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Optimization of Radiological Protection in Pediatric Patients Undergoing Common Conventional Radiological Procedures: Effectiveness of Increasing the Film to Focus Distance (FFD)

Vahid Karami [1], *Mansour Zabihzadeh [1, 2], Nasim Shams [3], Abdolreza Gilavand [4]

[1]Department of Medical Physics, School of Medicine, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran. [2] Department of Clinical Oncology, Golestan Hospital, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran. [3]Department of Oral and Maxillofacial Radiology, School of Dentistry, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran. [4] Employed Experts on Faculty Appointments, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.

Abstract

Background

Increasing the x-ray film to focus distance (FFD), has been recommended as a practical dose optimization tool for patients undergoing conventional radiological procedures. In the previous study, we demonstrated a 32% reduction in absorbed dose is achievable due to increasing the FFD from 100 to 130 cm during pediatric chest radiography. The aim of this study was to examine whether increasing the FFD from 100 to 130 cm is equally effective for other common radiological procedures and performing a literature review of published studies to address the feasibility and probable limitations against implementing this optimization tool in clinical practice.

Materials and Methods

Radiographic examination of the pelvis (AP view), abdomen (AP view), skull (AP and lateral view), and spine (AP and lateral view), were taken of pediatric patients. The radiation dose and image quality of a radiological procedure is measured in FFD of 100 cm (reference FFD) and 130 cm (increased FFD). The thermo-luminescent dosimeters (TLD) were used for radiation dose measurements and visual grading analysis (VGA) for image quality assessments.

Results: Statistically significant reduction in the ESD ranged from 21.91% for the lateral skull projection to 35.24% for the lateral spine projection was obtained, when the FFD was increased from 100 to 130 cm ($P<0.05$). Optimum image quality was obtained for all projections in both FFDs. VGA of the resultant images demonstrated a statistically non-significant minor increase in image quality of lateral skull and spine projections, when increasing from 100 to 130 cm FFDs ($P>0.05$).

Conclusion

Increasing the FFD from 100 to 130 cm has significantly reduced radiation exposure without affecting on image quality. Our findings are commensurate with the literatures and emphasized that radiographers should learn to use of an updated reference FFD of 130 cm in clinical practice.

Key Words: Film to focus distance (FFD), Image quality, Pediatrics, Radiation protection.

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Corresponding Author:

Mansour Zabihzadeh, PhD, Department of Medical Physics, School of Medicine, Ahvaz Jundishapur University of Medical Sciences, Ahvaz 61357-33118, Iran. Tel/ Fax: (+98) 613-3205168

E-mail: manzabih@gmail.com

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1- INTRODUCTION

One of the basic principles of radiological protection recommended by the international commission on radiological protection (ICRP) is optimization of patients radiation protection in which all exposures should be kept as low as reasonably achievable (ALARA), without decreasing patients benefit (1, 2). Optimization of radiological protection has particular importance today than in the past due to dramatically increase the number of patients exposed to ionizing radiations (3). Recommendations for optimization of radiological protection come mainly from this fact that ionizing radiation has potential to result in health effects, especially the lifetime risk of developing cancer (4-10).

The risk of radiation related cancer is inversely proportional with patients age, suggests the high sensitivity of pediatrics and young children to ionizing radiations (10). Hence, the radiation-induced cancer risk in pediatrics is believed to be 10 times higher than that of the adults received the same dose (6, 11-13). Optimization of radiological protection is therefore significant for pediatric X-rays, especially for frequent and high-dose procedures which contribute significantly to the collective dose.

Increasing the X-ray film to focus distance (FFD) has been advocated as one of the aspects of optimization of radiological protection in patients undergoing X-ray procedures (14-16). The reduction in patients' dose is facilitated by the principle known as inverse square law and is independent from the film receptor (16). According to the inverse square law, increasing the FFD by a factor of two has potential to reduce the radiation intensity by a factor of four. Reducing the amount of tissue irradiated by tissue cut off is an added advantage of this optimization tool in clinical practice (14, 17, 18). In the previous work, we demonstrated that a 32% reduction in absorbed radiation dose is achievable due to increasing the FFD from 100 to 130 cm during pediatric chest radiography (16). Although the merits of this optimization technique has been studies for various examinations, much works needed to be done for implementing in clinical practice (14, 16, 19).

