ORIGINAL ARTICLE

A Regional Effective Dose, Risk of Exposure-Induced Death, and Annual Per Capita Dose in Diagnostic Radiology Procedures

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Abstract

Purpose: Ionizing radiation exposure doses during radiological procedures may increase the patient dose; therefore, dose assessment is an important subject. The current study aimed to estimate the Effective Dose (ED), Risk of Exposure-Induced Death (REID), as well as Annual Per Capita Dose (APCD) in routine radiography procedures in Yazd province (Iran).

Materials and Methods: The data related to the exposure parameters and Entrance Surface Air Kerma (ESAK) of 9 public high-patient-load radiography centers (11 radiology devices) were collected from 783 patients. Five routine planar radiological examinations were included: lumbar spine, pelvis, abdomen, chest, and skull. The ED and REID values for each device and examination were obtained using a personal computer-based Monte Carlo (PCXMC, v. 2.0) software. The APCD was estimated by dividing the annual collective effective dose (ACED) to the Yazd population.

Results: The estimated mean ESAK values ranged from 0.26±0.11 mGy (chest examination) to 8.45±5.3 mGy (lumbar examination). The lumbar spine examination had the highest ED value (1.02 ± 0.75 mSv). The highest REID value for abdominal, chest, lumbar, pelvic, and skull examinations is associated with stomach (6.58±7.72), lung (2.36±2.79), stomach (7.03±6.11), colon (3.31±5.49), and other cancers (0.58±0.56). The ACED value due to the radiology examinations was obtained at 45.782 man-Sv.

Conclusion: Our results demonstrated that the dose variations among the patients were remarkably high. Choosing appropriate imaging parameters, reducing the frequency of unnecessary radiology examinations, and performing quality control procedures of radiology machines could reduce the patients' doses.

Keywords: Radiography; Entrance Surface Air Kerma; Effective Dose; Cancer Mortality; Annual Per Capita Dose.

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1. Introduction

Although there are several applications used to diagnose human diseases, radiography is still one of the methods used for medical diagnosis [1, 2]. Radiology modalities, which are X-ray-based imaging, cause side effects to the organs, especially the sensitive ones [3-5]. So, exposure to a high value of ionizing radiation may cause breakage in molecular bonding and induce cancers [6].

Effective Dose (ED) is the metric used for measuring the delivered radiation dose to the population/patient. ED is used primarily prospectively for dose assessment, planning new methods for dose reduction, and optimization of occupational and public exposures. ED values can also be used retrospectively for determining compliance with dose limits and regulatory purposes in radiological protection [7]. X-ray examinations are not distributed uniformly among the population; therefore, the annual per capita dose (APCD) provides a better indication of overall trends in individual doses than the annual collective effective dose (ACED) [8]. ED is not recommended for epidemiological assessment, and it is calculated for a Reference Person and cannot be implemented as an estimate of specific individual risk [7]. In addition, it has been reported that the per capita dose might not be used for estimating individual risks [9]. In this regard, the studies recommend the risk of exposure-induced cancer death (REID) for estimating the individual risk [10, 11]. The REID definition provided by the ICRP Publication 103: “REID is defined as the difference in a cause-specific death rate for unexposed and exposed populations of a given age and sex at exposure, as an additional cause of death introduced into a population” [7].

Several studies assessed the cancer risks and/or REID values induced by radiology examinations [8, 12-15]. For example, Zangeneh et al. [12] calculated the lifetime attributable risk of cancer incidence and mortality in 12 routine digital radiography examinations (skull, cervical spine, chest, thoracic spine, lumbar spine, pelvic, and abdomen) based on organ-absorbed doses. In another investigation [13], the researchers assessed the REID values in a cohort of 5,573 women with spine disorders (such as scoliosis) exposed to frequent diagnostic X-ray procedures in the United States (14 orthopedic medical centers). The mentioned studies concluded that the cancer risks and REID depend on the X-ray examination type and the patient's sex and age [8, 12-15]. In addition, Bouzarjomehri *et al*. [8] investigated the ED and APCD of conventional radiology examinations (18 different types) of the Yazd population in 2007. Since the number of radiology examinations was more than in the Malaysian population (as a country for comparison in their study), they recommended the justification of radiography requests.

