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Evaluation of the Entrance Surface Dose (ESD) and Radiation Dose to the Radiosensitive Organs in Pediatric Pelvic Radiography

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Abstract

Background
Patients' dosimetry is crucial in order to enhance radiation protection optimization and to deliver low radiation dose to the patients in a radiological procedure. The aim of this study was to assess the entrance surface dose (ESD) and radiation dose to the radiosensitive organs in pediatric pelvic radiography.

Materials and Methods: The studied population included 98 pediatric patients of both genders referred to anteroposterior (AP) projection of pelvic radiography. The radiation dose was directly measured using high radiosensitive cylindrical lithium fluoride thermo-luminescent dosimeters (TLD-GR200). Two TLDs were placed at the center point of the radiation field to measure the ESD of pelvis. Moreover for each patient, 2 TLDs were placed upon each eyelid, 2 TLDs upon each breast, 2 TLDs upon the surface anatomical position of the thyroid gland and finally 2 TLDs at the surface anatomical position of the gonads to measure the received dose.

Results
The ESD ± standard deviation for AP pelvic radiography was obtained 591.7±76 µGy. Statistically significant difference was obtained between organs located outside and inside of the radiation field with respect to dose received ($P<0.001$), as well as between the average dose received by the breast and lens of the eyes ($P<0.05$). There was no difference between boys and girls with respect to average ESD, while the testes dose was statistically non-significantly lower than ovaries dose.

Conclusion
The ESD received by patients are relatively accordance to the international recommendations. However further reduction in patients' dose in achievable by adherence to the radiation protection optimization guidelines. The data presented in our study will serve as a baseline needed for deriving local reference doses for pediatric pelvic radiography in our hospital. The study is expected to increase the awareness of medical professionals about the radiation doses in pediatric pelvic radiography.

Key Words: Dosimetry, ESD, Pediatrics, Pelvic Radiography, Radiation Protection.

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1- INTRODUCTION

Medical diagnostic x-ray examinations are a significant source of ionizing radiation to the population (1). Although patients can undoubtedly obtain enormous benefit from these examinations, their use involves some well-known risks of developing radiogenic cancer (2, 3). The risk of radiation carcinogenesis is inversely proportional with patients' age, suggests the high vulnerability of pediatrics to the biological effects of radiation (4-7). It is assumed pediatrics as an ultimate risk group to be 10 times higher probability for late radiation detriment effects compared to the middle-aged adults, since the longer life time expectancy combined with higher radiosensitivity of their cells and tissues (4, 8-10). Pediatric x-ray examinations accounted for approximately 10% of all radiological procedures (11) and this scale is increasing each year (12).

Patients' dosimetry is crucial in order to enhance radiation protection optimization and to deliver low dose to the patients during a radiological procedure (13, 14). The need for radiation dose surveys has been highlighted (13, 15). The increasing concern expressed in the literature regarding poor knowledge of pediatricians in term of the radiation effects and doses, have reinforce these statements (12). Entrance surface dose (ESD) is the most widespread indicator to assessing the amount of radiation dose to the patient in a single x-ray exposure. The ESD has been identified as a best quantity by which to monitoring the diagnostic reference level (DRL) in order to manage the radiation doses to the patients in diagnostic radiology (16). The ESD can be directly measured by thermo-luminescent dosimeters (TLD), or indirectly by measurement of the tube output at free-air or by the applied exposure parameters using the mathematical formula (17). However the reliability of the ESD measurements by TLD has been well known (18). There are scanty studies in pediatric dosimetry in Iran. Malekzadeh et al. (19), and Faghihi et al. (20), studied the ESD for neonates in several x-ray centers at Mashhad and Shiraz, respectively. Moreover, Bahreyni-Toossi et al. (6) studied the radiation dose to the chest and abdomen radiography for 195 neonates in eight neonatal intensive care units (NICU) of different hospitals in Mashhad and reported there are wide variations in dose from center to center.

The aim of this study was to assess the ESD and radiation dose to the radiosensitive organs in pediatric pelvic radiography. We was focused on pelvis radiographs; since this is one of the most common and more frequent radiographic examination performed in pediatrics and involves the direct irradiation of ionizing radiation to the radiosensitive organs within the lower part of the abdomen, such as the gonads, the lower part of the colon and the pelvis bone (21).

