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Radiation Protection for Patients Undergoing Diagnostic Pelvic X-ray Examinations

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ABSTRACT

The aim of the current study is to measure the entrance skin dose (ESD) for patients undergoing pelvic diagnostic X-ray examinations in King Faisal Specialist Hospital (KFH), Saudi Arabia, and reduce the scattered x-ray to gonads during the examination. The thermo-luminescence dosimeters (TLDs) are processed for low energy X-ray calibration. Three sets of thermo-luminescence dosimeters LiF (TLD-100) detector were irradiated by using a Xstrahl machine with following operating conditions: 60 cm FSD, 1 mA, irradiation time 1 min., 2 mm HVL(Al) and tube voltage of 80 kV. Each TLD set was irradiated for specific air and the mean value of the air kerma was used for calculation the calibration factor. The (ESD) was assessed for forty patients undergoing pelvic diagnostic X-ray examinations using thermo-luminescence dosimeters (TLDs). The patients were classified into three groups according to weights from 40-60 kg, 60-80 kg and 80-110 kg respectively. The ESDs associated with AP-pelvic examinations for the classified patients were 2.91 ± 0.25 mGy , 3.92 ± 0.22 mGy and 4.92 ± 0.6 mGy respectively. The results are compared with the reference levels of the European Union, (EU), International Atomic Energy Agency,(IAEA) and United Kingdom) . Another irradiation for TLD-100 chips was performed above and under the surface of the Lawrence Livermore National Laboratory phantom (LLNL, USA), and a scatter dose absorbed by sensitive organ attenuated by a factor of 20.6% due to using a flat contact gonadal shield .

KEYWORDS

Entrance Skin Dose, TLDs, Radiology, Gonad Shield, LLNL Phantom.

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INTRODUCTION

A TLD is a phosphor, such as lithium fluoride that dopant by thallium , LiF(Tl) detector or calcium fluoride (CaF), in a solid crystal structure. When a TLD is exposed to ionizing radiation at ambient temperatures, the radiation interacts with the phosphor crystal and deposits all or part of the incident energy in that material. Some of the atoms in the material that absorb that energy become ionized, producing free electrons and areas lacking one or more electrons, called holes. Imperfections in the crystal lattice structure act as sites where free electrons can become trapped and locked into place. Heating the crystal causes the crystal lattice to vibrate, releasing the trapped electrons in the process. Released electrons return to the original ground state, releasing the captured energy from ionization as light, hence the name thermo luminescent. Released light is counted using photomultiplier tubes and the number of photons counted is proportional to the quantity of radiation striking the phosphor. The amount of light released versus the heating of the individual pieces of thermo luminescent material is measured. TLD(s) dosimeters can be used for patient dosimetry external to the body or phantom in the same way as an ionization chamber are used for direct dose assessment **(IAEA, 2014**). Measurement of the (ESD for patients undergoing pelvic x-ray examinations should be performed in hospitals in order to use its results as a guideline for the optimization of the radiation protection of the patients. The ESD is a measure of the radiation dose that is absorbed by the skin as it reaches the patient, the radiation being in our case the X-ray beam used for the treatment of the patient. The x-ray exposure in medicine field contributes significantly to about 95% total medical exposures. In Saudi Arabia, some work has been done for calculations of radiation dose to patients exposed in diagnostic radiology. Several calculations of the ESD were carried out for some routine X-ray examinations in the Security Forces Hospitals in Riyadh **(Akhdar, 2007)**. Additionally, it has to be mentioned the work concerning the calculation of ESD for patients undergoing diagnostic x-ray carried out by **(Taha *et al.,* 2014)** in King Abdullah Medical City , Makkah, Saudi Arabia and the effective dose calculation for the chest and abdomen performed by **(Allehyani *et al.*, 2015)**. The radio-sensitive organs such as gonads are susceptible of radiation risk due to the non-stochastic effects that can be expressed by a value of tissue weighting factor (W_T) reported by the International Commission on Radiological Protection **(ICRP-103, 2007)**. The ICRP reduced the tissue weighting factor of gonads from 0.2 to 0.08. The present paper aims to assess the entrance skin dose to patients undergoing diagnostic pelvic x-ray examinations in King Faisal Specialist Hospital (Saudi Arabia) and to minimize the scattered x-ray to gonads during the pelvix x-ray examination,

