 5 Percentage Distribution of Causes for 37 Repeated Pediatric CXR Examinations at MNH, July-December 2022.



A Rotated CXR image of a 3-year-old boy. B CXR image of a 2-year-old boy showing poor imaging due to radiopaque clothing material (collar buttons) caused by inadequate patient preparation. C Poorly collimated AP CXR image of a 6-year-old girl, with the inferior heart border, lower lung zones, and both costophrenic and cardiophrenic angles excluded. D Low-quality CXR image of a 4-week-old baby with significant noise. All four CXR examinations were repeated due to diagnostic uncertainty.

Figure 6

e. Application of Radiation Shielding Tools

None of the CXR examinations implemented thyroid or abdominal radiation shielding measures. Due to the consistent lack of shielding, no statistical analysis was conducted for this variable (Table 3).

f. Console Exposure Parameters

As detailed in (Table 3), optimal radiographic exposure parameters were used in 202 (63.1%) of CXR examinations, while 118 (36.9%) used sub-optimal values. Younger participants were more likely to receive optimal exposure values (mean age=1.6 years, SE=0.15) compared to older participants (mean age=5.8 years, SE =0.46) ($p<0.001$). Table 4 presents the range of exposure parameters used during CXR examinations, including 55.0-125.0 kVp, 251.6-2075.0 mA, 0.7-71.9 ms, and 0.8-20.7 mAs, compared to the recommended European guidelines of 60-80 kVp for voltage, 320-400 mA for tube current, <10 ms for exposure time, and <4 mAs for current-time product.

Table 4 Console Exposure Parameters for Pediatric Chest Radiography at MNH, July-December 2022, Compared to European Guideline Recommendations for Diagnostic Radiographic Image Quality.

	CXR Exposure Parameters (at MNH, July-Dec 2022)		European Guideline Recommendations
	Mean (+/-SD)	Range	
Voltage (kVp)	80.0 (23.9)	55.0 - 125.0	60 – 80kv
Tube current (mA)	532.2 (321.9)	251.6 - 2075.0	320 – 400mA
Exposure time (ms)	7.5 (8.6)	0.7 - 71.9	< 10ms
Current-time product (mAs)	3.2 (4.2)	0.8 - 20.7	< 4mAs*

*Optimal current-time product (mAs) depends on individual optimal values of tube current and exposure time.

4. DISCUSSION

This cross-sectional, hospital-based study evaluated the "justification" and "optimization" principles of radiation protection for pediatric patients undergoing CXR examinations at Muhimbili National Hospital over six months. Given the frequency of CXRs in children, who are more vulnerable to the lifelong effects of ionizing radiation, protecting them from unnecessary exposure is crucial. Our study included 320 participants under the age of 15 years, with the majority being aged between 1 to 5 years and an average age of 3.2 years. The higher number of males than females in the study is consistent with similar studies in the region.

Regarding the justification principle, approximately 37% of CXR examinations were unjustified, raising significant concerns about unnecessary X-ray requests for children. This finding aligns with other studies, where the proportion of unjustified CXR requests ranges from 20% to 77%, depending on the facility and the use of imaging referral guidelines [5, 16, 17]. The non-use of standardized imaging referral guidelines and the absence of sufficient clinical information in imaging requests were key reasons for unjustified examinations in our study. This is consistent with research from other countries, where poorly documented clinical information complicates the justification process. A study from the UK found that using imaging referral guidelines significantly improved justification rates [5, 18–22].

Unjustified CXR examinations were more common in outpatient settings than in inpatient ones, a trend observed in similar studies from Greece and the USA [15, 16, 22 ,24]. This could be due to limited access to patient records, time constraints, and reduced supervision by radiology professionals in outpatient departments. These findings suggest a need for targeted interventions in outpatient settings to reduce unnecessary imaging.

Concerning the optimization principle, our study found that the anteroposterior (AP) projection was predominantly used for CXR exams across all ages, consistent with the literature [9, 25]. AP CXRs expose juvenile breast and thyroid tissues to more radiation, while posteroanterior (PA) projections minimize magnification and reduce radiation doses to these sensitive areas by about 99% [26]. However, PA projection is less common in pediatric practice due to challenges with positioning uncooperative young children [9, 25].