The aims of this study was to examine whether increasing the FFD from 100 to 130 cm is equally effective for other common radiological procedures and performing a literature review of published studies to address the feasibility and probable limitations against implementing this optimization tool in clinical practice.

2- MATERIALS AND METHODS

The protocol used in this study involved the collection of dosimetry data and image quality assessment to establish the efficacy of an increased FFD in clinical practice. The radiation dose and image quality of a radiological procedure is measured in FFD of 100 cm (reference FFD) and 130 cm (increased FFD). The visual grading analysis (VGA) was used for image quality assessments (20).

2-1. Equipment

The study was performed in a single academic center using a single general radiographic unit (Varian Radiography system, UAS). The total filtration was 3 mm Al (inherent: 0.5 mm, added: 2.5 mm). Konica Computed Radiography system (REGIUS 210, Japan), were used for the image acquisition. The equipment was recently calibrated by an experienced local quality control team.

2-2. Patients and Radiographic Techniques

The University Ethical Committee has approved the concept of the study (U-94150). Written consent was obtained from the parents before the study. After assessing each patient against specific inclusion-exclusion criteria, 159 patients (<16 years old) referred to radiographic examination of the pelvis (anteroposterior [AP] view), abdomen (AP view), skull (AP and lateral views), and spine (AP and lateral views), in university hospital were selected and radiation dose measurements were performed in FFD of 100 cm.

Following this, 162 other patients were included in the study for radiation dose measurements in FFD of 130 cm. More care be taken in selection patients for examine in FFD of 130 cm. In order to access to the reliable results, only 2% variation between the mean age, weight, height, and body mass index (BMI), of patients were considered to be permissible (16). The standard beam collimation was respected for all exposures.

2-3. Dosimetry data collection and thermo-luminescent dosimeter (TLD) placement

The high sensitive cylindrical lithium fluoride thermo-luminescent dosimeters (LiF: Mg, Cu, P; Thermo Fisher Scientific, Waltham, MA), commercially known as TLD GR200 was used for radiation dose measurements. These TLDs were accurate in the range of 0.1 μGy-10 Gy (21). Before measurements, the TLDs were annealed and calibrated to a quantity of 6 mGy. A reader (LTM model, Fimel, Velizy, France) was used to anneal and read the TLDs. The dosimetry data collection was included the absorbed dose in the center of the field at the surface of entry of radiation corresponding to entrance surface dose (ESD). For each projection, 15 refresh TLDs were located at the center of the field to measure the ESD. The calibration of TLDs was performed at the Secondary Standard Dosimetry Laboratory (SSDL) of Karaj, Iran.

2-4- Image quality

Image quality assessments were fulfillment by two experienced radiologists using European image criteria (**Table.1**) (22), and visual grading analysis (VGA) (20). The validity of VGA for such investigations has been well established (20, 23).

A standard radiographic reference image was provided for each projection on which all criteria had optimum visualization. The resultant radiographs at 100 and 130 cm FFDs were consecutively compared with radiographic reference image on adjacent monitors which have equal and constant light intensity overall the study. Follow the majority of previous investigators (16, 20), four-point scoring scale was employed for image quality assessments (**Table.2)**.

Table-1: European guidelines for image quality assessments.

IMAGE CRITERIA
Pelvis AP
1. Visualization of the sacrum and its intervertebral foramina depending on bowel content.
2. Reproduction of the lower part of the sacroiliac joints.
3. Reproduction of the necks of the femora.
4. Visualization of the trochanters consistent with age.
5. Visualization of the peri-articular soft tissue planes.
6. Reproduction of the pubic and ischial rami.
7. Reproduction of the spongiosa and corticalis.
Skull AP
1. Symmetrical reproduction of the skull, particularly cranium, orbits and petrous bones.
2. Projection of the upper margins of the petrous temporal bones into the lower half of the orbits in AP projection.
3. Reproduction of the paranasal sinuses and structure of the temporal bones consistent with age.
4. Visually sharp reproduction of the outer and inner tables of the entire cranial vault consistent with age.

5. Visualization of the lambdoid and sagittal sutures.

Skull Lateral

1. Visually sharp reproduction of the outer and inner tables of the entire cranial vault and the floor of the sella consistent with age.
2. Superimposition of the orbital roofs and the anterior part of the greater wings of the sphenoid bones.
3. Visually sharp reproduction of the vascular channels and the trabecular structure consistent with age.
4. Reproduction of the sutures and fontanelles consistent with age.

