Received: 23 March 2023 | Revised: 29 June 2023 | Accepted: 1 July 2023
DOI: 10.1002/hsr2.1424

ORIGINAL RESEARCH

Health Science Reports Open Access WILEY

Pelvic radiation dose measurement for trauma patients in multifield radiographic examinations: A phantom-based TLD dosimetry study

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Funding information
Ahvaz Jundishapur University of Medical Sciences, Grant/Award Number: U -98154

Abstract

Background and Aims: Trauma patients often suffer from multiple injuries and require undergoing various radiography which is referred to as multifield radiographic examinations. Protective measures may be ignored for these examinations due to stressful emergency situations or patients' conditions. This study was conducted to evaluate the scattered doses received by the pelvis during different common multifield radiographic examinations with an emphasis on field size adjustment.

Methods: A whole-body phantom, PBU-50, resembling the body mass, was used to carry out the common examinations for trauma patients (extremities, skull, chest, abdomen, pelvis, femur, and lumbar radiography), using a Pars Pad X-ray machine. To measure the primary entrance skin doses, three calibrated GR 200 thermoluminescence dosimeter (TLD) chips were placed in the central X-ray beam of scanned organs. Three TLDs were also placed on the pelvis symphysis pubis to measure the scattered dose received by the pelvis due to each carried-out radiography for standard and clinically used field sizes. A Harshaw 3500 TLD Reader was used to read the chips. TLD readouts (nano-Coulomb) were converted to dose (milli Gray [mGy]) using the predefined calibration curve.

Results: The scattered doses to the pelvis due to scanning a single organ differed from 0.80 to 1.70, and 0.82 to 4.09 mGy for standard and clinically used field sizes, respectively. The scattered doses to the pelvis in multifield examinations varied from 0.80 to 8.43 and 0.82 to 13.6 mGy for standard and clinically used field sizes, respectively, depending on the number of scanned organs and their distances from the pelvis.

Conclusions: Multiple and repeated radiographs combined with insufficient protective measures can increase the patient's dose. The findings indicate that the scattered doses received by the pelvis can exceed the reference values in multifield radiography, especially if the radiation field is not restricted properly to the scanned organ.

KEYWORDS
multifield radiography, pelvis dose, radiation field size, scattered dose, TLD dosimetry, trauma patients

1 | INTRODUCTION

X-ray imaging plays a crucial role in medical diagnosis.[1] The ionizing nature and high penetration feature of X-rays, along with the sensitivity of various body tissues, resulted in biological effects that have necessitated special protective considerations. The biological effects of X-rays are generally divided into stochastic and deterministic effects. Stochastic effects such as cancer and genetic or hereditary diseases have no threshold doses, and the probability of these effects is proportional to the dose. Deterministic effects such as cataracts, fibrosis, and reduced sperm counts have threshold doses and the severity of these effects rises with the dose.[2,3]

The International Commission on Radiological Protection (ICRP) has recommended two principles of justification and optimization for radiation protection in medical imaging. According to the justification, any practice involving radiation exposure should be beneficial, and all radiological procedures must be in accordance with the diseases. The examination should also produce more benefit than harm to prevent tissue reactions and limit the risk of stochastic effects to acceptable levels.[2] Concerning the incidence of dose levels below 100 mSv in diagnostic radiography, deterministic effects are not expected in these procedures. However, as a single or cumulative dose in a year, cancer risk and heritable effects are expected. Therefore, radiation protection is always a main concern.[2] According to the National Council On Radiation Protection and Measurements report, no. 160 in 2006,[4] effective dose per individual in the US population was 3 mSv and the collective effective dose was 8.99×10^5 Sv. Also, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[1] in a recent report estimated the collective effective dose of the world's population as 4.2×10^6 man-Sv from 2009 to 2018 period. However, regarding the increased use of ionizing radiation for medical practices, annual cumulative doses of up to 100 mSv have been reported.[1,5,6]

As known, the majority of referrals to medical centers, are injured and trauma patients.[7] These patients may typically be subjected to various imaging examinations during admission, hospitalization, and even after discharge.[8] Studies have shown excessive radiology orders for such patients.[9] Sharma et al.,[10] recorded a cumulative effective dose of 11.76 mSv per patient in the first 24 h after admission for traumatic injuries. Kim et al.,[6] reported a mean cumulative effective dose of 106 mSv per patient during hospitalization greater than 30 days.

