



Cumulative Effective Dose Caused by Diagnostic Imaging and its Associated Risk for Cancer Development in Trauma Patients Referred to the Emergency Department

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Background: The current study aimed to determine the cumulative effective dose caused by diagnostic imaging and its associated risk for cancer development in trauma patients referred to an emergency department. **Methods:** This study was carried out retrospectively in an emergency department (Kashan, Iran) from April 2015 to October 2015. Then, the types of diagnostic radiologic studies performed on adult trauma patients in their first 24 h upon presentation were recorded. Finally, the cumulative effective dose of trauma patients and its associated risk for cancer development were obtained. **Results:** In total, the patients received 3323 radiologic examinations including 2169 radiographs and 1154 computed tomography (CT)-scans. The most common type of plain radiographic and CT-scan examinations included anterior posterior and posterior anterior chest as well as head, respectively. The mean cumulative effective dose received by trauma patients referred to the emergency department was 2.47 ± 4.29 mSv. Most of the effective dose was from CT-scan examinations (90.65% of total cumulative effective dose; 2181.91 mSv). The majority of patients (83.40%) received between 0.00 and 5.00 mSv cumulative effective dose. Moreover, the cancer risk per average cumulative effective dose received by trauma patients was 1.01×10^{-4} . **Conclusions:** In current study, the mean cumulative effective dose per each trauma patient (2.47 mSv) was relatively less than that of the other evaluated studies. It was also found that although the number of CT-scans was relatively few compared to plain radiographs, most of the cumulative effective dose of patients resulted from CT-scans; hence, using unnecessary CT-scan examinations should be avoided.

Key words: Cancer risk, computed tomography, cumulative effective dose, emergency department, radiology, trauma

INTRODUCTION

Diagnostic radiology studies are widely performed in emergency departments. They provide accurate and rapid diagnosis for emergency physicians to evaluate life-threatening injuries of emergency patients.¹ Trauma patients are highly at risk, especially for high-dose radiation exposure. Most of these patients receive multiple radiographs and computed tomography (CT) scans during their hospitalization.²

The ionizing radiation generated by radiologic studies (radiographs and CT scans) has been associated with certain

risks.¹ Overall, these associated risks can be classified into two radiation effects which can be measured in dose values: (1) radiation dose for acute exposure effect and (2) effective dose for chronic exposure effect.¹ It is notable that due to the lack of producing harmful level of radiation dose (usually <10 mGy), the radiologic studies are not accompanied by acute exposure effect.³ Nevertheless, the chronic exposure effect or stochastic effects, which include hereditary and carcinogenesis effects,

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are the most concerning effects of radiologic studies.¹ Despite these risks, using radiologic imaging has been growing over the past decades, especially in emergency departments. One of the reasons is that the radiologic imaging is greatly beneficial for emergency physicians in time-limited settings. In addition, compared to other presently available modalities, the radiologic imaging is highly accurate, noninvasive, and has a very high sensitivity to diagnose blunt injuries.^{4,5}

The international commission on radiation protection (ICRP) Publication No. 103⁶ has suggested an assessment of the radiation risks caused by diagnostic imaging using received doses to tissues at risk. Moreover, effective dose can be applied for comparing dose values from similar diagnostic procedures and technologies in various medical clinics and countries. In addition, if reference patient groups are same by sex and age, this quantity can be used to compare various technologies for similar examinations.⁶ Effective dose is defined as sum of the tissue dose equivalents and it is a single quantity representing the overall radiation effect on the whole organism.² Cumulative effective dose is also calculated to determine the biological effects of absorbed dose.⁷ This quantity is defined as sum of the effective dose values of all radiologic studies.² Both of these quantities are measured by rem and Sievert.^{7,8}

Because of the severity of injuries, trauma patients undergo multiple diagnostic imaging, even during their initial 24 h of evaluation after their presence at emergency departments. This issue has raised concerns among radiologists and emergency physicians believing that these patients may have been over-radiated which it increases their risks of developing malignancy along with ionizing radiation.¹ On the other hand, the injured patients are usually at a young age and hence, they are more sensitive to radiation effect.⁹ Hence, the optimization of scan parameters should be powerfully emphasized according to the as low as reasonably achievable principle in trauma radiology, particularly in trauma CT scans.¹⁰