The development of medical diagnostic X-ray techniques affects the patient dose. Therefore, it is important to assess the patient dose values for every diagnostic imaging method as well as geographical region. This process can be carried out at various periods to provide reference data for further modification and enable specialists to make better and more accurate estimations of health risks. Thus, in the current study, we aimed to estimate the ED, REID, and APCD values induced from routine radiology examinations in Yazd province (Iran).

2. Materials and Methods

2.1. Data Collection

The current work is a cross-sectional and multi-center study, performed from April 2020 to March 2021 on the data of 783 patients referring to 9 public high-patient-load radiography centers (11 radiology devices). The study was approved with the registration number of “IR-SSU.MEDICINE.REC.1397.044” by Shahid Sadoughi University of Medical Sciences (Yazd, Iran). The information related to patients’ names and national numbers was not recorded, and a number was allocated to each patient, making them anonymous. The patient demographic information (average weight, height, age, organ thickness, and Body Mass Index [BMI]) was acquired. Furthermore, the exposure parameters information, like kVp, mAs, and Source to Imaging Distance (SID, cm), was obtained for each examination. The data from 12 planar radiology procedures were selected: chest (Anterior-Posterior [AP], Posterior-Anterior [PA], and lateral [LAT]), abdomen (AP), lumbar spine (AP, LAT, and oblique [OB]), pelvis (AP and LAT), and skull (AP, PA, and LAT). The investigated radiology centers were coded as "A", "B", "C", "D", "E", "F", "G", "H", and "I" affiliated to Shahid Sadoughi University of Medical Sciences.

2.2. Entrance Surface Air Kerma (ESAK, mGy) Measurement

To calculate ESAKs, the indirect dosimetry was performed using the Barracuda package (RTI Electronics, Sweden) according to the Technical Report Series (TRS) No. 457 International Atomic Energy Agency (IAEA) [16]. For each test, at least 10 patients' data with standard size were used. The distance from the X-ray tube and X-ray field size were 100 cm and 10*10 cm2, respectively. X-ray tube voltages ranged from 40 to 150 kVp (with the steps of 10 kVp). The ESAK values were obtained using Equation 1 [16, 17].

$$ESAK = O_Q.mAs.\left(\frac{100}{FSD}\right)^2.BSF \quad (1)$$

Where OQ (mGy/mAs) is the normalized tube output measured 1 m from the focal spot, mAs refers to the tube current-time product, and FSD is the focus-to-surface distance. BSF (dimensionless) stands for backscatter factor, considered between 1.3 and 1.5 according to IAEA-TRS457 [16].

2.3. Absorbed Dose, ED, and REID Calculations

The personal computer-based Monte Carlo (PCXMC) software (v.2, Helsinki, Finland) was used for the mean organ dose and ED calculations [18]. Patient gender, age, height, and weight, as well as irradiation parameters (kVp, mA, exposure time, FSD, filter thickness, and field size), and geometry (patient positioning, field angle, and region of interest) were defined for all the patients. The PCXMC software uses irradiation parameters, the number of photons, SID, image size, the coordinate of the location, and maximum X-ray energy to calculate the organ doses on the defined phantom.

The organs' absorbed doses were obtained using the ESAK values and exposure parameters in PCXMC software [15]. Then, the EDs were calculated using the following equation: E=∑▒W_T H_T, in which WT and HT are the tissue weighting factor and equivalent dose, respectively. To calculate the ED, the tissue weighting factors of both ICRP 60 and ICRP 103 reports were used [7, 19].

The REID values in PCXMC software were estimated based on the calculated organ doses using the models published by the Committee on the Biological Effects of Ionizing Radiation (BEIR) Phase 2 report [20]. In the PCXMC software, lifetime cancer risk mortalities are stated in terms of REID. The REIDs were approximated for leukemia and solid cancers such as colon, bladder, lung, ovaries, prostate, liver, breast, and thyroid for both genders. The REID values were averaged over the patients and calculated for each patient regarding his/her age and gender. The relative risks were obtained for each patient by interpolating the risk values between available defined ages in BEIR VII-Phase 2.

2.4. Frequency Contribution, Annual Collective Dose, and APCD

The radiological examinations included in the current study were selected regarding the contribution of the collective dose based on a previous survey by Bouzarjomehri *et al*. [8]. To determine the annual collective dose, the annual frequency of each X-ray examination was multiplied by its ED. The APCD was calculated by dividing the ACED by the Yazd province population over a given time [8].

