Radioprotection to the Gonads in Pediatric Pelvic Radiography: Effectiveness of Developed Bismuth Shield

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Abstract

Background: The use and effectiveness of traditional lead gonad shields in pediatric pelvic radiography has been challenged by several literatures over the past two decades. The aim of this study was to develop a new radioprotective gonad shields to be use in pediatric pelvic radiography.

Materials and Methods: The commercially available 0.06 mm lead equivalent bismuth garment has cropped squarely and used as ovarian shield to cover the entire region of pelvis. In order to prevent deterioration of image quality due to beam hardening artifacts, a 1-cm foam as spacer was located between the shield and patients pelvis. Moreover, we added a lead piece at the cranial position of the bismuth garment to absorb the scatter radiations to the radiosensitive organs. In girls, 49 radiographs with shield and 46 radiographs without shield was taken. The radiation dose was measured using thermoluminescent dosimeters (TLDs). Image quality assessments were performed using the European guidelines. For boys, the lead testicular shields was developed using 2 cm bismuth garment, added to the sides. The prevalence and efficacy of testicular shields was assessed in clinical practice from February 2016 to June 2016.

Results: Without increasing the dose to the breast, thyroid and the lens of the eyes, the use of bismuth shield has reduced the entrance skin dose (ESD) of the pelvis and radiation dose to the ovaries by 62.2% and 61.7%, respectively (P<0.001). Image quality remained diagnostically acceptable in all shielded and non-shielded images, without non-diagnostic or poor quality image. In boy patients, the prevalence of shielding in lead and developed testicular shields were obtained 63.25% and 19.74%, respectively; the accuracy positioning of the shield 90% and 34%, as well as.

Conclusion: The ovarian shield designed in this study has significantly reduced the radiation dose to the ovaries without adversely affecting diagnostically image quality. The testicular shield has improved the accuracy positioning of the shield. These developed shields have potential to be use in clinical practice.

Key Words: Bismuth, Gonad shielding, Lead, Pediatric pelvic radiography, Radiation protection.

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1- INTRODUCTION

Radiography of the pelvis is one of the more frequent and high-dose examinations (1-3). More than one million pelvic radiographs were annually documented in the United Kingdom (4). Pediatric pelvic radiographs inevitably contribute to the radiation exposure of ionizing radiation to the radiosensitive organs located at the lower part of the abdomen, especially to the gonads (1, 5-7). Evidence suggested that irradiating the pelvis may be responsible for the consequent genetic and somatic malignancies (6, 8). The radiation risk in pediatrics and young children are more concern than in adults (9-11).

It has been estimated that a 1-year-old patient is 10–15 times more likely to develop radiation-induced malignancy than a 50-year-old patient followed to exposure to an identical dose (12). Pediatrics who suffer from chronic diseases of pelvic region, frequently receives multiple pelvic radiographs for follow up and are at risk due to increasing the cumulative dose of radiation (1, 13). Therefore, it is important to consider the safety guideline by which to reduce radiation exposure to the patients as low as reasonably achievable (ALARA).

Gonad shielding has been advocated as an effective method by which to reduce radiation exposure to the gonads in patients undergoing pelvic radiographs (4, 14-16). Two types of gonad shields are available: contact (flat or curve contact), and shadow shields, available in various shapes of hearts, diamonds, triangles, and squares (14, 17). Optimum gonad shielding can result in 14 and 7 fold reduction in the radiation exposure to the testes and ovaries, respectively (4). The popular method of gonad shielding is locating a lead shield in the midline of pelvis; directly on the true pelvis (basin pelvis) for the females and on the scrotum region for the males (6, 17, 18). Gonad shielding is considered to be optimum if completely concealed the gonads region without compromising diagnostic image quality (19). The extent and efficacy of gonad shielding has been the focus of many researchers over the past two decades (2, 4, 6, 15, 20-25). The results of these studies anecdote of challenges associated with gonad shield employing. Gonad shields frequently positioned incorrectly and resulted in obscuring the diagnostic criteria of the images, especially in pediatric girls (20, 23). These obstructions can lead to repeat examination and even increase the gonads dose (6). Doolan et al. (4), and Liakos et al. (23), reported gonad shields were incorrectly positioned in 100% and 98% of the female pelvic radiographs, respectively. Moreover, it has been identified the ovaries are almost located in the lateral aspect of the pelvis instead of the midline that intended to be shielded (17, 18). Accordingly, it has been suggested completely protection the ovaries requires entirely shielding the pelvis which is not consistent in practice (17). To avoid of these concerns, there is good agreement in the literatures that gonad shielding during female pelvic radiography should be discontinue (6, 7, 17, 20, 23). However taken into account the superficial position of the testes and the significant dose reduction of 95%, decision on the use of lead testicular shields (LTS) for boy subjects remained controversial (20).

Although some gonad shielding protocols have been recommended (26, 27), they are often time consuming and rigorously depend on the landmarks that are difficult to identify particularly in obese patients. Accordingly design a new ovarian shield (7, 17) and redesign of testicular shields (7, 22) have been recommended. It seems the best way to ovaries protection is entirely shielding the pelvis with materials that attenuate and modify the primary beam before reaching to the patient but yet

allow osseous details to be seen. The bismuth element with atomic number of 83 and density of 9.78 g/cm^3 has such similar characteristics. Indeed, in contrast to the conventional lead-shields that eliminate exposure from the areas which are not clinically interest, the bismuth could be used to attenuate radiation from the areas which are clinically interested and should be seen in the image (28). To the best of our knowledge no research was reported on bismuth use in general radiography. The aim of this study was to design and dosimetry of new developed bismuth shields for the gonads to be used in pediatric pelvic radiography.