While several studies have been previously carried out in other countries to investigate the effective dose from the radiologic studies in trauma patients referred to emergency departments,^{1,2,9,11-14} to the best of our knowledge, there is no similar study conducted in Iran. Therefore, the current study aimed to determine the amounts of cumulative effective dose caused by diagnostic imaging in trauma patients referred to an emergency department in Iran. The present study also aimed to find out that which specific types of diagnostic imaging procedures exposed trauma patients with the highest effective radiation dose. In addition, the cumulative effective dose of diagnostic imaging obtained from the current study was compared with that of the other studies. Finally, the cancer risk following diagnostic imaging in trauma patients was estimated.

METHODS

Study period and population

Using the hospital information system, all radiographic studies of trauma patients referred to the emergency department of Shahid Beheshti hospital with Level III trauma center (Kashan, Iran) were retrospectively reviewed from April 2015 to October 2015. Types of diagnostic radiologic examinations performed on adult trauma patients (>18 years) in their first 24 h upon presentation were also recorded. Furthermore, those patients who were transferred from other institutions were excluded from the study. Demographic data including sex, age, and number and type of diagnostic radiologic examinations of the patients were also assessed. In terms of age, the patients were classified into three groups: young (>18–35 years), middle aged (>35–50 years), and old (>50 years).

During the 6th-month study period, 975 adult patients (685 male and 290 female patients) met the study inclusion criteria and incorporated in this study with an age ranging from 18 to 98 years (mean age of 43.46 ± 20.33 years). Number of patients in young, middle aged, and old age groups was 465, 202, and 308, respectively.

Radiographic studies

In the current research, the radiographic studies included plain radiographs and CT scans. The plain radiographic examinations incorporated in this study were anterior posterior (AP) and lateral (Lat) lumbar spine, AP pelvis, AP, posterior anterior (PA), and Lat chest, AP, PA, and Lat skull, and AP abdomen. Furthermore, CT scan examinations included head, abdomen, pelvic, and chest. In total, there were 3323 radiologic examinations, of which 2169 plain radiographs and 1154 CT-scans were recorded for all groups. Figure 1a and b shows the frequency of plain radiographic and CT-scan examinations for each radiologic study, respectively.

It is noteworthy that the plain radiographic equipment applied in this research was all analog, the film screen combination speed was 400, and the total filtration ranged from 2.00 to 3.5 mm Al. Furthermore, CT scan examinations were performed based on standard protocols using single-slice CT scanner (Toshiba, Japan). Mean values of kVp and mA for plain radiographic were 73.5 ± 6.0 and 24.8 ± 7.9 , respectively. However, values of kVp and mA range for CT scan examinations were 120 and 120–200, respectively.

Estimation of the effective dose and cumulative effective dose

For each type of diagnostic imaging, an effective dose was estimated from data presented in our previous studies.^{15,16} The

effective doses of plain radiographs were extracted from¹⁶ and the calculation method of effective doses is explained in details in this reference. In addition, the effective doses of CT-scan examinations were obtained by multiplying dose-length product (DLP) by conversion coefficients presented¹⁷ which DLP values for each CT-scan examination were extracted from.¹⁵ There are several studies which have used the estimation method of effective dose for calculating the radiation dose from radiologic studies of trauma patients.^{1,2,18,19} The cumulative effective dose was calculated as the sum of effective doses of all radiographic studies. Tables 1 and 2 demonstrate the effective dose related to each procedure of diagnostic imaging investigated in the current study.

Cancer risk estimation

In the current study, the cancer absolute risks following radiologic examinations were estimated on the basis of the risk model described in ICRP Publication 103.⁶ Absolute risk is defined as the probability that a person who is disease-free at a specific age will develop the disease at a later time following exposure to a risk factor, e.g., the probability of cancer induction following exposure to radiation. To obtain this cancer risk, average cumulative effective dose resulting from radiologic examinations was multiplied by the risk coefficient (0.041 Sv^{-1}).