3. Results and Discussion

The 783 patients' information (340 females and 443 males), including the mean and standard deviation values of age (years), organ thickness (cm), weight (kg), height (cm), and body mass index (BMI, kg/m^2), is depicted in Table 1. The exposure parameters (kVp, mAs, and SID) are provided in Table 2.

3.1. ESAK Values

The mean estimated ESAK values for each radiography examination and center are represented in Table 3. The values ranged from 0.26±0.11 mGy (center G, chest examination) to 8.45±5.3 mGy (center A, lumbar examination), which varied among different centers and examinations.

Table 1. Mean and standard deviation of patient anatomical information in the assessed centers

Exam	No. (sex)	Age (year)	Organ thickness (cm)	Weight (kg)	Height (cm)	BMI (kg/m^2)
Abdomen	139 (78M,61F)	42±14	23±5	70±16	170±9	24±6
Chest	205 (122M,83F)	43±14	24±5	70±16	169±9	25±5
Lumbar spine	188 (102M,86F)	40±13	25±5	69±12	168±8	25±5
Pelvis	111 (61M,50F)	43±14	22±4	70±12	170±9	24±4
Skull	140 (81M,60F)	39±14	21±3	63±12	167±8	22±4
Total	784 (441M,343F)	41±14	23±5	69±14	169±9	24±5

M: male; F: female

Table 2. Mean and standard deviation values of the exposure parameters and SID

Exam	View	kVp	mAs	SID (cm)
Abdomen	AP	73±5	36±27	113±25
Chest	Total	76±8	5±15	166±27
	AP	70±10	9±11	104±8
	LAT	81±5	17±8	160±35
	PA	77±6	17±17	174±16
Lumbar spine	Total	75±8	46±23	107±18
	AP	71±6	40±22	105±14
	LAT	79±7	52±24	110±22
	OB	78±6	48±18	100±1.0
Pelvis	Total	70±7	35±17	109±23
	AP	70±7	35±17	109±24
	LAT	73±5	27±11	109±16
Skull	Total	67±5	27±18	119±19
	AP	66±5	33±22	119±20
	LAT	66±5	21±11	121±16
	PA	70±5	25±16	119±20

AP: anterior-posterior projection; PA: posterior-anterior projection; LAT: lateral projection

The ESAK values from the present study were higher than several investigations, like Ibrahim I. Suliman [21] performed in Oman, so the mean ESAK values (mGy) of the abdomen, chest, lumbar spine, and pelvis were 1.8, 0.3, 4.05, and 1.92, respectively. However, our ESAK values were more comparable with Milatovic *et al.*'s [22] study performed in Montenegro. In their study, the mean ESAK values (mGy) were estimated as 1.94, 0.39, 4.93, and 2.57 for the abdomen, chest, lumbar spine, and pelvis, respectively. The discrepancies can be attributed to several reasons, including different types of radiography systems, types of X-ray examinations, the number of patients investigated, the selection of radiation parameters (such as kVp and mAs), and the tube distance to the patient [17]. Owing to the results, the LAT position compared to AP/PA views had a higher received dose, especially in lumbar, chest, and pelvis examinations, which can be related to the higher thickness in the LAT position [23].

3.2. ED Values

The ED values for each examination were obtained using the values of ESAK and are shown in Figure 1. For ICRP 60 and ICRP 103, a considerable difference was shown in the skull (AP), chest (AP), and pelvic (AP) examinations (32%, 36%, and 31%, in that order). Obed *et al.* [19] compared the ED from the abdomen-pelvic CT scan using the ICRP 60 and ICRP 103 recommendation tissue weighting factors. They have expressed that the mean ED values obtained were 375.0 and 341.3 mSv for the ICRP 60 and ICRP 103, respectively. In agreement with their study, we have found that the mean ED for the pelvic and abdominal examinations was higher for ICRP 60, which can be attributed to the higher weighting factors of the mentioned organs. For instance, the tissue weighting factor for the gonads is considered 0.20 for ICRP 60 and 0.08 for ICRP 103, which causes a higher estimated ED for the pelvic and abdomen regions. Furthermore, it has been reported that the AP position causes a higher organ dose than the PA view. For instance, the absorbed dose in sensitive organs like the

Table 3. Measured mean values of ESAK (mGy) for different radiographic examinations in 11 investigated radiology devices

