International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Radiation Doses Received by Paediatric Patients During Chest X-Ray Examinations at a Central Hospital in Harare, Zimbabwe

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Abstract

This study sought to measure the mean entrance skin dose and third quartile value for paediatric chest x-ray examinations, to find the correlation between mean ESD, age, kVp and weight and compare these to findings and recommendations from other studies. A descriptive, quantitative cross sectional design was used. Thermo luminescence dosimeters placed on the anterior surface of the chest coincident with the primary beam were used to measure radiation dose. Demographic data and exposure parameters were recorded for 20 patients below the age of 5years. The TLDs were read by qualified radiation physicists at the Radiation Protection Authority of Zimbabwe (RPAZ). Data was analysed using SPSS version 16.0 and Microsoft Excel. Entrance surface dose was measured for all patients and the mean dose calculated was higher than those from previous studies in literature. A strong co-relation was found between ESD and weight and also between ESD and age. Results showed that there was a possibility that children were receiving higher doses during chest x-ray examinations as compared to the recommended levels of the ICRP and other previous studies.

Keywords: Entrance skin dose; Chest x-ray; Paediatric; Radiation protection.

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1. Introduction

Diagnostic Radiography is a vital tool during the childhood period as it is used in diagnosing and managing conditions which affect the respiratory system, with the most common examination requested being the chest x-ray. Frequent monitoring of x-ray exposure received by paediatric patients is therefore necessary as their body tissues are highly radiosensitive in the early stages of development. The risk of radiation induced malignancies is higher in preterm neonates because of their radiosensitive tissues, longer life expectancy and large number of radiographs taken during their stay in hospital [1]. Radiation exposure in the first 10 years of life may have an attributing lifetime risk three to four times greater than that after the age of 30 years [2]. The importance of constant monitoring of the radiation dose received by paediatrics during a radiological examination cannot be understated as studies done indicate that risk for radiation related cancer in children is a result of early life exposure to ionizing radiation [3]. Dose optimization and image quality are important during x-ray examinations and these should be adequately monitored to ensure that children are receiving proper medical assistance during their stay in the hospital. Diagnostic reference levels (DRLs) were recommended by the International Commission for Radiation Protection (ICRP) firstly in 1990 and further recommended in 1996. The Commission recommended the use of DRLs on all patients undergoing examinations which use ionizing radiation. A representative phantom or individual is used to measure dose which will be used to identify unusually high doses and apply corrective measures to reduce the doses [4,5].

Huda in 2009 asserts that medical doses contribute almost half in the United States population dose and are predicted to increase, hence the need to accurately and continuously monitor radiation dose amongst patients who are exposed to it [6]. Of all the radiographs taken in the first year of life, approximately 60% are thoracic radiographs and 10% are abdominal radiographs [7]. Chest radiographs are the most commonly requested examination for paediatric patients at Parirenyatwa Hospital. This may be due to the fact that neonates born prematurely commonly suffer from conditions such as pulmonary diseases, respiratory disease syndrome and meconium aspiration syndrome [8]. The lungs, undeveloped mammary glands and thyroid are exposed during chest imaging, hence it is important to carefully monitor the doses received. Selecting as low as reasonably achievable exposure factors reduces the radiation burden to the patient by applying only the dose which will produce an image of high diagnostic value to the doctor or radiologist who will interpret the image. The use of Diagnostic reference levels (DRLs) is a very widespread method in many countries as a measure to reduce over exposure or under exposure [9]. Before DRLs are set, dose surveys are conducted in different hospitals using different machines.