RESULTS

The average cumulative effective dose received by each trauma patient was $2.47 \pm 4.29 \text{ mSv}$ (ranged from 0.02 to 25.61 mSv). Most of the effective dose was from CT-scan examinations (90.65% of total cumulative effective dose), while plain radiographic examinations contributed to a smaller proportion of it (9.35% of total cumulative effective dose). In addition, the cumulative effective doses related to each radiologic study were obtained as well [Figure 2a and b].

In total, cumulative effective dose of patients ranged from 0.00 to 25.00 mSv. Figure 3 shows the distribution of these doses received by trauma patients per visit.

Furthermore, Table 3 presents the cumulative effective dose of patients from diagnostic studies for different age groups.

Number of radiologic studies (by age groups and gender) and associated cumulative effective doses are listed in Tables 4-7.

Patient cancer risk per average total cumulative effective dose (plain radiographic and CT-scan examinations) received by trauma patients was 1.01×10^{-4} .

DISCUSSION

The present study was prospectively designed to determine the cumulative effective dose of diagnostic imaging in trauma

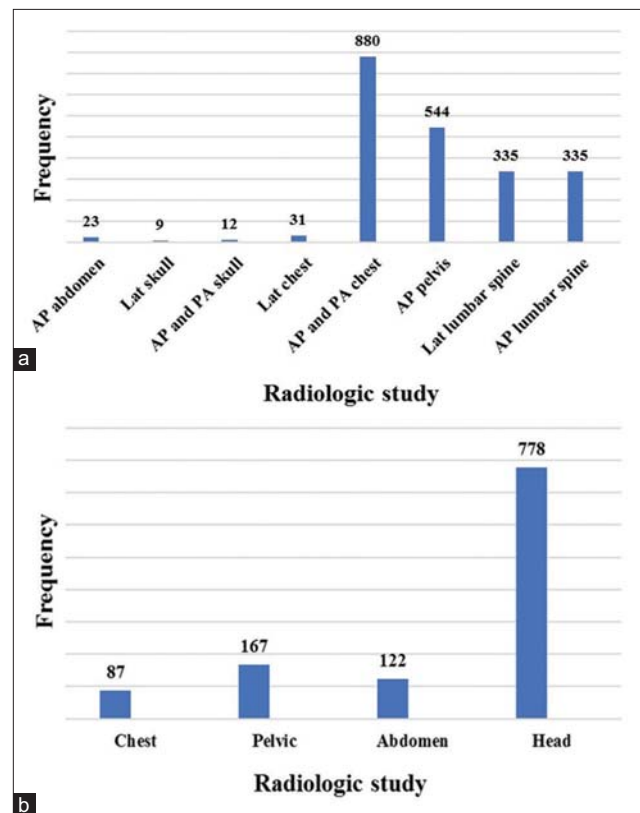


Figure 1: Frequency of plain radiographic (a) and computed tomography-scan (b) examinations performed on trauma patients

Table 1: The mean entrance surface dose and effective dose of each plain radiographic procedure

Types of plain radiographic procedures	Mean ESD (mGy)	Effective dose (mSv)
AP abdomen	1.62±0.06	0.23
Lat skull	0.8±0.03	0.01
AP and PA skull	0.98±0.04	0.01
Lat chest	0.88±0.04	0.09
AP and PA chest	0.31±0.01	0.03
AP pelvis	1.21±0.05	0.19
Lat lumbar spine	4.1±0.2	0.1
AP lumbar spine	1.5±0.06	0.16

ESD=Entrance surface dose; AP=Anterior posterior; PA=Posterior anterior; Lat=Lateral

patients referred to an emergency department in Kashan, Iran. Furthermore, cumulative effective doses related to each of the diagnostic imaging modality, age groups, and gender were obtained as well. Finally, cumulative effective dose caused by diagnostic imaging in trauma patients was used to estimate the cancer risk.

According to the demographic data, most of the trauma patients referred to the emergency department were

males (70.26%; in terms of gender) and young (47.69%; in terms of age group).