			ESAK (mGy)		
Devise	**Abdomen**	**Chest**	**Lumbar**	**Pelvis**	**Skull**
A	3.17±2.10	0.43±0.21	8.45±5.3	5.23±4.2	2.13±1.89
B	2.60±1.50	0.44±0.32	5.45±4.32	2.68±1.54	1.67±1.21
C	6.16±3.41	0.46±0.33	6.76±5.3	-	2.19±1.90
D	4.29±4.11	1.01±0.88	7.52±4.3	2.78±1.44	-
E	0.45±0.21	0.63±0.43	0.87±0.55	0.36±0.20	-
F	3.19±1.70	0.61±0.43	4.32±3.54	2.43±2.11	1.07±0.44
G	1.41±0.91	0.26±0.11	1.17±0.82	0.67±0.43	0.6±0.20
H	3.94±2.30	0.7±0.54	4.2±3.21	2.18±2.1	2.28±1.12
I	2.76±1.72	0.52±0.32	4.36±4.1	2.25±1.99	1.22±0.99
J	2.44±1.92	0.44±0.31	6.72±5.40	2.35±1.32	1.84±1.32
K	2.82±1.41	0.67±0.45	5.37±4.32	3.58±2.10	2.04±1.00
Total	**3.02±1.40**	**0.56±0.55**	**5.01±4.98**	**2.45±2.32**	**1.67±1.62**

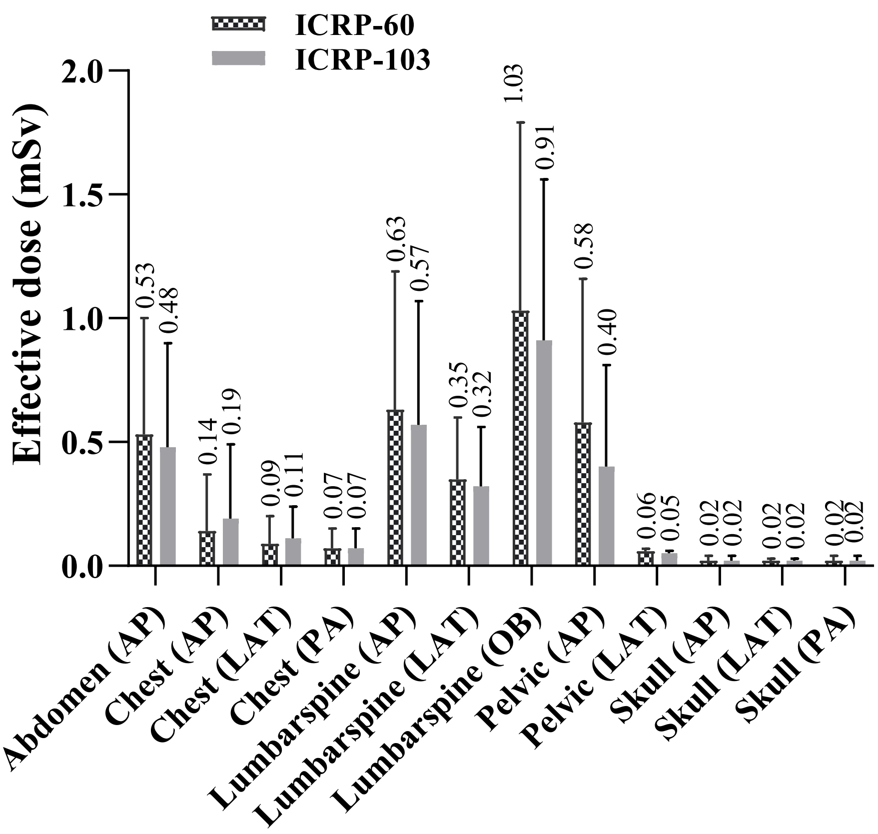

Figure 1. Mean and standard deviation values of ED according to the tissue weighting factors of ICRP 60 and ICRP 103 recommendations

breast and thyroid is approximately three to eight-fold higher in chest AP [24, 25]. Thus, for chest radiography examinations, the PA position (as the standard projection) must be performed.

3.3. REID Values

From the clinical perspective, there are several studies that recommend using REID instead of ED [10, 11]. The REID illustrates the probability of death from cancers associated with ionizing exposure, which can also be compared to other potential health risks in everyday life. By calculating the REID values based on BEIR VII, one can find the risks of the most frequent cancers, such as leukemia, thyroid, bladder, breast, lung, liver, prostate, ovary, and stomach cancer, regarding the patient's age and gender.