Spine AP

1. Reproduction as a single line of the upper and lower plate surfaces in the center of the beam.
2. Visualization of the intervertebral spaces in the center of the beam area.
3. Visually sharp reproduction of the pedicles, dependent on the anatomical segment.
4. Visualization of the posterior articular processes (for lumbar spine examinations).
5. Reproduction of the spinous and transverse processes consistent with age.
6. Visually sharp reproduction of the cortex and trabecular structures consistent with age.
7. Reproduction of the adjacent soft tissues.

Spine Lateral

1. Reproduction as a single line of the upper and lower plate surfaces in the center of the beam.
2. Full superimposition of the posterior margins of the vertebral bodies.
3. Reproduction of the pedicles and the intervertebral foramina.
4. Visualization of the posterior articular processes.
5. Reproduction of the spinous processes consistent with age.
6. Visually sharp reproduction of the cortex and trabecular structures consistent with age.
7. Reproduction of the adjacent soft tissues.

Abdomen AP

1. Reproduction of the abdomen, from the diaphragm to the ischial tuberosities, including the lateral abdominal walls.
2. Reproduction of the properitoneal fat lines consistent with age.
3. Visualization of the kidney outlines consistent with age and depending on bowel content.
4. Visualization of the psoas outline consistent with age and depending on bowel content.
5. Visually sharp reproduction of the bones.

Table-2: Image quality scoring scale

Image Score	Image quality	Comment
1	Poor	Anatomy visualized worse than the reference image and unacceptable
2	Acceptable	Anatomy visualized worse than reference image but acceptable
3	Optimum	Anatomy visualized equal to the reference image
4	Excellent	Anatomy visualized better than reference image

2-5- Data Analysis

Dosimetry and image quality data are shown as mean ± Standard deviation (SD). Statistical analysis was performed using the standard Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) version 16.0. Statistical differences between FFDs in terms of image quality and radiation dose were assessed using the non-parametric Mann-Whitney U-test. $P < 0.05$ was considered to be statistically significant for all test results.

3- RESULTS

No statistically differences between patients who had examined in 100 and 130 cm FFDs were seen for weight, height, and BMI in all studies ($P>0.05$). Statistically significant reduction in the ESD ranged from 21.91% for the lateral skull projection to 35.24% for the lateral spine projection were obtained when the FFD was increased from 100 to 130 cm (**Table.3**).

VGA scores showed optimum image quality for all projections in both 100 and 130 cm FFDs, without non-diagnostic or poor quality study (**Figure.1**). VGA of the resultant images demonstrated a statistically non-significant minor increase in image quality for lateral skull and spine projections, when the FFD was increased from 100 to 130 cm (P>0.05). A sample of each x-ray in 100 and 130 cm FFDs is shown in **Figure.2**.

Table-3: ESD (µGy) in 100 and 130 cm FFDs for common pediatrics radiographic examinations

Radiographic examination	No. of patients Mean age (range), year	FFD (cm)	ESD ± SD (µGy)	Dose reduction (%)	P-value
Pelvis AP	32 6.9 (0-13)	100	623 ± 83	30.65	<0.05
	30 7.2 (1-13)	130	432 ± 58		
Abdomen AP	29 7 (0-12)	100	762 ± 52	25.19	<0.05
	30 7.4 (0-13)	130	570 ± 43		
Skull AP	24 6.64 (2-12)	100	1002 ± 80	23.35	<0.05
	25 6.72 (1-13)	130	768 ± 44		
Skull Lat	24 6.75 (2-12)	100	651 ± 40	21.91	<0.05
	25 6.81 (2-13)	130	485 ± 18		
Spine AP	25 8.35 (4-13)	100	1032 ± 102	26.55	<0.05
	26 8.41 (4-14)	130	758 ± 61		
Spine Lat	25 8.9 (4-13)	100	1640 ± 130	35.24	<0.05
	26 8.7 (1-14)	130	1068 ± 74		