As seen in Figure 1, the most common type of examinations for plain radiographic and CT-scans included AP and PA

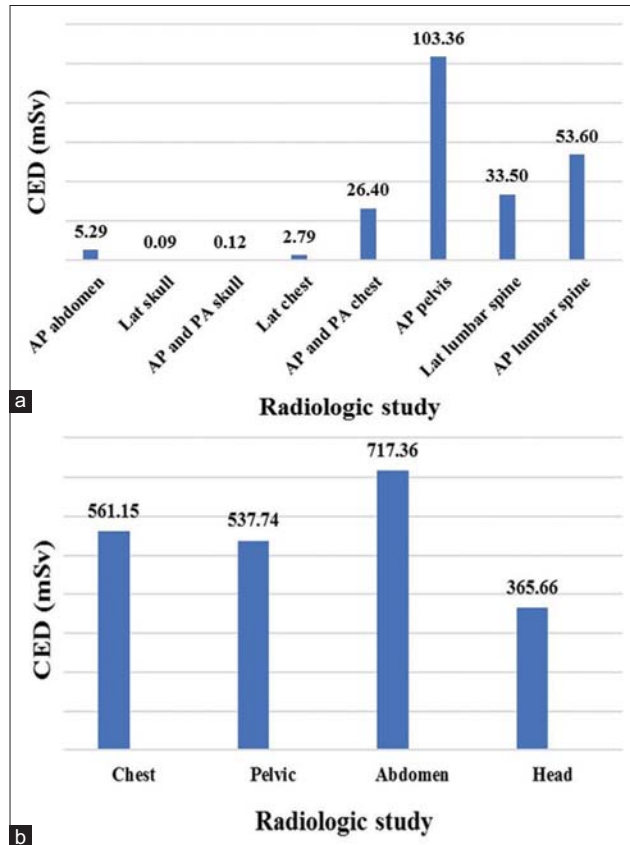


Figure 2: Cumulative effective doses of different plain radiographic (a) and computed tomography-scan (b) examinations

chest (40.57%) and head (67.42%), respectively. Furthermore, the Lat, AP, and PA skull plain radiographic (0.97%) and chest CT-scan (7.54%) were less common than others.

Based on the results of the current study [Figure 1a], most of the plain radiographic examinations included AP and PA chest, while [Figure 2a] the most cumulative effective dose resulted from AP pelvis (45.91%); because AP pelvis effective dose is higher than the AP and PA chest effective dose (0.19 mSv vs. 0.03 mSv). In addition, most of the CT-scan examinations were taken from the head; however, the highest cumulative effective dose of these examinations was related to abdomen (32.88%). The lowest cumulative effective doses were related to Lat skull plain radiographic (0.004%) and head CT-scan (15.19%), because these radiologic images were the least requested by physicians.

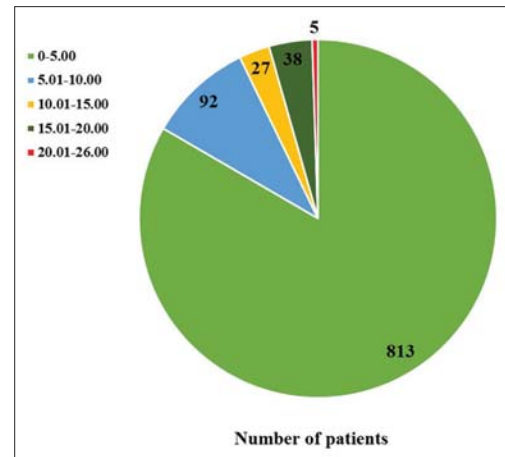


Figure 3: Distribution of cumulative effective doses received by trauma patients per visit

Table 2: The mean computed tomography dose index, dose-length product and effective dose of each computed tomography-scan procedure

Types of CT-scan procedures	CTDI (mGy)	DLP (mGy.cm)	Conversion factor (mSv/mGy/cm)	Effective dose (mSv)
Chest	15.47±0.82	307.33±18.37	0.021	6.45
Pelvis	10.08±1.45	189.37±31.85	0.017	3.22
Abdomen	13.95±0.45	346.07±16.98	0.017	5.88
Head	34.11±2.77	362.67±1.68	0.0013	0.47

CT=Computed tomography; DLP=Dose-length product; CTDI=CT dose index

Table 3: Average cumulative effective dose caused by diagnostic studies in different age groups