Table 4 depicts the REID values for the investigated radiological examinations in the nine hospitals. According to this table, the largest contribution is associated with chest examination (32%). In addition, the REID values from leukemia and solid cancers (colon, breast, lung, liver, ovary, bladder, stomach, and others) for each radiography examination (per million) are provided in Table 5.

The highest REID value for the chest, lumbar, pelvic, abdominal, and skull examinations is associated with lung (2.36±2.79), stomach (7.03±6.11), colon (3.31±5.49), stomach (6.58±7.72), and other cancers (0.58±0.56), respectively. The stomach and colon had the highest REID values because they are positioned in the abdomen, pelvic, and lumbar spine regions, which received high radiation doses during the radiology examinations. In agreement with our study, Zangeneh *et al*. [12] stated that thyroid in the skull and cervical spine X-rays, breast and lung in the thoracic spine and chest X-rays, and bladder and colon in the abdomen, pelvic, and lumbar spine X-rays had the highest REID values i.e. a close relation between REID values and organ location during X-ray examinations was reported. Ronckers *et al*. [13] assessed the REID values among women exposed to frequent diagnostic X-ray procedures due to scoliosis and other spine disorders. They reported that the estimated average cumulative radiation doses to the thyroid, breast, lung, and bone marrow were 7.4, 10.9, 4.1, and 1.0 cGy, respectively. The breast cancer mortality rate was higher (standardized mortality ratios, SMR=1.68) than several other cancers, like lungcervical, and (SMR=0.77), liver (SMR=0.31), and lung (SMR=0.17). In another study, Hosseini *et al*. [15] estimated the cancer risks and REID values from different digital routine radiology examinations in Mazandaran province. The REID value of the present assessment was lower than that of Hosseini *et al*., which can be related to the different methods used for REID estimation, different radiography systems, and radiation parameters.

The REID values due to radiation exposure are not trivial; hence, efforts should be carried out to reduce patient doses while maintaining image quality, in which, two strategies can help to this purpose, in general. The first one is to reduce the number of unnecessary examinations performed with such modalities using ionization radiation, such as radiology. If possible, refer the patients to non-ionizing radiation modalities like ultrasound and magnetic resonance imaging. The second one is related to the ALARA (as low as reasonably achievable) principle. Following this, the radiation dose can be reduced by implementing appropriate approaches like creating specific standards, dose reduction methods, and establishing diagnostic reference levels.

3.4. Frequency Contribution, Annual Collective Dose, and APCD

Figure 2 shows the number of radiological examinations performed from April 2019 to March 2020 in the nine investigated hospitals. Over the study period, 213962 examinations were carried out of the abdomen, chest, lumbar spine, pelvis, and skull, and we used 783 patients' data for further investigation. The Hospital "A" had the most considerable contribution (34%) among the investigated hospitals. The chest radiology with 132129 examination numbers (62%) was the most significant contributor; therefore, it can be concluded that the organs involved in this region, such as breasts and lungs, would have higher cancer mortality.

The ACED (man-Sv) for the routine radiological examinations performed for the investigated hospitals

Table 4. The REID values (per million) related to the common radiological examinations performed for the nine hospitals

Exam	A	B	C	D	E	F	G	H	I
Abdomen	0.14	0.09	0.03	0.05	0.02	0.02	0.01	0.02	0.00
Chest	0.18	0.12	0.11	0.07	0.04	0.03	0.02	0.02	0.00
Lumbar	0.26	0.06	0.05	0.06	0.03	0.05	0.04	0.02	0.01
Pelvis	0.15	0.03	0.02	0.02	0.02	0.03	0.01	0.01	0.00
Skull	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Mean and standard deviation (minimum-maximum) values of REID from leukemia and solid cancers induced by routine radiological procedures (per million)