Moreover, some trauma patients who need radiographs may be pregnant women. According to ICRP recommendations,[2] fetus lethal effects for doses <100 milli Gray (mGy) are infrequent. However, fetus exposure to ionizing radiation can increase cancer risk in the first or second decade of newborn life.[11] Also, ionizing radiations may have genetic effects, so gonads must be protected. Wall et al.,[12] documented dose levels of 0.63 and 0.15 mGy for plain abdominal X-rays of ovaries and testes, respectively. Additionally, they reported values of 0.52 and 2.1 mGy for the ovaries and testes, respectively, in pelvic radiographs.

Considering the increased number of patients admitted to trauma centers,[7] and ordering different imaging examinations for them,[13] radiation protection should be considered, especially in sensitive groups. Even in the cases of not limiting the dose due to more clinical imaging benefits compared to radiation risks, an increase in cumulative dose is inevitable.[10] However, protective measures as fundamentals of radiation safety,[14] may be neglected in emergencies due to special circumstances.[15]

Effective and cumulative effective doses in trauma patients have been studied by some researchers.[8–10] However, until the time of this study, no research has been conducted to measure the scattered doses received by the pelvis in multifield radiography examinations for patients with multiple injuries. Therefore, this study aimed to measure the total scattered doses received by the pelvis in common multifield radiography examinations. Since the approximate location of the gonad is within the pelvis cavity,[16] we focused on the pelvis as a critical organ. Also, the term multifield has been applied to a situation where a patient with multiple injuries has undergone several radiographs at the same time. Given the significance of cumulative radiation doses and their relevance to the incidence of stochastic effects, primary entrance skin doses (ESDs) were also measured for these common trauma studies (extremities, skull, chest, abdomen, pelvis, lumbar, and femur examinations).[13]

2 | MATERIALS AND METHODS

The study protocol was approved by the institutional ethics committee (Ethics code: IR. AJUMS. MEDICINE. REC.1398.025). No human or animal samples were used in this study and an anthropomorphic phantom was scanned using the considered study scanning protocol (summarized in Table 1) to measure the radiation doses.

2.1 | Imaging system and scan protocol

A Pars Pad X-ray machine (model PMX-600, Iran) calibrated by a dose-area product meter (model NE Technology) was used for

TABLE 1 Scan protocols (standard and clinically used exposure factors, field sizes, and FFDs) and the scanned organs.

Organs		kVp		mAs		Field Size (cm^2)		FFD (cm)	
		Standard	Clinically Used	Standard	Clinically Used	Standard	Clinically Used	Standard	Clinically Used
Skull	**AP**	65	65	25	25	20 × 32	30 × 35	100	100
	LA	60	60	20	20	28 × 32	42 × 35	100	100
Arm (AP and LA)		58	58	15	15	18 × 43	28 × 50	100	100
Forearm (AP and LA)		55	55	8	8	13 × 38	22 × 50	100	100
Leg (AP and LA)		60	64	12	12	15 × 43	26 × 54	100	110
Chest (AP)		70	70	10	12	40 × 35	54 × 45	100	110
Abdomen (AP)		72	72	30	40	35 × 43	54 × 45	100	110
Pelvis (AP)		68	68	30	40	43 × 35	45 × 45	100	100
Femur (AP and LA)		70	74	20	20	20 × 43	32 × 54	100	110
Lumbar (AP and LA)		70	70	40	40	23 × 35	25 × 54	100	110

Note: Standard exposure factors (kVp, and mAs) and field sizes are set according to Merrill's Atlas of Radiographic Positioning & Procedures, a guideline in diagnostic radiology techniques.[14] Mean clinically used field sizes are set according to the study of Farzanegan et al.[15] Clinically used exposure factors (kVp, and mAs) were obtained through questionnaires completed by radiographers at different university training hospitals.