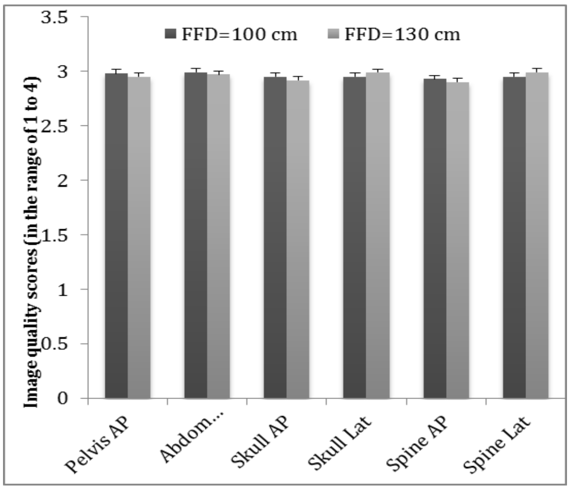
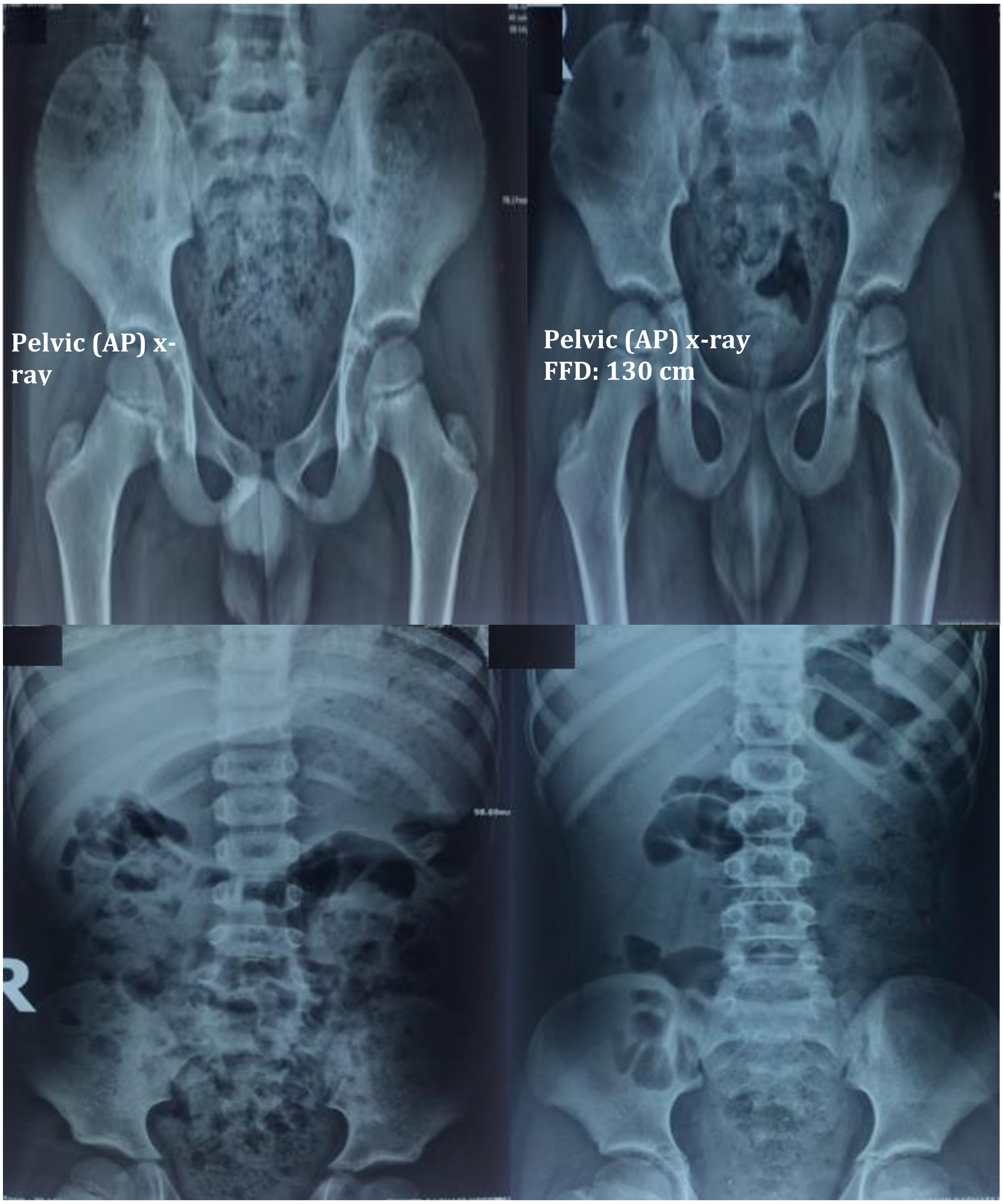