Exam	View	Leukemia	Breast	Colon	Liver	Lung	Ovary	Stomach	Bladder	Other
Abdomen	AP	0.52±0.65	0.09±0.42	3.19±4.55	3.63±6.12	1.25±1.57	0.20±0.31	6.58±7.72	2.37±2.59	1.97±2.53
		(0.08,7.40)	(0.00,4.85)	(0.01,51.40)	(0.21,69.70)	(0.01,12.30)	(0.00,1.58)	(0.19,85.50)	(0.00,28.30)	(0.31,29.00)
Chest	Total	0.26±0.33	0.18±0.61	0.03±0.05	0.49±1.01	2.36±2.79	0.00±0.00	0.59±1.22	0.00±0.00	0.65±0.93
		(0.01,2.31)	(0.00,6.35)	(0.00,0.52)	(0.01,12.00)	(0.11,22.90)	(0.00,0.01)	(0.03,12.90)	(0.00,0.01)	(0.05,10.00)
	AP	0.24±0.40	0.44±1.16	0.05±0.09	1.11±2.03	2.34±3.14	0.00±0.00	1.40±2.19	0.00±0.00	1.08±1.68
		(0.01,2.31)	(0.00,6.35)	(0.00,0.52)	(0.06,12.00)	(0.11,17.90)	(0.00,0.01)	(0.08,12.90)	(0.00,0.01)	(0.07,10.00)
	LAT	0.23±0.30	0.42±0.80	0.03±0.04	0.08±0.15	2.17±2.51	0.00±0.00	1.08±1.50	0.00±0.00	0.76±0.98
		(0.04,1.43)	(0.00,2.76)	(0.00,0.18)	(0.01,0.68)	(0.28,11.10)	(0.00,0.01)	(0.17,6.64)	(0.00,0.00)	(0.10,4.21)
	PA	0.27±0.31	0.06±0.11	0.03±0.04	0.41±0.47	2.41±2.76	0.00±0.00	0.26±0.27	0.00±0.00	0.50±0.49
		(0.02,1.97)	(0.00,0.52)	(0.00,0.25)	(0.02,2.81)	(0.30,22.90)	(0.00,0.01)	(0.03,2.03)	(0.00,0.01)	(0.05,3.60)
Lumbar spine	Total	0.70±0.59	0.09±0.20	2.91±3.11	2.30±3.97	1.33±1.36	0.20±0.36	7.03±6.11	1.86±2.19	2.17±1.91
		(0.05,4.86)	(0.00,1.63)	(0.12,30.10)	(0.01,37.10)	(0.10,8.92)	(0.00,2.66)	(0.65,48.60)	(0.05,17.00)	(0.20,15.50)
	AP	0.63±0.64	0.06±0.10	3.86±3.82	4.23±4.94	1.27±1.16	0.24±0.38	7.67±6.19	2.91±2.33	2.36±2.32
		(0.05,4.86)	(0.00,0.40)	(0.28,30.10)	(0.22,37.10)	(0.13,7.02)	(0.00,2.66)	(0.89,48.60)	(0.36,17.00)	(0.20,15.50)
	LAT	0.77±0.56	0.11±0.25	1.69±1.34	0.22±0.23	1.27±1.25	0.12±0.21	5.22±3.79	0.47±0.34	1.85±1.26
		(0.06,2.78)	(0.00,1.63)	(0.12,6.86)	(0.01,1.18)	(0.10,8.92)	(0.00,1.03)	(0.65,17.40)	(0.05,1.59)	(0.20,5.92)
	OB	0.68±0.50	0.19±0.29	4.86±3.30	2.97±2.18	2.24±2.82	0.56±0.71	16.06±10.56	4.29±2.69	3.17±2.15
		(0.15,1.39)	(0.00,0.76)	(1.06,9.91)	(0.53,6.54)	(0.29,7.88)	(0.00,1.85)	(4.75,33.10)	(1.29,8.14)	(0.76,6.52)
Pelvic	Total	0.41±0.71	0.01±0.03	3.31±5.49	0.92±1.84	0.08±0.13	0.19±0.41	2.09±2.99	2.54±3.13	2.97±5.06
		(0.01,7.20)	(0.00,0.28)	(0.00,55.30)	(0.00,18.80)	(0.00,1.18)	(0.00,3.17)	(0.00,28.00)	(0.00,29.30)	(0.04,49.90)
	AP	0.42±0.72	0.01±0.03	3.42±5.56	0.96±1.86	0.08±0.14	0.19±0.42	2.15±3.03	2.63±3.16	3.07±5.12
		(0.01,7.20)	(0.00,0.28)	(0.00,55.30)	(0.00,18.80)	(0.00,1.18)	(0.00,3.17)	(0.00,28.00)	(0.00,29.30)	(0.04,49.90)
	LAT	0.14±0.02	0.00±0.00	0.35±0.05	0.01±0.00	0.02±0.02	0.05±0.04	0.50±0.34	0.14±0.03	0.26±0.11
		(0.12,0.15)	(0.00,0.01)	(0.30,0.39)	(0.00,0.01)	(0.01,0.04)	(0.00,0.08)	(0.12,0.79)	(0.09,0.16)	(0.16,0.36)
Skull	Total	0.10±0.09	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.04	0.00±0.00	0.00±0.00	0.00±0.00	0.58±0.56
		(0.01,0.75)	(0.00,0.03)	(0.00,0.00)	(0.00,0.00)	(0.00,0.46)	(0.00,0.00)	(0.00,0.00)	(0.00,0.00)	(0.05,5.21)
	AP	0.13±0.10	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.06	0.00±0.00	0.00±0.00	0.00±0.00	0.66±0.65
		(0.02,0.75)	(0.00,0.03)	(0.00,0.00)	(0.00,0.00)	(0.00,0.46)	(0.00,0.00)	(0.00,0.00)	(0.00,0.00)	(0.10,5.21)
	LAT	0.08±0.04	0.00±0.00	0.00±0.00	0.00±0.00	0.02±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.55±0.32
		(0.01,0.18)	(0.00,0.00)	(0.00,0.00)	(0.00,0.00)	(0.00,0.07)	(0.00,0.00)	(0.00,0.00)	(0.00,0.00)	(0.06,1.71)
	PA	0.09±0.10	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.05	0.00±0.00	0.00±0.00	0.00±0.00	0.49±0.63
		(0.01,0.57)	(0.00,0.02)	(0.00,0.00)	(0.00,0.00)	(0.00,0.28)	(0.00,0.00)	(0.00,0.00)	(0.00,0.00)	(0.05,3.72)
Total		0.40±0.55	0.09±0.38	1.74±3.54	1.46±3.58	1.17±1.92	0.11±0.28	3.31±5.51	1.23±2.22	1.57±2.58
		(0.01,7.40)	(0.00,6.35)	(0.00,55.30)	(0.00,69.70)	(0.00,22.90)	(0.00,3.17)	(0.00,85.50)	(0.00,29.30)	(0.04,49.90)