Abbreviations: AP, Anterior-Posterior; FFD, film-focus distances, LA, Lateral.

performing multifield radiography examinations. The efficiency of the X-ray machine was verified over a wide range of Kilovoltage peaks. To simulate a real situation, average clinically used exposure factors for plain radiography (kVp, mA, and time) were determined through questionnaires completed by technicians from different hospitals.[15] Furthermore, to simulate common technical errors of radiographers in applying radiation safety protocols, studies were done without gonads shielding. To evaluate the impact of radiation field size on patient dose, each exposure was performed with two different field sizes (standard and nonstandard or clinically used field sizes). The standard field size for each study was adjusted according to *Merrill's Atlas of Radiographic Positioning & Procedures*, a guideline in diagnostic radiology techniques.[14] Nonstandard radiation fields (referred to as clinically used) which were typically larger than the standard ones, were obtained according to the study of Farzanegan et al.[15] The reason for using larger field sizes can be patients' emergency conditions in addition to concerns about the need to repeat the examination due to missing the diagnostic target area. Used scan protocols including exposure factors, radiation field sizes, and film-focus distances (FFD) for scanned organs are summarized in Table 1.

2.2 | Phantom and scanned organs

An anthropomorphic whole-body phantom (model PBU-50, Japan), with a height of 165 cm and a weight of approximately 50 kg representing the body mass was used to perform multifield radiography examinations. As mentioned the extremities (arms, forearms, legs), skull, chest, abdomen, pelvis, lumbar, and femur radiography which are more common in the assessment of trauma patients[13] were performed (Table 1). To simulate a trauma patient condition, all exams were performed in the supine position.

2.3 | Dosimetry

To assess the ESDs of different scanned organs and the associated scattered doses to the pelvis, a total of 100 thermoluminescence dosimeter (TLD) chips specifically, the GR-200 series (composed of LiF: Mg, Cu, P, manufactured by China) were used. All chips had a cylindrical shape with a diameter of 4.5 mm and a thickness of 0.8 mm. Given their small size and effective atomic number similar to soft tissues, the radiation field remains unperturbed by these chips. To compensate for the potential variations in the sensitivity of TLD chips, initially calculated ECC (element correction coefficient) factors in our previous study[17] were used. To establish the calibration curve, chips were organized into 20 groups of 5 and subjected to various X-ray doses falling within the diagnostic radiology dose ranges (from 1.23 to 19.183 mGy). Following a similar approach as our previous study,[17] the correlation between the absorbed doses and TLDs responses was determined (Equation 1) by fitting a curve to the data.

$$R(nC) = 69.4(\text{nC/mGy}) \times D\ (\text{mGy}) - 55.8(\text{nC})\,, \quad (1)$$

where R represents TLD readings in nano-Columb (nC) and X represents the dose in mGy.[17]

To determine the primary ESD for each study, a set of three chips enclosed in a radiolucent bag was placed on the phantom body in the middle of the radiation field. Additionally, three other chips were also positioned on the pubic symphysis to measure the scattered radiation dose associated with each study. An additional three chips were considered for background measurements. Within 0–24 h after exposure, the chips underwent the read-out process using a Harshaw TLD reader (3500, USA), with the results recorded in nC. To account for sensitivity variations, the reading of each chip was multiplied by the ECC factor. Each group's readings were averaged and corrected for background and subsequently converted to mGy using the calibration curve (Equation 1).

2.4 | Statistical analysis

Calculations were performed in Microsoft Office Excel 2016. Scattered doses to pelvis and ESDs were stated as mean ± standard deviation.

