MSD

Medical Science and Discovery
ISSN: 2148-6832

Assessment of radiation dose to pediatric patients during routine digital chest X-ray procedure in a government medical centre in Asaba, Nigeria

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ABSTRACT

Objective: Radiation dose to pediatric patients have been widely reported, it is however necessary that imaging expert keep doses as low as possible to forestall stall long term cancer risk. This study is aimed at determining pediatric entrance surface dose (ESD), 75th percentile ESD, absorbed dose (D) and effective dose (E) for 0-15 years.

Material and Methods: The study used a digital radiography (DR) unit with a grid system for each chest X-ray. The thermoluminescent dosimeter (TLD) used was encapsulated in transparent nylon, it was then attached to the patient skin (chest wall) and the second was placed directly at the posterior end of it.

Results: The mean ESDs for the 4 age groups were as follows: 0- < 1 (1.54±0.74mGy), 1- < 5 (1.53±0.83mGy), 5- < 10 (0.55±0.39mGy) and 10- ⩽15 (1.30±0.57mGy), with an overall mean of 1.23mGy. The 75th percentile ESD for each age group above 10 patients (excluding 5- < 10yrs) was 2.18, 2.19 and 1.75mGy respectively. The absorbed dose (D) ranged from 0.03-2.39mGy. The mean effective dose (E) for the 4 age groups was 0.18±0.03mSv. There was a good correlation between ESD and D (P = 0.001). A One-Way ANOVA shows that the field size and focus to film distance (FFD) affected the ESD and D (P < 0.001) respectively. The risk of childhood cancer from a single radiograph was of the order of (1.54-23.4) $\times 10^{-6}$.

Conclusion: The 75th percentile ESD, E and childhood risk of cancer was higher than most studies it was compared with. The study reveals that machine parameters such as the field size and FFD played a major role in dose increase. Protocol optimization is currently needed for pediatric patients in the studied facility.

Keywords: Thermoluminescent dosimeter (TLD), Digital Radiography (DR), Entrance Surface Dose (ESD), Absorbed Dose (D), Exit Dose (ED), Effective Dose (E)

Research Article

Received 17-02-2020

Accepted 13-03-2021

Available Online: 22-03-2021

Published 30-03-2021

INTRODUCTION

The use of X-ray for pediatric radiography has increased over the years because it requires no invasive approach but radiation stochastic effects cannot be ruled out (1-3). Referrals for routine chest X-rays are common and it has served as the first line of diagnostic pathways for clinicians. Notably in pediatrics, about 40% of all images are of chest radiographs (4). Several medical conditions affecting the chest may occur from birth and the majority of these illnesses require chest X-rays for proper diagnosis and follow-up (prognosis) (5-7).

X-ray investigations involve the use of modalities that involves ionizing radiation. Medical exposure to radiation has been documented to carry some health risks especially in fast-dividing tissues and organs such as seen in children (8). Pediatrics has a higher average risk of incurring cancer, when compared with adults receiving the same dose (9). This is complicated by the tendency of longer life expectancy in children which allows more time to any harmful effect of radiation to manifest (10-12). Therefore, adequate care must be taken when imaging pediatric patients.

The report of the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), 2008 further indicates an increase in the use of X-rays globally especially since the advent of digital technology (8). Although digital techniques have the potential to minimize radiation dose to the patient and improve practice, it can increase the same due to its wide image range and post-processing window without easily adversely affecting the image quality. The risk of overexposure is not easily noticeable in digital radiography and this increases the risk to the patient. Although the detector current exposure Index (EXI) is a parameter currently used with the DR systems to determine if a radiograph is either optimal, overdose or underdose. (13).