To the researchers' knowledge, there are no radiation dose survey measures present specifically for paediatric patients at central hospitals in Harare, despite the fact that children are highly radiosensitive, and there is a possibility of high exposure. Regulatory boards in Zimbabwe which are responsible for Radiation Protection to the patients, the general public and the medical staff have not yet come up with baseline doses which are applicable to each hospital, specifically to paediatric patients. Materials and methods used by the ICRP and other countries to come up with a range of acceptable radiation dose on paediatrics cannot be solely depended upon and or replicated at hospitals in Harare. This is because of the different techniques, exposure factors, type of machine, weight of the children and the radiographs accepted as being of great diagnostic value by the reporting radiologists or doctors. A dosimetric survey was therefore important to ensure that children are not put at higher risk of developing radiation-induced cancer. The purpose of this article is to report on a study that sought to investigate the radiation doses received by children below the ages of 5 years by measuring the entrance skin dose (micro grays) for pediatrics chest x-ray examinations at Parirenyatwa Hospital, calculating the mean dose received in chest examinations, determining the correlation between entrance surface dose with other parameters (weight, age, KVp and mAs) and analyzing the doses received in comparison with those reported in literature.

2. Materials and Methods

A descriptive quantitative cross sectional survey design was used for this study. The target population was pediatric patients below 5 years of age at Parirenyatwa Group of Hospitals. The accessible population was that of patients presenting with a chest x-ray request in the months of November and December 2013. Included were all male and female pediatric patients with request forms for chest x-ray examinations, below the ages of 5years and whose parents or guardians were willing to allow them to participate in the study. A sample of 20 patients (10 male and 10 female) was the target for recruitment as recommended by the European Commission approach to reference levels which states that for general diagnostic pediatric examinations, a sample of 10 patients between 4-6 years olds weighing 15-25kg, should be included [10]. However, the researchers ended up with an actual sample of 11 males and 9 females. Consent was obtained from parent or guardians. Age, sex and weight for each child were recorded on a data sheet. The instrument used to record radiation dose in this study was the thermo luminescence detector (TLD) because they were readily available, easier to use and do not leave obvious artifacts. AP chest x-rays were taken with the patient in supine position and immobilisation was employed to reduce movement unsharpness, which reduces image quality. A nurse was given a lead rubber apron to protect herself when stabilizing the patient and the TLD placed on the anterior surface of the midline of the chest region, below the sternum. This position was chosen as it was coincident with the primary beam and also because the TLD was giving artefacts on the x-ray image; hence the lung field was avoided in this case. The focus to film distance of 100cm, kVp, mAs and film type were recorded for each corresponding child. All the other TLDs which were not in use were kept behind the control panel away from any radiation. Non gridded cassettes were preferably used to gridded cassettes as they reduce the radiation dose to the patient. Each exposed TLD was taken to RPAZ to be read by the TLD reader equipment and the results returned after some time. Four TLDs were used during the course of the research, with each one, colour and number coded. One TLD was used on a single child for a single exposure and the TLD code would be recorded against the child's age, sex and weight to avoid mixing up results. Each exposed TLD was taken to the Radiation Protection Authority Zimbabwe (RPAZ) in an envelope for the read out process by qualified radiation physicists. The results were compiled into an accessible file which could only be reviewed by the people directly involved in this research. Un-exposed TLDs were kept safely away from direct heat and moist areas. The TLDs were calibrated before use to ensure validity and reliability. Dose values were measured without the use of an anti-scatter grid throughout the research as the children were place on top of the imaging table, and the cassette directly below the child's chest. Non grided cassettes were used. Data was analyzed using SPSS version 22 (SPSS Inc, Chicago, Illinois, USA) and Microsoft Excel 2010 (Microsoft Corp., Redmond, Washington, USA). The standard deviation was calculated from this data including simple descriptive statistics which were employed. The results were averaged to give a mean entrance skin dose for paediatric chest imaging using a mobile unit and a fixed x-ray unit (room 7). A correlation was calculated between age, weight, mAs and entrance surface dose and the standard doses published by the ICRP were used to compare with the ones from this study.

Specifications of the x-ray machines used are presented in Table 1. The mobile machine was used for those patients who were not able to come to the x-ray department for imaging because of critical medical conditions. A constant FFD of 100cm was maintained throughout the examinations using both the mobile and fixed x-ray machines. Selection of exposure factors was based on the physical built of the patient, i.e. body thickness and the clinical indication of the patient under examination. The images from both machines were processed by a single automatic processor. The chest radiographs were evaluated by a qualified radiographer to assess if they were of diagnostic value.