3 | RESULTS

A total of 46 radiographs (23 examinations for standard and 23 examinations for clinically used field sizes) were performed using the mentioned scan protocols (Table 1). The measured primary ESDs of the studied organs and the scattered doses to the pelvis associated with each study (in mGy) are presented in Table 2. The pelvis received doses in some multifield examinations are presented in Table 3 and compared between standard field sizes and clinically used ones. These results are presented as the sum of all values received by pubic symphysis (in mGy) for each field type. As mentioned, we performed extremities, skull, chest, pelvis, abdomen, femur, and lumbar radiography as the most common examinations in emergencies,[14] for trauma patients with multiple injuries.[9,14,18] However, the previous study results[17] are also included in Table 3. Table 4 represents the mean ESDs, and diagnostic reference levels (DRLs) reported by other researchers compared to our results (the total received pelvis dose from each group of multifield examinations). This table highlights the adverse effect of enlarged field sizes and multiple examinations on scattered doses to the pelvis compared to typical pelvis doses in common pelvis radiographs.

4 | DISCUSSION

Many people experience accidents and trauma every year[7] and mainly radiography examinations constitute the initial part of trauma management. Trauma patients may have multiple injuries and may require multiple X-ray studies.[13] There is evidence of an increasing use of ionizing radiation in medical imaging.[1] Some studies have reported unjustified demand for X-ray imaging in trauma patients.[28] The insufficient awareness of physicians about ionizing radiation risks and patient protection, has also led to requesting unnecessary X-ray examinations.[18,29] So that some concerns have been raised about increasing patients' radiation doses.[30,31] Although dose limitation is not recommended in medical imaging, dose optimization must be done accordingly.[2] Therefore, this study was conducted to measure the total scattered dose received by the pelvis in a typical trauma patient who undergoes several radiographs. Since ESD is an effective tool for radiation optimization in medical imaging, ICRP introduced a DRL in 1996 based on ESD measurements.[32] So, ESDs for scanned organs were also measured using TLDs.

Moreover, radiography examinations were conducted with standard field sizes as well as average clinically used field sizes (mostly larger than studied organs). The reason was to simulate the real clinical conditions of emergencies and to perceive the impact of radiographers' radiation protection errors on patient-received doses.

Even though the slight variations of primary doses for the same organs at two different used field sizes, to apply a larger field

TABLE 2 Mean values of entrance skin doses (primary doses) and the associated scattered dose to pelvis, for each common radiography examination in traumatic patients with standard and clinically used filed sizes.

Organ	Primary dose (mGy)		Scattered dose to pelvis (mGy)	
	Standard	Clinically used	Standard	Clinically used
AP				
Pelvis	1.82 ± 0.06	1.83 ± 0.12	-	-
Chest	1.12 ± 0.02	1.14 ± 0.03	0.80 ± 0.01	0.82 ± 0.03
Abdomen	2.00 ± 0.02	2.36 ± 0.03	0.90 ± 0.05	2.20 ± 0.04
AP and LA				
Arm	1.15 ± 0.03	1.12 ± 0.07	0.81 ± 0.01[a]	0.99 ± 0.14[a]
Forearm	0.95 ± 0.01	0.92 ± 0.01		
Leg	1.08 ± 0.02	1.01 ± 0.01		
Femur	3.90 ± 0.14	2.80 ± 0.20	1.70 ± 0.01	2.35 ± 0.27
Lumbar	6.32 ± 0.22	5.40 ± 0.18	1.70 ± 0.02	4.09 ± 0.03
Skull	3.11 ± 0.10	3.06 ± 0.12	0.83 ± 0.05	0.82 ± 0.02

Abbreviations: AP, Anterior-Posterior; LA, Lateral.

[a]Average scattered dose to the pelvis due to scanning arm, forearm, and leg, right and left side, AP, and LA positions.

TABLE 3 Comparison of scattered doses to the pelvis in some studied multifield radiologic imaging examinations performed for trauma patients with standard and clinically used field sizes.

