Assessment of patient dose in routine digital radiography in Iran

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ABSTRACT

Background: The present study aimed to investigate patient dose in common X-ray examinations to estimate effective dose in the digital radiography in Iran. ***Materials and Methods:*** Entrance surface dose (ESD) was measured based on applied exposure parameters for the common actual examination; and then effective dose (ED) was calculated by use of PCXMC software. The study was conducted on 15358 patients in 85 X-ray rooms; and the necessary data was collected for five age groups, 0-1 year, 1-5 years, 5-10 years, 10-15 years old and adults in each projection. ***Results:*** The ranges of ESD and ED in different examinations for all the age groups are 0.02-10.20 mGy and 2.42-378.96 µSv respectively. ***Conclusion:*** The effective dose as criteria can be used to reduce patients' doses. The special considerations such as: adequate training of imaging staff; updating clinical audits; patient dose considerations; implementation of systematic and regular quality assurance and quality control programs in medical imaging departments should be taken into account to optimize radiological practices.

Keywords: *Patient dose; dose reference level; dosimetry in diagnostic radiology; entrance surface dose; effective dose.*

INTRODUCTION

Radiology is a specialty that uses medical imaging techniques and improves the diagnosis of numerous medical conditions in children and adults [1,2]. Patients' exposure to radiation has increased worldwide due to the widespread use of diagnostic radiography [3]. Diagnostic radiology has a large contribution of the population [4] exposure to ionizing radiation at least in developed countries [5]. Radiological procedures such as plain films or digital equipment, are included in 48% of all diagnostic radiology examinations; and 41% of collective dose is due to these procedures [6].

Development of digital radiography is an advance in the diagnostic radiology [7]. The digital radiography produce images with lower radiation and the same quality compared to traditional radiography [8]. Due to a large dynamic range in digital radiography, it can eliminate the need for repetition of exposures but, various amounts of radiation can be delivered to patients without leading to an overexposed image [9].

İnal and Ataç [10] have determined radiation doses to patients in digital radiography systems in Turkey. Their study was an initial assessment for establishing a local dose reference level (DRL) for digital radiography systems. Wachabauer *et al.* [11] have updated Austrian DRL for conventional radiography examinations. The obtained results were compared with the international dose reference levels. The Nuclear Safety and Radiation Protection French Institute [12]have analyzed the DRL data for radiology procedures. Their analyses showed discrepancies between regulatory examinations and clinical procedures. Mohsenzadeh *et al.* [13] established DRLs for routine examinations in digital radiography in Iran. An indirect method was applied to measure entrance surface air kerma (ESAK); and the third quarter was specified as the diagnostic reference level. Asadinezhad *et al.* [14] have surveyed the entrance surface dose to patients in conventional radiography for most typical examinations. The obtained Iranian DRLs were compared with reference dose values reported by different international bodies. Khoshdel-Navi *et al.* [15] established a local DRL in Mazandaran (Iran) for 12 projections of the most conventional radiology examinations. Entrance skin doses (ESD) were calculated for conventional radiography.

To the best of our knowledge, patient dose were not determined for digital radiography examinations in Iran. The present study aimed to investigate pediatrics and adults dose for a random sample of patients who underwent different examinations in digital radiography in Iran during 2015- 2016.

MATERIALS AND METHODS

Data collection

The present study was conducted at hospitals of various provinces in Iran during February 2015 to February 2016. Up to the end of 2016, a total of 647 digital radiology units, which were manufactured by different companies, were used in the research. Measurements were performed in 85 hospitals and private medical imaging centers with 96 X-ray rooms for about 15358 patients. The hospitals were selected based on the number of patients referred to them. Patients were classified into five age groups according to their ages as follows: 0-1 year, 1-5 years, 5-10 years, 10-15 years old and adults.

