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Efficacy of Increasing Focus to Film Distance (FFD) for Patient's Dose and Image Quality in Pediatric Chest Radiography

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Abstract

Background: Increasing the X-ray focus to film distance (FFD) has been advocated as an effective method to reduce the patients' radiation dose. The aim of this study was to investigate the efficacy of this technique in patients' dose and image quality in pediatric chest X-ray.

Materials and Methods: Sixty pediatric patients were X-ray imaged at FFDs of 100 and 130 cm. Dose measurements were performed using thermo-luminescent dosimeters (GR200). The quality of images was independently assessed using the anatomical criteria recommended by the European guidelines.

Results: Increasing the FFD from 100 to 130 cm has reduced the entrance skin dose (ESD) of patients by 32.2% (P <0.05). There was no statistical difference for image quality scores between the two techniques (P>0.05).

Conclusion

Increased FFD to 130 cm reduce the pediatric radiation dose with no significant changes in image quality.

Key Words: Chest radiography, Focus to film distance (FFD), Pediatric, Radiation protection.

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1- INTRODUCTION

Rapid increasing use of medical X-ray procedures in the past decades has increased concerns about radiation induced cancer risks, especially in pediatric population (1-5). It is estimated that medical diagnostic X-rays are annually responsible for 5,695 case of cancer in the population of United State (6). The international commission on radiological protection (ICRP) recommended that all patient exposure should be kept as low as reasonably achievable (ALARA), while consistent with obtaining good image quality (7). Dose optimization methods for common and more frequent X-ray procedures should therefore be regularly investigated, especially for pediatric patients with respect to their high cell sensitivity to ionizing radiation.

One of such examinations is the chest X-ray as the most common X-ray procedure frequently ordered by physicians to address the clinical problems in pediatrics (1, 2, 8). It is estimated that chest X-rays are contribute 60% of all pediatric X-rays in the first year of life (8). It is remained a main concern that pediatric chest X-rays are contribute to the radiation exposure to the radiosensitive organs such as the lungs, thyroid and undeveloped mammary glands (1,2,8) and suggests the need for optimization the dose received.

Increasing the X-ray focus to film distance (FFD) has been advocated as an effective method to reduce the patients' radiation dose during radiological examinations (9-11). The effectiveness of the FFD technique has been highlighted by several studies over the past two decades (9-15); the effective dose reduction ranging from 6.7% by Monte Carlo calculations (15) to a maximum of 44% by measurements on patients (9) has been reported. The reduction in radiation dose relies on the principle known as inverse square law in which the intensity of radiation decreases by a factor of $1/d^2$, where d is the distance between the X-ray focus and patient (9). Reducing the amount of tissue irradiated is an added benefit when using of the FFD technique (9, 10, 15). However, the efficacy of this technique was investigated in film-screen (9, 10, 12), computed radiography (15), and direct digital radiography (16) imaging systems, the need for more investigations has been highlighted (9, 13). The aim of this study was to investigate the efficacy of the FFD technique in patients' dose and image quality in computed radiography (CR) of pediatric chest X-ray.

2- MATERIALS AND METHODS

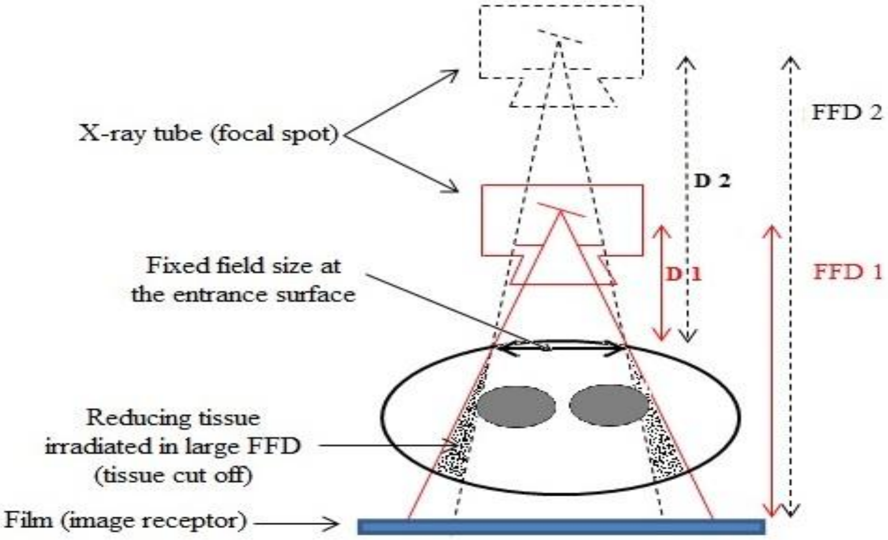
2-1. X-ray and imaging equipment

The Varian X-ray machine (Varian Medical Systems, USA) with a total filtration of 3 mm Al and a focal spot of 1.0 mm^2 were used for all exposures. All images were processed using the CR-KONICA MINOLTA, REGIUS 210 processor system which supports the C-PLATE cassette with columnar crystal phosphor that is ideal for pediatric use.