## 2- MATERIALS AND METHODS

2-1. X-Ray and Imaging Equipment

The study was performed in a single academic center using a single general radiographic unit (VARIAN Radiography system, UAS). Total filtration was 3 mm Al (inherent 0.5, added 2.5 mm). Konica Computed Radiography system (REGIUS 210, Japan) were used for the image acquisition. This unit supports the C-PLATE cassette with columnar crystal phosphor that is ideal for pediatric imaging (11). Initially, equipment calibration has been performed by an experienced local quality control team.

2-2. Patients (Girls)

Follow the study approval by the University Ethic Committee (Grant N0.U-94150), 95 pediatric girls, who were referred to anteroposterior (AP) projection of pelvic radiography in university hospital, meeting our criteria outlined below, were included in the current study. Our inclusion criteria were patients who their ages were at or below 15 years, could cooperative to the requirements of the study (placement of dosimeters on the skin) and their parents have given informed consent. Before irradiation, the anatomical characteristic of each patient (age, height, weight, and pelvic thickness) was recorded. A standard AP-pelvic radiograph was taken for each patient with respect to standard beam collimation at 100 cm film to focus distance (FFD). According to the European guidelines (29) and the policy of X-ray department, all exposures were performed with no anti-scatter grid. The commercially available 0.06 mm lead equivalent bismuth garment has cropped squarely and used as pelvis shield. As recommended by Hohl et al. (30), during CT exams, in order to prevent deterioration of image quality due to beam hardening artifacts, a 1-cm foam as spacer was located between the shield and patients pelvis. Moreover, we added a lead piece (5 cm in height and 0.25 mm in thickness) at the cranial position of the bismuth garment to absorb the scatter radiations to the radiosensitive organs (**Figure.1**).

Following the majority of other investigators (20, 31-36), we classified patients in age groups of 0-1 year, 1-5 years, 5-10 years and 10-15 years and dose measurements were carried out with and without bismuth garment. First, 46 pediatric girls were radiographed and dose measurements were performed without bismuth garment, and then, 49 other pediatric girls were radiographed with bismuth garment extended to the entire of pelvis. To obtain reliable results, patients were considered eligible for radiographed with shield, if they have similar anatomical characteristics compared to the patients who had examined with no shield. According to the standard protocols (11), only 2% variation between the mean age, weight, height, and body mass index (BMI), of patients were considered to be permissible. The average of tube voltage and tube current were 60.5 kVp and 7.2 mAs for shielded and 63 kVp and 8.1 mAs for non-shielded patients.
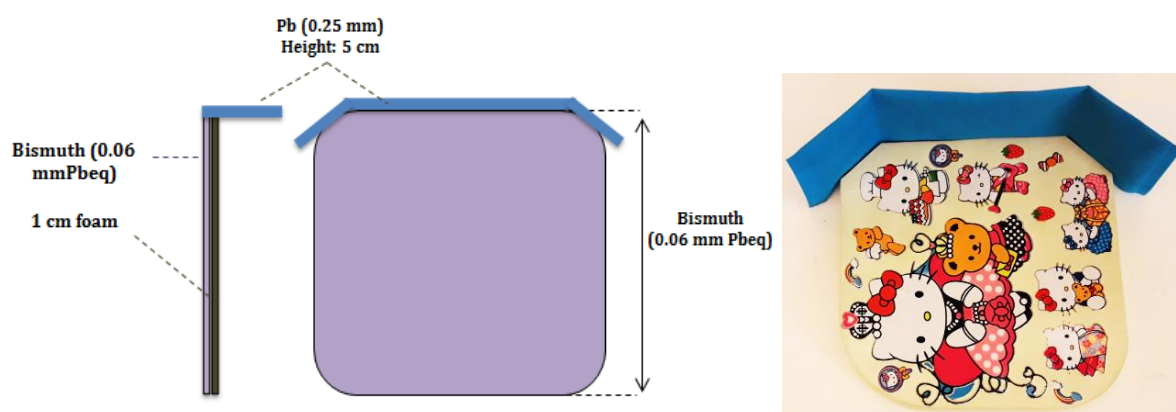
Fig.1: Diagram of developed bismuth gonad shield for girls' pelvic radiography, top and side views (left); actual view (right).

2-3. Dosimetry

The high radiosensitive cylindrical lithium fluoride thermo-luminescent dosimeters (TLD, LiF: Mg, Cu, P; Thermo Fisher Scientific, Waltham, MA), commercially known as TLD GR-200, were used for radiation dose measurements. According to the manufacturer's data sheet, the TLDs were accurate in the range of 0.1 μGy to10 Gy. Before irradiation, TLDs were annealed at 245˚C for 10 minutes and calibrated to a quantity of 6 mGy. A LTM reader (Fimel, Velizy, France) was used to anneal and read the TLDs. In order to prevent of physical and chemical damages, each TLD chip was placed inside a thin plastic bag and transported by a vacuum forceps when handling.