Rotation was observed in 63.7% of radiographs, which can cause diagnostic uncertainty and lead to unnecessary repeat imaging. This proportion is higher compared to various studies, and variations in CXR rotation across facilities may be due to differences in radiographers' skills, equipment condition, patient cooperation, and the use of immobilizing devices [25, 27–29]. These findings highlight the need for improved training and the use of immobilization tools to reduce rotation during imaging.

Poor X-ray beam collimation, which was observed in about 70% of pediatric CXR radiographs, is a significant source of unnecessary radiation doses [30]. This finding is consistent with studies from Iran, Israel, and Austria but lower than in a Nigerian study [12, 31, 32]. The higher prevalence of poor collimation among children under 1 year old may be due to their restlessness and difficulty following instructions during X-ray procedures. This issue underscores the need for enhanced techniques and possibly more personnel to assist with pediatric imaging.

The lack of thyroid and abdominal shielding devices in all the radiographs is concerning, especially since these shields can reduce radiation exposure by up to 99% [12, 33, 34]. Similar studies have found that many CXR exams do not utilize shielding devices, even when available [12]. The reasons for this may include a lack of awareness among radiology professionals about the importance of shielding, limited availability of appropriate tools, and practical challenges in implementing these measures during pediatric imaging [12, 35]

Regarding the optimization of X-ray console exposure parameters, around 37% of the total CXR images did not adhere to optimal values for at least one of the three console exposure parameters (tube voltage, tube current, or exposure time), as recommended by European guidelines [14]. Using suboptimal exposure settings can compromise image quality and increase the likelihood of repeat exams, further exposing patients to unnecessary radiation [36]. Potential reasons for suboptimal exposure values include inadequate training, equipment calibration issues, and reliance on automatic technique selection without proper adjustments [26].

Unnecessary radiation exposure from repeat CXR examinations due to previous technical errors was observed in 12% of cases, which is slightly above the 10% threshold reported in the literature for all X-ray procedures [36]. Ideally, repeat exams in a busy healthcare setting should not exceed 5% [26]. In our study, repeat CXR exams were primarily due to rotation, followed by poor collimation and external radiopaque materials (e.g., clothing) [36, 37]. Addressing these issues through better training and standardizing imaging protocols could help reduce repeat exams.

4.1 Study Limitations and Implications for Policy and Practice

This study has several limitations. As a single-center study, the findings may not be generalizable to all healthcare facilities in Tanzania. However, given that Muhimbili National Hospital serves as a national referral center with extensive coverage of medical services, the findings offer valuable insights into pediatric chest radiography practices at a national level. Additionally, the study did not assess the knowledge and attitudes of clinicians, radiographers, or radiology technologists toward the principles of justification and optimization. This limitation was due to time constraints, financial limitations, and a small sample size.

The implications of this study for policy and practice are significant. The high proportion of unjustified and suboptimal CXR examinations highlights the need for standardized imaging referral guidelines and improved training for radiology professionals in Tanzania. Implementing these changes could reduce unnecessary radiation exposure in children, improve diagnostic accuracy, and enhance overall patient safety. Furthermore, future research should focus on multi-center studies to validate these findings and explore interventions that can address the identified gaps in radiographic practices. Addressing these challenges could lead to more effective and safer radiographic practices, benefiting pediatric patients nationwide.

5. CONCLUSION

The principles of "Justification and Optimization" are fundamental for ensuring radiation protection in pediatric imaging, aiming to achieve necessary diagnostic outcomes while minimizing the associated risks. Our study found that one-third of pediatric chest X-rays (CXRs) were unjustified and many used suboptimal radiographic techniques, underscoring the need for standardized practices in pediatric X-ray imaging. We recommend that healthcare professionals in developing countries like Tanzania adopt standardized referral guidelines and enhance training in optimal radiographic techniques. Policymakers should integrate these guidelines into national protocols to minimize unnecessary radiation exposure. Future research should assess knowledge and awareness of health professionals on radiation protection and the effectiveness of these interventions across multiple centers to improve patient safety and optimize pediatric radiographic practices.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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REFERENCES

[1] White Paper: Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging FDA. https://www.fda.gov/radiation-emitting-products/initiative-reduce-unnecessary-radiation-exposure-medical-imaging/white-paper-initiative-reduce-unnecessary-radiation-exposure-medical-imaging. Accessed 14 Aug 2024