2-2. Inclusion criteria

Following the ESD value reported in a similar study by Brennan et al. (10) and Cochran's sample size formula, a total of sixty pediatric patients who were undergoing chest radiography in radiology department of our institution, were included in the current study. Our inclusion criteria was patients younger than 12- month, could cooperate and their parents give informed consent. Other patients that did not meeting our criteria excluded from the study. The demographic characteristic of each patient (age, height, weight, and chest thickness) was recorded before the study.

The Anterior-Posterior (AP) X-ray projection of patients' chest was taken by FFD of 100 or 130 cm. According to the European guidelines (17) and also, the policy of our X-ray department, all exposures were performed with no grid; the standard beam collimation was also, taken into account. As shown in **Figure 1**, this study was carried out in 2 phases; in the first phase, 30 pediatric patients were examined in traditional 100 cm FFD and following in phase two, 30 pediatric patients were examined in 130 cm FFD. Patients were considered eligible for inclusion into phase 2 of the study (130 cm FFD), if they have similar characteristics compared to the patients who had examined in the phase 1 (100 cm FFD). The tolerance level of variation between demographic characteristics of two groups of patients was considered to be ≤2 %.



$$\frac{I\,2}{I\,1} = \left(\frac{D\,1^2}{D\,2^2}\right)$$

Fig.1: Dose measurements were carried out in 100 and 130 cm FFD; low beam intensity and low tissue irradiated in the large FFD.

2-3. Dosimetry

The high radiosensitive Lithium-fluoride thermo-luminescent dosimeter chips, TLD-GR200, with dimensions of 3.2 × 3.2 × 8.9 mm^3 were used. Before and after each irradiation, TLDs were annealed at 245˚C for 10 minutes according to the manufacturer's instructions and then placed inside a thin plastic bag.

Fifteen TLDs were placed in different positions of the patient's chest skin. In order to prevent of fading effect, all TLDs were read within 48 h of exposure using LTM TLD reader. Calibration of the TLDs was performed in the Secondary Standard Dosimetry Laboratory (SSDL) of Karaj-Iran. Three control TLDs were used to monitor background radiation. The average dose of TLD chips was calculated and recorded as entrance surface dose (ESD).

2-4. Image quality

The quality of all images was independently evaluated by an evaluation panel of two radiologists and two experienced radiographers with a mean experience of 5.8 and 8.6 years in general radiography, respectively. The criteria used for assessing the images were compliance with the European guidelines on quality criteria for diagnostic radiographic images in pediatrics (17), as shown in **Table.1**. Similar to the study reported by Grondin et al. (2004) (12), a standard reference image provided from the archived images in digital image library, on which each criterion was independently interpret as optimum by each member of our evaluation panel. Following to the other investigators (11, 18-20), we distinguished images into four groups: poor (anatomy visualized worse than the reference image and unacceptable), acceptable (anatomy visualized worse than reference image but acceptable), optimum (anatomy visualized equal to the reference image) and excellent (anatomy visualized better than reference image).

Table 1: The Anatomical criteria used for evaluation the images in 100 and 130 cm FFD based on European guidelines

Image criteria	Source			
	Poor (1)	Acceptable (2)	Optimum (3)	Excellent (4)
Reproduction of the vascular pattern in the lungs				
Reproduction of the trachea				
Reproduction of the spine				
Reproduction of the paraspinal structures				
Visually sharp reproduction of the diaphragm				
Visually sharp reproduction of the costopherenic angles				
Visualization of the retrocardiac lung				
Visualization of the mediastinum				
Low magnification of the heart				

* The possible score is shown in parenthesis.

2-5. Ethical considerations

The institutional ethical approval was obtained before the study (Grant No. U-94150). Informed consent was provided from the parents.

2-6. Data Analysis

Dosimetry results were analyzed using a one-way analysis of variance (ANOVA) (9, 10). The non-parametric Mann-Whitney U-test was used to compare the image quality values between groups (9, 12). P-value<0.05 was considered statistically significant for all analysis.

3- RESULTS

The anatomical characteristic of two groups of patients (100 and 130 cm) is shown in **Table.2**. There was no meaning statistical difference between patient's weight, height and body mass index (BMI). The dosimetry data showed (**Table.3**) that increasing the FFD from 100 cm to 130 cm has statistically reduced the ESD by 32.2% (mean ESD of 0.059 and 0.040 mGy for 100 and 130 cm, respectively, P<0.05).

Image quality assessments revealed that there were no statistical differences for image quality scores between the two techniques (**Figure.2**).

