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STATUS OF RADIATION DOSE LEVELS IN PAEDIATRIC CHEST RADIOGRAPHY IN A TERTIARY HOSPITAL IN GHANA

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Determination of appropriate radiation doses to paediatric patients in accordance with the as low as reasonably achievable (ALARA) principle is important, as it allows for effective optimization of imaging techniques. This study assessed the status of radiation dose levels in paediatric patients undergoing chest X-ray examinations at a tertiary hospital in Ghana. A population encompassing 86 paediatric patients categorised as infants (<1 y), young children (1-5 y) and older children (6–12 y) was selected using a quasi-experimental study design. The patients' anatomical data and X-ray beam exposure parameters were used to indirectly calculate the entrance surface doses (ESDs) received during the examinations. The infants received the highest mean ESD of 196 μGy (uncertainty = 0.37) compared to 158 μGy (uncertainty = 0.46) among the older children. The risk of developing radiation-induced biological effects was therefore higher for infant patients. The ESDs were generally higher than the internationally recommended reference doses. Careful adoption of internationally accepted exposure factors (high tube voltage and low tube load) is most recommended to optimise the dose.

INTRODUCTION

Conventional chest X-ray imaging remains the most frequent radiological examination among children worldwide, irrespective of the advent of computed radiography (CR) and digital imaging. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), utilisation of X-rays for diagnostic medical imaging is the largest man-made source of exposure to ionising radiation(1). Children have a greater cell proliferating rate and are more radiosensitive to ionising radiation. The International Commission on Radiological Protection (ICRP) estimated risk coefficients of 5% per Sievert and 1.3% per Sievert for the average population, in respect of cancer effects and hereditary effects, and 13% per Sievert and 4% per Sievert for children for the same effects(2). The ICRP further reported that cumulative injuries of ∼5% per Sievert of cancer risk and hereditary disorders are predominantly stochastic in nature(3). Hence, early life exposure of paediatric patients to ionising radiation increases long-term risk of developing cancer such as leukaemia and brain cancer(1, 4, 5). It has been reported that the risk of harmful effects of radiation exposures during the first 10 y of life is about three to four times higher than exposures for 30–40-y-old adults(6). The probabilistic nature of this risk means that children have more time to accumulate exposures and damage and more time after exposure to develop and manifest the effects(3, 5, 7). Stochastic effects therefore constitute the main hazards and concern in justifying radiographic procedures, especially in paediatrics.

It has been reported in the literature that related issues, such as the actual magnitude of radiation dose, justification of referred cases, standardisation of procedures and optimization of protection, have gained attention in recent times and have subsequently necessitated discussions on the need for estimation and periodic review of actual patient doses during radiographic examinations, especially in paediatric cases(5, 8). Therefore, acceptable radiation protection measures and compliance with all medical exposures and the principle of justification and optimization, in particular, are required in paediatric radiology(5, 9).

Radiation dosimetry quantities give an indication of typical dose delivered to patients(10). Patient entrance surface dose (ESD), including backscatter for simple X-ray projections and dose area product (DAP) for complex examinations, are reliable dosimetry quantities commonly used in diagnostic radiology(11, 12). The National Radiation Protection Board(9) recommended ESDs in the range of 50–120 μGy (<1 y: 50 μGy; 1–5 y: 70 μGy; 5–10 y: 120 μGy) for paediatric patients presenting for AP and PA chest examination. Diagnostic reference levels (DRLs) recommended by the European Commission have a similar magnitude(13). Some studies have indicated that ESDs received by most patients during radiologic procedures are either lower or usually higher than national diagnostic reference levels (NDRLs)(14, 15). According to Ramanaidu *et al.*(16), ESD decreases with age (much higher in children below 5 y), and

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hence, higher doses are predominant among the younger age group. In another study, Beremauro *et al*.[17] found the ESD to increase with age and patient diameter among patients below 5 y of age (age range: 0.25–5 y).