Every radiological investigation involving the use of ionizing radiation must the justified and the procedure itself optimized based on the International Commission on Radiological Protection (ICRP) 60 (14) . Radiation must not be used for medical investigations arbitrarily especially when other non-ionizing image modalities can offer better diagnostic values. Optimization requires the use of the lowest radiation as possible without profound adverse effects on the image quality. This concept is called ALARA (As Low As Reasonably achievable) principle. To ascertain that dose is constantly low, dose survey and audit is recommended by the ICRP. In practice, the entrance surface dose (ESD) or Entrance Surface Air Kerma can either be assessed using thermoluminescent (TL) chips, which is called the direct approach or can be computed using exposure parameters and mathematical software (indirect approach) as recommended by International Atomic Energy Agency (IAEA) and the International Commission on Radiation Units and Measurements (ICRU) (15, 16). This present study investigated the radiation dose to pediatric patients' between 0-15 years by determining their mean ESD, 75th percentile ESD, absorbed dose (D), effective dose (E) and cancer risk during chest procedures, Meanwhile, this research remains crucial considering the paucity of research in pediatric radiology in Nigeria.

MATERIAL and METHODS

This study was undertaken using a direct digital (DR) X-ray machine (serial number 19021033). It has a total tube filtration of 3.3 mm Al equivalent at 75 kVp and peak kilovoltage (kVp) ranging from 40-150. Other specifications of the machine are presented [Table 1].

Table 1. Digital X-ray specifications

Digital Radiography machine specifications	
Manufacturer	RADIOLOGIA
Type	Ceiling Mounted Unit (DR System)
Serial Number	19030007
Machine Model	POLYRAD PREMIUM CS
Power Capacity	50kW
kVp Range	40-150kVp
mAs Range	0.1-630mAs
Maximum Current	3.5-1.6A
Minimum Filtration	2mmAl @75kVp
Focal Spot	1.2/0.6
Grid	Yes (14×17 inches)
Total Filtration	3.3mmAl
Line Voltage	115-240V
Phase	3, 50/60Hz
Target	Tungsten
Manufactured Date	February 2019

The study also used a calibrated meter rule for the measurement of height, a digital weighing balance, calibrated in kilogram (kg) for weight, TLD chips, a TLD Cube-400 reader and TLD furnace type LAB-01/400 annealing oven.

The ESD of 50 pediatric patients undergoing chest procedures was estimated using TLD-100 chips made of Lithium Fluoride, doped with Magnesium and Titanium (LiF: Mg, Ti) with sizes of 3.2 mm × 3.2 mm and thickness of 0.90±0.05.

It was preferred because of its tissue-equivalent nature. The TLD chips were calibrated at the secondary standard dosimetry laboratory (SSDL) using a Cesium (Cs)-137 source and the TLD element correction factor (ECF) and homogeneity were within the acceptable range for use (17, 18).

A total of 100 TLD (LiF: Mg, Ti) were placed in a TLD furnace type LAB-01/400 at a temperature of 400 ^{0}C for one (1) hour and allowed to cool to room temperature. In other to remove lower peaks, it was further subjected to another temperature of 100 ^{0}C for two (2) hours and was allowed to cool. After 48 hours (2 days) the chips were ready for use. The TLD chips were carefully placed in transparent nylon and were numbered serially.

It was attached to the patients' skin at the anterior and posterior end. After exposure the TLD chips were removed and read. A RadPro cube 400 manual TLD Reader (Friedberg Instruments GmbH, Germany) was used to determine the corresponding TLD count for the chips. The average background count was obtained from five (5) TLD chips that were not exposed to radiation (TLD_0). Obtained TLD counts ($TLDi-TLD_0$) were multiplied with a pre-determined X-ray calibration factor, which was previously determined (17).

Anthropometric parameter such as age, sex, height, and weight of the each patient were measured. Similarly machine parameter like kVp, mAs and Focus to Film Distance (FFD) was measured and recorded.

The patient effective dose (E) was calculated using the mathematical relation:

Effective dose (E) = Σ [Tissue weighting factor (W_T) ×Equivalent dose (H_T)] [1]

The tissue weighting factor (W_T) was determined using the International Commission on Radiological Protection (ICRP) report 103 and the equivalent dose (H_T) was determined from the product of the absorbed dose and radiation quality factor for X-ray.

Similarly, the Equivalent dose (H_T) = Quality factor (Q) × Absorbed dose (D_T) [2]

In this case the radiation quality factor (Q) for X-ray ≡ 1.