2- MATERIALS AND METHODS

2-1. X-ray Equipment

The study was performed in a single academic center using a single Varian radiographic unit (Varian medical systems, USA). The x-ray tube filtration was 3 mm Al (inherent 0.5, added 2.5 mm). Equipment calibration of this x-ray unit has recently been performed by an experienced local quality control team.

2-2. Patients and Ethical Considerations

The University Ethic Committee approved the study (ID number: U-94150), and written informed consent was obtained from all patients/parents. The studied population included 98 pediatric patients of both genders referred to anteroposterior (AP) projection of pelvic radiography during a period of 6 months (July 2016 to January 2017). Before irradiation, the anatomical characteristic of each patient (weight, height and pelvis thickness) was obtained in AP-supine position using a digital balance and a physical ruler. The exposure parameters (tube voltage and tube load) were recorded during the study. All exposures were performed in 95-110 cm film to focus distance (FFD), with respect to standard beam collimation according to patients' size. Follow the majority of other investigators (15, 17, 22-27), patients were categorized into age groups of 0–1 years, 1–5 years, 5–10 years and 10–16 years.

Patients were considered eligible for inclusion in the study if they were below 16 years of old, could cooperate for the mount of dosimeters at their skin, and their parents have given written consent. All uncooperative, very thin and obese patients were excluded from the study. Departmental policy was allowed all exposures to be done without anti-scatter grid. The patient position was supine and feet toward the anode of x-ray tube in all exposures.

2-3. Dosimetry Data Collection

The quantity measured in this study was Entrance Surface Dose (ESD) at the center point of intersection of the beam axis with the surface of patient, backscatter radiation included (28). The ESD was calculated by direct method, with use of the cylindrical lithium fluoride thermo-luminescent dosimeters (LiF: Mg, Cu, P), commercially known as TLD GR-200. These TLDs have small size, near tissue equivalent and has potential to detecting high dose gradients (29). The high radiosensitivity of these TLDs has demonstrated to be able to measure doses at microgray (µGy) levels or even below (29, 30), and consequently are ideal for pediatric dosimetry. At the onset of the study, the TLDs were annealed by a LTM reader (Fimel, Velizy, France) at 240 °C for 10 min to reduce the background radiation (29), and then were calibrated to a quantity of 6 mGy. Sixteen TLD chips were used for each pediatric and two TLDs for measuring the background radiation. Two TLDs were placed at the center point of the radiation field to measure the ESD. Moreover for each pediatric, 2 TLDs were placed upon each eyelid, 2 TLDs upon each breast, 2 TLDs upon the surface anatomical position of the thyroid gland and finally 2 TLDs at the surface anatomical position of the gonads (the ovaries in girls and the testes in boys) to measure the received dose. The TLDs were read within 48 hour of exposure.

2-4. Statistical analysis

Data were transferred to an Excel spreadsheet (Microsoft, Redmond, Washington), and statistical analysis was performed using the standard Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) version 16.0. P-value less than 0.05 obtained from inferential statistics were considered statistically significant.

3- RESULTS

The patient characteristics (Body mass index (BMI], weight, height, and pelvis thickness) and exposure parameters (tube voltage and tube load) are presented in **Table.1**. In **Figure.1**, ESD ± SD as a function of patients' age is provided. Statistically significant increase in ESD were obtained with increasing patients' age ($P<0.05$). The radiation dose to the radiosensitive organs located outside (the lens, thyroid, and breast) and inside (the testes and ovaries) of the radiation field is presented in **Figure.2**.

Statistically significant difference were obtained between organs located outside and inside of the radiation field with respect to average dose received (21.6 µGy vs. 550.2 µGy; $P<0.001$), as well as between the average dose received by the breast and lens of the eyes (11 µGy vs. 32.7 µGy; $P<0.05$), (**Table.2**). There was no difference between boys and girls with respect to average ESD (girls: 588.7 µGy vs. boys: 594.7 µGy; P>0.05), while the testes dose was statistically nonsignificantly lower than ovaries dose (testes: 516.6 µGy vs. ovaries: 583.7 µGy; P>0.05).

Table-1: Registered patient data and mean exposure parameters arising from AP projection of pediatric pelvic radiography

Age groups (year)	No. of patients			Height (cm)	Weight (kg)	BMI (kg/m^2)	AP thickness	KVp	mAs
	Boy	Girl	Total						
0-1	9	7	16	57	6.8	19	7.40	48	4.2
1-5	14	10	24	92	14.5	17.5	11.15	54	5.2
5-10	18	12	30	122	26	18	13.06	59	6.3
10-16	15	13	28	136	44.4	22.2	15.60	68	11.8

KVp: kilo voltage peak; mAs: milliampere second; AP: anteroposterior; BMI: body mass index.