According to Osman *et al*.[10], periodic dose monitoring and assessment of techniques employed in the use of radiological equipment is a requirement for dose optimization. However, it is reported in the literature that patient radiation doses, especially among adults in Ghana, are sometimes not optimised and are often above internationally recommended averages[18, 19]. Furthermore, most of the studies conducted in Ghana have not addressed radiation dose assessment among paediatric patients. Children are highly radiosensitive and have a greater likelihood of developing long-term risk of radiation-induced cancer. Hence, the need for regular assessments of the status of radiation doses among paediatric patients is imperative. This study was therefore conducted to assess the current status of radiation dose levels in paediatric patients presenting for chest X-ray examination in a tertiary hospital in Ghana. The study involved measurement of patients' anthropometric characteristics (thickness, height and weight) and exposure parameters (tube voltage, tube-current-time-product and exposure time), indirect estimation of ESDs for chest examination and comparison of the measured data with international values. These are necessary for dose reduction strategies and development of local diagnostic reference levels (LDRLs) for paediatric chest X-ray examinations.

METHOD

The study was conducted at the imaging unit of the child health department of a tertiary hospital. Due to the lack of a patient appointment system at the department and the need for easy access to patients, the use of a quasi-experimental study design provided for non-random sampling and data comparison as suggested by Martin[20], while a non-probability, convenient sampling method allowed for selecting a population encompassing 86 paediatric patients referred for chest X-ray diagnostic examinations during the study period. Ethical clearance was obtained from the Ethical and Protocol Review Committee of the School of Biomedical and Allied Health Sciences, University of Ghana, while the hospital management granted approval. Only patients of consenting parents or guardians were included in the study, and anonymity and confidentiality of patients' information were ensured. All patients aged 12 y and more, as well as those considered as weak or on oxygen life support, and those whose parents/guardians declined consent were excluded from the study.

Patients' gender and anatomical data (thickness, weight and height) were recorded for each examination. In particular, their anatomical thicknesses were measured at the level of inferior angle of the scapula from the back to the same level in front of the body. The actual exposure factors (tube voltage: 53.0–60.74 kVp; tube-current-time-product: 4.43–5.65 mAs; exposure time: 9.1–11.3 ms) used in the chest examinations for each patient as well as the focus-image receptor distance (FID) (119.4–151.8 cm] were also recorded. Postero-anterior (PA) in erect position and antero-posterior (AP) in supine projection were the main projections used in this study.

According to Servomaa[21], paediatric patients of the same age group may vary in size. Therefore, in calculating the mean ESDs, the patients were categorised into three separate age groups (infants: < 1 y; young children: 1–5 y; older children: 6–12 y). Using, their anatomical data and exposure parameters for chest examinations, the ESDs were indirectly determined via the approach reported by Kiljunen *et al*.[22]

$$\mathrm{ESD} = T_o I_t \left(\frac{\mathrm{FDD}}{\mathrm{FSD}}\right)^2 \mathrm{BSF} \tag{1}$$

where T_o is the X-ray tube output or yield (dependent on the tube voltage and filtration) at the focus-detector distance (FDD), I_t is the tube-current-time-product (mAs), FSD is focus-skin distance used for the examination of patients and BSF is the backscatter factor. In the dosemeter measurements, an FDD value of 100 cm was used to generate T_o values. Based on reported values of BSF in the range of 1.132–1.42,[23, 24] a BSF value of 1.3 (average of maximum and minimum values to 1.dp) was used in the calculation.

In particular, the tube output is the ratio of the air kerma to the tube-current-time-product. It is reported in the literature that incident air kerma is easier to measure accurately and could ease the practical problems associated with achieving equilibrium in the field[25]. Hence the incident air kerma at different tube voltage settings were measured using a manufacturer-calibrated Piranha solid-state detector located at 1 m FDD to determine the ESD from the generator output. The technical specifications of the Shimadzu diagnostic X-ray unit and the Piranha solid-state diagnostic dosemeter are presented in Table 1.

RESULTS

The patients' age, gender and anthropometric data are shown in Tables 2 and 3.

All the imaging units were tested and passed the QA requirement based on the Institute of Physics and Engineering in Medicine (IPEM)[26] and American

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Table 1. Technical specifications of instrumentation.