RESULTS

The distribution of males and females and the age range of patients' are presented [Figures 1 &2].

http://dx.doi.org/10.36472/msd.v8i3.493

The mean kVp, mAs, field size, height, weight, age, FFD and BMI among 13 female subjects from age 0- <1 years was 54.77±4.02kVp, 6.29±1.13mAs, 488±180cm^2, 0.5±0.10m, 4.9±1.66kg, 0.18±0.29years, 108.9±21.78cm and 18.02±8.61kg/m^2 respectively, while that of 8 male subject was 56.25±1.98kVp, 5.98±0.60mAs, 571±239cm^2, 0.57±0.14m, 8.06±5.47kg, 0.18±0.29years, 103.9±10.96cm and 23.5±8.83 kg/m^2 respectively.

There was strong correlation between the ESD and D (P = 0.001) [Table 2].

Also the mean kVp, mAs, field size, height, weight, age, FFD and BMI among 6 female subjects from age 1-<5 years was 58.33±2.07kVp, 8.53±0.74mAs, 789±117cm^2, 0.83±0.17m, 17.1±9.29kg, 2.33±0.82years, 128.8±31.59cm and 24.79±11.6 kg/m^2 respectively, while that of 6 male subject from was 56.17±3.06kVp, 6.78±1.68mAs, 692.3±313.1cm^2, 0.80±0.18m, 12.28±4.38kg, 1.50±0.84years, 109.7±23.7cm and 20.69±9.67 kg/m^2 respectively.

The ESD and D was correlated significantly (P < 0.001) [Table 3].

Furthermore, the mean kVp, mAs, field size, height, weight, age, FFD and BMI among 2 male subjects from age 5-<10 years was 60±0.00kVp, 8.20±0.28mAs, 725±162.6cm^2, 1.21±0.15m, 27±0.00kg, 7.0±2.83years, 164±8.49cm and 19.02±4.65 kg/m^2 respectively. There was no correlation in ESD and D (P = 0.254) owing to the limited sample size [Table 4].

The mean kVp, mAs, field size, height, weight, age, FFD and BMI among 10 female subjects from age 10- ≤15 years was 66.1±3.34kVp, 12.31±0.82mAs, 1126±227.5cm^2, 1.61±0.09m, 57.9±12.85kg, 14.8±0.63years, 161.1±9.31cm and 22.21±4.37 kg/m^2 respectively, while that of 4 male subjects was 66.25±4.79kVp, 10.85±2.01mAs, 850.25±228cm^2, 1.48±0.18m, 58.3±20.49kg, 12.5±2.89years, 170±9.00cm and 25.83±5.12 kg/m^2 respectively. The ESD and D correlated significantly (P = 0.001) [Table 5].

Lastly, comparison was made with similar studies. There was no correlation in ESD between this study and studies in Nigeria (P = 0.811), Ethiopia (P = 0.926), Sudan (P = 0.903), and Brazil (P = 0.791; P = 0.811) [Table 6].

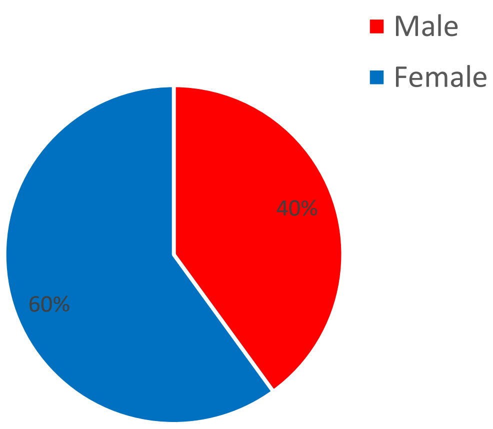

Figure 1: Gender classifications of the participants

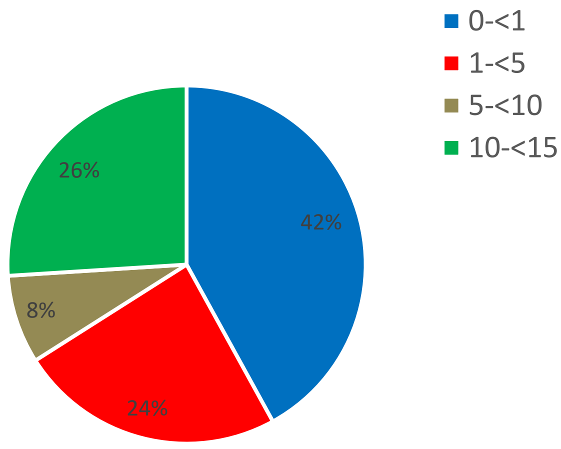

Figure 2: Age range classification

Table 2. Anthropometric and exposure parameter for chest X-ray for age 0- <1 years