Even though irradiation of all TL chips with the same uniform dose at same geometrical conditions, their efficiency may be different. Calibration of TLDs as essential procedure can reduce variance in the efficiency of TLDs from 10-15% to 1-2% (37). To equalization the responses of different TLDs in the batch, all TL chips (40 in general) were exposed three times by a single dose of 50 mGy from Caesium-137 radioactive source (9). By knowing the TL efficiency (TLE) of each dosimeter, the element correction coefficients (ECC)

of each TL chips were calculated by the following equation (1):

$$ECC_i = <TLE>/TLE_i \quad (1)$$

Where, ECC_i is the ECC of a dosimeter i and $<TLE>$ is the mean TLE of all used dosimeters and TLE_i is the TLE of the dosimeter i (9). More details could be found in the literatures (37). The calibration procedure was repeated three times and finally 33 TLD chips were selected with calibration constants within ±2% standard deviation. Following Karami et al. (2016) (9), six set of five TL chips was independently irradiated by various doses of Caesium-137 radioactive source (0.1, 0.5, 1, 2, 4 and 6 mGy) and three TL chips were considered as control to record the background dose. The TLD calibration curve and its equation were obtained (**Figure.2**). From the reading values of TLDs, ESD was calculated using the following equation (2):

$$ESD(mGy) = (L - L_{BG}) \cdot C_f \cdot S_i \quad (2)$$

Where, L is the average of the irradiated dosimeter readings (in nC); L_{BG} is the reading of non-irradiated dosimeters (background radiation); C_f is the calibration factor (mGy/nC) obtained from calibration curve; S_i is the sensitivity factor

for each TLD. The uncertainty of C_f and S_i was in the order of 3% and 12%, respectively. To overcome complications for calibrating the TLDs in patient exposure conditions, due to difference of photon energies between the ^{137}Cs (γ=662 keV) and the Varian x-ray equipment, energy correction factor was applied when the ^{137}Cs dose calibration curve was employed for the Varian x-ray dose data analysis. An external x-ray dosimeter (Keithley model 35050A; Keithley Instruments, Inc., Cleveland, OH) with a 15 cm^3 probe (96035 model) was used to measure exposure. The kVp of the beam was checked using a calibrated kVp meter along with the Keithley x-ray dosimeter. The TLD and Keithley x-ray dosimeter were irradiated simultaneously and then the TLD outputs were compared. There were eight areas of dosimetry data collection for each exposure: the central X-ray beam entrance surface dose (ESD), the thyroid area, the lens of the eye (right and left), the breast (right and let), and the ovaries (right and left).

2-4. TLD placements

Twenty-three refresh TLD chips were used for each exposure. Nine TLDs were located at the center point of the field at the surface of entry of radiation to measure the ESD of pelvis. In order to measure the radiation dose to the radiosensitive organs, 3 TLDs were positioned on the surface anatomical position of each eyelid (right and left), each breast (right and left), and thyroid gland. Moreover, 3 TLD chips were positioned at the approximate anatomical position of each ovary (right and left) to measure the dose received.
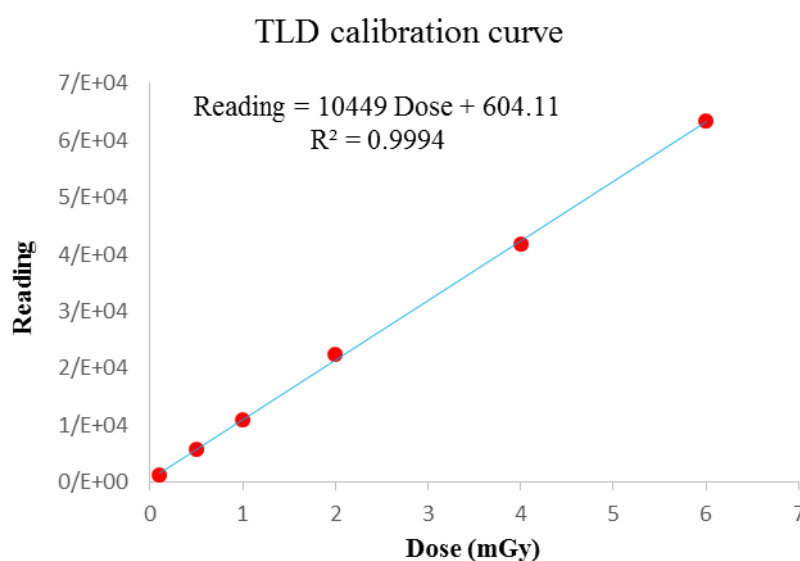
**Fig.2:** TLD calibration curve and its equation.

2-5. Boys

As it has been known from literatures (6, 7, 22, 24, 38), the main problem of lead testicular shields (LTS) is obscuring the lower part of the pelvis bone and particularly the symphysis pubis joint. To overcome this obstacle, the traditional LTS was developed using 2 cm bismuth garment (0.06 mm lead equivalent), added to the sides (**Figure.3**). After training, 15 radiographers agreed to participate in the study. Eight developed testicular shield (DTS), and 7 LTS were given to each

