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Entrance Surface Dose from Pediatric Diagnostic X-ray Examinations in a Developing World Setting: Are We 'ALARA Principle' Compliant?

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Authors' contributions

Author OMA conceived the study idea, designed the study, wrote the protocol, and proof read the drafts of the manuscript. Author BIA did the quality control measurement of x-ray unit, performed the statistical analysis, managed the analyses of the study and did literature search. Author AJA managed the literature searches wrote the introduction, part of methodology and discussion. Author OS did the data collection and wrote the methodology. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Background: Radiation protection in paediatric radiology requires special attention than in adult because children are more sensitive to radiation and at higher risk. This risk is explained by the longer life expectancy in children which allows for harmful effects of radiation to manifest and their developing organs and tissues being more sensitive to radiation. Hence, the need for determination of appropriate radiation dose for paediatric patients.
Aims: To estimate entrance skin dose (ESD) received by paediatric patients during diagnostic x-ray examinations.
Materials and Methods: A total of 253 paediatric patients undergoing various x-ray examinations between June 2011 and December, 2012 in a teaching hospital in the South West Nigeria were considered in this study. This hospital has no dedicated x-ray

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unit for paediatric radiology. The ESD received during x-ray examination was calculated using mathematical formula that incorporated the use of x-ray beam output and exposure parameters selected for the examination. Correlation coefficient (r) analysis was used to test the relationship between ESD, patient size (age and weight) and exposure parameters (kVp, mAs).
Results: The ESD and ED received by paediatric patients from all the x-ray examinations considered in this study ranged from 10.29 ± 3.80 - 880.04 ± 89.44 μGy and 1.44 ± 0.53 - 66.74 ± 30.84 μSv respectively. The correlation coefficient analysis at 0.01 level of significant showed that there is a correlation between patient dose and *exposure factors but there is no correlation between ESD, age and weight of patients.*
Conclusion: The ESD received by paediatric patients is higher than the internationally recommended reference dose. This is attributed to lack of dedicated x-ray unit and personnel for paediatric radiology.

Keywords: Paediatric; X-ray examinations; entrance skin dose; radiation protection.

1. INTRODUCTION

The prevention of the potential hazardous effect of ionizing radiation has been a critical focus and great concern despite thein valuable contribution of ionizing radiation in medical imaging to diagnosis and subsequent treatment of various disease entities [1].

Radiation exposure, either from radiation accident or medical x-ray examination at the early stage of life usually results in a likelihood of two or three fold increase in lifetime risk for certain detrimental effects, including solid cancer, compared with that of adult [2,3].

Radiation protection in pediatric radiology requires special attention than in adult radiology because children are more sensitive to radiation and at higher risk than adults [4]. The higher risk is due to longer life expectancy in children for any harmful effects of radiation to manifest and the fact that developing organs and tissues are more sensitive to the effects of radiation [5]. To prevent the detrimental effects of ionizing radiation, several international bodies on radiation protection have strictly stipulated three fundamental principles as the bedrock of sound radiological protection, namely justification, optimization, and the application of dose limits. They've also provided a range of reference dose in all population, including pediatric age group [6-12].

It is known that patient doses from x-ray examinations vary widely, even for the same projection [13]. The dose variation may be due to: patient weight, exposure factors, radiological technique, focus to film distance (FFD), film-screen speed, equipment type and processing performance. This variability can be reduced through Quality assurance programme in hospitals and thereby providing Diagnostic Reference dose levels for various radiological procedures through Entrance Skin Dose (ESD) and effective dose calculations [13].

In Nigeria, most diagnostic x-ray centres do not have dedicated x-ray unit for pediatric patients and X-ray operators sometimes used exposure parameters and radiographic techniques that are not appropriate for children. Although, there is no consensus on the optimal radiographic techniques that could be used on patients, however, if radiographic parameters are optimized, a significant reduction in ESD to patients would be achieved [2].