A questionnaire was completed and it consisted of information about the following issues: Technical exposure settings (including the applied tube voltage, tube current, exposure time, and X-ray field size on the detector), patient data (sex, age, weight, height, organ thickness, examination type and projection), institutional data (hospital name, room number and annual patient load), and X-ray machine data (kVp_{Max}, mAs_{Max}, half value layer (HVL), focus to skin distance (FSD), output in some clinical kVps, production year of machine, type of image receptor, type of generator, grid usage, and exposure setting). The whole data was collected via the direct observation by trained radiologic technologists in the center. Doses were measured for skull (PA), skull (Lat), cervical spine (AP), cervical spine (Lat), chest (PA), chest (Lat), abdomen (AP), lumbar spine (AP), lumbar spine (Lat), pelvis (AP), thoracic spine (AP) and thoracic spine (Lat) examinations based on exposure parameters that were used by local technologists.

Table 1 presents names of Iranian provinces, cities and total number of X-ray rooms in each province in which evaluations were performed. Table 2 presents the total number of radiology units which were used in the present study. This data of units was obtained by direct checking of equipment. To obtain this data, the types and frequencies of different digital radiology units were evaluated thorough Iran and some numbers were selected among each type (model) of unit. The selection for each unit model was based on the total frequency of the model. Table 3 presents the distribution of studied groups according to age, sex, mean of patient weight, patient height and number of patients in each age group that was used in the present study. The age groups were selected based on the classification which were presented in the ICRP report No. 103. Based on this report, the ages were divided into 5 groups. The total numbers of male and female samples are 8000 and 7358, respectively, and the samples which used in the study are relatively equal. These numbers indicate that the total results will not be affect by the distribution of sex of patients. Table 4 presents number of patients who underwent each X-ray examination according to their sex. For evaluation of the patients, 12 common radiology examinations were selected and the numbers of examinations were classified based on the sex of the patients. There was an effort to have relatively equal numbers of patients in the two sex groups (male and female). Table 5 indicates the FFD and exposure settings (X-ray tube voltage (kV_p), tube current-time product (mAs) and radiation field size) associated with each X-ray examination.

Table 1. Names of Iranian provinces, cities and the total number of centers in each province in which evaluations were performed.

Province	Cities	Total number of X-ray rooms
Eastern Azerbaijan	Tabriz, Marand, Shabestar	4
Western Azerbaijan	Urmia	4
Ardabil	Ardabil	2
Isfahan	Isfahan, Shahin Shahr, Kashan	5
Alborz	Karaj	4
Bushehr	Bushehr, Borazjan	3
Tehran	Tehran	14
Chaharmahal and Bakhtiari	Shahrekord, Borujen	2
Southern Khorasan	Birjand, Ferdows	2
Khorasan-e Razavi	Mashhad	4
North Khorasan	Bojnurd	3
Khuzestan	Ahvaz, Behbahan	4
Zanjan	Zanjan, Abhar	3
Semnan	Semnan, Damghan	2
Sistan and Baluchestan	Zahedan, Chabahar	2
Fars	Shiraz, Fasa, Estahban	4
Qazvin	Qazvin, Takestan	2
Qom	Qom	3
Kordestan	Sanandaj, Saqqez	2
Kerman	Kerman, Baft, Sirjan	3
Kermanshah	Kermanshah, Sarpol Zahab	2
Kohgiluyeh and Boy-er-Ahmad	Yasuj	3
Golestan	Gorgan, Gonbad Kavus, Ali Abad	3
Lorestan	Khorramabad, Borujerd, Kuhdasht	3
Mazandaran	Sari, Amol, Babol, Qaemshahr	4
Markazi	Aarak, Tafresh	2
Hormozgan	Bandar Abbas	2
Hamedan	Hamedan, Malayer, Aasad Abad	3
Yazd	Yazd	1
31	58	96

Table 2. Characteristics of radiography equipment and number of digital radiology units compared to studied units in Iran.

Manufacturer of digital radiology unit	Total number of radiology units	Number of evaluated cases
Mehran Teb Co. (Iran)	121	27
Arian Darman Pajouh Co. (Iran)	51	17
Payamed Co. (Iran)	41	10
Raouf Co. (Iran)	25	6
Siemens	21	6
Shimadzu	18	8
Sedecal	18	2
Comed	16	2
Electronic Hastei	15	2
GMI	12	2
Italray	10	2
DRGEM	7	1
Arcoma AB	7	1
Control Xmedical	6	2
Choongwae	6	1
Swiss Ray	5	1
General Medical Merate Spa (GMM)	4	1
Eco Ray	4	
Care Stream Health	4	1
Philips	3	1
Shima Parto	3	
Vatech	2	1
X-Aliiance	2	1
WDM Wandong	2	
GE	1	1
Kodak	1	
Toshiba	1	1
Konika Minolta	1	
Dong Kang	1	
Total: 29	408	96

Table 3. Patients' characteristics (age, height and weight) of the present study.