radiographers and encouraged to use of it during pediatric boys pelvic radiography. The prevalence and accuracy positioning of the shield were assessed from January 2015 to April 2016 by investigating the archived images in digital image library.
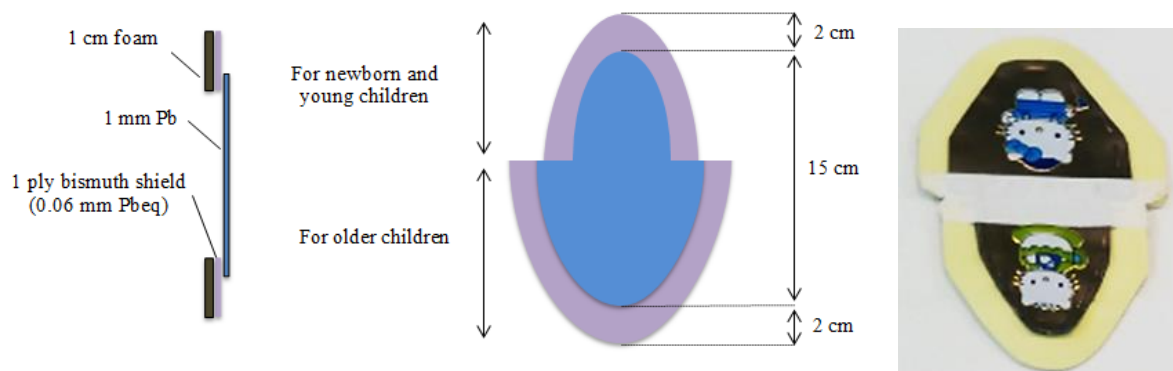
Fig.3: Diagram of RTS for use in boys pelvic radiography, top and side views (left); actual view (right).

2-6. Image quality

The evaluation panel of two radiologists and two experienced radiographers was independently evaluated the quality of all images using well-established visual grading analysis (VGA) (39, 40). The criteria used for images assessments were compliance with the European guidelines on quality criteria for diagnostic radiographic images in pediatrics (29) (**Table.1**). Following the Grondin et al. (2004) (41), and Karami et al. (2016) (11), a standard reference image was provided, on which each criterion was independently interpret as optimum by each member of our evaluation panel. The resultant radiographs with and without shield, were consecutively compared with radiographic reference image on adjacent monitors which have equal and constant light intensity overall the study. Following Joyce et al. (39), four-point scoring scale was employed for image quality evaluations: "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)* and 4- excellent *(anatomy visualized well than reference image)".*

Table-1: European guidelines used for image quality assessments in shielded and non-shielded patients

Image criteria	Score *			
	1	2	3	4
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 periarticular soft tissue planes,				
6. Reproduction of the pubic and ischial rami,				
7. Reproduction of the spongiosa and corticalis.				

 * Poor (1), Acceptable (2), Optimum (3), Excellent (4).

2-7- 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. Taking into consideration that dosimetry data have symmetric distribution, the parametric independent sample t-test were used for data analysis. Due to image quality data have no symmetric distribution; the non-parametric Mann-Whitney U-test was used to compare the image quality values between groups. $P < 0.05$ was considered to be statistically significant for all test results.

3- RESULTS

3-1. Girls

The anatomical characteristics of shielded and non-shielded girl patients are presented in **Table.2**. No statistical differences were found between shielded and non-shielded patients for weight, height, BMI and exposure parameters ($P > 0.05$). Dosimetry data demonstrated a statistically significant reduction in both the ESD and ovaries dose in shielded compared with the non-shielded patients (**Table.3**).

The use of bismuth garment has effectively reduced both the ESD and ovaries dose by approximately 62% for the age group of ≤15 years old. Statistically non-significant minor reduction in the dose of the lens of the eyes, thyroid gland and breasts were found in shielded compared with the non-shielded patients ($P>0.05$) (**Table.4**). VGA

scores revealed there were no statistical differences between the quality of resultant images for each shielded and non-shielded patients (**Figure.4**). All resultant images were diagnostically acceptable without poor or non-diagnostic image. Examples of resultant images in both the shielded and non-shielded patients are shown in **Figures 5 and 6**.

3-2. Boys

A total of 238 pelvic radiographs were identified of which the shield were present in 108 radiographs (47 LTS and 61 DTS). Of 47 (19.75%) radiographs with LTS, the shield had adequate positioning in 16 (34%) radiographs and placed too lower in 6 (12.7%) radiographs; the shield partially protected the testes in 5 (10.6%) radiographs and in the 20 (42.5%) remaining radiographs, the shield had obscured the anatomical criteria of the images. When images were reviewed, we found repeat of the examination were required in 7 (14.9%) radiograph due to obscuring diagnostic images criteria (**Figure.7**).

The DTS was present in 61 (25.6%) radiographs of which the shield had adequately protected the testes in 49 (80.3%) radiographs, partially protected the testes in 6 (9.8%) radiographs, and has obscured the diagnostic criteria in 6 (9.8%) radiographs. Despite in 32 (52.4%) radiographs the actual positioning of the DTS was incorrect, but the image quality was acceptable in 27 (84.4%) radiographs due to presence of bismuth layer as an additional filtration (**Figure.7**).

Table-2: Anatomical characteristics of girl patients in shielded and non-shielded groups

Patients	Age groups (year)	No. of patients	Mean			
			Height (cm)	Weight (kg)	BMI (kg/m^2)	Pelvic thickness (cm)
	0-1	9	58	6.82	19	7.40
	1-5	11	92	14.71	17.5	11.15

|					
Non-shielded	5-10	15	120	26.2	18	13.06
	10-15	11	138	44.84	22.3	15.60
	0-15	46	104	23.2	19.2	12.05
	0-1	10	52	6.65	18.6	7.12
	1-5	11	85	14.1	18.2	11.8
Shielded	5-10	16	128	24.7	17.7	13.5
	10-15	12	130	46.2	21	15.16
	0-15	49	103	22.9	19	12.25