The estimates of ESD specific to pediatric radiology are very crucial as the skin of children is tender and can easily be damaged by excessive radiation dose. Also, knowledge of entrance skin dose is needed to formulate national diagnostic reference level for optimizing radiation protection of patients in pediatric radiology [14]. Despite the fact that conventional radiographs are one of the most requested diagnostic imaging modality in Nigeria, which may be due to X-ray examination being widely available, cheap and quick to acquire. There is a paucity of studies on diagnostic dose references in Nigeria. Although a legal framework for use of ionization radiation in diagnostic and interventional radiology was established in Nigeria in the year 2003 and updated in 2006 [15,16] and yet there is no national reference dose limits.

The purpose of this study was to assess the exposure parameters selected for x-ray examinations of pediatric patients in a large teaching hospital in the South Western region of Nigeria and to estimate the entrance skin dose (ESD) delivered to pediatric patients during medical x-ray examination. The results of this study will complement the existing few data on pediatric dose from medical x-ray examinations in Nigeria.

2. MATERIAL AND METHODS

This study was performed to estimate, using mathematical method, the entrance skin dose (ESD) received by pediatric patients who were referred for various diagnostic x-ray examinations at the University College Hospital, Ibadan. It is a large teaching hospital in the South Western region of Nigeria and do not have a dedicated x-ray facility for children. A total of 253 children between the ages of 6 months and 15 years, who require medical X-ray examinations for diagnosis of their ailments were selected for this study between June 2011 and December, 2012. The general purpose x-ray unit at the out-patient section of the hospital was considered for this study. This x-ray machine with model number ALO 1F was manufactured in the year 2005 by General Electric (GE) medical system, Kemnath Germany. The x-ray tube has total filtration of 1.0 mm Al at 70 kV and powered by 3-phase type generator. The average daily workload on this x-ray machine was 80 (adults and children) patients.

The quality control checks of exposure parameters (kVp, mA and time) and measurements of beam output of the x-ray machine were performed with Radcal Accu Pro model 9096 manufactured by Radcal Corporation, USA . This measuring device has both kVp divider (Accu-kV) and ionization chamber digitizer (model 10X6-6) connected to an electrometer. The equipment was still under the initial calibration by the manufacturer during this study.

The weight of all patients was measured with a digital weighing scale after taking informed consent from the parent or guardian, using the local language apart from English if need be. Their ages were obtained from the X-ray request cards sent by the clinician for diagnostic examination. Most children who needed support and reassurance during the examination were ably supported by their parents. The operators ensured that according to the laid down routine departmental practice, the parents or guardian had lead jacket on and stayed away from the primary beam of x-ray during the examination.

The film type used for all patients was Kodak while the screen-film speed used for pediatric patients was usually alternated between medium and fast speed screen depending on the operator and available screen. All films were processed using automatic processor.

The diagnostic x-ray examinations performed on pediatric patients were classified into five groups according to the section of the body examined namely, head and neck, upper limb, chest, pelvis and lower limb. The x-ray projections include anterior-posterior (AP), posterior-anterior (PA) and Lateral view.

The use of formula to calculate ESD is less cumbersome when compared with the use of thermo luminescence dosimetry (TLD). In this study, entrance skin doses received by pediatric patients undergoing x-ray examinations were calculated using the formula [4,17].

$$ESD - OP \times (kV/80)^{\wedge}2 \times mAs \times (100/FSD)^{\wedge}2 \times BSF \quad (1)$$

where OP is the beam output in µGy/mAs of the x-ray tube at 80 kV at a distance of 1 m, kV is the tube potential, mAs is the product of tube current (mA) and exposure time (sec), FSD is the focus-to-skin- distance (m) and BSF is the backscatter factor. The value 1.35 was used as BSF in this study [2]. The effective dose(ED) was thereafter calculated from the ESD and the tissue weighting factors published by ICRP 107 report [18].

The data collected were entered and analyzed using SPSS version16. Results were presented in tables of means and standard deviations. The correlation coefficient between variables: patient dose, age, size, weight and exposure factors were tested for significance at 0.01 level.