Age group	Weight (kg)		Height (cm)		Female	Male	Total
	Mean	Range	Mean	Range			
0 -1 year	7.10	2.90-11.30	63.80	48.60-79.00	468	432	900
1 - 5 years	15.95	8.50-23.40	93.00	72.00-114.00	523	773	1296
5 - 10 years	26.25	16.50-36.00	126.00	105.00-147.00	578	821	1399
10 - 15 years	48.75	28.5-69	153.50	135.00-178.00	749	934	1683
Adult	74.70	60.00-80.00	172.30	146.00-190.00	5040	5040	10080
Total					7358	8000	15358

Table 4. Distribution of studied groups according to sex and examination in all evaluated examinations.

X-ray examination	Female	Male	Total
Skull (AP/PA)	924	957	1881
Skull (Lat)			
Cervical spine (AP)	965	1023	1988
Cervical spine (Lat)			
Chest (PA)	1083	1328	2411
Chest (Lat)	585	673	1258
Thoracic spine (AP)	976	1032	2008
Thoracic spine (Lat)			
Lumbar spine (AP)	1123	1141	2264
Lumbar spine (Lat)			
Pelvis (AP)	797	842	1639
Abdomen (AP)	905	1004	1909
Total	7358	8000	15358

Table 5. Exposure settings (X-ray tube voltage (kVp), tube current-time product (mAs) and radiation field size) and FFD for each X-ray examination.