Make	Shimadzu, Japan
Type	CR
Model	0.6/1.2P38DE-85
Serial No	532-24558
Power rating	40–150 kVp
Exposure setting	Manual
Maximum focus	150 kV/0.5/1.2 mm
Inherent filtration	1.5 mmAl at 70 Kv
Detector used	Fujifilm CR IP
Piranha dosemeter	
Metre(s)	Piranha S/N CB2-11020219
Detector(s)	MPD S/N MP2-11020211

Table 2. Number of patients per age group and gender.

Gender	Patient groups			
	Infants	Young children	Old children	Total
Male	17 (19.8%)	21 (25.4%)	8 (9.3%)	46 (53.5%)
Female	13 (15.1%)	16 (18.6%)	11 (12.8%)	40 (46.5%)
Total	30 (34.9%)	37 (43.0%)	19 (22.1%)	86 (100.0%)

Table 3. Anthropometric data of patients.

Patient group	Number	Mean	Std. dev.	Minimum	Maximum
		Weight (kg)			
Infants	30	5.02	2.06	1.20	10.20
Young children	37	12.54	4.00	6.00	23.50
Old children	19	19.76	6.48	10.50	31.00
Total	86	11.51	6.90	1.20	31.00
		Height (m)			
Infants	30	0.57	0.09	0.40	0.72
Young children	37	0.93	0.15	0.64	1.18
Old children	19	1.21	0.14	0.96	1.50
Total	86	0.84	0.28	0.4	1.50
		Thickness (cm)			
Infants	30	9.16	1.24	6.20	11.60
Young children	37	12.05	1.73	7.00	16.00
Old children	19	13.67	1.48	11.20	16.50
Total	86	11.40	2.32	6.20	16.50

Association of Physicists in Medicine (AAPM)[27] protocols.

Descriptive statistics of projections

Tables 4 and 5 illustrate the distribution of patient exposure factors, ESDs and FIDs for AP and PA projections, respectively. The applied tube voltages and tube-current-time-products ranged from 53 (infants) to 60.7 kVp (old children) and from 4.53 (infants) to 5.65 mAs (old children). The mean exposure factors were 56.2 kVp and 4.83 mAs. The results show that the mean ESDs decreased with age (highest among infants and lowest among old children). The mean ESD for the entire population (173 μGy; $U = 0.22$) was accordingly lower than the mean ESD for the infants (196 μGy; $U = 0.37$). There were more PA projections ($n = 53$, 61.6%) than AP projections ($n = 33$, 38.4%). Majority of AP projections were used for the infants, while more PA projections were used for older children. The ESDs were also higher for AP supine projections than PA erect projection across all patient groups.

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Table 4. Exposure factors and ESD.

Patient group	Statistic	Exposure factors			FID (cm)	ESD (μGy)	N
		Tube voltage (kVp)	Tube-current-time-product (mAs)	Exposure time (ms)			
Infants	Mean ± s.d	53.00 ± 3.31	4.43 ± 3.31	9.1 ± 1.0	119.4 ± 3.3	196.4 ± 38.5	30
Young children	Mean ± s.d	56.35 ± 1.90	4.73 ± 0.53	9.4 ± 1.1	138.5 ± 12.0	160.6 ± 41.9	37
Old children	Mean ± s.d	60.74 ± 4.99	5.65 ± 1.53	11.3 ± 3.1	151.8 ± 17.3	158.2 ± 41.5	19
Total	Mean ± s.d	56.15 ± 4.33	4.83 ± 0.96	9.7 ± 1.9	134.8 ± 18.2	172.6 ± 43.9	86

s.d, standard deviation.

Table 5. ESD and FID for AP and PA projections.

Patient group	Projection	ESD (μGy)					FID (cm)		
		N	Min	Max	Mean	U	Min	Max	Mean ± std.
Infants	AP	26	107	266	205	0.39	105.0	150	116 ± 8
	PA	4	116	180	142	1.00	130.0	150	144 ± 9
	Total	30	107	267	196	0.37	105.0	150	119 ± 3.3
Young children	AP	7	138	282	206	0.76	107.0	152	123 ± 16
	PA	30	92	232	150	0.37	120.0	153	142 ± 7
	Total	37	92	282	161	0.33	107.0	153	139 ± 12
Old children	PA	19	152	255	158	0.46	114.0	180	152 ± 17
	Total	19	255	152	158	0.46	114.0	180	152 ± 17
Total	AP	33	107	282	205	0.35	105.0	152	117 ± 11
	PA	53	92	255	152	0.27	114.0	180	146 ± 13
	Total	86	92	282	173	0.22	105.0	180	135 ± 18

U, uncertainty.