3. RESULTS

The quality control checks on exposure parameters (kVp, mA and time) of x-ray machines showed that the deviation between setting and measured values were within 2 %. The regression curve plotted between beam output (µGy/mAs) and tube potential (kVp) showed a regression coefficient of 0.9996. Among all the patients considered in this study, there were 144 males (56.9%) and 109 females (43.1%) with ratio 1.3 to 1. Their mean age was 5.5 ± 4.13 years and the median age was 4 years.The demographic pattern of x-ray examinations among pediatric patients is presented in Table 1 and it showed that chest x-ray examination was the highest followed by head and neck examination and pelvic x-ray examination was the least performed. The analysis of x-ray examination performed on patient with respect to sex showed that more females (60%) did pelvic examination.

The weight, height and BMI of all pediatric patients with respect to their ages are presented in Table 1. In all age groups, the minimum weight, height and BMI were 4.08 ± 1.18kg, 44.67 ± 12.60 cm and14.01 ± 1.45kg/m^2 respectively. The maximum weight, height and BMI were 44.80 ± 9.65 kg, 154.80 ± 4.60 cm and 23.77 ± 16.6 kg/m^2.

The mean tube potentials (kVp) and tube loading (mAs) selected for pediatric patients with respect to their ages is presented in Table 2.It can be seen that the mean tube voltage used for different x-ray examinations vary slightly with the age groups. The minimum kVp selected for all age groups was 46.00±1.83 while the maximum kVp was 74.40±6.35. The corresponding tube loading (mAs) is presented in Table 2. The mean tube loading (mAs) used in combination with the tube voltage for different x-ray examinations showed that the mAs used for all x-ray examinations performed on age group less than 1 year were between 3.60 ± 0.57 and 5.13 ± 0.88 . The minimum mAs for all ages was 3.60 ± 0.57 while the maximum value was 23.00±9.80.

Table 1. Demographic pattern of paediatric patients that presented for X-ray examinations

	Examination				
	Head &Neck (N= 57)	Upper limb (N= 26)	Chest (N= 122)	Pelvis (N= 10)	Lower limb (N= 38)
Weight(kg)					
<1yr	6.03±2.17	4.60±0.28	4.97±1.05	-	4.08±1.18
1-5yr	12.54±3.41	14.22±2.68	11.94±3.04	14.36±1.56	11.91±4.42
5-10yr	24.50±1.88	25.43±10.67	20.98±7.06	20.75±4.86	21.06±6.84
10-15yr	44.80±9.65	35.00±7.07	30.06±11.36	27.80±3.35	32.25±4.13
Height(cm)					
<1yr	53.00±10.15	46.00±1.41	62.08±31.49	-	44.67±12.60
1-5yr	86.452±10.6	86.56±22.87	84.73±11.94	89.20±6.46	84.94±13.08
5-10yr	122.25±5.89	125.57±15.62	112.29±20.11	121.00±7.44	114.40±23.51
10-15yr	154.80±4.60	146.00±1.41	137.10±20.32	140.20±12.21	135.74±14.93
BMI(kg/m^2)					
<1yr	21.12±4.39	21.73±0.01	17.77±1.19	-	23.30±11.55
1-5yr	16.65±2.67	23.77±16.6	16.59±2.49	18.36±4.08	16.51±4.63
5-10yr	16.41±0.97	15.50±3.38	16.44±3.24	14.01±1.45	16.30±1.33
10-15yr	18.57±3.13	15.45±3.64	15.60±3.69	14.37±2.77	17.93±4.08

Table 2. kVp and mAs of paediatric patients presenting for X-ray examinations

	Examination				
	Head &Neck (N= 57)	Upper limb (N= 26)	Chest (N= 122)	Pelvis (N= 10)	Lower limb(N= 38)
kVp					
<1yr	61.00±0.00	47.50±3.54	55.33±54.15	-	46.00±1.83
1-5yr	59.78±4.77	47.00±2.96	58.54±5.74	60.00±2.00	50.36±3.56
5-10yr	66.00±6.25	50.29±4.65	61.84±3.60	67.00±4.24	54.36±5.48
10-15yr	74.40±6.35	46.00±0.00	61.83±3.21	69.25±3.30	58.07±5.79
mAs					
<1yr	5.00±0.00	3.60±0.57	5.13±0.88	-	3.89±0.87
1-5yr	6.22±2.60	3.72±1.06	5.48±1.20	6.30±0.00	4.15±0.91
5-10yr	13.80±7.49	5.09±0.94	6.14±1.17	12.00±5.66	4.66±0.63
10-15yr	23.00±9.80	4.00±0.00	6.18±1.32	18.34±5.38	7.25±4.47