X-ray examination	Age	kVp (mean (Min-Max))	mAs (mean (Min-Max))	FFD (cm) (Min-Max)
Skull (AP/PA)	0 - 1 year	48.6 (45.0-55.0)	14.5 (10.0-20.0)	90.0-100.0
	1 - 5 years	55.6 (49.0-59.0)	19.6 (16.0-25.0)	
	5 - 10 years	58.3 (52.0-60.0)	21.8 (20.0-25.0)	
	10 - 15 years	63.5 (56.0-69.0)	25.7 (20.0-32.0)	
	Adult	68.2 (56.0-77.0)	28.5 (10.0-32.0)	
Skull (Lat)	0 - 1 year	46.2 (44.0-56.0)	11.7 (10.0-20.0)	90.0-100.0
	1 - 5 years	52.9 (46.0-56.0)	16.6 (16.0-25.0)	
	5 - 10 years	55.1 (50.0-58.0)	18.3 (20.0-25.0)	
	10 - 15 years	61.7 (50.0-63.0)	21.5 (20.0-32.0)	
	Adult	65.6 (51.0-75.0)	26.2 (10.0-32.0)	
Cervical spine (AP)	0 - 1 year	46.7 (40.0-48.0)	8.3 (6.0-16.0)	90.0-100.0
	1 - 5 years	52.3 (45.0-50.0)	13.9 (14.0-20.0)	
	5 - 10 years	54.7 (49.0-56.0)	18.2 (16.0-25.0)	
	10 - 15 years	60.1 (52.0-66.0)	22.1 (20.0-32.0)	
	Adult	65.3 (50.0-75.0)	26.6 (8.0-32.0)	
Cervical spine (Lat)	0 - 1 year	46.7 (40.0-48.0)	8.3 (6.0-16.0)	90.0-100.0
	1 - 5 years	54.6 (44.0-53.0)	15.8 (14.0-20.0)	
	5 - 10 years	55.3 (50.0-60.0)	18.8 (16.0-25.0)	
	10 - 15 years	61.5 (55.0-71.0)	22.4 (20.0-32.0)	
	Adult	66.5 (58.0-75.0)	14.6 (8.0-32.0)	
Chest (PA)	0 - 1 year	47.8 (41.0-55.0)	4.1 (3.2-8.0)	80.0-130.0
	1 - 5 years	56.3 (51.0-63.0)	6.3 (5.0-10.0)	
	5 - 10 years	63.8 (58.0-71.0)	7.9 (8.0-14.0)	
	10 - 15 years	72.4 (61.0-79.0)	9.8 (10.0-20.0)	
	Adult	80.2 (61.0-135.0)	12.3 (3.2-25.0)	
Chest (Lat)	0 - 1 year	48.3 (48.0-59.0)	4.6 (3.2-10.0)	80.0-130.0
	1 - 5 years	59.8 (54.0-68.0)	8.1 (8.0-14.0)	
	5 - 10 years	67.6 (61.0-77.0)	10.5 (10.0-16.0)	
	10 - 15 years	78.7 (66.0-85.0)	14.2 (14.0-28.0)	
	Adult	87.3 (70.0-135.0)	17.5 (6.4-28.0)	
Thoracic spine (AP)	0 - 1 year	46.6 (42.0-55.0)	6.7 (3.2-8.0)	90.0-100.0
	1 - 5 years	53.3 (51.0-63.0)	13.5 (5.0-16.0)	
	5 - 10 years	59.5 (58.0-71.0)	18.2 (8.0-20.0)	
	10 - 15 years	67.4 (61.0-79.0)	23.6 (10.0-28.0)	
	Adult	74.5 (61.0-86.0)	25.4 (12.0-40.0)	
Thoracic spine (Lat)	0 - 1 year	47.6 (43.0-59.0)	7.9 (6.4-10.0)	90.0-100.0
	1 - 5 years	57.1 (55.0-68.0)	15.5 (8.0-18.0)	
	5 - 10 years	65.2 (61.0-79.0)	19.7 (10.0-25.0)	
	10 - 15 years	76.8 (67.0-87.0)	25.4 (14.0-32.0)	
	Adult	81 (61.0-90.0)	31.5 (16.0-51.0)	
Lumbar spine (AP)	0 - 1 year	48.7 (44.0-55.0)	13.5 (10.0-18.0)	90.0-100.0
	1 - 5 years	56.6 (52.0-65.0)	19.6 (14.0-32.0)	
	5 - 10 years	62.3 (60.0-69.0)	23.4 (20.0-38.0)	
	10 - 15 years	69.1 (66.0-75.0)	30.1 (25.0-50.0)	
	Adult	76 (62.0-96.0)	35.6 (25.0-64.0)	
Lumbar spine (Lat)	0 - 1 year	49.5 (46.0-59.0)	15.3 (12.0-20.0)	90.0-100.0
	1 - 5 years	61.3 (57.0-73.0)	23.6 (16.0-38.0)	
	5 - 10 years	70.4 (62.0-71.0)	28.2 (20.0-42.0)	
	10 - 15 years	78.3 (65.0-80.0)	39.8 (25.0-64.0)	
	Adult	85.3 (65.0-100.0)	45.3 (25.0-80.0)	
Pelvis (AP)	0 - 1 year	46.1 (40.0-50.0)	13.3 (6.4-14.0)	90.0-100.0
	1 - 5 years	52.4 (48.0-61.0)	17.6 (8.0-20.0)	
	5 - 10 years	57.9 (52.0–65.0)	19.4 (14.0-32.0)	
	10 - 15 years	65.7 (56.0–68.0)	22.8 (18.0-40.0)	
	Adult	73.6 (61.0-85.0)	26.5 (12.0-45.0)	
Abdomen (AP)	0 - 1 year	48.8 (40.0-50.0)	13.3 (6.4-14.0)	90.0-100.0
	1 - 5 years	55.6 (48.0–64.0)	19.1 (8.0-20.0)	
	5 - 10 years	59.3 (52.0–65.0)	22.3 (14.0-32.0)	
	10 - 15 years	68.2 (56.0–68.0)	26.4 (18.0-40.0)	
	Adult	75.7 (65.0-90.0)	29.7 (12.0-50.0)	

Patient dosimetry

The various steps were taken to determine patients' doses. The set-up geometry was used for measurement of X-ray tubes' outputs as shown in figure 1. Dose values were measured based on the following steps:

- The dosimeter (a Barracuda solid state detector (RTI Electronic manufacturing Co.) was put on the radiology table at a distance of 100 cm from the focal spot of the X-ray tube (focus to dosimeter distance (FDD)) and the radiation field size on the detector was set to 10 cm × 10 cm.