MATERIALS AND METHODS

The equipment used in this study includes an automatic TLD oven model PTW-TLDO (Physikalisch-Technische Workstation, Freiburg, Germany) , (TLD-100) of LiF(Tl) detector, Harshaw TLD™ Model 3500 Readers and two X-ray machines .First x-ray machine model Xstrahl -100 is used for irradiation of (TLD-100) of LiF(Tl) detector and examination the gonadal lead shield for decreasing scatter dose to radiosensitive organs. . Xstrahl -100 is adjusted for following operating conditions: 60 cm FSD, 1 mA, irradiation time 1 min., 2 mm HVL(Al) and tube voltage of 80 kV. The irradiation air kerma measured by Unidose meter connected with 0.2 cc soft X-ray ionization chamber . the second X-ray machine manufactured by Siemens model Yasio , gemany manufacturer and model number 22814 is used for investigation of patients in radiology department in King Faisal Specialist Hospital (Saudi Arabia) and has the following features: automatic exposure control (AEC), fully digital flat detector technology that can used for flexible and versatile imaging in table, bulky wall stand (BWS) for free examinations and universal grid. The experimental arrangement for TLD dosimeter calibration and gonadal lead shield presented in figure **1(.a and b.)** The procedure for assessment of entrance skin dose to patients includes three main parts, namely: (1) Calibration of of thermoluminscence dosimeters (TLDs); (2) distribution the (TLDs) on the skin of a patient in at the center of X-ray beam; (3) reading of the dosimeters by using a thermo-luminescence reader. Calibration of the thermo luminescence dosimeters (TLDs) includes several processes, as follows: pre-irradiation annealing, irradiation, sorting/identification of the golden chips, pre-read annealing (preheating), irradiating- reading, and generation of the calibration factor.

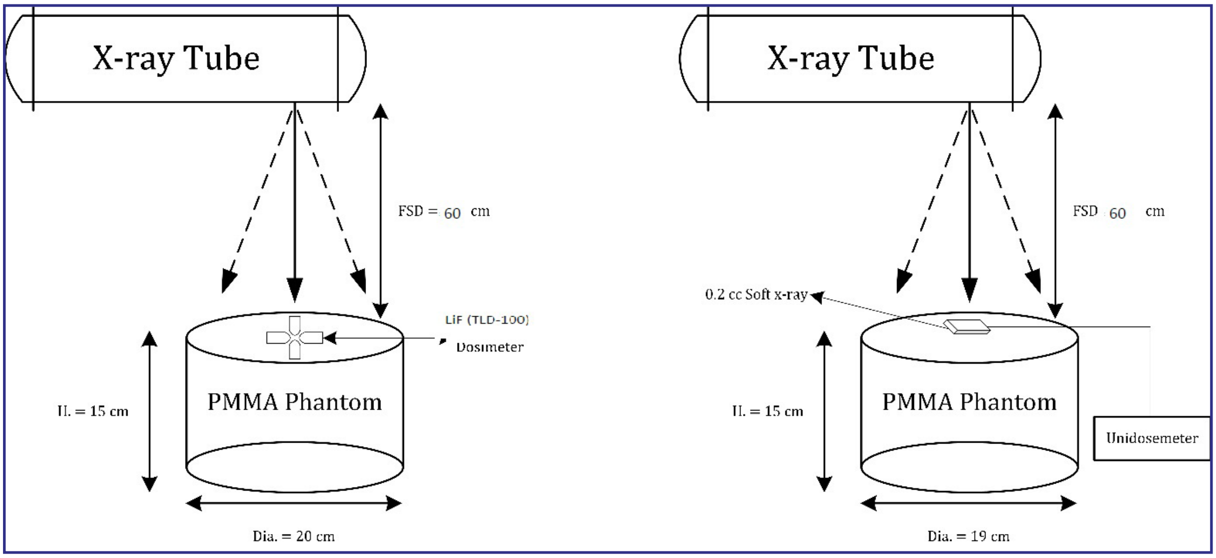

Fig. (1): The experimental arrangement for TLD dosimeter calibration.