[2] Goodman TR, Mustafa A, Rowe E (2019) Pediatric CT radiation exposure: where we were, and where we are now. Pediatr Radiol 49:469–478. https://doi.org/10.1007/S00247-018-4281-Y/TABLES/2

[3] Roobottom CA, Mitchell G, Morgan-Hughes G (2010) Radiation-reduction strategies in cardiac computed tomographic angiography. Clin Radiol 65:859–867. https://doi.org/10.1016/J.CRAD.2010.04.021

[4] Brody AS, Frush DP, Huda W, et al (2007) Radiation Risk to Children From Computed Tomography. Pediatrics 120:677–682. https://doi.org/10.1542/PEDS.2007-1910

[5] Ebdon-Jackson S, Frija G (2021) Improving justification of medical exposures using ionising radiation: considerations and approaches from the European Society of Radiology. Insights Imaging 12:1–11. https://doi.org/10.1186/S13244-020-00940-0/METRICS

[6] Do KH (2016) General Principles of Radiation Protection in Fields of Diagnostic Medical Exposure. J Korean Med Sci 31:S6–S9. https://doi.org/10.3346/JKMS.2016.31.S1.S6

[7] Narendran N, Luzhna L, Kovalchuk O (2019) Sex difference of radiation response in occupational and accidental exposure. Front Genet 10:427795. https://doi.org/10.3389/FGENE.2019.00260/BIBTEX

[8] Sodhi KS, Krishna S, Saxena AK, et al (2015) Clinical application of 'Justification' and 'Optimization' principle of ALARA in pediatric CT imaging: "How many children can be protected from unnecessary radiation?" Eur J Radiol 84:1752–1757. https://doi.org/10.1016/J.EJRAD.2015.05.030

[9] Khong PL, Ringertz H, Donoghue V, et al (2013) ICRP PUBLICATION 121: Radiological Protection in Paediatric Diagnostic and Interventional Radiology. Ann ICRP 42:1–63. https://doi.org/10.1016/J.ICRP.2012.10.001

[10] Brenner DJ, Hricak H (2010) Radiation Exposure From Medical Imaging: Time to Regulate? JAMA 304:208–209. https://doi.org/10.1001/JAMA.2010.973

[11] Nuclear Law. https://doi.org/10.1007/978-94-6265-495-2

[12] Karami V, Zabihzadeh M, Gilavand A (2016) Survey of the Use of X-ray Beam Collimator and Shielding Tools during Infant Chest Radiography

[13] Hooghe L (2001) The European Commission and the integration of Europe: images of governance

[14] Tschauner S, Marterer R, Gübitz M, et al (2016) European Guidelines for AP/PA chest X-rays: routinely satisfiable in a paediatric radiology division? Eur Radiol 26:495–505. https://doi.org/10.1007/S00330-015-3836-7/FIGURES/6

[15] Triantopoulou C, Tsalafoutas I, Maniatis P, et al (2005) Analysis of radiological examination request forms in conjunction with justification of X-ray exposures. Eur J Radiol 53:306–311. https://doi.org/10.1016/J.EJRAD.2004.02.012

[16] Street M, Brady Z, Van Every B, Thomson KR (2009) Radiation exposure and the justification of computed tomography scanning in an Australian hospital emergency department. Intern Med J 39:713–719. https://doi.org/10.1111/J.1445-5994.2009.01956.X

[17] Akintomide AO, Ikpeme AA, Ngaji AI, et al (2015) An audit of the completion of radiology request forms and the request practice. J Family Med Prim Care 4:328. https://doi.org/10.4103/2249-4863.161308

[18] Weissman A, Solano M, Taeymans O, et al (2015) A SURVEY OF RADIOLOGISTS AND REFERRING VETERINARIANS REGARDING IMAGING REPORTS. Vet Radiol Ultrasound 57:124–129. https://doi.org/10.1111/VRU.12310

[19] Chilanga CC, Olerud HM, Lysdahl KB (2022) The value of referral information and assessment – a cross sectional study of radiographers' perceptions. BMC Health Serv Res 22:1–9. https://doi.org/10.1186/S12913-022-08291-W/FIGURES/3

[20] The Development and Impact of Referral Guidelines: https://healthmanagement.org/c/imaging/issuearticle/the-development-and-impact-of-referral-guidelines. Accessed 14 Aug 2024