Table-3: Mean ESD of pelvis and ovaries dose for shielded and non-shielded girls

| Age groups (year)	Mean ovaries dose± SD (mGy) ESD of pelvis ± SD (mGy)		P-value	Dose reduction (%)
	Non-Shielded	Shielded		
0-1	0.069±0.011	0.025±0.004	<0.001	63.76
	0.074±0.010	0.027±0.004	<0.001	63.50
1-5	0.488±0.099	0.179±0.039	<0.001	63.31
	0.498±0.101	0.184±0.045	<0.001	63.05
5-10	0.785±0.0.160	0.301±0.070	<0.001	61.65
	0.804±0.167	0.305±0.075	<0.001	62.06
10-15	0.993±0.185	0.389±0.090	<0.001	60.82
	1.01±0.204	0.392±0.091	<0.001	61.18
0-15	0.586±0.155	0.221±0.078	<0.001	62.28
	0.598±0.165	0.229±0.083	<0.001	61.7

Table-4: Radiation dose to the breast, thyroid gland and the lens of the eyes in shielded and non-shielded girls

| Age (year)	Received dose ± SD (mGy) Non-shielded Shielded			P-value
	Breast	Thyroid	Lens	
0-15	0.033±0.011	0.021±0.008	0.012±0.008	>0.05
	0.029±0.009	0.019±0.011	0.011±0.008	
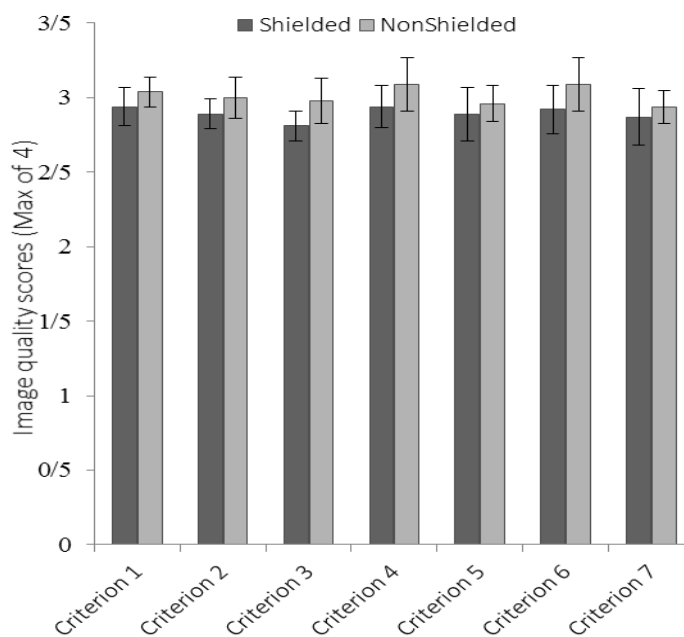
Fig.4: VGA scores in shielded and non-shielded girl patients (standard deviations are shown in error bars).
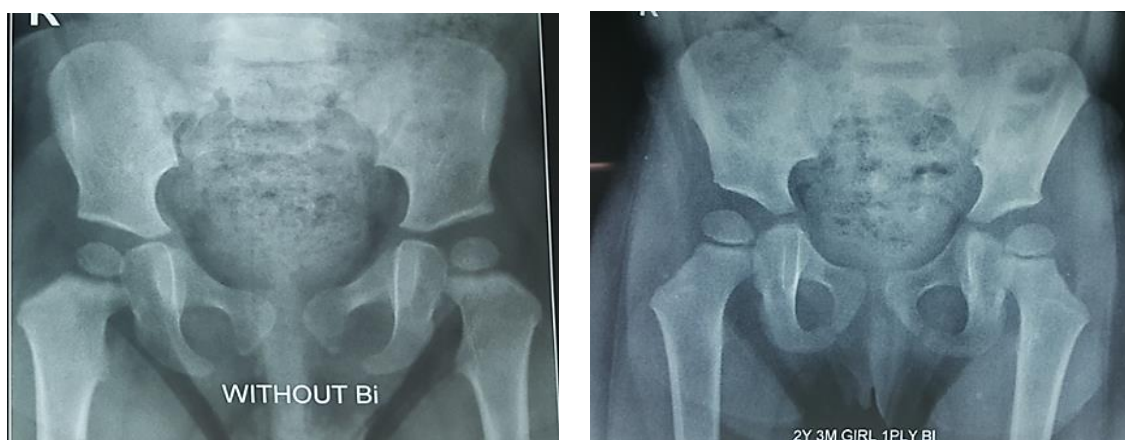
Fig.5: Pediatric girl pelvic radiographs with (left) and without (right) bismuth shield.