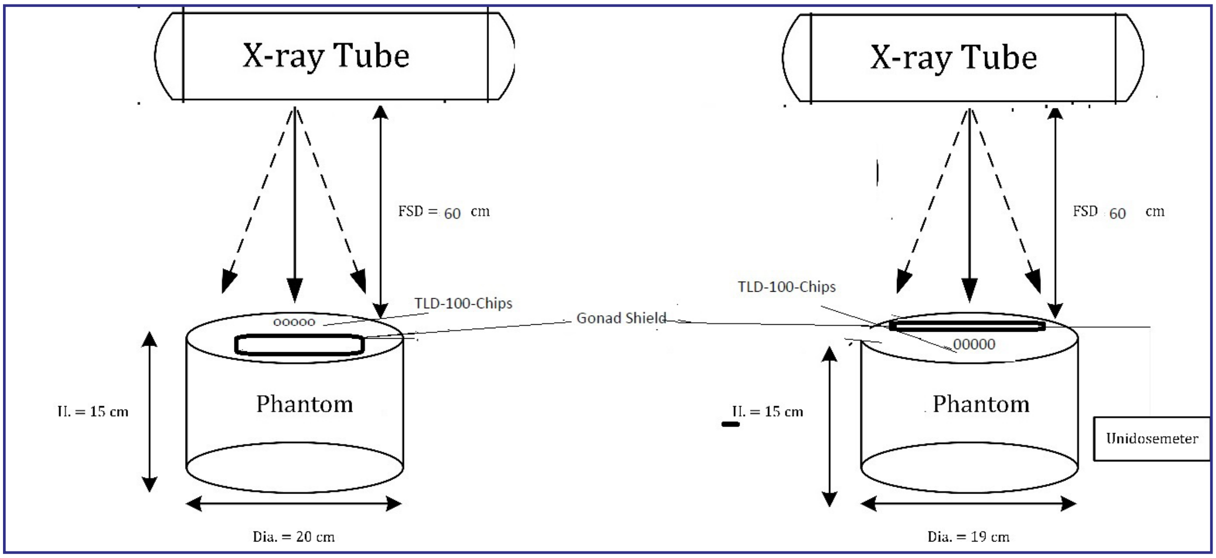

Fig. (2): The experimental arrangement for TLD dosimeter above and under gonad shield.

Irradiation

Two batches of thirty TLD-100 each were annealed by using an automatic TLD oven model PTW-TLDO (Physikalisch-Technische Workstation, Freiburg, Germany). The pre-irradiation annealing procedure consisted of three steps, including high and low-temperature annealing according to the following sequence: 1 hour at 400 °C, immediately followed by 2 hours at 100°C , and finally 1 hour for cooling to room temperature. The TLD chips were irradiated with the x-ray generator. For each TL measurement by TLD-3500, reader background subtraction was performed. For each session of TLD exposure to radiation, up to 5 chips from the same group, with about the same sensitivity as those used for measurement, were set aside without being irradiated. This baseline group was subject to the same pre-readout procedure as the irradiated TLDs **(Abulfaraj *et al.*, 2004)**. TLD technique characterized by high precision and reproducibility of dose measurement is presented by addressing pre-readout annealing, group sorting, dose evaluation. Two hundred and forty TLD chips were annealed for 1 hour at 400^0 C followed by 2 h at 100^0 C. After exposure of 1 mGy air kerma from X-ray .irradiator TLDs were subjected to pre-readout annealing at 100^0 C, then readout, sorted into groups each with nearly equal sensitivity, golden ships. The golden chips are defined as response for each dosimeters comparable to an average response of designed group of the dosimeters maintained as calibration dosimeters. TLD-100 chips have almost the same sensitivity, within ± 3%, corresponding to standard deviation below 2.5%. These chips are identified as the master to chips be used for the purpose of Dose Conversion Factor (DCF) generation. Upon repeating the procedures, TLDs having response >3.5% from group mean were dropped to assuring group stability. Effect of pre-readout annealing has been studied. Series of repeated measurements were conducted to stabilize calibration procedures and DCF generation using standard X-ray machine.