Table 1: Equipment details

Parameters	**Fixed xray machine**	**Mobile equipment**
Model	Siemens Germany	Philips Italy, Practix 33
Generator type	Siemens	1 Phase Philips
Total filtration	1,0mm Al	2.7mm Al, 1.8mm
Processor	SRX-301 Konica	
Film type	Konica KR-II	
Screen type/speed	Rare earth/400	
Processing	Automatic	
Mean patient flow per month	40 Pediatric chest x-rays	20 Pediatric chest x-rays

The parents of the paediatric patients involved in this study gave a written informed consent. Permission to conduct the study was sought and granted by the Parirenyatwa and UZ - College of Health Sciences Joint Research Ethics Committee [(JREC), (Approval number: JREC 114/13)], the Radiation Protection Authority of Zimbabwe and the Department of Radiology at Parirenyatwa Hospital. No additional radiation dose was received by the patients during the study and the standard technique and exposure factors used during normal examinations were also used during the study.

3. Results

Male patients were 55% (n=11) of the sample whereas 45% (n=9) were female patients. The participants were grouped into four separate age-group categories which were: 0-12months (50%), 13-24months (35%), 25-36months (5%) and 49-60months (10%) because of the wide variation in body size which are most noticeable amongst pediatrics. This was done for the convenience of calculating the mean entrance skin dose [11]. The parameters recorded in this study are summarized in Table 2.

Table 2: Summary of patient demographics and exposure parameters

	Weight/kgs	Age	kVp	mAs
Minimum	3.8	3months	49	1.6
Mean	7.7	1.85years	54	3.6
Maximum	19.0	5years	60	5.6
Standard Deviation	3.6	1.2	3.2	1.1

Participants were also categorized into eight different groups according to weight, with the groups with the most representation being the 4.0kg-4.9kg, 6.0kg-6.9kg and 7.0kg-7.9kg all with 20% of the participants. The lowest representation was from 3.0kg-3.9kg, 5.0-5.9kg and 19.0-19.9kg which all had 5% of the total population.

Table 3: Mean Entrance Skin Doses from TLD's and third quartile value

ESD Values	Skin dose (mGy)
Minimum	0.241
Mean	0.537
Maximum	1.103
Std Deviation	0.22
Range	0.862
Percentiles 25th	0.386
50th	0.467
75th	0.676

The skin dose was measured 0.07millimetres from the skin surface and stated in mGy. In the section for comparison, relevant conversion factors were applied to the dose values. Results collected for the patients showed a minimum dose of 0.241mSv and a maximum of 1.103mSv. A third percentile of 0.676mSv was calculated; including a mean ESD value of 0.537mGy which was also calculated.

Entrance skin dose (ESD) was plotted against weight (Figure 1) and age (Figure 2) There is a gradual increase in the ESD values as weight increases, as shown by the trend line in the graph. The peak ESD value of 1.103mGy corresponds to the highest value of weight, 19kg. The lowest weight of 3.8kg however does not correspond to the lowest ESD value of 0.241mGy, but instead it is equal to an ESD value of 0.328mGy.

There was a gradual rise in ESD as age increased, as the trend line drawn in the graph shows. The minimum age was 3months, corresponding to an ESD value of 0.546mGy, one of the higher doses. Two 6months patients received different ESD values of 0.241mGy and 0.328mGy respectively. The maximum age was 5years which had a 10% representation of the total population. The two 5year olds received different quantities of ESD individually with the first one receiving 0.719mGy and the other receiving 1.103. The maximum dose of 1.103mGy was recorded from a 5year old.