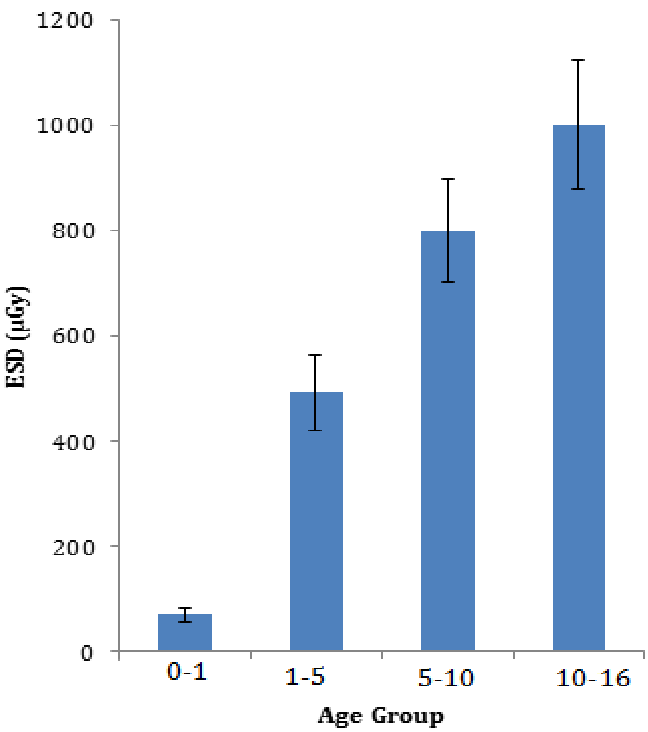

Fig.1: Mean ESD (µGy) in pelvic x-ray examination as a function of patient age in the AP projection.

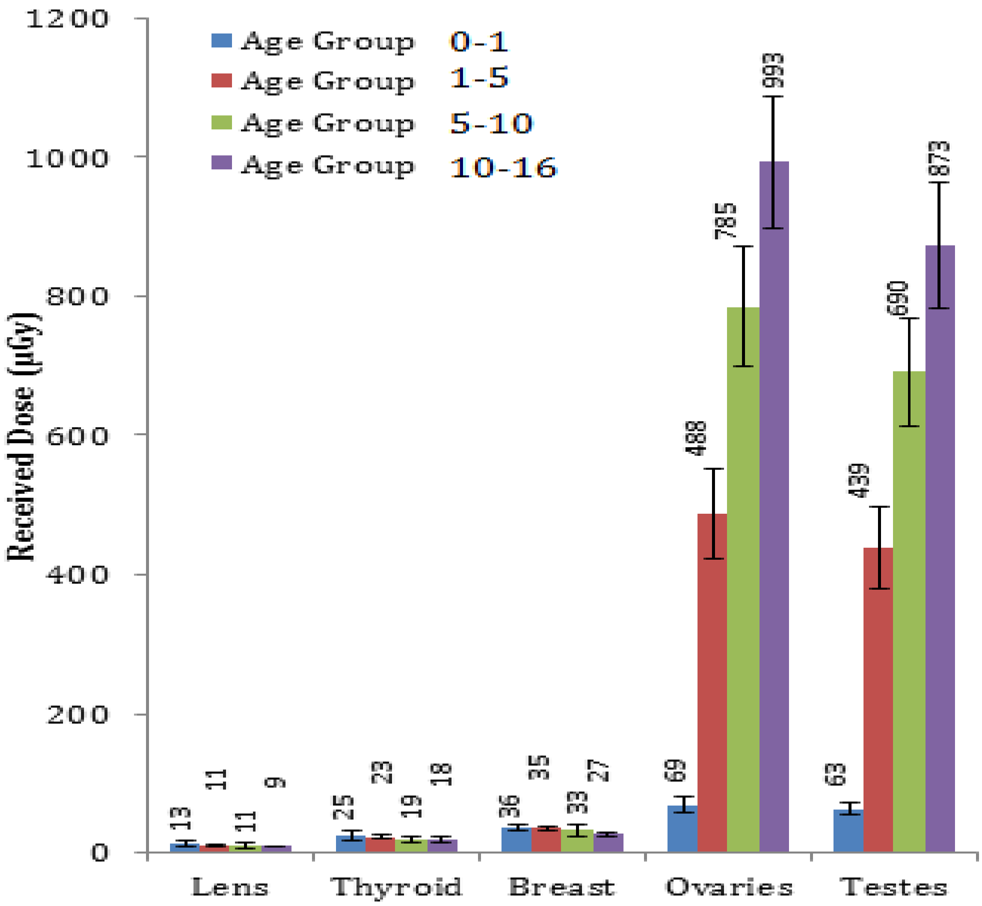

Fig.2: The Radiation dose to the radiosensitive organs located outside (the lens, thyroid and breast) and inside (the ovaries and testes) of the radiation field arising from AP projection of pediatric pelvic x-ray.