Fig.6: Pediatric girl pelvic radiograph with bismuth shield, before (left) and after (right) contrast/density manipulation.
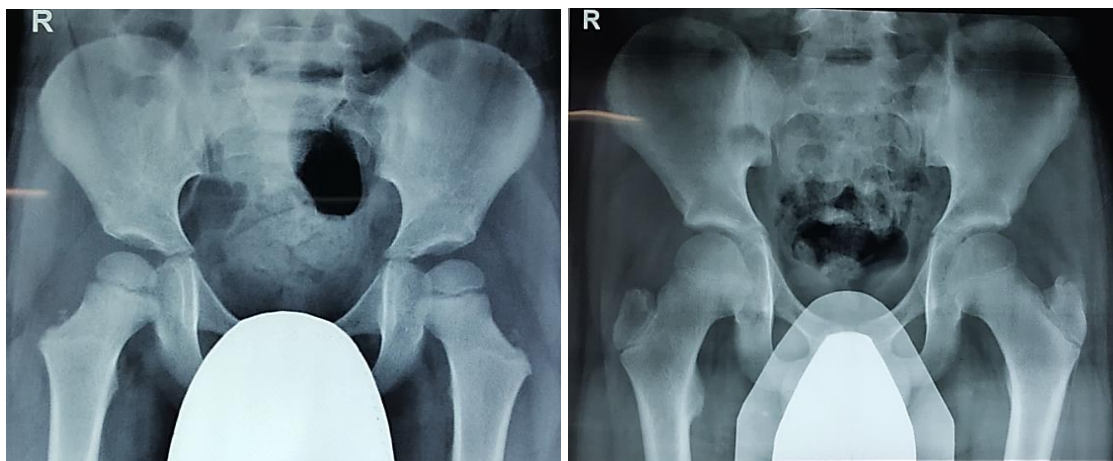
Fig.7: Pediatric boy pelvic radiograph with testicular shield: The traditional TLS has obscured the diagnostic criteria and repeat of the radiograph is required (left). Despite the DTS covered the lower section of pelvis, image quality remained diagnostically acceptable (right).

4- DISCUSSION

Access to the good image quality associate with low patients dose is the philosophy of any radiological examination (42, 43). Our study demonstrated the use of bismuth shield is an effective dose optimization tool for pediatric pelvic radiography. With respect to diagnostic image quality, the use of bismuth shield has resulted in 62% reduction in both the ESD and ovaries dose. Reduction of patients' dose is facilitated by absorbing the lower energy spectra of the beam due to presence of the bismuth garment as an additional filtration. Despite the shielded images have more noise compared with the non-shielded images, but it did not influence interpretation of the images by our evaluation panel (Figures 4 and 5).

It is significant, especially for pediatrics who suffers from developmental dysplasia of the hip (DDH) that frequently receives multiple pelvic X-rays for monitoring. The lead piece located at the cranial position of the bismuth shield has resulted in statistically non-significant minor reduction in the dose of the lens of the eyes, thyroid gland and breasts in shielded compared with the non-shielded patients (Table.4).

Pediatric pelvic radiographs need to be optimize in order to reduce the unnecessary radiation exposures which are not contribute to the clinical purposes (5). The use of bismuth shield in our study has effectively reduced the ESD of pelvis by about 62% and has potential to be considered as an eligible optimization tool for pediatric pelvic X-rays. Our bismuth shield poses twofold protective advantage; not only the entire of ovaries are adequately protected, the colon and pelvic bone are also adequately protected. Ease in use, and conformity with patients are interesting advantages of this flexible bismuth shield in clinical practice. The properties of bismuth and lead shields are summarized in **Table.5**.

Our audit showed accuracy positioning of the DTS was significantly higher compared with the LTS (90% vs. 34%; P<0.05). Although the use of developed testicular shield has significantly improved testes protection, it should be note that more care needed to be taken in accuracy positioning of the shield, yet. Training the best qualified radiographers (7), provision the written gonad shielding protocols in X-ray rooms (14), has important roles for increase accurate positioning of the shield in boy subjects. The total risk associate with a singular

AP-pelvic radiography in an individual patient lower than 15 years of old has been estimated to be lower than 3 per million (20), and may be underestimated by the radiographers. Taken into account the cumulative nature of radiation and the high radio cell sensitivity and long life time expectancy of pediatrics that allow more time to manifest the radiation effects, adherence to the dose reducing tools such as our gonadal protective shields are of particular importance. Difficulty associated with gonad shield positioning and the risk of compromising image quality has been identified as one of the main reasons for low adherence to gonad shielding in pelvic radiography (14, 44-46). Easy uses of bismuth shield due to extending on the entire of pelvis regions encourage radiographers to apply it; hence improve radiation protection subjects.

Our finding showed these developed shields are consistent with ALARA guidelines and have potential to be recommended for routine use in clinical practice, albeit more work needed to be done. We advocate use of these shields during pediatric pelvic radiography or any radiological examinations that gonads lies in the primary beam, especially when osseous evaluations are more desire than in high resolution image. Advent of flat panel detectors (FPD) has provided interesting opportunities in which the quality of images can significantly be improve. FPDs are very thin and offer ultra-sharp images in which can provide sharp details even from attenuated penetrating X-rays from such bismuth shield (47).

Table-5: Comparison the properties of the traditional gonad lead-shields and developed bismuth shields for boy and girl subjects

Conventional lead-shields	Developed bismuth shields
Females	**Females**
1. Accurate positioning of the shield is so problematical and result in inaccurate gonad shield positioning, compromising diagnostic images information, and repetition of the examination (4, 6).	1. Bismuth shield extended to the entire of pelvis and is ease in use, inaccuracy positioning of the shield will not occur.
2. Even accuracy positioning the shield, did not necessarily provide protection to the ovaries over 30-50% of patients (18, 48).	2. The entire of the ovaries, the lower section of the colon and pelvic bone are adequately protected and result in approximately 62% reduction in pediatrics dose.
4. Cannot be used for patients with or suspected to sacrum and coccyx fracture.	4. The shield is applicable for all patients.
5. Many sizes of the shield is require depends on patients age.	5. Only one size of the shield is require for pediatrics less than 15 years of old and is economically.
6. Prevalence of shielding is poor or completely ignored (4).	6. Radiographers will happy with bismuth shield and the prevalence of gonad shielding will be increase.