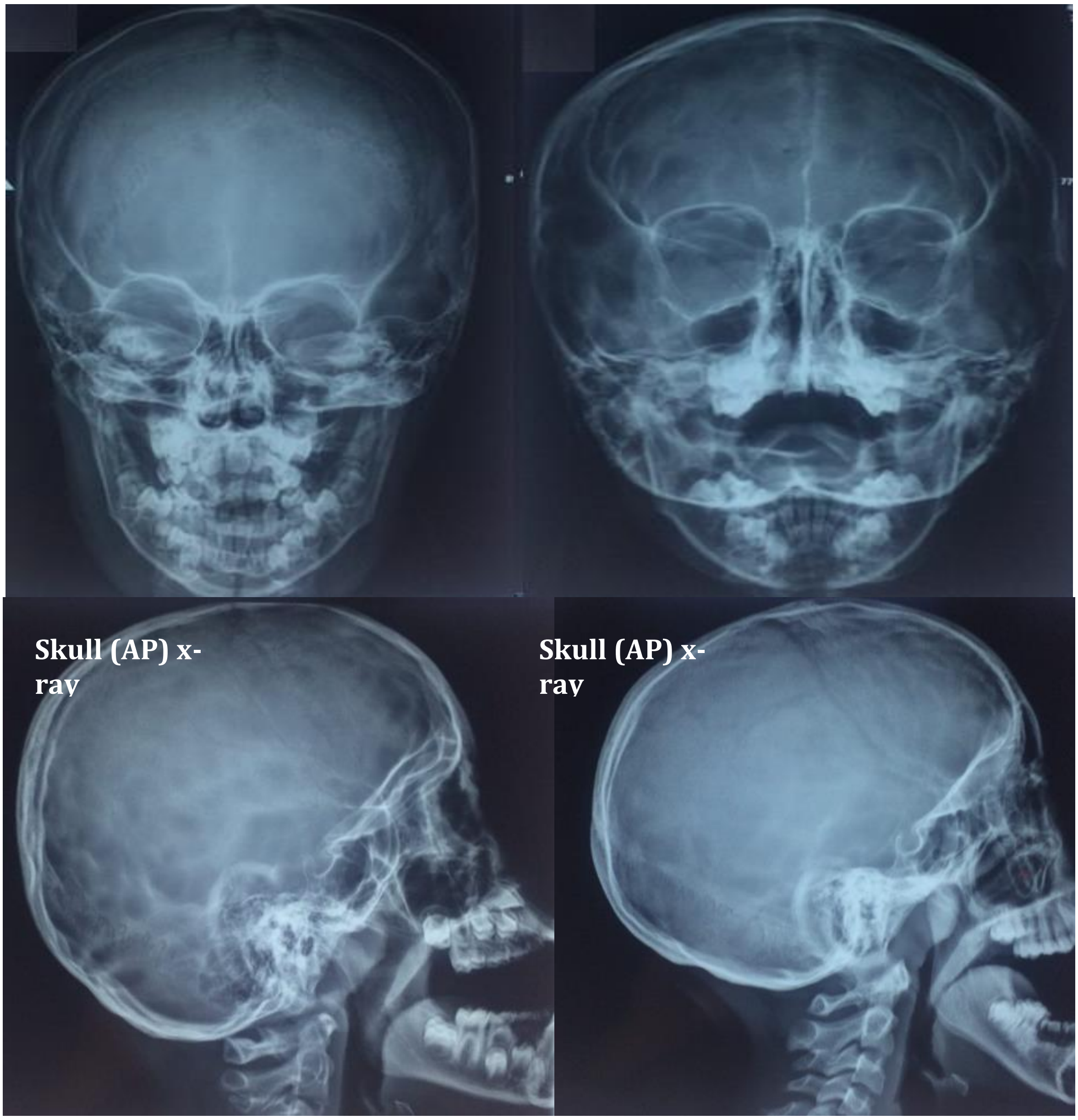