[21] Tay YX, Foley S, Killeen R, et al (2024) Impact and effect of imaging referral guidelines on patients and radiology services: a systematic review. Eur Radiol 1–10. https://doi.org/10.1007/S00330-024-10938-7/FIGURES/1

[22] Malone J, Guleria R, Craven C, et al (2012) Justification of diagnostic medical exposures: some practical issues. Report of an International Atomic Energy Agency

Consultation. British Journal of Radiology 85:523–538. https://doi.org/10.1259/BJR/42893576

[23] Vartanians VM, Sistrom CL, Weilburg JB, et al (2010) Increasing the Appropriateness of Outpatient Imaging: Effects of a Barrier to Ordering Low-Yield Examinations 1. https://doi.org/101148/radiol10091228 255:842–849. https://doi.org/10.1148/RADIOL.10091228

[24] Waite S, Scott JM, Legasto A, et al (2017) Systemic error in radiology. American Journal of Roentgenology 209:629–639. https://doi.org/10.2214/AJR.16.17719/ASSET/IMAGES/LARGE/09_16_17719_08_CMYK.JPEG

[25] Triantopoulou C, Tsalafoutas I, … PM-E journal of, 2005 undefined Analysis of radiological examination request forms in conjunction with justification of X-ray exposures. Elsevier

[26] Bushong S (1988) Radiologic science for technologists

[27] Chand R, Thapa N, Paudel S, et al (2013) Evaluation of image quality in chest radiographs. nepjol.infoRB Chand, N Thapa, S Paudel, GB Pokharel, BR Joshi, DK PantJournal of Institute of Medicine Nepal, 2013•nepjol.info 35:1

[28] Mahmoudabadi A, Moghadam M, … MS-BM, 2018 undefined (2018) Improving the quality of positioning and reducing the rotation factor during pediatric portable chest radiography using infant immobilizer. researchgate.netA Mahmoudabadi, MS Moghadam, M Sajjadi, M Shams, L AmeriBali Medical Journal, 2018•researchgate.net 7:420–425. https://doi.org/10.15562/bmj.v7i2.737

[29] Lacey G De, Morley S, Berman L (2012) The chest X-ray: a survival guide

[30] Mark M, Okeji C, Angel M, et al (2010) Radiation exposure from diagnostic radiography: an assessment of X-ray beam collimation practice in some Nigerian Hospitals. ajol.infoMC Okeji, AM Anakwue, K AgwunaInternet Journal of Medical Update-EJOURNAL, 2010•ajol.info 5:31–33

[31] Datz H, Ben-Shlomo A, … DB-R protection, 2008 undefined The additional dose to radiosensitive organs caused by using under-collimated X-ray beams in neonatal intensive care radiography. academic.oup.comH Datz, A Ben-Shlomo, D Bader, S Sadetzki, A Juster-Reicher, K Marks, T SmolkinRadiation protection dosimetry, 2008•academic.oup.com

[32] Debess J, Johnsen K, Sørensen K, Thomsen H (2015) Digital chest radiography: collimation and dose reduction

[33] Hawking N, technology TS-R, 2013 undefined Decreasing radiation exposure on pediatric portable chest radiographs. search.ebscohost.comNG Hawking, TD SharpRadiologic technology, 2013•search.ebscohost.com

[34] Karami V, Zabihzadeh M, Pediatrics MG-… J of, 2016 undefined (2016) Dose reduction to the thyroid gland in pediatric chest radiography. eprints.lums.ac.irV Karami, M Zabihzadeh, M Gholami, N Shams, Z Fazeli NezhadInternational Journal of Pediatrics, 2016•eprints.lums.ac.ir. https://doi.org/10.22038/ijp.2016.7081

[35] sciences SK-J of medical radiation, 2014 undefined (2014) A paediatric X-ray exposure chart. Wiley Online LibrarySP KnightJournal of medical radiation sciences, 2014•Wiley Online Library 61:191–201. https://doi.org/10.1002/jmrs.56

[36] Dunn M, Radiography AR-, 1998 undefined X-ray film reject analysis as a quality indicator. Elsevier

[37] Ofori E, Antwi W, Arthur L, et al Analysis and economic implications of X-ray film repeat/reject in selected hospitals in Ghana. journals.lww.com