Males	Males
1. Due to incorrectly gonad shield positioning, decision on the use of shield remained controversial (20).	1. Accuracy positioning of the shield is improved significantly. Moreover, inaccuracy positioning of the shield is unlikely to obscure diagnostic criteria.

4-1. Limitations of the study

Selecting the patients with matched anatomical characteristics for radiation dose measurements (with and without shields) and image quality assessments were the main limitations of this study as time consuming processes.

5- CONCLUSION

For pediatric pelvic radiography, the use of developed bismuth shield is an effective tool to reduce radiation exposure without adversely affecting diagnostically image quality. Based on our findings, these developed gonad shields are consistent with radiation protection guidelines and has potential to be recommended for use in clinical practice. However, more studies are needed to ascertain the efficacy of bismuth materials, as a radioprotective shield in general radiography.

6- CONFLICT OF INTEREST

There is no conflict of interest.

7- ACKNOWLEDGMENT

8- REFERENCES

1. Chan C, Fung K. Dose optimization in pelvic radiography by air gap method on CR and DR systems–A phantom study. Radiography 2015;21(2015):214-23.

2. Gul A, Zafar M, Maffulli N. Gonadal shields in pelvic radiographs in pediatric patients. Bulletin-hospital for joint diseases New York 2005;63(1/2):13.

3. Brennan PC, McDonnell S, O'Leary D. Increasing film-focus distance (FFD) reduces radiation dose for x-ray examinations. Radiation protection dosimetry 2004;108(3):263-8.

4. Doolan A, Brennan PC, Rainford LA, Healy J. Gonad protection for the antero-posterior projection of the pelvis in diagnostic radiography in Dublin hospitals. Radiography 2004;10(1):15-21.

5. Ofori EK, Antwi WK, Scutt DN, Ward M. Optimization of patient radiation protection in pelvic X-ray examination in Ghana. Journal of Applied Clinical Medical Physics 2012;13(4):165.

6. Warlow T, Walker-Birch P, Cosson P. Gonad shielding in paediatric pelvic radiography: Effectiveness and practice. Radiography 2014;20(3):178-82.

7. Karami v, Zabihzadeh m, Shams N. Gonad shielding during pelvic radiography: A systematic review and meta-analysis. Archive of Iranian Medicine 2016;20(2):113-23.

8. Winfeld M, Strubel N, Pinkney L, Lala S, Milla S, Babb J, et al. Relative distribution of pertinent findings on portable neonatal abdominal radiographs: can we shield the gonads? Pediatric radiology 2013;43(10):1295-302.

9. karami V, Zabihzadeh M, Gholami M, Shams N, Fazeli-Nezhad Z. Dose Reduction to the Thyroid Gland in Pediatric Chest Radiography. International Journal of Pediatrics 2016;4(5):1795-802.

10. Karami V, Zabihzadeh M, Gilavand A, Shams N. Survey of the Use of X-ray Beam Collimator and Shielding Tools during Infant Chest Radiography. International Journal of Pediatrics 2016;4(4):1637-42.

11. Karami V, Zabihzadeh M, Danyaei A, Shams N. Efficacy of Increasing Focus to Film Distance (FFD) for Patient's Dose and Image Quality in Pediatric Chest Radiography. Int J Pediatr 2016;4(9):3421-29.

12. Hall EJ. Lessons we have learned from our children: cancer risks from diagnostic radiology. Pediatric radiology 2002;32(10):700-6.

13. Culp MP, Barba JR, Jackowski MB. Shield Placement: Effect on Exposure. Radiologic technology 2014;85(4):369-76.

14. Karami V, Zabihzadeh M, Gholami M. Gonad shielding for patients undergoing conventional radiological examinations: Is there cause for concern? Jentashapir J Health Res. 2016;7(2):1-4.

15. Wainwright A. Shielding reproductive organs of orthopaedic patients during pelvic radiography. Annals of the Royal College of Surgeons of England 2000;82(5):318.

16. McCarty M, Waugh R, McCallum H, Montgomery RJ, Aszkenasy OM. Paediatric pelvic imaging: improvement in gonad shield placement by multidisciplinary audit. Pediatric radiology 2001;31(9):646-9.

17. Bardo DM, Black M, Schenk K, Zaritzky MF. Location of the ovaries in girls from newborn to 18 years of age: reconsidering ovarian shielding. Pediatric radiology 2009;39(3):253-9.

18. Fawcett S, Gomez A, Barter S, Ditchfield M, Set P. More harm than good? The anatomy of misguided shielding of the ovaries. The British Journal of Radiology 2014;85(2012):442-7.

19. Silva C, Silva P, Ventura SMR, editors. The use and relevance of gonad protection shields in children during hips radiography. 1th Congresso Internacional da Saúde Gaia-Porto; 2010: Instituto Politécnico do Porto. Escola Superior de Tecnologia da Saúde do Porto-Politema. Available at: http://recipp.ipp.pt/handle/10400.22/3252.

20. Frantzen MJ, Robben S, Postma AA, Zoetelief J, Wildberger JE, Kemerink GJ. Gonad shielding in paediatric pelvic radiography: disadvantages prevail over benefit. Insights into imaging 2012;3(1):23-32.