No	kVp	mAs	Field size (cm^2)	Height (m)	Weight (kg)	Age (yrs)	Sex	FFD (cm^2)	BMI (kg/m^2)	ESD (mGy)	D (mGy)
1	56	6.3	304	0.5	3.4	0.008	F	100	13.6	0.89	0.04
2	57	6.3	690	0.7	5.2	0.75	F	100	10.6	1.68	0.57
3	49	5	368	0.6	3.9	0.3	F	100	10.8	1.53	0.51
4	49	5	810	0.4	3.8	0.003	F	100	23.8	2.88	1.35
5	57	6.3	705	0.6	4	0.005	F	100	11.1	2.21	0.78
6	57	6.3	413	0.6	4.8	0.07	F	100	13.3	2.74	1.95
7	50	5	192	0.4	4	0.02	F	100	25.0	0.76	0.75
8	54	6.3	630	0.5	4.5	0.005	F	100	18.0	1.24	0.29
9	55	5	414	0.4	4.4	0.003	F	100	27.5	0.41	0.15
10	50	8	442	0.5	9.8	0.25	F	100	39.2	1.88	0.92
11	58	8	520	0.6	6.2	0.083	F	100	17.2	0.52	0.16
12	60	6.3	530	0.58	4.3	0.041	F	158	12.78	0.57	0.38
13	60	8	330	0.69	5.4	0.83	F	158	11.34	1.18	0.38
14	55	5	930	0.7	18.3	0.75	M	100	37.3	2.56	1.38
15	58	6.3	506	0.7	14	0.25	M	100	28.6	1.38	0.60
16	54	6.3	389.5	0.5	5	0.008	M	100	20.0	2.55	0.26
17	58	6.3	361	0.5	3.9	0.005	M	100	15.6	2.11	0.38
18	54	6.3	930	0.4	5.5	0.03	M	100	34.4	1.61	0.92
19	57	5	329	0.4	3.2	0.003	M	100	20.0	1.52	0.46
20	59	6.3	525	0.6	4.9	0.055	M	100	13.6	1.06	0.41
21	55	6.3	594	0.73	9.7	0.92	M	131	18.2	1.09	0.80

kVp = Peak kilovoltage, mAs = milliampere-seconds, FFD = Focus to film distance, BMI =Body mass index, ESD =Entrance surface dose, D = Absorbed dose

Table 3. Anthropometric and exposure parameter for chest X-ray for age 1- <5 years

No	kVp	mAs	Field size (cm^2)	Height (m)	Weight (kg)	Age (yrs)	Sex	FFD (cm^2)	BMI (kg/m^2)	ESD (mGy)	D (mGy)
1	60	8.4	840	0.85	10.2	2	F	158	14.11	0.87	0.17
2	60	8	840	1.1	18.8	4	F	100	15.5	1.81	0.45
3	60	10	840	0.8	27	2	F	100	42.2	3.31	2.39
4	58	8	550	0.9	29	2	F	100	35.8	0.87	0.15
5	57	8.4	825	0.71	9.1	2	F	158	18.05	0.84	0.22
6	55	8.4	840	0.6	8.3	2	F	157	23.05	0.86	0.25
7	57	6.3	918	1	14.8	2	M	100	14.8	0.89	0.03
8	58	6	810	0.9	12	1	M	100	14.8	1.95	1.48
9	50	4	196	0.5	6	1	M	100	24	1.53	0.12
10	57	8	990	0.8	11.8	1	M	100	18.4	2.80	1.35
11	58	8	420	0.7	19	1	M	100	38.8	1.71	0.74
12	57	8.4	820	0.87	10.1	3	M	158	13.34	0.92	0.26

kVp = Peak kilovoltage, mAs = milliampere-seconds, FFD = Focus to film distance, BMI =Body mass index, ESD =Entrance surface dose, D = Absorbed dose