Age groups	Number of patients (male:female)	Cumulative effective dose (mSv)			Average cumulative effective dose (mSv) Total
		Male	Female	Total	
Young	465 (367:98)	918.69	216.15	1134.84	2.44±4.49
Middle-aged	202 (144:58)	441.38	191.92	633.30	3.13±4.69
Old	308 (174:134)	395.76	243.16	638.92	2.07±3.62

Table 4: Number of plain radiographic examinations and associated cumulative effective doses in different age groups

Radiologic studies	Number of diagnostic imaging			Cumulative effective doses (mSv)		
	Young	Middle-aged	Old	Young	Middle aged	Old
AP abdomen	6	6	11	1.38	1.38	2.53
Lat skull	5	1	3	0.05	0.01	0.03
AP and PA skull	6	3	3	0.06	0.03	0.03
Lat chest	16	6	9	1.44	0.54	0.81
AP and PA chest	405	187	288	12.15	5.61	8.64
AP pelvis	244	105	195	46.36	19.95	37.05
Lat lumbar spine	149	76	110	14.90	7.60	11.00
AP lumbar spine	149	76	110	23.84	12.16	17.60
Total	980	460	729	100.18	47.28	77.69

AP=Anterior posterior; PA=Posterior anterior; Lat=Lateral

Table 5: Number of computed tomography-scan examinations and associated cumulative effective doses in different age groups

Radiologic studies	Number of diagnostic imaging			Cumulative effective doses (mSv)		
	Young	Middle-aged	Old	Young	Middle aged	Old
Chest	35	28	24	225.75	180.60	154.80
Pelvic	78	42	47	251.16	135.24	151.34
Abdomen	66	33	23	388.08	194.04	135.24
Head	361	162	255	169.67	76.14	119.85
Total	540	265	349	1034.66	586.02	561.23

According to the results shown in Figure 3 and 83.40% of the patients received between 0.00 and 5.00 mSv cumulative effective dose from diagnostic imaging, while 0.50% of the patients received between 20.1 and 25 mSv. A small percentage of the patients (16.10%) received between 5.01 and 20 mSv of cumulative effective doses.

On average, the cumulative effective dose of patients from diagnostic studies was obtained 2.44 ± 4.49 , 3.13 ± 4.69 , and 2.07 ± 3.62 mSv for young, middle-aged, and old age groups, respectively [Table 3]. Among different age groups, the highest cumulative effective dose was received by the young group.

In terms of age groups, most of the plain radiographic and CT-scan examinations belonged to young population, which it consequently resulted in the most cumulative effective dose in this age group [Tables 4 and 5]. Considering the three age groups, the most plain radiographic examinations and cumulative effective dose were related to AP and PA chest and AP pelvis respectively [Table 4]. Furthermore, the most CT-scan examinations and cumulative effective dose (young

Table 6: Number of plain radiographic examinations and associated cumulative effective doses in male and female groups

Radiologic studies	Number of diagnostic imaging		Cumulative effective doses (mSv)	
	Male	Female	Male	Female
AP abdomen	16	7	3.68	1.61
Lat skull	6	3	0.06	0.03
AP and PA skull	8	4	0.08	0.04
Lat chest	26	5	2.34	0.45
AP and PA chest	644	236	19.32	7.08
AP pelvis	394	150	74.86	28.50
Lat lumbar spine	226	109	22.60	10.90
AP lumbar spine	226	109	36.16	17.44
Total	1546	623	159.10	66.05

AP=Anterior posterior; PA=Posterior anterior; Lat=Lateral

Table 7: Number of computed tomography-scan examinations and associated cumulative effective doses in male and female groups

Radiologic studies	Number of diagnostic imaging		Cumulative effective doses (mSv)	
	Male	Female	Male	Female
Chest	65	22	419.25	141.90
Pelvic	122	45	392.84	144.90
Abdomen	89	33	523.32	194.04
Head	556	222	261.32	104.34
Total	832	322	1596.73	585.18

and middle-aged groups) were related to head and abdomen, respectively [Table 5].