21. Kenny N, Hill J. Gonad protection in young orthopaedic patients. BMJ. 1992;304(6839):1411-3.

22. Gürsu S, Gürsu T, Camurcu Y, Yıldırım T, Gürsu A, Şahin V. Efficacy of gonadal shielding in pediatric pelvis X-rays. Eklem hastaliklari ve cerrahisi= Joint diseases and related surgery 2012;24(2):87-90.

23. Liakos P, Schoenecker PL, Lyons D, Gordon JE. Evaluation of the efficacy of pelvic shielding in preadolescent girls. Journal of Pediatric Orthopaedics 2001;21(4):433-5.

24. Sikand M, Stinchcombe S, Livesley P. Study on the use of gonadal protection shields during paediatric pelvic X-rays. Annals of the Royal College of Surgeons of England 2003;85(6):422.

25. Karami V, Zabihzadeh M, Shams N, Sarikhani S. Evaluation of the Prevalence and Utility of Gonad Shielding in Pediatrics Undergoing Pelvic X-Ray. Int J Pediatr 2016;4(11):3735-40.

26. Krepler P, Vana N, Havranek C. Dosimetric studies in the radiological examination of the hips in young infants with a special fenestration method of gonad protection. Pediatric radiology 1977;5(4):231-5.

27. Manny E, Brown R, Shaver J. Gonad shielding in diagnostic radiology. Recommendation of the FDA and ACR. Postgraduate medicine 1979;65(3):207-11.

28. Karami V, Zabihzadeh M. Prevalence of radiosensitive organ shielding in patients undergoing computed tomography examinations: an observational service audit in Ahvaz, Iran. Asian Biomed journal 2015;9(6):771-5.

29. European Union. European Commission. Directorate-General XII-Science R, Development. European guidelines on quality criteria for diagnostic radiographic images in paediatrics: Office for Official Publications of the European Communities; 1996.

30. Hohl C, Wildberger J, Süß C, Thomas C, Mühlenbruch G, Schmidt T, et al. Radiation dose reduction to breast and thyroid during MDCT: effectiveness of an in-plane bismuth shield. Acta Radiologica 2006;47(6):562-7.

31. Martin C, Farquhar B, Stockdale E, MacDonald S. A study of the relationship between patient dose and size in paediatric

radiology. The British journal of radiology 1994;67(801):864-71.

32. Kyriou J, Fitzgerald M, Pettett A, Cook J, Pablot S. A comparison of doses and techniques between specialist and non-specialist centres in the diagnostic X-ray imaging of children. The British journal of radiology 1996;69(821):437-50.

33. McDonald S, Martin C, Darragh C, Graham D. Dose–area product measurements in paediatric radiography. The British journal of radiology 1996;69(820):318-25.

34. Hufton AP, Doyle S, Carty H. Digital radiography in paediatrics: radiation dose considerations and magnitude of possible dose reduction. The British journal of radiology 1998;71(842):186-99.

35. Ruiz M, Gonzalez L, Vano E, Martinez A. Measurement of radiation doses in the most frequent simple examinations in paediatric radiology and its dependence on patient age. The British journal of radiology 1991;64(766):929-33.

36. Azevedo A, Osibote O, Boechat M. Paediatric x-ray examinations in Rio de Janeiro. Physics in medicine and biology 2006;51(15):3723.

37. Savva A. Personnel TLD monitors, their calibration and response. PhD thesis, Department of Physics, Faculty of Engineering and Physical Sciences University of Surrey, September 2010.

38. Fawcett SL, Barter SJ. The use of gonad shielding in paediatric hip and pelvis radiographs. The British Journal of Radiology 2009;82(977):363-70.

39. Joyce M, McEntee M, Brennan PC, O'Leary D. Reducing dose for digital cranial radiography: The increased source to the image-receptor distance approach. Journal of Medical Imaging and Radiation Sciences 2013;44(4):180-7.

40. Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. Radiologic technology 2011;83(1):20-8.

41. Grondin Y, Matthews K, McEntee M, Rainford L, Casey M, Tonra M, et al. Dose-reducing strategies in combination offers substantial potential benefits to females requiring X-ray examination. Radiation protection dosimetry 2004;108(2):123-32.

42. Zabihzadeh M, Karami V. Poor collimation in digital radiology: A growing concern. Internet Journal of Medical Update-EJOURNAL 2016;11(9):29-30.

43. Gholami M, Nemati F, Karami V. The Evaluation of Conventional X-ray Exposure Parameters Including Tube Voltage and Exposure Time in Private and Governmental Hospitals of Lorestan Province, Iran. Iranian Journal of Medical Physics 2015;12(2):85-92.

44. Karami V, Zabihzadeh M. Radiation Protection in Diagnostic X-Ray Imaging Departments in Iran: A Systematic Review of Published Articles. J Mazandaran Univ Med Sci. 2016 26(135):175-88.

45. MacKay M, Hancy C, Crowe A, D'Rozario R, Ng C. Attitudes of medical imaging technologists on use of gonad shielding in general radiography. The Radiographer. 2012;59(2):35-9.

46. Clancy CL, O'Reilly G, Brennan PC, McEntee MF. The effect of patient shield position on gonad dose during lumbar spine radiography. Radiography 2010;16(2):131-5.

47. Kotter E, Langer M. Digital radiography with large-area flat-panel detectors. European radiology 2002;12(10):2562-70.

48. International Commission on Radiological Protection (ICRP). Protection of the patient in diagnostic radiology. ICRP Publication 34. Ann ICRP 1982;9(2-3): 22-40. Available at: http://www.icrp.org/publication.asp?id=ICRP%20Publication%2034.