Fig.1: VGA scores in both 100 and 130 cm FFDs for various radiographic examinations (standard deviations in shown as error bars).


Pelvic (AP) x-
ray
Pelvic (AP) x-ray
FFD: 130 cm
R


Skull (AP) x-ray
Skull (AP) x-ray

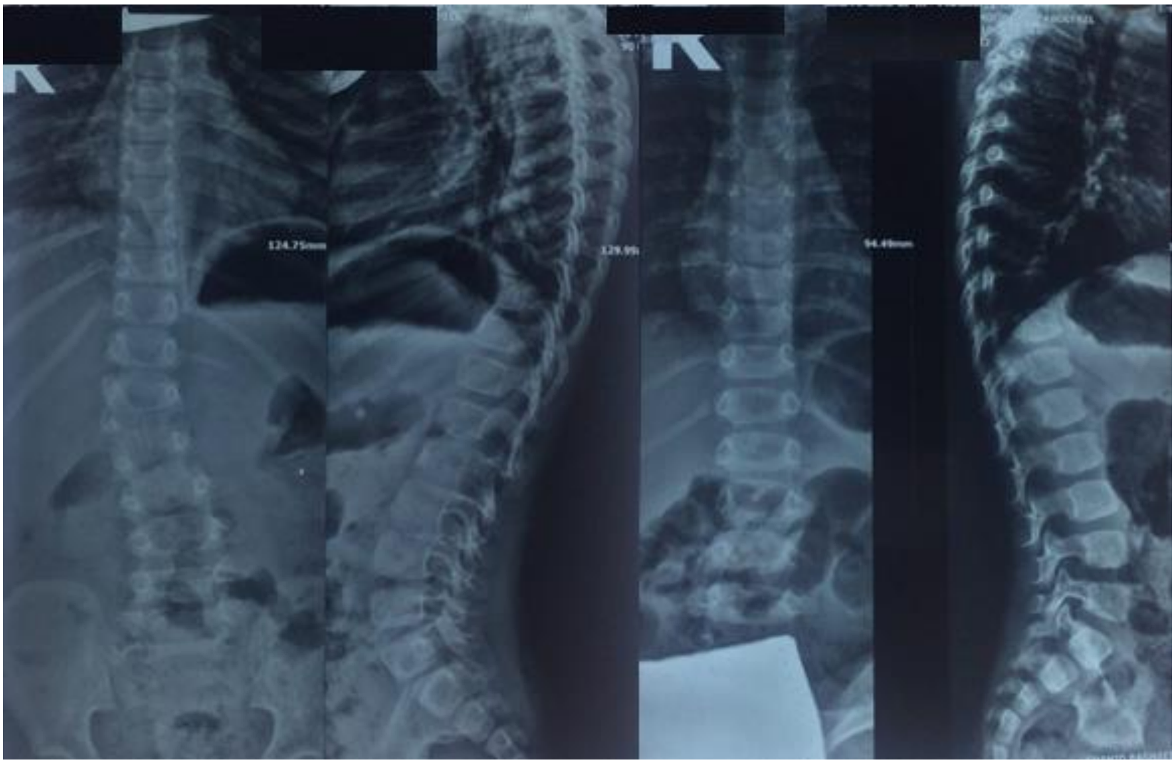


Fig.2: Samples of each radiographic examination imaged at 100 cm (left) and 130 cm (right) FFDs.

4- DISCUSSION

Earlier work in 1991 by Kebart and James (24), demonstrated a 12.5% reduction in both the integral and cumulative dose of radiation due to increasing the FFD from 40 inches to 50 inches. Using Monte Carlo simulations, Poletti (1994) (18), reported 17-19% reduction in ESD for AP abdomen projection, when the FFD was increased from 100 to 150 cm. Vañó et al. (1995) (25), reported a reduction of radiation exposure up to 17% can be achieved by a 10 cm increase in FFD for AP lumbar spine projections.

In 1998, Brennan and Nash (14), investigated the effects of increased FFD on patient dose and image quality for lateral lumbar spine projections and reported a mean reduction of 44% in the patients' ESD, when the FFD was increased from 100 to 130 cm. They underlined that increasing the FFD from 130 to 150 cm offered no further advantage and recommended routine use of 130 cm for lateral lumbar spine projections. Brennan et al. (17), established a similar study on pelvic X-ray examinations in 2004 and reported about 34% reduction in the ESD, without loss of image quality when the FFD was increased from 100 to 130 cm in both the patient and anthropomorphic phantom. Their research was replicated by Tugwell et al. (2014) (19), who reported 22.6% and 54.1% reduction in ESD follow the increasing of FFD from 100 to 130 cm with and without utilized of automatic exposure control (AEC), in an anthropomorphic pelvis phantom, respectively. In a more recent study in 2009, Woods and Messer (26), demonstrated increasing the FFD definitively has potential to reduce the ESD for computer radiography systems, albeit they noted that very high FFDs may decrease the quality of images. Considering improvements in the geometric properties with minimum distortions, Farrell et al. (2008) (27), declared that increasing the FFD may even result in image quality benefits. Kwonet al. (2014) (28), reported a significant reduction in entrance surface air kerma (ESAK), without loss of image quality, when the FFD was increased from 180 cm to 240 cm, 280 cm and 320 cm in an anthropomorphic chest phantom. These researches has been followed and replicated by other investigators for various radiographic examinations such as: AP pelvis examinations (23, 26, 29-31),