is represented in Table 6. According to this table, the highest ACED is contributed to Hospital “A”, with 40% of the total ACED over the study period. Notably, the lumbar spine examination has the largest

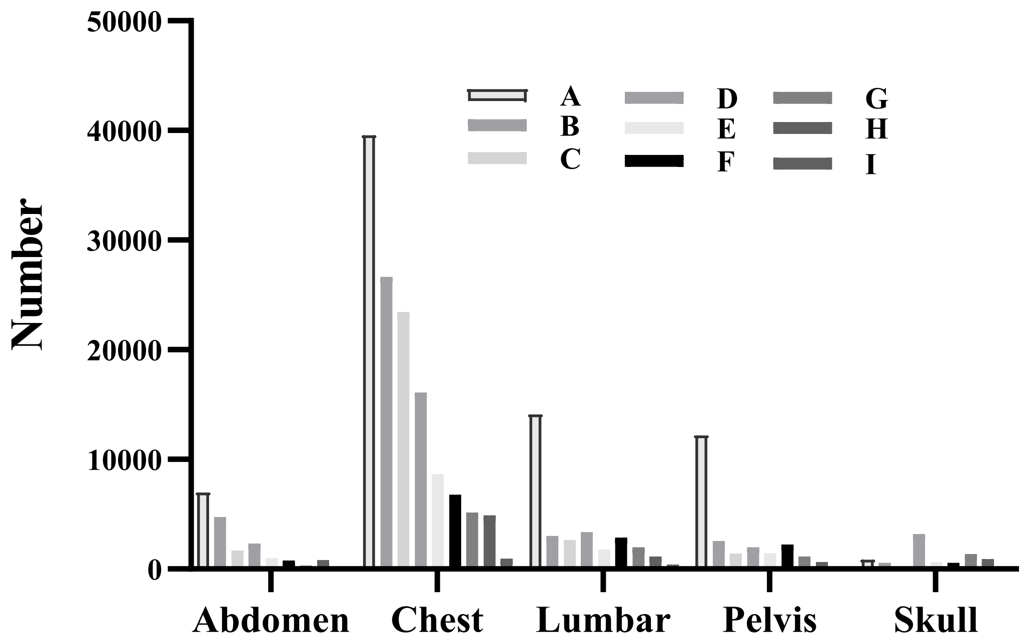

Figure 2. Number of each radiology examination in the investigated hospitals

Table 6. Annual collective effective dose (man-Sv) for routine radiological examinations performed for the investigated hospitals