Table-2: Comparison between applied exposure parameters arising from pediatric pelvic radiography in this study with the previous studies

Patients age (year)	This study [a, b]		Frantzen et al (22) [a, c]		Atalabi et al (15) [d]		Nahangi et al (31) [e, d]		Ademola et al (17) [f, d]		Kiljunen et al (11) [g]	
	kVp	mAs	kVp	mAs	kVp	mAs	kVp	mAs	kVp	mAs	kVp	mAs
0-1	48	4.2	50	4.2	-	-	45	20.5	-	-	57	4.4
1-5	54	5.2	55	5.2	60	6.3	48.8	27.9	70	5	60	4.2
5-10	59	6.3	55/60	6.5	67	12	56.3	33.4	60	30	62	13.2
10-16	68	11.8	70	12	69.2	18.3	58.8	37.9	60	30	65	45.2

[a] Without anti-scatter grid; [b] The average FFD of 95-110 cm; [c] The average FFD of 117±24 cm; [d] No data provided about anti-scatter grid; [e] Age groups (years) 0, 1,5, 10; [f] Age groups (years) 5, 5-10, 12-14; [g] Age groups (years) 0.3, 1.4, 4.8, 10.8.

4- DISCUSSION

The applied exposure parameters such as the tube voltage (kVp), current-time product (mAs), and film to focus distance (FFD), which influences the ESD, were 48-68 kVp, 4.2-11.8 mAs and 95-110 cm in our study, which are comparable with one reported by Frantzen et al. (22), however they are lower than Nahangi et al. (31), and Ademola et al. (17), (**Table.2**). The European Commission (32) has discouraged applying tube voltage lower than 60 kVp for pediatrics undergoing x-ray examination. However the tube voltage used in our study (except for the group of 10-16 years) was lower than 60 kVp, also accordance to Frantzen et al. (22), and Nahangi et al. (31).

The average ESD obtained in our study have a wide range of 34-1620 μGy for the <16 years age group. We have compared our data with similar works done elsewhere in **Table.3** and found considerable spread in ESD values for pediatric pelvic x-rays. This wide range of ESD could be attributed to different x-ray units (i.e. x-ray tube filtration), exposure parameters, image receptors and particularly variations in patient sizes (6, 33). The ESD in our study are generally lower than some previous studies (23, 31); however they are higher than others (15, 22). The ESD reported by Frantzen et al. (22), for 1-15 years pediatrics arising from AP pelvic x-ray was particularly lower than one reported by the previous investigators (11, 15, 17, 23, 25, 26, 31, 34), including our own. This variation may be due to they added an additional copper (Cu) filter of 0.1 mm in x-ray tube for 1-15 years patients and use of relatively increased FFD of 117±24 cm in their study. The effect of radiation filtration (35) and increased FFD (36, 37) for radiation protection optimization of patients has been well established elsewhere.

We have also compared ESD data from our and previous studies with the DRL values established by the national radiological protection board (NRPB; 1992) in **Table.3**. Note that the ESDs in **Table.3** are as a dose-in-air including backscatter, while our data are ESD in tissue which is typically 5% higher than the entrance dose-in-air (22). For the 0-1, 1-5 and 5-16 years age groups, most of reported ESDs are lower than that recommended DRL, while for the 5-10 years age group, 4 studies including our own, were higher. The radiation dose to the radiosensitive organs located outside of the radiation field was ranged from 9 μGy for the lens of the eyes to 36 μGy for the breasts. This variation in ESD value could be attributed to the distance from the primary radiation field which is particularly shorter for the breast compared to the lens of the eyes. Hence, the use of shielding tools for protection of the breast may be recommended. There was no difference between boys and girls with respect to average ESD, while the testes dose was statistically nonsignificantly lower than ovaries dose by 11.5%. Taken into consideration that our patients were feet toward the anode in all exposures, the reduction in testes dose could be attributed to the anode heel effect which particularly associated with reducing of radiation intensity in the anode side of x-ray tube. Such similar findings has reported by Mraity et al. (38), for adult pelvic x-ray. The risk of exposure-induced cancer death (REID) arising from AP pelvic x-ray in an individual pediatric patient <16 years has been estimated ranged from 10.94 per million for boys and 6.76 per million for girls, respectively (31). However it is influenced by various factors such as applied exposure parameters, FFD, radiation field size and patient sizes. Although the ESD values in our study (except for 5-10 years age group) were lower than recommended DRL by the NRPB, further reduction in patients' dose is achievable. A list of the best and simple practices for radiation protection optimization in pediatric pelvic x-rays is provided in **Table.4**.