Table 4. Anthropometric and exposure parameter for chest X-ray for age 5- <10 years

No	kVp	mAs	Field size (cm^2)	Height (m)	Weight (kg)	Age	Sex	FFD (cm^2)	BMI (kg/m^2)	ESD (mGy)	D (mGy)
1	57	6.3	690	0.62	25	6	F	158	14.3	1.00	0.76
2	60	8	840	1.1	27	5	M	158	22.31	0.40	0.06
3	60	8.4	610	1.31	27	9	M	170	15.73	0.26	0.22

kVp = Peak kilovoltage, mAs = milliampere-seconds, FFD = Focus to film distance, BMI =Body mass index, ESD =Entrance surface dose, D = Absorbed dose

Table 5. Anthropometric and exposure parameter for chest X-ray for age 10- ≤15 years

No	kVp	mAs	Field size (cm^2)	Height (m)	Weight (kg)	Age (yrs)	Sex	FFD (cm^2)	BMI (kg/m^2)	ESD (mGy)	D (mGy)
1	60	12.5	572	1.6	52	15	F	180	20.3	1.65	1.23
2	68	12.8	1225	1.6	83.2	15	F	157	32.5	0.64	0.60
3	68	12.5	1225	1.6	52	15	F	157	20.3	1.36	0.80
4	68	12.5	1225	1.7	65.7	15	F	157	22.7	1.39	1.23
5	68	12.5	1225	1.6	58	15	F	157	22.7	1.00	0.85
6	68	12.5	1225	1.6	65	15	F	157	25.4	1.24	0.72
7	68	12.8	1225	1.6	57	15	F	158	22.3	1.82	0.62
8	68	12.5	1362	1.7	61	15	F	148	21.1	1.49	0.49
9	60	10	1050	1.4	33	13	F	170	16.83	2.10	1.19
10	65	12.5	930	1.7	52	15	F	170	17.99	1.68	1.14
11	60	8.4	621	1.21	29	10	M	170	19.8	0.33	0.16
12	70	10	1224	1.6	75	15	M	158	29.29	0.95	0.76
13	65	12.5	930	1.6	60	15	M	170	23.43	0.43	0.18
14	70	12.5	626	1.5	69.2	10	M	180	30.8	2.13	1.22

kVp = Peak kilovoltage, mAs = milliampere-seconds, FFD = Focus to film distance, BMI =Body mass index, ESD =Entrance surface dose, D = Absorbed dose

Table 6: Comparison of ESD (mGy) of this work with other similar works

Age (years)	This study (TLD-100)	Nigeria[22] (DoseCal)	Ethiopia[25] (Tube output)	Sudan[24] (DoseCal)	Brazil[21] (TLD-100)	Brazil[21] ($CaSO_4$:Dy)
0-<1	1.54	0.110	1.82	0.057	-	-
1-<5	1.53	0.109	1.72	0.138	0.047	0.06
5-<10	0.55	0.109	3.40	0.220	0.09	0.06
10-≤15	1.30	0.101	5.87	0.664	0.12	0.15

DoseCal = Software for computing ESD

DISCUSSION

This study investigated radiation dose to pediatric patients undergoing chest X-ray (representing the most commonly referred cases) investigations in a non-dedicated X-rays unit using direct digital technology. In total, 50 patients from 0-15 years were studied. The EU (1996) recommends a sample of minimum of 10 patients for the survey to be statistically significant, however, this study can be said to be a good dose representative of the pediatric patients in Asaba metropolis, thus providing a reliable base-line data for subsequent researchers since this is a novel study of this category in the studied facility (17).

Findings from this study show that the 75th percentile ESD (2.00mSv) was 17 times higher in dose compared to the DRL in the American College of Radiology-American Association of Physicists in Medicine-Society for Pediatric Radiology (ACR-AAPM-SPR) report, where the pediatric dose was 0.15mSv (19, 20). Although there was a good correlation between ESD and D ($P = 0.001$), however, a One-Way ANOVA shows that the field size and focus to film distance (FFD) significantly affected ESD and D ($P < 0.001$) respectively.