Fields types	Scattered dose to pelvis (mGy)		
	Standard FS	Clinically used FS	Percentage Diff%
Chest	0.80 ± 0.01	0.82 ± 0.03	2.50
Chest, abdomen	1.76 ± 0.06	3.02 ± 0.07	71.60
Chest, abdomen, lumbar (AP, LA)	3.40 ± 0.07	7.11 ± 1.00	109.12
Chest, abdomen, lumbar (AP, LA), femur (AP, LA), skull (AP, LA)	5.93 ± 0.13	10.29 ± 1.29	73.52
Chest, abdomen, lumbar (AP, LA), femur (AP, LA), skull (AP, LA), extremities	6.74 ± 0.14	11.27 ± 1.43	67.21
Chest, abdomen, lumbar (AP, LA), both side femurs (AP, LA), skull (AP, LA)	7.62 ± 0.14	12.63 ± 1.56	65.75
Chest, abdomen, lumbar (AP, LA), both side femurs (AP, LA), skull (AP, LA), extremities	8.43 ± 0.15	13.62 ± 1.70	61.57

Note: Percentage Diff% are calculated as (Clinically Used-Standard)/Standard*100.
Abbreviations: AP, Anterior-Posterior; FS, field size; LA, Lateral.

TABLE 4 The pelvis dose in some other studies.

Pelvis dose	
Study	**Dose (mGy)**
Mean ESD	
IAEA (Muhogora et al., 2008)[19]	3.68
IRAN (Nikzad et al., 2018)[20]	2.47
UK (Hart et al., 2010)[21]	3.2
Saudi Arabia (Taha et al., 2015)[22]	5.41
Greece (Metaxas et al., 2019)[23]	2.57
DRLs	
UK (Hart et al., 2010)[21]	3.9
JAPAN (Yonekura, 2019)[24]	3
IRAN (Zarghani, 2018)[25]	1.47
IRAN (Deevband, 2018)[26]	1.62
Canada (Tonkopi, Daniels et al. 2012)[27]	5

Abbreviations: DRL, diagnostic reference level; ESD, entrance skin dose.

(in clinical conditions), the FFD must be increased. To compensate for increased FFD, exposure factors (kVp or mAs) have been increased correspondingly (Table 1). This circumstance emphasizes more on negligence in maintaining radiation protection principles.

Based on the findings, under the circumstances in which a typical patient was subjected to several radiographic examinations, the scattered doses to the pelvis were up to 8.43 ± 0.15 and 13.62 ± 1.70 mGy for standard and clinically used field sizes, respectively. These levels of dose emerged from scattered radiation of other radiographic examinations well as overlapping parts of some primary fields adjacent to the pelvis which contributed to these doses.

In addition, when the pelvis is examined likewise, the total radiation dose can be increased (e.g., up to 15.5 mGy based on the data in Tables 2 and 3). These values are higher than accepted values from other studies in routine conditions[19–27] (Table 4). Also, Metaxas et al.,[23] studied 222 patients who underwent pelvis radiography and reported an average pelvis ESD of 2.57 mGy. Furthermore, Mohsenzadeh et al.,[33] evaluated a total of 1639 patients who performed pelvis radiography. A mean ESD of 1.43 ± 0.69 mGy was reported by these researchers.

Although patient dose is less in plain radiography compared to other X-ray procedures, severely injured trauma patients may be exposed to several radiation fields leading to higher doses to the pelvis (see Table 3). Furthermore, during the treatment period, some patients may be subjected to extra X-ray examinations. Kim et al.,[6] showed the mean number of 70 plain film radiography and eight CT scans per patient for trauma patients. Some studies have also reported an increased demand for CT scans particularly in trauma patients, that are independent of patient characteristics.[8] Unnecessary repetition of radiological practices has a significant contribution to patient dose. Lumbreras et al.,[34] retrospectively studied the rate of radiography repeatitions. They found a higher rate of repetitive X-ray examinations, especially in the age group of 0–20 years.

Considering the life expectancy in the young group and the sensitivity of gonads, radiation protection is a paramount matter. However, due to critical conditions in emergencies, radiation protection measures may not be observed which results in a high gonadal dose.