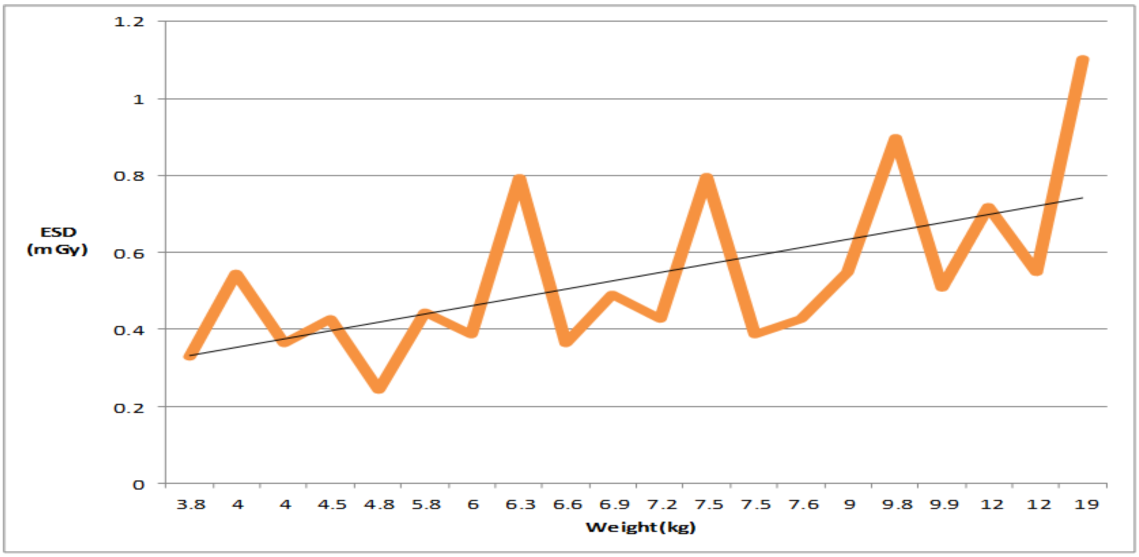

Figure 1: Weight plotted against dose of the patients

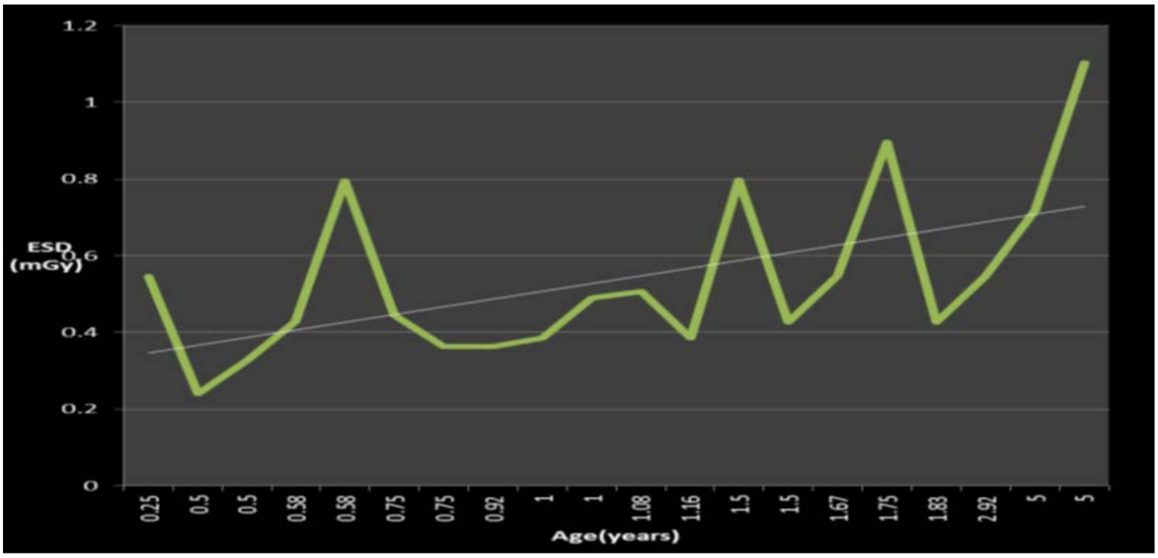

Figure 2: Age against dose of the patients

During the examinations, high kV technique was not used. The tube output ranged from 48kVp to 60kVp. The mean tube output was 54kVp for the 20 chest x-ray examinations. The minimum tube output applied during the study was 48kVp, with 20% of the population receiving 56kVp. A maximum tube voltage of 60kVp was used on only 5% of the total population. 56kVp was used on 20% of the patients, which was more than the other patients.