Table 3: Comparison between mean ESD (µGy) arising from AP projection of pediatric pelvic x-ray in this study with previous studies and NRPB DRLs for pediatric pelvic x-rays

Patients age (year)	Entrance Surface Dose (µGy)											DRL
	This study [a]	Ref (17) [b]	Ref (34) [c]	Ref (15)	Ref (26)	Ref (23)	Ref (25)	Ref (22)	Ref (31) [d]	Ref (11) [e]	Ref (28) [f]	Ref (39) [g]
0-1	70.5	-	67	-	140	513	-	110	321	140	20–1370	500
1-5	493	570	480	102	350	797	410	62	587	-	-	600
5-10	801	854	450	321	550	1286	680	116	1088	420	90–2790	700
10-16	1003	1354	690	645	1070	1816	1230	324	1475	2540	90–4170	2000

[a] ESD in tissue which is typically 5% higher than entrance doses in air, includes backscatter, according to Frantzen et al. (22); DRL: diagnostic reference level; [b] Age groups (years) 5, 5-10, 12-14; [c] Age groups (years) <1, 1-4, 5-9, 10-16; [d] Age groups (years) 0, 1,5, 10; [e] Age groups (years) 0, 5, 15; [f] Age groups (years) infants, 5, 10; [g] Age groups (years) 1, 5, 10, 15.

Table 4: A list of simple dose optimization practices for pediatrics pelvic x-ray examinations

Contributor	Patients Dose	Comments	Ref
Increasing the film to focus distance (FFD)	Reduce patient dose	Reduction of x-ray intensity by inverse square low	(36, 37)
Anode heel orientation	Reduce testes dose	Provided feet toward the anode	(38)
Additional filtration (i.e. 0.1 mm Cu)	Reduce patient dose	Absorb the soft radiation	(22, 40)
Gonad shielding	Reduce testes dose	Absorb the primary radiation to the testes	(21, 41)
Beam collimation	Reduce patient dose	Reducing amount of tissue irradiated	(1, 4, 42)
Use of high kVp and low mAs	Reduce patient dose	Reducing photoelectric absorption	(43)
Patients dosimetry	Awareness of dose levels	Radiation protection optimization	(14)
Use of fixator tools for immobilization of uncooperative pediatrics	Image quality improvement	Avoid repetition	(40)
Automatic exposure control (AEC)	Reduce patient dose	Manual selection of exposure factors	(40)
Quality control and assurance of x-ray units	Reduce patient dose	Optimization of patients dose and image quality	(44, 45)
Avoid use of grid *	Reduce patient dose	Low exposure parameters	(44)
Air gap technique	Reduce patient dose	Scatter rejection	(46)
High frequency generator	Reduce patient dose	Improve the accuracy and reproducibility of exposures	(40)

* Traditionally for x-ray imaging of pediatrics or small structures, the anti-scatter grid should not be used.

5- CONCLUSION

Patient radiation doses in pelvic radiography was assessed and compared with the previous literatures and recommended DRLs. The study showed the radiosensitive organs located outside of the radiation field received negligible radiation doses and the ESD received by patients is relatively accordance to the international recommendations. However, further reduction in patients' dose in achievable by adherence to the radiation protection optimization guidelines. The data presented in our study will serve as a baseline needed for deriving local reference doses for pediatric pelvic radiography in our hospital. Follow the radiation protection guidelines recommended in this study can significantly reduce the patients' radiation doses. The study is expected to increase the awareness of medical professionals about the radiation doses in pediatric pelvic radiography.

6- CONFLICT OF INTEREST

There is no conflict of interest to declare.

7- ACKNOWLEDGMENT

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