Identification of the golden chips

It identified by careful analysis of the irradiated chips. TLD chips were readout within 24 hrs of irradiation and sorted 50 TLD chips. In the first step, 30 chips were chosen from batch of the total number of 50 chips. After irradiation, the readout session was carried out in an uninterrupted manner. After readout, each TLD chip was kept in an assigned bin with the identification number for sorting purpose. This was done based on their statistical variation of recorded nC. Out of the 30 TLDs, the chosen group of 20 chips is representing the largest group in the statistical distribution having standard deviation below 10%, and the chips were identified as master chips. In the second step, from these 20 master chips, 10 chips were identified with almost the same sensitivity, within ± 3%, corresponding to standard deviation below 2.5%. These chips were identified as the golden chips to be used for the purpose of Dose Conversion Factor (DCF) generation.

Pre-read annealing (Preheating)

A simplified TLD annealing technique (**Luxton, 1999)** characterized by high precision and reproducibility of radiation dose measurement was followed for the pre-read annealing process. In this technique, the TLDs are annealed, sorted, and subjected to pre-readout annealing according to the procedure described as follows: high temperature and low-temperature annealing prior to irradiation, and pre-readout annealing at low temperature after irradiation. High-temperature annealing was accomplished as mentioned before, using the PTW–TLD-Oven microprocessor controlled furnace, at 400 °C for 1 hour, followed by a low-temperature annealing at 100 °C for 2 hours, and pre-readout heating at 100 ^{0}C for two hours.

Generation of reader calibration factor

The numerical results obtained from the interpretation of the entrance dose assessment for patients exposed to external radiations depend mainly on the accurate calibration of the radiation measurement instrument used by investigators. This can be done by the conversion of nC obtained by heating the TL chips to equivalent dose (in mGy) which has been designated by Dose Conversion Factor (DCF). Unidose Dose master, (PTW –manufacture) coupled with a 0.2 cc ion chamber located at a surface of LLNL's chest phantom, has been used for the reference doses measurement. These reference doses were carried out using the X-ray generator with an optimum operating conditions of kilo-voltage, miliamper second, and a suitable filter. The doses assessment was evaluated using the calibration factor that is based on X-ray energy, in mGy/nC.

Sample distribution

In the current study, the entrance surface dose (ESD) was determined for each patient undergoing radiographic pelvic examinations. The ESD was measured using thermo-luminescent dosimeters (TLDs) placed on the patient's skin, at the center of X-ray beam, and after exposure, the readings were taken using a calibrated Harshaw TLD reader -3500.

Gonadal shield attenuation

Two TLD(s) chips sets were annealed, sorted, and irradiated using X-ray generator operating conditions similar to those of X-ray pelvic examination. One set was located at the surface of gonad positions using Lawrence Livermore National Laboratory's body phantom and the other set was located under the gonadal shield.

RESULTS

Physical parameters of radiographic exposure data

Physical parameters of the radiographic exposure data of X-ray exposure parameters for Pelvic AP projection, Peak kilovoltage (kVp), Exposure time (in mAs), Film-focus distance (FFD, in cm), and Focus to skin distance (FSD, in cm) are shown in table (1).

Table (1) : *X-ray exposure parameters for Pelvic AP projection.*

Descriptive Value	KVp	mAs	FFD, cm	FSD, cm
Max	95	60	129	107
Min	*30*	*15*	*120*	*85*
Mean	76	30	120	96
StDev	10	20	09	11

Data Collection

The patients age was found to be in range from 14 to 80 years, weight was found to be in range from 40 to 109 kg and body mass index (kg/m^2) was found to be in range from 5 to 49 (kg/m^2). Minimum and maximum value for patients age, weight and body mass index presented in (table.2).