Inferential statistics

The statistical analysis (Table 6) revealed significant differences ($p = 0.001$) in ESD between infants and young children. However, no significant difference in ESD ($p = 0.838$) between the young and old children was found. The weak correlation may be caused by the small number of patients.

Comparison with international recommended reference levels and published data

Comparisons of the ESD results with the NRPB and EC recommended reference levels as well as the ESD and exposure factors with reported literature values[28, 29] are presented in Tables 7 and 8.

The ESD results obtained in this study across all the age groups are higher than values reported in the literature (Jaramillo-Garzon *et al.*[28], Atalabi *et al.*[29]) and by the National Radiation Protection Board[9] and European Commission[13] reference levels which are comparable for the infants and young children. Contrary to the observed decrease of ESD with age in this study, the National Radiation Protection Board[9], European Commission[13], Jaramillo-Garzon *et al.*[28] and Atalabi *et al.*[29] reported increased ESDs with age.

The applied tube voltages and tube-current-time-products ranged from 53 (infants) to 60.7 kVp (old children) and from 4.43 (infants) to 5.65 mAs (old children) in this study. The mean exposure factors were 56.2 kVp and 4.83 mAs. Comparatively, higher tube voltages were reported by Jaramillo-Garzon *et al.*[28] (66.2–77.6 kVp) and Atalabi *et al.*[29] (55.3–61.8 kVp). The tube-current-time-product range was also higher than the reported values by Jaramillo-Garzon *et al.*[28] (1.2–2.9 mAs) but lower than 5.1–6.1 mAs reported by Atalabi *et al.*[29].

DISCUSSION

Patient demographics

Chest X-ray is a common radiological procedure for children. The fact that 77.9% of the study population were infants is suggestive that chest X-ray examinations were frequently requested for this category of children. This is similar to the study reported by Beremauro *et al.*[17]. The reason for these findings may be due to the fact that newborns and infants

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Table 6. Independent *t-test* of anatomical thickness, exposure factors.

Test variables	*p*-Values	Mean diff.	Std. dev.	Lower 95% CI	Upper 95% CI
Infants and young children					
ESD (μGy)	0.001	35.741	9.945	15.879	55.603
Tube voltage (kVp)	0.000	−3.351	0.645	−4.640	−2.063
Tube-current-time-product (mAs)	0.023	−0.300	0.129	−0.557	−0.042
Young and old children					
ESD (μGy)	0.838	2.424	11.804	−21.241	26.089
Tube voltage (kVp)	0.000	−4.386	0.924	−6.237	−2.534
Tube-current-time-product (mAs)	0.002	−0.923	0.278	−1.481	−0.365
Projection AP and PA					
ESD (μGy)	0.000	52.736	7.919	36.989	68.483
Tube voltage (kV)	0.000	−4.327	0.843	−6.003	−2.650
Tube-current-time-product (mAs)	0.006	−0.578	0.204	−0.985	−0.1718

Table 7. Mean ESD and international reference levels and published data.

Patient group	ESD (μGy)				
	This study	National Radiation Protection Board[9]	European Commission[13]	Jaramillo-Garzon *et al.*[28]	Atalabi *et al.*[29]
Infants	196	50	50	67	66
Young children	161	70	80	94	105
Old children	158	120	—	113	136

Table 8. Mean exposure factors and international reference levels and published data.