- The tube conditions were set at 40 kVp and 10 mAs and the dosimeter reading was recorded in terms of air kerma. Each measurement was repeated three times and the average was determined. The measurement was repeated for 50, 60, 70, 80, 90, 100, 110 and 120 kVp with constant mAs value of 10 mAs.

- The kVp calibration curve (air kerma vs. kVp) was derived for each X-ray unit using the mentioned kVp set up and the fixed mAs. The curve was then utilized to calculate the X-ray tube output per mAs for different kVp settings.

-ESAK was calculated from the tube output measurement according to the equation 1 [16]:

$$\text{ESAK} = Y\ (\text{kVp}, \text{FFD}) \times \text{mAs} \times \left(\frac{\text{FDD}}{\text{FFD}}\right)^2 \times \text{BSF} \qquad (1)$$

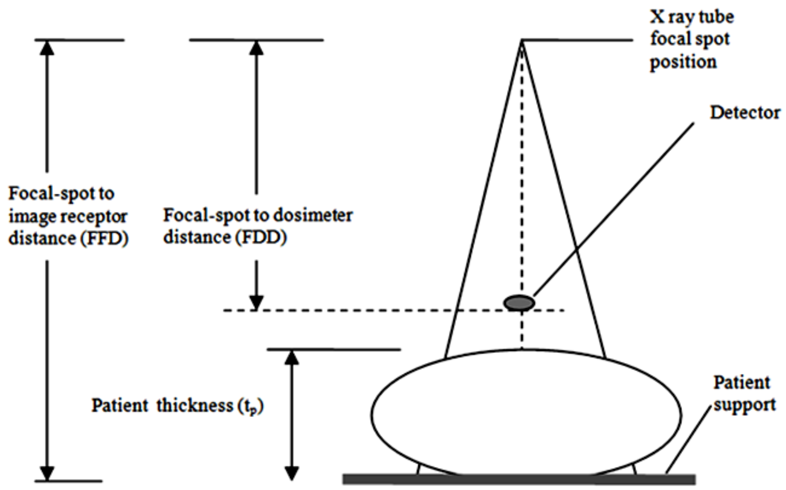

Figure 1. The applied geometry for measurement of X-ray output.

Where, Y (KVp, FDD) is the tube output for applied kVp during the X-ray examination (according to the output chart); mAs is the product of tube current and time used during the X-ray examination; FDD is the focus to dosimeter distance and FFD is the focal spot to film (detector) distance (typically 100 cm). BSF is the backscatter factor that depends on kVp, X-ray field size, thickness of patient and total filtration of the X-ray unit.

-ESD was calculated by multiplying ESAK to mAs and the ratio of mass energy absorption coefficients for tissue and air, and it was equal to 1.06. The equation number 2 shows the relation between the ESD and ESAK. In this equation, the ratio is approximately equal to 1.06 in the digital radiology in 110 kVp, with ± 1% error) [15]:

$$\text{ESD} = \text{ESAK} \times \text{mAs} \times 1.06 \qquad (2)$$

- Effective dose (E) was calculated based on the equation 3. Effective dose is the tissue weighted sum of equivalent doses in all specified body tissues or organs. The weighting factors for different organs can be adopted from International Commission on Radiological Protection (ICRP) 60 [17] and ICRP 103[18] reports.

$$E = \sum_i W_i \times H_i \qquad (3)$$

Where, W_i is the tissue or organ weighting factor; and H_i is the equivalent dose for that tissue or organ [19]. E has been widely used in medical exposure as it is evident from reports and publications in a variety of journals. Table 6 presents weighting factors that were derived from ICRP 60 and ICRP 103 reports.

Effective dose depends on X-ray beam quality, exposed region of body, patient size and X-ray beam area [18]. In the present study, the PCXMC (version 2.0) [20] commercial computer software was used for calculation of *E* in the diagnostic radiology. PCXMC is a computer program for calculation of organ doses and effective doses in medical X-ray examinations (radiography and fluoroscopy). This software accounts for the last present tissue weighting factors reported by the ICRP [18].