Ahmed and Shaddad[35] have reported 17 times higher gonadal dose for a maximum opening of the radiation field. Hence, under such conditions, protective measures for trauma patients especially for younger age groups must be an essential issue. Furthermore, X-ray procedures for female trauma patients with unclear pregnancy status or stage require special considerations. ICRP Publication 84[36] reported fetal doses of a maximum of 4 and 80 mGy for pelvic in plain radiography and CT scan, respectively. However, considering the risk-to-benefit ratio, radiographs are performed, but it is important to notice that the fetal doses of order 10 mGy, can increase the risk of childhood cancer.

Although our aim was to assess scattered doses to the pelvis in multifield radiography, we also emphasize that trauma series radiography can increase the clinical risk of accumulated doses over the treatment period. There is a number of reports that have evaluated cumulative radiation doses in radiological examinations.[1,4,6,37,38] Leeson et al.,[37] have reported median cumulative effective dose ranged from 16 to 29 mSv in trauma patients who were admitted to the emergency department over a 6-month period. They also estimated an increase in carcinogenesis attributed to ionizing radiation among these patients. Je Sung et al.,[38] studied injured patients for 1 year between 2010 and 2011. They found out that 2.7% of studied patients received cumulative effective doses of more than 20 mSv and 0.2% of patients received more than 100 mSv during admission. Kim et al.,[6] also found that during a period of greater than 30 days, the mean cumulative effective doses were in the range of 11–289 mSv per patient. The authors reported that the mean cumulative effective dose exceeded 30 times higher than the typical yearly dose per person in the United States.

Although in recent studies, CT scans were responsible for most of the total radiation exposures, plain radiography often has a greater contribution to the initial assessment of patients. As it is evident from our findings, if patients are exposed to multifield plain radiography with no proper protective measures, they may receive higher cumulative doses over time, which were not included in the practical investigations yet.

Some studies have focused on the effects of multiple imaging on the cumulative dose. Lemburg et al.,[8] have reported a median cumulative effective dose of 29.70 mSv in patients with multiple injuries and Nikzad et al.,[20] also showed an annual total collective dose of 57.67 mSv for patients who underwent different radiological examinations. But even so, their research did not consider the effect of enlarged field sizes on the cumulative dose.

When the radiation field is not restricted to the examined organ, a wider area can certainly be exposed. As reported in the study by Fauber et al.,[39] field size collimation in lumbar imaging resulted in a 27%–60% reduction in abdominal doses. Moreover, in multiple imaging, radiation fields overlap each other. For instance, a trauma patient undergoing pelvis, abdomen, and lumbar spine imaging at the same time, with field sizes greater than standard, will receive higher doses and such a matter has not been clearly addressed in studies.

Effective dose often is calculated for specific imaging based on the equivalent doses of individual tissues multiplied by the tissue weighting factors, without considering the impact of enlarged field sizes or their overlapping.[40] Although the current study has investigated pelvis dose in the case of multiple injured patients, it also demonstrated the risk associated with increasing the annual dose in traumatic events. Although the concept of justification in medical imaging is mainly based on risk-benefit assessments, the probability of malignant and hereditary disease at doses below 100 mSv should also be considered.[2]

The Biological Effects of Ionizing Radiation (BEIR) VII Committee[30] has developed a linear no-threshold model for estimating the relationship between low-linear energy transfer ionizing radiation exposure and carcinogenesis. According to this model, even the smallest dose has the potential to increase cancer risk. Also, the committee predicted the risk of developing solid cancer or leukemia at a dose rate of 100 mSv. Lemburg et al.,[8] estimated the cancer risk of about 1 case per 1000 persons associated with diagnostic imaging exposures. The potential risk of cancer incidence is more important among children, especially when the same radiation protocol is applied to all age groups. Lemburg et al.,[8] also found that only 0.7% of all CT scan exposure factors were altered with respect to patient age, and even plain radiography procedures were performed in the same settings. Pearce et al.,[41] also reported that cumulative doses of 50 mGy increase leukemia in pediatric patients.