The entrance skin dose (µGy) and effective dose (µSv) received from different x-ray examinations by various age groups are presented in Table 3. It showed that children below the age of 1 year received minimum and maximum ESD of 10.29 ± 3.80 µGy and 105.56 µGy respectively from all x-ray examinations. The minimum and maximum effective dose received from head and neck examination by the same age group was 10.59 ± 4.61µSvand 105.56 ± 0.00 µSv respectively. The children in the age group 1-5 year received the lowest mean ESD of 10.06±3.23µGy in the upper limbs and highest mean ESD of 128.18 ± 73.61µGy in the Head and neck examinations. For age groups 5-10 and 10-15, the minimum ESD received for all examinations was 56.36 ± 32.11 500 µGy, while the maximum ranges from mean value was 880.04 ± 89.44µGy. The highest ESD for age group 5 – 10 years was from pelvic examinations while age group 10 -15 year received highest ESD was from head and neck examinations.

The effective dose values of age groups 1-5 years, 5-10 years and 10-15 years were highest in the chest examinations with a mean of 50.20 ± 44.81μSv, 65.17 ± 22.32μSv and 66.74 ± 30.84 μSv respectively.

Table 3. ESD and ED of paediatric patients presenting for X-ray examinations

	Examination				
	Head &Neck (N= 57)	**Upper limb (N= 26)**	**Chest (N= 122)**	**Pelvis (N= 10)**	**Lower limb (N= 38)**
ESD (μGy)					
<1yr	105.56	18.59 ± 4.61	66.14 ± 36.78	-	10.29±3.80
1-5yr	128.18 ±73.61	10.06 ± 3.23	104.58 ± 93.35	102.58±13.43	34.52±19.07
5-10yr	205.26±73.12	36.05±18.54	135.77 ± 46.51	321.76±34.58	56.36±32.11
10-15yr	880.04±89.44	9.34±0.0	139.03 ± 64.24	644.95±97.82	76.17±16.89
Eff. Dose (μSv)					
<1yr	4.22±0.00	2.60 ± 0.06	31.75 ± 17.65	1.44 ± 0.53	-
1-5yr	5.13±2.95	1.40 ± 0.45	50.20 ± 44.81	4.83±2.67	8.21±1.11
5-10yr	6.21±2.92	5.05 ± 2.60	65.17 ± 22.32	7.89±4.50	25.74±2.77
10-15yr	35.20±3.58	1.31 ± 0.00	66.74 ± 30.84	10.66±2.36	51.60±7.82

The correlation coefficient (r) for the relationship between ESD and patient size (age and weight) and between ESD and exposure parameters is presented in Table 4. This table showed that only exposure parameters (kVp and mAs) had significant correlation with ESD whereas, the size (age and weight) of the patient had no significant correlationwith ESD.

Table 4. Correlation coefficients (r) for the relationship between ESD, patient age, weight, mAs and kVp for Pediatric x-ray examinations