AP and lateral lumbar spine examinations (29-31), AP abdomen examinations (30), AP knee examinations (32), AP chest examination (16), and AP and lateral skull examinations (20). Although various level of dose reduction has been reported, but all of these results confirm benefit upon its utilization in clinical practice. Our results demonstrated that increasing the FFD is a practical dose optimization tool in common conventional pediatric X-rays. Dosimetry data showed increasing the FFD from the traditional 100 to 130 cm FFD has resulted in 30.65%, 25.19%, 23.35%, and 26.55% reduction in patients' ESD for the AP projections of pelvis, abdomen, skull, and spine radiographic examinations, respectively. For the lateral spine and skull projections, increasing the FFD from 100 to 130 cm has resulted in 21.91%, and 35.24% reduction in ESD, respectively.

Our results are consistent with one reported by Brennan et al. (2004) (17), who reported 34% reduction in patients dose when the FFD was increased from 100 to 130 cm in pelvic X-ray examinations. Other studies that evaluated the efficacy of increasing the FFD during the chest (16), abdomen (18), and skull (20) examinations has reported relatively likewise similar results. The quality of all images in both 100 and 130 cm FFDs was adequately preserved. VGA scores showed no statistically differences between the qualities of resultant images in both the FFDs (**Figure.1**). Our study also indicated that increasing the FFD from 100 to 130 cm has resulted in image quality benefits for lateral skull and spine projections. The pelvis (19, 33), spine (34), and abdomen radiographic examinations are among the more frequent and high-dose examinations which contribute to the significant radiation exposure of the radiosensitive organs such as the gonads, colon and pelvis bone. When a pediatric undergoes multiple of these examinations, the radiosensitive organs receives substantial collective dose and are at risk due to the probability of radiation induced malignancy. Much focuses has been placed on such examinations in order to protection of organs at risk and unfortunately some of them has been challenged (35, 36).

It has been demonstrated that increasing the FFD may be the great opportunities for pelvic radiography (37). To the basis of this study and the currently published literatures, increasing the FFD is a well-established optimization tool and has potential to be recommended for routine use in clinical practice. Using of available dose reduction tools in clinical practice is limited due to time consuming and cost implication for the imaging departments, while the increased FFD is a practical low cost method, consistent with patients conforming and has not resulted in image quality degradation.

4-1. Limitations of implementation in practice

Despite increasing the FFD have been established as a worthwhile dose optimization tool, anecdotal evidence and our experience suggests there are the gap between the evidence and practice, so that this technique is not commonplace in many clinical settings. The main and tradition limitations discussed in the literatures are related to equipment and radiographers physical limitations. The physical dimensions of some radiography rooms may restricts further increasing the FFD in vertical and horizontal axis, a low ceiling radiography room, in particular. Moreover, frequently increasing the FFD in vertical axis may result in fatigue and even ergonomic disorders such as back pain to the radiographers. Furthermore, increased exposure output followed to increase of FFD may result in reducing of tube life; however, Brennan et al. (2004) (17), reported that increased tube loading would have a negligible effect on tube life. Joyce et al. (2014) (38), in an extensive study interviewed the allied health professionals to address the feasibility of implementing the increased FFD technique in clinical environment and found that there are no insurmountable issues against implementing of the technique in clinical environment. They added "the key to effective clinical implementation is to adopt a multi-disciplinary approach and to actively disseminate information amongst hospital management and radiographers".

5- CONCLUSION

Increasing the FFD from the traditional 100 to 130 cm has significantly reduced radiation exposure of patients without affecting image quality. Our findings are commensurate with the previous literatures and emphasized that radiographers should learn to use of an updated reference FFD in clinical setting.

6- CONFLICT OF INTEREST: None.

7- ACKNOWLEDGMENT

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