There was a strongly significant correlation between entrance skin dose and weight (r=0.730, p=<0.001), between entrance skin dose and age (r=0.638, p=0.002) and also between entrance skin dose and kVp (r=0.547, p=0.013) but mAs was not significantly correlated to entrance skin dose (r=-0.207, p=0.383).

Table 4: Comparison of entrance skin dose with previous studies

		ESD (µGy)			
Study	**Age-group**	**Minimum**	**Mean**	**Maximum**	**3rd Quartile**
Parirenyatwa ,2013	0-5yrs	241	537	1103	676
NRPB 2002	5yrs	50	110	230	150
Kim et al 2012	5yrs	18.8	140	2334	161
Freitas, Yoshimura 2012	<15yrs	-	150	-	200
Brindhaban, Al-Khalifah 2004	<1year		102		
Borisova et al 2008	5yrs		86		100
EC 1999	5yrs				100

Table 4 shows this current study's results in comparison to other studies done previously. The results show that Parirenyatwa hospital had higher mean ESD values and third quartile values than the other centers. A value of 537µGy for mean ESD which was calculated at Parirenyatwa was approximately five times that of NRPB 2002. The third quartile value of 676µGy was 4.5 times that of the NRPB 2002. As shown in Table 4, Kim et al had the highest maximum ESD value of 2334µGy, and the least minimum value of 18.8µGy as well. The lowest value of third quartile value was from EC 1999 with 100µGy.

4. Discussion

Twenty patients were measured their ESD's, 11 boys and 9 girls. The mean ESD value of 0,537mGy presented in Table 3 which is equal to 537µGy, as pediatric doses are usually cited in micrograys units was higher compared to other studies done in Europe and other countries [12,14,15,16,17,18]. The reasons why the ESD and third quartile values were different could be due to factors such as the equipment and technique used for imaging.

The quantity of radiation dose measured is affected by the equipment used and the radiographic technique applied. Each hospital has its own protocol for every examination, for example in a study done in Korea; they used an FFD of 180cm, whilst this study maintained 100cm [13]. This difference in FFD has an effect on patient dose and the difference in reported doses between authors. A study carried out showed a reduction in dose by increasing the FFD from the conventional 100cm to 130cm for lumbar spine and pelvis projections which were 44% and 33% respectively [18].

A large scale survey done in Korea used a 5year old phantom to measure the doses, and the results were within the range of those stated by the NRPB, 2002 [12, 13]. A mean tube voltage of 94.9 kVp and current of 4.30 mAs were stated, which shows higher exposure parameters than those from this study (48kVp to 60kVp). However a maximum ESD value of 2334µGy was recorded which is higher than this study's maximum value of 1103µGy. The high values observed in their study pointed out the possibility of dose creep contributing to the high doses [13]. Other differences to this study were firstly, the method which used to calculate ESD as they measured pre-dose by using a phantom, and then subtracted it after exposing and secondly, the high number of x-ray machines (149) involved in their study and the variety of the type of machines (42% computed radiography, 56% digital radiography and 2% conventional film-screen system). [13] Those machines with automatic exposure controls showed significantly lower mean ESD values. Digital and CR systems produce better image qualities at lower doses as compared to conventional film screen system [6,14]. On the contrary, studies done in Austria on 1yr old patients to compare effective dose rates received during examinations which used grids and automatic exposure control, with those which did not use grids showed that doses were higher for the former [19,20,21]. Digital systems have the potential to increase radiation dose to the patient if they are not used correctly [12].

Low kV and high mAs technique are attributing factors to dose received by a patient. In this study, there was a reasonable significant correlation between tube voltage and ESD values (r=0.547, p=0.013). A study carried out in Nigerian hospitals showed that those centers which used this technique obtained higher ESD values compared to those that used low kV and higher mAs [23]. This is the other reason why ESD values were higher as low kV (49-60kVp) and high mAs (1.6-5.6mAs) values were used throughout the study. The absence of additional filtration on the fixed x-ray tube had an inherent contribution to radiation dose because photons which have low energy are not attenuated. Film processing can also add to patient dose because if the processing conditions are poor, this can cause the radiographer to increase the exposure factors to come up with a good image.