With regard to the gender, most of the plain radiographic and CT-scan examinations belonged to the male group, which consequently led to the most cumulative effective dose in this gender [Tables 6 and 7]. In both male and female groups, the most plain radiographic examinations and cumulative effective dose were related to AP and PA chest and AP pelvis examinations, respectively [Table 6]. Furthermore, the most CT-scan examinations and cumulative effective dose were related to head and abdomen, respectively [Table 7].

In a study by Tien *et al.*,⁹ the radiation doses received by trauma patients from diagnostic imaging were measured. In that study, dosimetry of 172 patients was carried out during CT scans, plain film radiography, interventional radiography, fluoroscopy, and nuclear medicine scans. Their findings showed that 86% of the estimated cumulative effective dose was from CT-scan examinations; this amount was less than what is reported in the current study in which CT-scan examinations

contribute to 90.65% of total cumulative effective dose. In that study, the mean cumulative effective dose received by patients was 22.7 mSv, while it was 2.47 mSv in the current study. One of the reasons for this difference lies in having different radiologic studies in that study compared to our study. In another study, Tjiang and Richardson¹ determined the cumulative effective dose of adult trauma patients referred to an emergency department during the initial 24 h of their care. In this study, the cumulative effective dose of 118 patients was evaluated during a year. Their results demonstrated that average cumulative effective dose of patients from diagnostic studies was 11.3 mSv which it was more than what was estimated in the present study. In addition, their results indicated that most of the cumulative effective dose was from CT-scan examinations as it was also shown in the current study; indicating that their contribution in that study was higher than our study (94% vs. 90.65%). Other results showed that most of the trauma patients referred to the emergency department received 0.00 mSv to 5.00 mSv cumulative effective dose. These findings were in consistent with our results; however, their contribution in this study was less than our study (42.4% vs. 83.40%). In a cross-sectional study, You *et al.*¹² analyzed the radiation exposure of conventional radiographs and CT scans received by the injured patients referred to an emergency department. 11676 patients were incorporated in this study. The cumulative effective dose of CT-scan examinations consisted 87.1% of total cumulative effective dose which this amount was less than that of the current study. Additionally, the average cumulative effective dose was 2.6 mSv, and it was similar to the results of the current study. Most of the patients (87%) received 0.00–3.00 mSv effective dose. These findings were almost similar to our results in which 83.40% of the patients received 0.00–5 mSv cumulative effective dose. There are several other studies which showed a high cumulative effective dose compared to our study. In a study by Winslow *et al.*,¹¹ the amount of ionizing radiation of 86 adult blunt trauma patients during the initial 24 h of their care was

evaluated and the median cumulative effective dose of ionizing radiation was 40.2 mSv. In another study by Salerno *et al.*,¹³ the cumulative effective dose of 249 young adult patients was assessed. Their results revealed a mean cumulative effective dose of 27 mSv (ranged from 3 to 297 mSv). Moreover, Sharma *et al.*¹⁴ assessed the cumulative effective dose of 177 patients admitted to a trauma service center. The mean cumulative effective dose of the patients was 11.76 mSv in the first 24 h after arrival. In addition, Kim *et al.*² investigated the cumulative effective dose caused by radiologic studies in 46 trauma patients. Their findings showed a mean cumulative effective dose of 106 mSv (ranging from 11 to 289 mSv).

The mean cumulative effective dose obtained from the current study and other studies as well as the several properties of these studies are tabulated in Table 8.

There are some studies which have evaluated the cancer risk from diagnostic imaging.^{3,20-24} Alkhorayef *et al.*²⁰ measured the patient radiation dose during a CT angiography procedure and estimated the patient radiation biological risk. They revealed that the overall patient risk per CT angiography procedure ranged between 15 and 36 malignancy risks per 1,000,000 procedures. Furthermore, their findings showed that the patient cancer risk was high during abdomen and neck procedures. In another study, Smith-Bindman *et al.*²² stated that the estimated number of CT examinations leading to the development of a cancer varies widely depending on the particular type of CT-scan and the patient's sex and age. For example, they reported that an estimated 1 in 600 males who underwent a coronary angiography CT scan at age 40 would develop cancer from that CT procedure (1 in 270 females), compared with an estimated 1 in 11,080 males who had routine head CT at the same age (1 in 8100 females). In addition, for 20-year-old individuals, the cancer risks were about doubled, and for 60-year-old individuals, the cancer risks were about 50% lower. De Gonzalez and Darby³ stated that in the UK about 0.6% of cumulative cancer risk for those aged 75 years could be due to diagnostic X-rays, as this contribution was