Table 6. Organ weighting factors based on ICRP 60 and ICRP 103 reports.

Report	Tissue	Weighting factor
ICRP 60	Bone surface, skin	0.01
	Bladder, breast, liver, oesophagus, thyroid, remainder	0.05
	Bone marrow, colon, lung, stomach	0.12
	Gonads	0.20
ICRP 103	Bone surface, skin, brain, salivary glands	0.01
	Bladder, liver, oesophagus, thyroid	0.04
	Gonads	0.08
	Bone marrow, colon, lung, stomach, breast, remainder	0.12

Data analysis

In order to perform statistical analysis, all measurements such as the dosimetry in the reference point, measurement of output in a clinical range of kVp values, and the calculation of incident air kerma and ESAK were repeated at least three times to reduce the possibility of errors or prevent anomalous results. Thereafter, mean value, percentage error, coefficient of variation, standard deviation, minimum and maximum values were calculated using SPSS software (version 16.0, SPSS Inc., Chicago, IL, USA). Organ doses were calculated for 29 organs and tissues.

RESULTS

A considerable number of medical diagnostic procedures have been annually performed using X-ray systems worldwide. For instance, 37365294 X-ray examinations were performed on 15634986 patients in Iran in 2016 with almost 2.4 examinations per patient on average. Based on the population of Iran in 2016, this is equivalent to 474 examinations per 1,000 inhabitants. Based on total number of 12 X-ray examinations, which aims of this study, 26279476 exposures were performed in 2016. These statistics were obtained based on personal communications by the Social Security Organization of Iran.

Table 7 presents a summary of minimum, maximum, ratio of maximum to minimum and ESD (mGy) for each X-ray examination. For this presentation, the ESD values were calculated for male and female patients for different age groups (5 groups) and different techniques (12 techniques). The ESDs were then used for calculation of ED values by the PCXMC software. Table 8 presents the effective dose based on the tissue weighting factors adapted from the ICRP103 and ICRP60 reports. This table also presents the ratio of the effective doses from the ICRP103 to ICRP60 reports. The results presented in different age groups (5 groups) for 12 common techniques.

The total number of patients, who referred to radiology departments in 2015 and 2016, were 15103548 and 15634986 respectively. Furthermore, the contributions from public and private centers were 69% and 31% respectively in 2015. The contributions from public and private centers were 73% and 27% respectively in 2016. Figure 2 shows the total number of patients who referred to governmental and nongovernmental radiology departments in 2015 and 2016. It should be noted that these numbers are based on the patients who had registered in health insurance system. The total numbers of radiological units were 2550 and 3271 respectively in 2015 and 2016. Among these units, the numbers of digital X-ray units were 408 and 627 respectively in 2015 and 2016. Figure 3 shows a total of 12 completed exposure examinations with conventional X-ray units compared to digital X-ray units in 2015 and 2016. These statistics were obtained based on personal communications by the Social Security Organization and National Radiation Protection Department of Iran.

Table 7. Summary of mean, minimum and maximum ESD values for all studied age groups.