The total scores for patient images were 26.7 and 26.45 out of a possible 36 for the 100 and 130 cm FFDs, respectively (**Figure.3**).

Table-2: The anatomical characteristic of patients and exposure factors in 100 and 130 cm FFD

FFD	No. of patients	Age (year)	Mean					
			Weight (Kg)	Height (cm)	BMI	Chest thickness (cm)	kVp	mAs
100 cm	30	<1	7.11	64.8	16.43	10.76	53	3.8
130 cm	30	<1	7.15	65.1	16.21	10.92	54	3.8
P-value			>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

Table-3: The measured ESDs and standard deviations (SD) in FFD of 100 and 130 cm

FFD	No. of patients	Mean ESD (mGy)	SD	Dose reduction	P-value
100 cm	30	0.059	0.004	32.2%	<0.05
130 cm	30	0.040	0.003		

SD: Standard deviation.

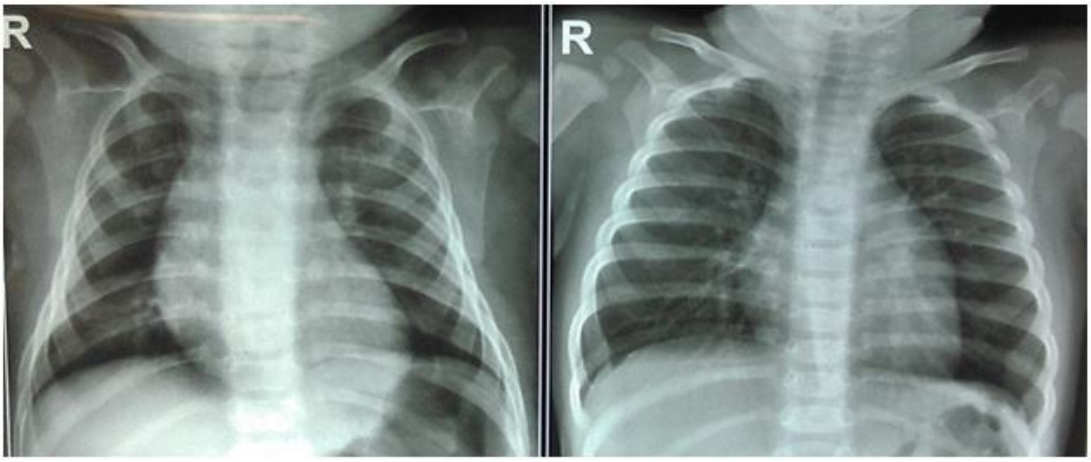


Fig.2: The AP pediatric chest x-ray images; at FFD of 100 cm (right) and 130 cm (left).

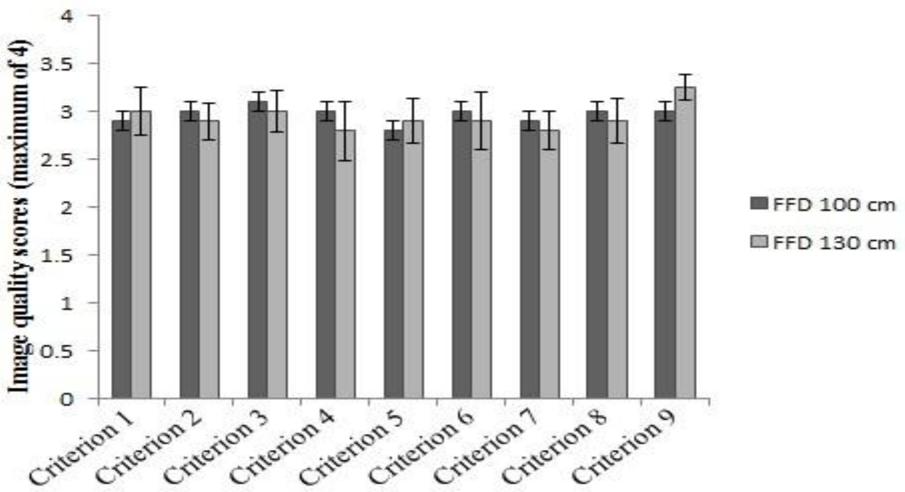


Fig.3: Image quality scores for each FFD; the error bars represent the SD.

4- DISCUSSION

Access to the good image quality associate with low patient dose is the aim of any X-ray procedure (11, 21, 22). Increasing the FFD from the traditional 100 cm to 130 cm resulted in ESD reduction by 32.2%, while image quality assessments revealed that there was no statistically difference between two groups of images. Our result is in good agreement with 32.5% reduction in the patient's ESD reported by Brennan et al. (2004) (10), when the FFD was increased from the 100 to 130 cm in pelvic radiography. Using of FFD technique for dose reduction reported by researches (**Table.4**); such this reduction was reported by Joyce et al. (2013) (11), in the ESD of 22.05% and 27.25%, when the FFD was increased from the 100 to 130 cm for the Caldwell and lateral projection of the skull X-ray, respectively. Brennan et al. (1998) (9), reported 65.18% reduction in the ESD for lateral projection of the lumbar spine radiography in anthropomorphic phantom (**Table.4**).