Correlations									
		Age	**Height**	**Weight**	**BMI**	**kVp**	**mAs**	**ESD**	**Effdose**
Age	Pearson Correlation	1	.817**	.808**	-.093	-.079	-.068	-.100	.035
	Sig. (2-tailed)		.000	.000	.142	.209	.281	.114	.584
	N	252	252	252	252	252	251	252	252
Height	Pearson Correlation	.817**	1	.876**	-.308**	.000	-.009	-.044	-.003
	Sig. (2-tailed)	.000		.000	.000	.998	.891	.485	.958
	N	252	252	252	252	252	251	252	252
Weight	Pearson Correlation	.808**	.876**	1	.016	-.004	-.008	-.051	-.007
	Sig. (2-tailed)	.000	.000		.803	.950	.905	.423	.908
	N	252	252	252	252	252	251	252	252
BMI	Pearson Correlation	-.093	-.308**	.016	1	-.070	-.046	.025	.114
	Sig. (2-tailed)	.142	.000	.803		.271	.473	.691	.071
	N	252	252	252	252	252	251	252	252
kVp	Pearson Correlation	-.079	.000	-.004	-.070	1	.671**	.262**	.144*
	Sig. (2-tailed)	.209	.998	.950	.271		.000	.000	.022
	N	252	252	252	252	252	251	252	252
mAs	Pearson Correlation	-.068	-.009	-.008	-.046	.671**	1	.266**	-.052
	Sig. (2-tailed)	.281	.891	.905	.473	.000		.000	.409
	N	251	251	251	251	251	251	251	251
ESD	Pearson Correlation	-.100	-.044	-.051	.025	.262**	.266**	1	.344**
	Sig. (2-tailed)	.114	.485	.423	.691	.000	.000		.000
	N	252	252	252	252	252	251	252	252
Effdose	Pearson Correlation	.035	-.003	-.007	.114	.144*	-.052	.344**	1
	Sig. (2-tailed)	.584	.958	.908	.071	.022	.409	.000	
	N	252	252	252	252	252	251	252	252

***. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed)*

4. DISCUSSION

Due to sensitivity of children to ionizing radiation, special attention is required in radiation protection of Pediatrics patients than in adults. The United Nation Scientific Committee on Effects of Atomic Radiation (UNSCEAR) reported that children exposed to radiation at the early age of less than 5 years are twice to thrice sensitive to effects of radiation than adults [19]. Some of the radiation quantities that could be used to set reference dose level, from where optimization of radiation protection of patients during x-ray examination could be assessed, are the entrance skin dose, ESD and the effective dose (ED).

In this study, ESD and ED received by 253 Pediatric patients of ages between 6 months and 15 years were measured. The x-ray examination considered in this study were classified into regions namely, head and neck, upper limb, chest, pelvis and lower limb. Of these, chest x-ray examination was the commonest among pediatric patients. This is similar to a study reported by Diaconescu et al. [20], where chest radiography was the most frequent examination among pediatric patients (aged 0-15 years) considered. This may be due to the fact that majority of pediatrics patients present in the hospital with respiratory symptoms, thus warranting request for chest x-ray examination.

The predominance of female patients for pelvic examination in this study requires that the x-ray operator must ensure that the radiation dose to the ovaries during pelvis examination is kept below that which could cause infertility (deterministic effect of radiation) in the latter years of these pediatric patients. In addition, gonad shields can be used for protecting the inguinal area if it will not obstruct the area of interest.

In addition owing to radio-sensitivity of breast, attention must also be paid to the frequency of radiation exposure to the chest region especially in female pediatric patients to avoid radiation induced breast cancer (stochastic effect of radiation) in their later years [7].

It can be seen in Table 2 that the tube voltage used for different x-ray examinations vary slightly with the age group. The European Commission [21] recommended the use of tube voltage values of 60 – 80 kVp for ages 0 – 1 year; and 100 – 120 kVp for ages 5 years and above. They also discouraged the use of tube voltage less than 60 kVp for pediatric patient. In this study, the mean tube voltages used for ages less than 1 year were between 46.00 ± 1.83 - 61.00 ± 0.00 kVp while the tube voltages used for ages 5-10 years was 50.29 ± 4.65 and 67.00 ± 4.24 kVp and 10 – 15 years between 46.00 ± 0.00 and 74.40 ± 6.35 kVp. When compared with a similar study by Huda et al. [22], where the range of tube voltage used for ages 0 – 1 year was 56 – 72 kVp and those for ages 5 years – 15 years was in the range of 62 – 79 kVp, it was found that the mean difference (30, 35, 17 and 26 respectively) of tube voltage used for pediatric patients (in age groups 0-15 years) in this study are wider than the EU recommended range. Although the mean difference of the kVp used for age group 0-1 year is similar to that of the Huda et al, lower kVp values were used in this study. The tube loading (mAs) used in combination with the tube voltage for different x-ray examinations are presented in Table 3. It showed that the mAs used for most x-ray examinations performed on age group less than 1 year were between 3.60 ± 0.57 and 5.13±0.88 for all examinations. It is important to note that among this age group, the highest mean tube voltage of 74.40 ± 6.35 kVp was used for head and neck radiography. It can also be seen from this table that the mean mAs of 23.00 ± 9.80 was used for head and neck radiograph of pediatric patients, in this age group. This practice is different from the study reported in literature [22], where 2 mAs was used for head examination of different age groups (Newborn – 15 years).