Generating reader calibration factor

A sample of about 24 TLDs - 100 chips located inside a plastic sachet of 3 mm thickness and irradiated to 30.3 mGy using Xstrah-100 X-ray machine. It was adjusted to the following operating conditions : x-ray at 80 kV, 1 mA, 1 min. exposure, filter number 4 and focal distance detector (FDD) of 50 cm.

The dose was measured using 0.2 cc soft x-ray connected with undoes meter (PTW manufacture). The calibration factor was found to be 0.075 mGy/nC and the coefficient of variation decreased from 5% to 2.5 % by application of by application the protocol of American National Socity **(ANSI,1993).** Table (3) presents the calibration of TLD-data response, ranging from 376 to 411 nC, and the resulting calibration factor of 0.077±17 mGy/nC.

Table (2) : *Demographic data for the patients.*

Demographic Data	Descriptive Statistics	Value
Age (years)	Min Max Mean ± SD	14 80 43 ± 19
Weights (kg)	Min Max Mean ± SD	40 90 66 ± 19
Body Mass Index (kg/m^2)	Min Max Mean ± SD	5 49 27 ± 5

Table (3) : *Generating Reader Calibration Factor, RCF.*

S.No	Reading (nC)	S.No	Reading (nC)	Cal. Factor, mGy/nC.
1	394	16	397	
2	410	17	377	
3	380	18	408	
4	415	19	398	
5	390	20	381	
6	405	21	405	
7	401	22	391	
8	406	23	390	RCF = 0.077 ± 17
9	395	24	343	
10	401	25	416	
11	405	26	397	
12	394	27	377	
13	390	28	407	
14	343	29	381	
15	416	30	398	

A radiation calibration factor, RCF, in mGy/nC, calculated using the following equation: $RCF = ECC \ X \ Ds/TLs$

where *ECC* is the element correction coefficient, D_s is the assigned dose measured by 0.2 cc ionization chamber connected with UNIDOS^{webline} Universal Dosimeter, TL_s is the measured TLD signal in nano -Coulomb units (nC) after background correction.

Analysis of entrance skin dose

The investigated patients are classified into three intervals according to their weights, 40- 60 kg , 60-80 kg and 80-110 kg respectively.

The mean and standard deviation values of ESD for pelvic x-ray examinations for each patient groups associated with AP-pelvic examinations were 2.95 ± 0.23 mGy , 3.49 ± 0.22 mGy and 4.98 ± 0.6 mGy respectively as presented in table 4. The results of reference weight of 60-80 kg were compared with the those available from international publications as presented in (table 5).

Table (4) : *The ESDs associated with AP-pelvic examinations for three weight intervals and their corre sponding standard deviation.*

Entrance Skin Dose, ESD (mGy)		
40-60 kg	**60-80 kg**	**80-110 kg**
2.5	4.1	4.6
3.1	3.9	5.9
2.7	4.4	4.4
3.1	3.8	5.2
3.1	3.9	5.4
3.1	4.1	5.2
3.1	4.5	5.5
3.1	3.8	5.4
2.9	4.4	5.5
2.6	3.8	5.4
3.2	4.1	4.6
2.5	3.8	4.2
2.8	3.7	4.5
3.2	3.6	4.3
3.1	3.5	5.4
2.8	3.7	5.0
2.7	3.8	4.1
2.9	3.6	4.5
3.2	3.9	4.8
2.5	4.1	4.7
Mean ± σ		
2.95 ± 0.23	3.5 ± 0.2	4.98 ± 0.57

Table (5) : *Mean of the ESDs (mGy) for pelvis examinations calculated for patients of reference weight of 70 ±10 kg. compared with international organizations.*

X-ray projection	Current work, ESD, mGy	(EC,1999) mGy	(IAEA,1996) mGy	(NRPB,2000) mGy
AP-Pelvic	3.5 ± 0.2 (20)	10	5	4