It is expected that as weight increases, the entrance skin dose should also increase. This is so from this study's results as shown in figure 1, but there are slight fluctuations in doses as weight increases. The highest weight value was recorded for a patient at 19kg, with an entrance surface dose of 1.103µGy which was expected. The lowest value of weight was 3.8kg which corresponded to the lowest dose value of 0,241µGy. A significant correlation was found between patient weight and ESD values (r=0.730, p=<0.001). Although there are wide variations in dose for all the patients with almost similar weight, there is a significant correlation between the weight and the individual doses. Mean weight used in the other studies used in comparison to this study has an effect on patient dose. A lower mean weight will result in low doses, and higher mean weight will result in higher doses. For the fixed x-ray equipment used in this study, it has been 11years since its installation in 2002. Even though a study done in Korea showed no correlation between machine's years and ESD values, the equipment age in this study could have affected functioning of the machine leading to poor performance. If a machine does not comply with international standards of installation and functioning, it is bound to produce the inaccurate exposures, therefore the issue of accuracy of the patient dose measurements should also be taken into account when comparing DRL values [11, 24].

There are various values for third quartile doses and mean ESD from literature. According to the NRPB 2000, DRLs are derived from a rounded figure of the 3rd quartile value in European surveys. Reference [25] In 1999, the NRPB set the pediatric DRL value for chest x-ray AP and PA examinations at 100µGy, whilst in 2000 it was at 70µGy, showing a slight fluctuation compared to the 2002 value. The European Commission suggested a reference value of 100µGy for 5year olds chest x-ray examinations, which are similar to those for NRPB 1999. [10, 26].

This current study had higher doses compared to previous studies done. The third quartile calculated was 150µGy, which is about four times that of the NRPB. Choice of films used contributes to the radiation dose, as slow films require higher exposures whilst fast films require lower exposures. The mean ESD is approximately five times those published in NRPB 2002, and the third quartile is around six times those published by the EC, 1996. [10] There are different methods used in measuring ESD and this could be the reason why there are so many different variations in dose values. This study used the direct method, with TLDs as the tool. Previous studies used phantoms, indirect methods, computer software known as Monte Carlo and ionization chambers. The NRPB devised methods of obtaining ESD values by placing all children below the ages of 15years into 5 categories which are: 0, 1yr, 5yrs, 10yrs and 15yrs old [25]. These were considered as standard sized patients from which DRL values can be derived from. However this study could not apply this method as the most number of patients who came to the department were below 5yrs, requesting chest x-ray examinations. A mean ESD of 110µGy was stated by the NRPB in 2002, and it is about five times the value of this current study. Other limitations in this study include the fact that firstly, only 2 machines were used, with the majority of the x-rays being taken by the fixed machine and secondly, a small sample size of only 20 patients was used which is smaller compared to the other studies from literature. The authors cannot state with confidence whether results would have been the same if a larger sample size was used. However the conclusions made from this study, are still worth noting.

5. Conclusion

These results suggest that pediatric patients below the age of 5years may be receiving higher radiation dose compared to the recommended doses. It is possible that the higher doses could be due to the age of the machine and lack of adequate quality control measures on the equipment. It is also possible that this was due to the use of a lower FFD of 100cm compared to 180cm used by other researchers. Further and bigger studies into this area are necessary.

6. Recommendations

Results obtained in this study may act as a baseline for the establishment of local DRLs for chest examinations and they serve as a guideline in improving radiographic practice and reducing dose to the radiosensitive children being examined, emphasising justification and optimization during radiologic examinations in Harare. However, due to the limitations in this study, the researchers recommend further studies designed to overcome such limitations as that may yield a more reliable mean ESD and third quartile value. The researchers also recommend careful implementation of the ALARA principle, application of more appropriate radiographic technique which is relevant to pediatric patients, procurement of pediatric equipment for radiologic procedures and adequate implementation of quality assurance programs on the x-ray equipment.

Acknowledgements

The authors acknowledge the Radiation Protection Authority of Zimbabwe, the participants and the parents and guardians of the paediatric patients recruited in this study.

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