Exam	A	B	C	D	E	F	G	H	I	Sum
Abdomen	3274	2215	803	1080	466	366	146	374	7	**8731**
Chest	3958	2664	2343	1612	865	676	515	488	93	**13214**
Lumbar	6627	1416	1236	1567	837	1342	924	529	191	**14669**
Pelvis	4638	977	523	749	549	842	443	240	27	**8988**
Skull	18	12	5	68	14	12	29	19	3	**180**
Sum	18515	7184	4910	5076	2731	3238	2057	1650	321	**45782**

contribution to the ACED (32%). In a previous study by Bouzarjomehri *et al.* [8], performed in Yazd province from April 2005 to March 2006, the ACED due to the conventional radiology examinations was 31.159 man-Sv, while this value was 45.782 man-Sv in our investigation. In addition, the annual per capita effective dose (µSv) for each radiological examination is presented in Figure 3. This value was obtained at 302.06 and 236.74 µSv, based on ICRP 60 and ICRP 103 recommendation tissue weighting factors, respectively. The relevant number in Bouzarjomehri *et al.*'s study [8] was 30 µSv, and it was 200 µSv in previous research performed in the UK [26]. Since our findings related to the ACED and annual per capita effective dose were higher than other reports, they can be attributedto the decrease in the frequency of unnecessary examinations.

The current investigation results could be helpful for radiographers, specialists in radiation protection, and radiologists to familiarize themselves with the ED, APCD, and REID values, and X-ray frequency associated with routine radiology examinations. The data presented in this work can be used to obtain a wider perspective of the radiology examination doses and cancer mortality risks for the population in Iran.

4. Conclusion

The results demonstrated that the estimated EDs for all the investigated radiology examinations except lumbar spine were comparably low; however, the variations among patient doses were remarkably high, even for a specific exam. Therefore, choosing appropriate imaging parameters, monitoring patient safety, and performing quality control procedures of

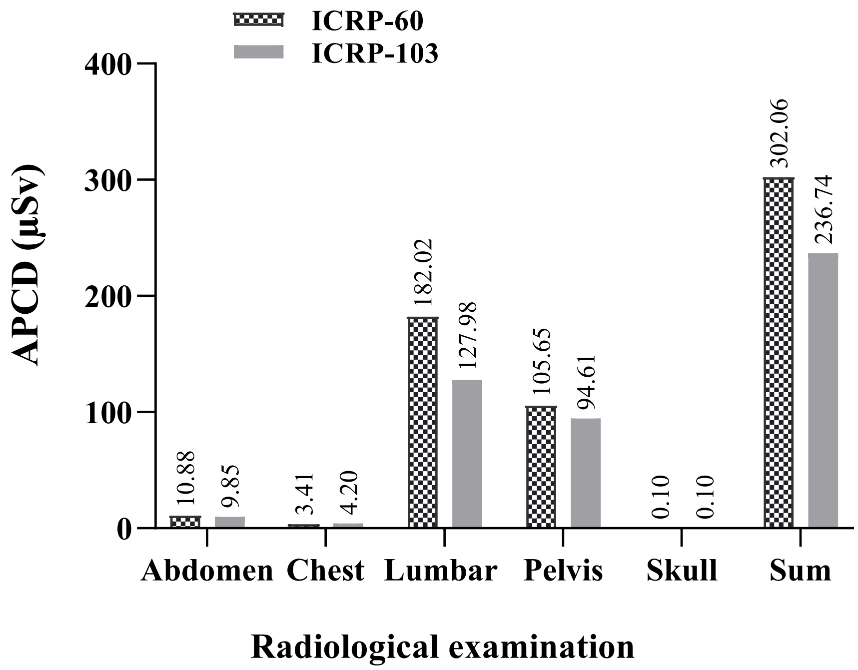

Figure 3. Annual per capita effective dose (µSv) due to the routine radiological examinations based on ICRP 60 and ICRP 103 recommendation tissue weighting factors

radiology machines for each center should be carried out to reduce patients' ED and REID values. Additionally, the annual per capita effective dose could be decreased by reducing the frequency of unnecessary radiology examinations (justified in the radiography requests).

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