In another study, the ESD for 0-1 (1.54mSv) and 1-5 years (1.53mSv) was higher than a study in Brazil by Mohamadain et al, where the ESD for AP chest X-ray for 0-1 and 1-5 was 0.07mSv with TLD ($CaSO_4$:Dy) and the PA view was 0.05 and 0.06mSv with TLD-100 respectively. The variation in dose was between 129-132%, in comparison with our study. The same trend in dose variation (>100%) was observed for 1- 5, 5-10 and 10-15 years for AP chest X-ray in Mohamadain's study. The reason for this variation despite the use of similar TLD chips for surface dose measurements was due to the field size and FFD, which was noted to be statistically significant in this study. Other variations could be from the TLD properties and uncertainties (**21**).

In a similar study in Nigeria by Egbe et al, who used TLDs, the mean ESD from AP chest X-ray from 3 facilities studied between the age group of 0-1 years were 0.64, 0.07 and 1.1mGy (**22**). The variation between Egbe's work and this study was 64, 129 and 24%. Dose discrepancies are likely due to the total tube filtration which ranged from 2.5-2.7mm Al, against this study which was 3.3mm Al.

This study used a flat panel system and Egbe's study used a film-screen system. Other factors may be field size and FFD related (**22**). Also, TLDs were used in a study in Turkey by Olgar et al, where the obtained mean ESD was 0.07mGy. The variation was 129%, compared to our study (**23**).

The mean ESD for 0- >1 (0.057mSv), 1- > 5 (0.138mSv), 5- > 10 (0.220mSv) and 10- >15 (0.664mSv) from a study by Alatts and Abukhiar in Sudan with DoseCal Software was lower compared to our study. Variation in dose was 131, 118, 102 and 56% respectively (**24**). Machine parameters like the kVp, mAs, field size and FFD may contribute to the difference in the dose and Since the Dose Cal software is a mathematical human model, the ESD obtained may vary significantly with our study.

Conversely, the mean ESD for 0-1 (1.82mSv), 1-5 (1.72mSv), 5-10 (3.4mSv) and 10-15 (5.87mSv) from a study by Mesfin et al in Addis Ababa in Ethiopia with the tube output method was higher than our study. Variation in dose was 12, 8, 106 and 90% respectively (**25**). ESD from both studies was considered to be high in comparison with other studies. An independent student-t-test shows that both study showed no difference in age, weight, kVp, mAs and field size for 0-1 ($P = 0.976$), 1-5 ($P = 0.947$), 5-10 ($P = 0.804$) and 10-15 ($P = 0.690$) respectively.

The mean effective dose (E) for the 4 age groups (0.18±0.03mSv) was 28 times higher than the Health Protection Agency (HPA-CRCE-028) report, where the mean effective dose for 0-15 years was 0.0065mSv based on ICRP 60 report (**26**).

In a related study by Vilar-Palop et al, the effective dose (E) for <1 (0.05mSv), 1-5 (0.05mSv), 6-10 (0.05mSv) and 11-15 (0.06mSv) was lower than our study. It was identified from this study that the field size and FFD primary affected dose. This may be a reason for the disparity noticed; since the effective dose was calculated from the equivalent dose (**27**).

Finally, the risk of childhood cancer from a single radiograph was of the order of (1.54-23.4) $\times 10^{-6}$. This was higher than a study by Armpilia et al and Aliasgharzadeh et al, where their childhood cancer risk was (0.3-1.3) $\times 10^{-6}$ (28) and (1.27-5.91) $\times 10^{-6}$ (**29**). The above results imply that the risk of childhood cancer will increase.

CONCLUSION

The local reference level for pediatric patients' for age 0-15 years based on the 75th percentile ESD was above studies it was compared with. The study identified the field size and FFD as major factors that contributed to the increase in patient dose. This increase affected the effective dose and cancer risk calculations. There is an urgent need for the facility to embark on protocol optimization in order to reduce cancer risk among pediatric patients'.

Acknowledgments: We sincerely want to thank the research team in the Federal Medical Centre Asaba for offering us their X-ray unit, TLD and manpower and other resources to carry out this work

Author contributions: COA, HUC, ADO, EMO; Study design, data collection and literature search, **COA & ADO;** Results analysis, critical reviews and revisions

Conflict of interest: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. This research did not receive and a specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical issues: All authors declare originality of research.

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