Increasing the FFD poses twofold protective advantages of reducing the ESD and also reducing the volume of tissue irradiated by the tissue cut off in the depth (**Figure.1**). Furthermore, the real dose reduction may be somewhat more due to this fact that our data was based on ESD measurements. The magnitudes of ESD measured at 100 cm are in consisting with the reported data in the literatures (**Table.4**). Due to the broad variation in the patient doses in the similar X-ray examinations, the quantity of diagnostic reference level (DRL) has been recommended by the ICRP in order to avoid of unnecessary radiation dose to the patients (23).

From **Table.5**, there is the broad variation ranging from 0.044 mGy (24) to 1.100 mGy (25) in the ESD for the pediatric chest X-ray in the literatures. Although the DRL for chest X-ray in an individual pediatric patient under 1 year old has been established to be 0.050 mGy (1), this study associate with the other studies represented in **Table.5**, [except the study reported by Makri et al. (24)], have ESDs larger than the recommended DRL. Increasing the FFD from 100 cm to 130 cm in pediatric chest X-ray has interestingly reduced the ESD from 0.059 to 0.40 mGy that is lower than the recommended DRL.

Optimization of the radiation dose for pediatric chest X-rays is significant as the chest X-ray has been identified as the most common X-ray examination (1, 2, 8), that contributes to the notable collective dose to the population. Newborns or neonates in the neonatal intensive cure unite (NICU) and especially immature neonates frequently receive multiple chest X-rays and are at risk due to the extra collective radiation dose to their radiosensitive organs. This extra dose have probability to be considered as a source of the increased risks of leukemia, thyroid and breast cancers from pediatric chest X-rays (26).

Although the substantial dose reduction to the breasts and thyroid gland can be achieve following use of posterior-anterior (PA) instead of anterior-posterior (AP) projection of the chest, as pediatrics are unable to sit up on their own, their chest radiographs is routinely performed in AP projection and consequent their radiosensitive organs are at risk (1). Although variety strategies were recommended to reduction the patient's radiation dose (27-29), but many of them are not commonly used in clinical practice mainly due to the cost and/or time implication. Accordingly, the FFD technique as a simple practical method could be a straight forward technique for optimization of patient's dose. We believes that pediatricians when ordering chest X-ray, should remind radiographers on the request card to use of dose reduction methods such as the FFD technique.

4-1. Limitations of the study

Collecting of the needed sample of patients with matched demographic characteristics to participate in two groups (with FFD of 100 cm or 130 cm) was the main limitation of this study as a time consuming process.

Table 4: Comparison the results of this study with other similar studies in the literatures

Investigator	Organ assessed	Study type	ESD±SD (mGy)		Dose reduction
			100 cm FFD	130 cm FFD	
Brennan et al. (10)	Pelvic x-ray	Patient	3.8±1.8	2.47±1.4	35%
	Pelvic x-ray	Phantom	3.03±0.04	2.01±0.04	33.66%
Tugwell et al. (13)	Pelvic x-ray	Phantom	1.021	0.79	22.62%
Brennan et al. (9)	Lat. lumbar spine	Patient	15.8	5.5	65.18%
	Lat. lumbar spine	Phantom	7.08	3.96	44.06%
Joyce et al. (11)	AP cranial	Patient	1.95±0. 10	1.52±0. 11	22.05%
	Lat. cranial	Patient	1.1±0.05	0.8±0.01	21.1%
This study	Chest x-ray	Patient	0.059±0.004	0.04±0.003	32.2%

Table 5: Comparison the ESD calculated in this study with other similar studies in the literatures (100 cm FFD)

Investigator		Age (year)	Projection	ESD (mGy)	SD
Karami et al (1)		<1	AP	0.065	0.003
BahreyniToossi et al (30)		<1	AP	0.076	-
Makri et al. (24)		<1	AP	0.044	0.016
Kiljunen et al (31)		<1	AP	0.060	0.040
Egbe et al. (25)	C1	<1	AP/PA	0.640	0.150
	C2	<1	AP/PA	0.700	0.010
	C3	<1	AP/PA	1.100	0.100
This study		<1	AP	0.059	0.004

C: X-ray center.

5. CONCLUSION

Our study demonstrated that increasing the traditional FFD of 100 cm to an updated reference FFD of 130 cm has reduced the pediatric radiation dose by 32.2%, with no significant changes in image quality. However further studies are needed to implementation of an increased FFD technique for reducing the dose in other pediatric X-ray examinations.

6- CONFLICT OF INTEREST

There was no conflict of interests in this article.

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