Moreover, postprocessing filters in digital systems allow technicians to set a wide range of exposure with no concern about image disruption. This capability of new radiography systems can result in higher radiation exposure to patients.[42] As Mohsenzadeh et al.,[33] recently found significant differences in mean ESDs of the same imaging between 85 studied digital radiology units. Radiation doses for age intervals 10–15 years varied by a factor of 7.46 and 7.25 for the pelvis (AP) and abdomen (AP) imaging, respectively. Their findings demonstrated applying the same exposure factors for all age groups. In summary, even in the context of plain radiography, the patient dose can rise to a higher level than it has ever been expected. Previous evidence from the literature revealed the annual collective dose exceeded 100 mSv in a number of patients[5,38] which can influence the prevalence of both stochastic and deterministic effects.[2]

The present study planned and the performed multiple X-ray examinations are consistent with ALTS protocols[13] and some other studies for trauma patients.[8–10]

The limitation of our study was the use of a fixed-size phantom, so we could not explore different types of body masses and evaluate various kVp and mAs corresponding to different patients' sizes and ages. In this work, the effect of different field sizes and overlapping edges on pelvis dose was evaluated. Further research is recommended to consider other sensitive organs in multiple injured patients.

To our knowledge, this study is the first that gathered important factors such as series radiography, field size, safety measures combined with digital radiography characteristics, and their adverse effects on the patient dose. We attempted to challenge radiation protection in the field of diagnostic radiology in the hope of using more justified and optimized X-ray imaging for trauma patients.

5 | CONCLUSIONS

In continuation of previous studies, we sought to clarify some neglected points in the field of radiation protection in diagnostic radiology. Considering our findings, it can be concluded that in multifield radiography examinations of trauma patients, scattered doses to the pelvis may exceed the reference accepted levels. Repeated and multiple examinations, with any or insufficient safety measures, and misuse of digital system facilities such as postprocessing filters, especially for children, will result in receiving a higher level of doses that in the increasing extent of trauma patients cannot be ignored. Finally, we emphasize that despite the limitations of the current study and just evaluating the plain radiography, these results can also be attributed to optimizing patient radiation dose in other X-ray examinations such as CT scans and fluoroscopy studies.

AUTHOR CONTRIBUTIONS

Ameneh Peiro: Conceptualization; data curation; formal analysis; methodology; writing—original draft; writing—review and editing. **Nahid Chegeni**: Conceptualization; data curation; formal analysis; methodology; project administration; supervision; writing—original draft; writing—review and editing. **Amir Danyaei**: Conceptualization; data curation; formal analysis; funding acquisition; supervision; writing—original draft. **Jafar Fatahiasl**: Conceptualization; data curation; formal analysis; methodology. **Marziyeh Tahmasbi**: Conceptualization; data curation; supervision; writing—original draft; writing—review and editing.

ACKNOWLEDGMENTS

This study is a part of the MSc thesis of Miss Ameneh Peiro which is financially supported by Ahvaz Jundishapur University of Medical Sciences (Grant No. U -98154). The authors would like to thank the Radiologic Technology Department of Allied Medical Sciences School for their sincere cooperation. The financial support received from Ahvaz Jundishapur University of Medical Sciences covered the costs of preparing TLDs, undertaking radiographic examinations, and costs related to the TLD reader system. We declare that Ahvaz Jundishapur University of Medical Sciences as the financial supporter of the study was not involved in the study design, collection, analysis, and interpretation of data, writing of the report, and the decision to submit the report for publication.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

TRANSPARENCY STATEMENT

The lead author Nahid Chegeni, Marziyeh Tahmasbi affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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How to cite this article: Peiro A, Chegeni N, Danyaei A, Fatahiasl J, Tahmasbi M. Pelvic radiation dose measurement for trauma patients in multifield radiographic examinations: a phantom-based TLD dosimetry study. *Health Sci Rep*. 2023;6:e1424. doi:10.1002/hsr2.1424