Generally, it can be seen that the exposure factors used for pediatric patients in this study comprises of low voltage (46.00±0.00 - 74.40±6.35 kVp) and high mAs (3.60±0.57 - 23.00 ± 9.80) instead of high voltage (60 – 79 kVp) and low mAs (2 – 7 mAs) as reported in literature [21]. This implies that the quantity of incident radiation is higher while its penetrating energy is low.

The weightsof pediatric patients (6 months - 15 years) considered in this study ranged between 4.08±1.18kg and 44.80±9.65 kg. These weights are higher than those of similar age group reported in Sudan [5], where their weights ranged from 2.4 kg to 34 kg. The reason for this is not known but may be attributed to genetic factors in the two different groups. The mean ESD received by patients in the age group less than 1 year was between 10.29±3.80 - 105.56 µGy during head and neck examination. It is important to note that x-ray examination that recorded highest exposure factors of 74.40±6.35 kVp against 23.00 ±9.80 mAs and ESD of 880.04±89.44 µGy in this age group was head and neck radiography. Huda et al [20] used exposure factors of 67kVp against 2.0 mAs for similar pediatric age group and reported ESD of 100 µGy for head radiography. Generally, the mean ESD of 10.29±3.80 - 880.04±89.44 µGy received by all pediatric age groups considered in this study are on the high side when compared with ESD reported in literatures namely, 77 - 550 µGy [21]; 60 – 2010 µGy [22]; and 13 – 1550 µGy [23], received from x-ray examinations that are common to pediatric patients of similar age groups. Similar study carried out in other hospitals in Nigeria by Ogundare et al. [24] also showed significantly higher ESD when compared with the international diagnostic reference levels. This can be attributed to non-availability of dedicated x-ray unit for pediatric radiology in most centers in Nigeria and inadequate trained personnel. The effective doses in all paediatric age groups in this study, were significantly higher in the chest (31.75 ± 17.65µSv - 66.74 ± 30.84 µSv) and lower limb(8.21±1.11µSv - 51.60±7.82 µSv) examinations than the value of 19 -36 µSv and 0.21-0.92 µSv reported by Huda et al. [22] for Chest and extremity examination respectively.

Age, weight, mAs and kVp parameters are expected to influence the value of ESD received by pediatric patients, however it can be seen from this study that out of the four parameters, only two (mAs and kVp) significantly affected the ESD received by pediatric patients. In this study, age and weight of patients did not contribute significantly to the patient dose. This is similar to the findings in a study reported by Suliman et al. [4], where similar correlation coefficient analysis was performed on dose related parameters, it was found that there was no significant correlation between patient dose and their age or weight.

In conclusion, this study has shown that chest radiograph is the commonest x-ray examination performed in the pediatric setting. It also showed that pediatric patients are being over exposed to radiation as their ESD is higher than reference values. This is essentially attributed to poorly selected exposure parameters. It is therefore important that necessary steps have to be taken to ensure good quality assurance practices. The departmental radiation protection Committee has to be more aggressive in ensuring that the "ALARA" (As Low As Reasonably Achievable) principle is strictly adhered to.

We recommend adoption of the internationally accepted exposure parameters (high kVp and low mAs) technique for pediatric radiology.

We also recommend the use of protective shield for the ovaries, breast, testicles and the thyroid at all times when imaging pediatric patients as this practice has been established as departmental routine.

Further study is aimed at evaluation of radiation dose and image quality in pediatric radiology following the use of recommended internationally accepted protocol.

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CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable.

COMPETING INTERESTS

Authors declare that all authors have no conflict of interest with any organization or individual.

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