Work	Patient group	Sample size	Tube voltage (kVp)		Tube-current-time-product (mAs)	
			Mean	Range	Mean	Range
This work	Infants	30	53.0	45.0–57.0	4.4	3.2–5.0
	Young children	37	56.4	53.0–60.0	4.7	3.2–5.6
	Old children	19	60.7	55.0–70.0	5.7	3.6–10.0
Jaramillo-Garzon *et al.*[28]	Infants	30	62.2	50.0–95.0	1.2	0.8–4.0
	Young children	182	70.8	50.0–102.0	1.9	0.8–6.0
	Old children	119	77.6	50.0–109.0	2.9	0.8–10.0
Atalabi *et al.*[29]	Infants <1	122	55.3 ± 5.4	—	5.1 ± 0.9	—
	Young children		58.5 ± 5.7	—	5.5 ± 1.2	—
	Old children		61.8 ± 3.6	—	6.1 ± 1.2	—

are more susceptible to respiratory-related diseases which require chest X-ray diagnostic examinations. The weight range (5.02–9.76 kg) of the patients presenting for chest X-ray examinations is comparable to those used in the Beremauro *et al.*'s[17] (3.8−19 kg) and Atalabi *et al.*'s[29] (4.97–20.98 kg) studies.

Radiographic technique and exposure factors

The higher ratio of PA to AP projections (61.6:38.4%) could be attributed to the advantage of PA over AP projections in terms of radiation safety and diagnostic image quality as reported by the International Atomic Energy Agency[30]. Although PA projection is preferred to AP, cases involving newborns, very weak patients, as well as some infants that cannot cooperate with standing or sitting, may require AP projections in supine position. This accounts for the use of AP projections for the infant patients.

However, the use of AP projections could result in increased ESD. Two main reasons account for this: lower FSDs and the additional absorption by

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the patient support table. In particular, the supine position requires patients to lie on a support table that also has to be penetrated by the X-rays. The lower the X-ray energy is, the more X-rays are absorbed in the patient support and hence the more X-rays have to be issued from the X-ray source to reach the image receptor.

Low tube potential and high tube-current-time-product exposure factors were employed for both AP and PA projections (Table 3) in this study. The European Commission[13] recommended the use of tube voltage values of 60–80 kVp and 80–120 kVp for patients up to 5 y of age and older, respectively, and discouraged tube voltages <60 kVp. Although the mean tube voltages used for the various patient groups are similar to the findings reported by Atalabi *et al*.[(29)], they are, however, lower than values reported by Jaramillo-Garzon *et al*.[(28)] for patients of similar age (Table 4). The mean tube voltage (56.2 kVp) was below the EC recommended threshold (60 kVp) and was contrary to the EC's recommended tube potentials of 60–120 kVp. Hence, the use of a low tube potential (45–70 kVp) and high tube-current-time-product (3.2–10.0 mAs) combination as observed in this study is contrary to the high voltage (60–120 kVp) and low tube-current-time-product (2–7 mAs) technique recommended by the European Commission[(13)] and reported in the literature[(28, 31)]. In particular, high patient doses or exposures in diagnostic radiography have been attributed to the low tube potential and high tube-current-time-product technique. This is because, the lower-energy photons created by the lower tube voltage have less penetrating power and hence a smaller number of the incident photons arrive at the image receptor. On the other hand, for a radiograph of sufficient diagnostic quality, a certain amount of photons at the detector is needed. This means that the number of incident photons has to be increased accordingly, resulting in higher tube-current-time-product needed to create the radiograph. Hence, the higher tube-current-time-product found in this study is the direct consequence of the tube voltages being too low.

Patient entrance surface dose for AP and PA projections

The measured radiation dose is affected by the equipment system, generator performance and the radiographic technique deployed. The low tube potential and high tube-current-time-product technique is expected to produce high ESD. This explains the high ESDs measured across all age groups in this study. Related studies by Atalabi *et al*.[(29)] and Ademola *et al*.[(32)] reported similar findings where the use of low tube potentials and high tube-current-time-products for paediatric chest radiography resulted in high ESDs. This is suggestive that if high tube voltage is used, then the ESD could be reduced with lower tube-current-time-product and with a compromise on contrast and image quality (to some extent). Hence, as seen in Tables 7 and 8, the use of high tube voltage (62.2–77.8 kVp) and lower tube-current-time-product (1.2–2.9 mAs) resulted in reduced ESD for same paediatric age groups[(28)]. It was observed in this study that the highest mean ESD was associated with the lowest FSD (and by extension the FID) via the low tube voltage and high tube load imaging technique. Patients imaged via AP projection also received higher doses than PA-imaged patients. As mentioned earlier, the higher doses received by the infant patients may also be attributed to additional absorption by the patient support table to cause the higher ESDs for AP projections, and shorter FSDs for AP than for PA projections, in accordance with the inverse square law.