Table 8: Mean cumulative effective dose (mSv) caused by diagnostic imaging studies in trauma patients

Author and year	Country	Type of radiologic study	Mean cumulative effective dose (mSv)
Tien <i>et al.</i> , 20079	Canada	Plain radiography, interventional radiography, fluoroscopy, and nuclear medicine scans, and CT scans	22.7
Tjiang and Richardson, 2011 ¹	Australia	Plain radiography and CT scans	11.3
You <i>et al.</i> , 2013 ¹²	South Korea	Plain radiography and CT scans	2.6
Winslow <i>et al.</i> , 2008 ¹¹	The USA	Plain radiography and CT scans	40.2
Salerno <i>et al.</i> , 2016 ¹³	Italy	CT scans	27
Sharma <i>et al.</i> , 2011 ¹⁴	The USA	Plain radiography and CT scans	11.76
Kim <i>et al.</i> , 2004 ²	The USA	Plain radiography, CT scans, fluoroscopic study, and nuclear medicine	106
Current study	Iran	Plain radiography and CT scans	2.47

CT=Computed tomography

equivalent to approximately 700 cases of cancer per year. Furthermore, they estimated that the attributable cancer risk ranged from 0.6% to 1.8% in 13 other developed countries.

The results of the current research demonstrated that the mean cumulative effective dose received by trauma patients was 2.47 mSv which this amount of ionizing radiation is almost near the normal background effective dose received by an individual in a year (3.00 mSv).²⁵ On the other hand, using the linear nonthreshold model – an accepted method for estimation of the risk of low level ionizing radiation – it can be pointed out that there is no safe level of radiation exposure; hence, any dose can lead to cancer or genetic mutations.¹⁸ Therefore, clinicians should try to minimize the received radiation dose by the patients. The first and the most effective approach to diminish radiation exposure is to avoid implementation of unnecessary examinations (especially CT-scans). Second approach is to reduce the repeated imaging studies. Third, if technically possible, dose reduction techniques like automatic modulation of tube current/voltage, and image noise reduction through using iterative reconstruction algorithms should be used. Fourth, using alternative imaging modalities such as magnetic resonance imaging or ultrasonography can diminish the radiation exposure. Finally, fifth approach is that clinical evaluation criteria rather than a radiologic study can present a diagnosis plan or alternative treatment.

Limitations

There are several limitations in the current study. First, this study was carried out retrospectively which it indicates the limitations related to missing data as well as the possibility of errors in data collection. Second, the current study includes only the findings from a single emergency department; hence, it does not take various practice patterns at different centers. Third, the data presented in the current study might underestimate the mean cumulative effective dose received by trauma patients because other imaging modalities (like fluoroscopy and angiography which have higher exposure of effective dose) were not included in this study (because the trauma center was level III). Fourth, this study was conducted on adult trauma patients, while radiation exposure is a more important health issue for children because they are more radiosensitive and have more years to present stochastic effects.

CONCLUSIONS

The findings showed that the mean cumulative effective dose received by trauma patients referred to an emergency department was 2.47 ± 4.29 mSv. Although this amount of dose was relatively low, clinicians should keep radiation doses from

diagnostic imaging as low as reasonable. Number of CT-scans was relatively few compared to plain radiographs, but most of the cumulative effective dose of patients resulted from CT-scans. Hence, using unnecessary CT-scan examinations should be avoided. Furthermore, the results demonstrated that the most cumulative effective doses for plain radiography and CT-scan examinations were related to AP pelvis and abdomen, respectively. Finally, the patient cancer risk per average total cumulative effective dose received by trauma patients was 1.01×10^{-4} .

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Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed. The study is approved by Institutional Review Board of Kashan University of Medical Sciences. The approval number is IR.KAUMS.REC.1398.042.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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