Radiation protection

Radiation protection to Gonads during pelvic X-ray examination. Ten TLD-100 dosimeters is distributed above and under 0.5 mm lead gonadal as presented in figure (1.b) . the percentage relative coefficient attenuation is presented in **(table 6) .**The percentage relative coefficient attenuation for gonadal shield is calculated according to the following equation. Af = TLDf /TLDi

Where as Af : attenuation coefficient

TLD_f: reading with gonadal lead shield

TLD_i: reading without gonadal lead shield

Table (6) : *TLD response without and with gonadal shield.*

TLD response without gonadal shield nC	*TLD response with gonadal shield* nC	*Relative Attenaution coefficient* %
300.7	69	22.9
308.8	67	22.0
289.2	75	25.9
286.6	69	24.1
298.6	80	26.8
304.0	63	20.0
308.2	63	20.4
304.2	65	21.
308.2	70	23.0
313.3	62.1	20.6

The flat shield used to protect the gonads is made of lead, with a thickness of 0.5 mm. When the shield was used, the intensity of the scattered radiation to gonads attenuated by a factor 20.6%.

DISCUSSION

It can be seen in Table (1) that the mean value and standard deviation of tube voltage used for pelvic x-ray examination was found to be 76± 10 kVp. The European Commission, **(EC, 1999)** recommended the use of tube voltage values of 100-120 kVp for adults. The range of tube voltage used for pelvic X-ray conventional radiography was within the operating conditions of the peak kilo-voltage settings. Table (3) presents the mean and standard deviation values of ESD for pelvic x-ray examinations for three patient weights interval , 40-60 kg, 60-80 kg and 80-110 kg respectively. The ESDs associated with AP-pelvic examinations were 2.95 ± 0.23 mGy , 3.49 ± 0.22 mGy and 4.98 ± 0.6 mGy respectively. The measured mean ESDs ± standard deviation for the three patient weight groups are within the range of entrance skin dose carried out using TLD-100 and cited by the International Atomic Energy Agency, **(IAEA-cn-85-142)** .Table (4) presents the ESDs for patients of a reference weight of 70±10% kg . It can be seen that the ESD (mGy) for AP pelvic x-ray examination decreased by 65 % comparatively with the reference dose recorded by the European Commission **(EC, 1996)**, by 30% from the reference dose reported by International Atomic Energy Agency **(IAEA, 1996)** ,and by 12.5 % from the reference dose given by the National Radiological Protection Board of United Kingdom **(NRPB, 2000)**. The measurement of the ESD for patients in KFH was lower than the value of the international organizations, **(NRPB, 2000)** and that values reported by **(Alatta, 2018**) too. In addition, the ESD value for Pelvic is less than 10 times lower than that reported by **(Alghoul *et al.,* 2017).** The mean and standard deviation of the ESDs received by patients of a reference weight of 70±10% kg and weights in range 40-60 kg and 80-110 kg in KFH Hospital were within the mean and standard deviation doses measured by thermoluminscence dosimetes which reported by **(Begum, 1999)** . Table (5) presented the gonadal shield effectiveness by taken into account the ratio factor between TLD-response with 0.5 mm lead gonadal shield and TLD-response without shield .Flat contact gonadal shield reduces the dose to sensitive organ of LLNL's phantom by a factor of 22.6 . This is lowered than that percentage attenuation coefficient found **by (Fauber, 2011)** .The reason could be due to difference in the beam field size between the two studies.

CONCLUSION

The mean and standard deviation of the ESDs for pelvic x-ray examinations received by patients of a reference weight of 70±10% kg and weights in range 40-60 kg and 80-110 kg in KFH Hospital were within reference doses levels. The results obtained in this study shown also that the using of a gonadal shield reduce the scattered x-ray radiation dose to gonads by a factor of 20.6 % during X-ray pelvic examination. This study minimized a dose delivered to gonads and verify the optimization principle**.** It is mandatory advice for the technologist to use gonad shield made of 0.5 mm lead to assure the protection of gonads during Pelvic x-ray examination.

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Conflict of interest

The authors declare that they have no conflict of interest.

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