In general, the inverse square law is subject to the assumption that reductions in radiation intensities are attributable to only the geometrical divergence of the radiation, provided there are no physical processes such as absorption or scattering by the medium of travel. In particular, the inverse square law is only directly applicable when other parameters, such as tube output and exposure time, are constant. By the inverse square law, increases in FSD significantly reduce patient doses.

The mean patient ESDs estimated in this study were similar to the results reported by Atalabi *et al*.[(29)] and Egbe *et al*.[(31)] but higher than the findings of Jaramillo-Garzon *et al*.[(28)] and the international recommended reference levels. This can be ascribed to wrong exposure factor combination used for paediatric imaging. Generally, for smaller patients or infants, shorter exposure times might be sufficient for appreciable image quality, and then the ESD need not necessarily be higher as a consequence of the inverse square law (shorter FSD), although doses are higher at shorter distances. The exposure settings do certainly impact the ESD more than the FSD, as changes in exposure settings could lead to differences in ESDs.

Inferential statistics

Generally, weight and thickness increase with age; therefore, it is expected that the ESD will increase across age groups. This observation is supported by the report of Jaramillo-Garzon *et al*.[(28)] and Atalabi *et al*.[(29)]. Similar findings were reported by Ramanaidu *et al*.[(16)] and Beremauro *et al*.[(17)]. Also the National Radiation Protection Board[(9)] and European Commission[(13)] DRLs, which increase with age, support the expectation that the ESD should increase with age since these values are also derived from large-scale patient measurement initiatives. An independent *t*-test revealed significant differences in

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tube potential, tube-current-time-product and ESD, whereas estimated values between the younger and older children revealed a significant difference in tube potential and tube current time but no significant differences in ESD.

The higher doses received by younger children are credited to the radiographers' decision of using lower tube voltages and higher tube-current-time-product exposure technique to enhance radiographic contrast[29, 31]. Patient ESDs are generally lowered at high tube voltages because better beam penetration leads to less scattering within the body[32]. According to Herrmann *et al*.[33], the best practice in paediatric digital imaging requires higher tube voltages (low tube-current-time-product) within the optimal range to provide an adequate exposure to the image receptor. Ramanaidu *et al*.[16] have reported that tube voltages within the range of 60–80 kVp could yield a significant ESD reduction by 34% for infants. However, the high tube voltage technique is not recommended for cases where high contrast images are needed[34, 35] and may compromise image quality though. There was also an observed significant difference in the ESD used for AP and PA projections in the patients to suggest that the current practices give higher doses in AP projections than PA projections.

CONCLUSION

Entrance surface doses of paediatric patients undergoing PA and AP chest examinations in a tertiary hospital have been assessed. Compared to the NRPB and EC recommended reference levels and other literature, the individual ESD values were observably much higher. In particular, the results suggest that paediatric patients, especially infants, received higher radiation doses. This is principally attributed to poor selection of exposure factors, i.e. low tube potential coupled with high tube current time product. Higher doses received by the infant patients may also be attributed to additional absorption by the patient support table to cause the higher ESDs for AP projections, and shorter FSDs for AP than for PA projections, in accordance with the inverse square law. It is therefore imperative to standardise the exposure distances and consequently establish the standard protocols necessary for each age group. It is also important to ensure good practices of radiographic techniques.

Careful implementation of the as low as reasonably achievable (ALARA) principle and appropriate radiographic techniques are relevant to optimising paediatric chest imaging. Adoption of internationally accepted exposure factors (high tube voltage and low tube load) is most desired. The introduction and use of NDRLs based on patient dose data is necessary to compare with the internationally accepted DRLs to enable proper optimization technique application.

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