X-ray examination	Age	Entrance surface dose (mGy)			
		Mean ± standard deviation	Minimum	Maximum	Ratio (Max/Min)
Skull (AP/PA)	0 - 1 year	0.37 ± 0.41	0.18	1.12	6.22
	1 - 5 years	0.58 ± 0.38	0.21	1.37	6.52
	5 - 10 years	0.69 ± 0.43	0.25	1.56	6.24
	10 - 15 years	0.94 ± 0.42	0.31	1.85	5.97
	Adult	0.97 ± 0.41	0.32	2.14	6.68
Skull (Lat)	0 - 1 year	0.36 ± 0.39	0.09	0.76	8.44
	1 - 5 years	0.51 ± 0.41	0.22	1.29	5.86
	5 - 10 years	0.62 ± 0.38	0.28	1.42	5.07
	10 - 15 years	0.82 ± 0.40	0.28	1.93	6.79
	Adult	0.86 ± 0.39	0.30	2.13	7.10
Cervical spine (AP)	0 - 1 year	0.09 ± 0.25	0.08	0.56	7.00
	1 - 5 years	0.27 ± 0.27	0.09	0.74	8.22
	5 - 10 years	0.37 ± 0.28	0.12	1.05	8.75
	10 - 15 years	0.44 ± 0.23	0.15	1.29	8.60
	Adult	0.52 ± 0.26	0.17	1.38	8.11
Cervical spine (Lat)	0 - 1 year	0.09 ± 0.29	0.08	0.53	6.63
	1 - 5 years	0.31 ± 0.27	0.09	0.81	9.00
	5 - 10 years	0.45 ± 0.31	0.13	1.13	8.69
	10 - 15 years	0.52 ± 0.28	0.16	1.35	8.44
	Adult	0.66 ± 0.29	0.19	1.67	8.78
Chest (PA)	0 - 1 year	0.06 ± 0.31	0.02	0.15	7.50
	1 - 5 years	0.16 ± 0.33	0.09	0.59	6.56
	5 - 10 years	0.38 ± 0.29	0.09	0.77	8.56
	10 - 15 years	0.54 ± 0.34	0.11	1.08	9.82
	Adult	0.60 ± 0.31	0.13	1.12	8.61
Chest (Lat)	0 - 1 year	0.07 ± 0.43	0.03	0.21	7
	1 - 5 years	0.18 ± 0.45	0.07	0.62	8.86
	5 - 10 years	0.47 ± 0.41	0.12	1.02	8.50
	10 - 15 years	0.71 ± 0.42	0.21	1.46	6.95
	Adult	0.85 ± 0.43	0.25	1.98	7.92
Thoracic spine (AP)	0 - 1 year	0.13 ± 0.50	0.08	0.61	7.63
	1 - 5 years	0.52 ± 0.52	0.16	1.43	8.94
	5 - 10 years	0.95 ± 0.48	0.23	1.76	7.65
	10 - 15 years	1.23 ± 0.53	0.29	1.80	6.21
	Adult	1.44 ± 0.50	0.60	3.23	5.38
Thoracic spine (Lat)	0 - 1 year	0.21 ± 0.72	0.08	0.70	8.75
	1 - 5 years	0.62 ± 0.74	0.20	1.36	6.80
	5 - 10 years	1.27 ± 0.70	0.44	3.72	8.45
	10 - 15 years	1.70 ± 0.75	0.47	4.08	8.68
	Adult	2.00 ± 0.72	0.64	4.72	7.35
Lumbar spine (AP)	0 - 1 year	0.43 ± 1.29	0.09	0.86	9.56
	1 - 5 years	0.92 ± 1.27	0.33	2.31	7.00
	5 - 10 years	1.53 ± 1.32	0.52	4.14	7.96
	10 - 15 years	2.14 ± 1.32	0.69	6.48	9.39
	Adult	2.36 ± 1.29	0.85	7.20	8.47
Lumbar spine (Lat)	0 - 1 year	0.63 ± 1.78	0.25	1.75	7.00
	1 - 5 years	1.60 ± 1.76	0.63	3.98	6.32
	5 - 10 years	2.44 ± 1.75	0.81	5.87	7.25
	10 - 15 years	3.37 ± 1.80	1.21	9.66	7.98
	Adult	3.62 ± 1.78	1.66	10.20	6.14
Pelvis (AP)	0 - 1 year	0.41 ± 0.69	0.25	1.75	7.00
	1 - 5 1years	0.82 ± 0.71	0.28	2.03	7.25
	5 - 10 years	1.09 ± 0.68	0.32	2.67	8.34
	10 - 15 years	1.35 ± 0.72	0.48	3.58	7.46
	Adult	1.43 ± 0.69	0.56	4.33	7.73
Abdomen (AP)	0 - 1 year	0.39 ± 0.79	0.25	1.75	7.00
	1 - 5 years	0.81 ± 0.77	0.28	2.33	8.32
	5 - 10 years	1.12 ± 0.78	0.30	2.21	7.37
	10 - 15 years	1.53 ± 0.81	0.51	3.70	7.25
	Adult	1.65 ± 0.79	0.58	4.04	6.96

Table 8. The effective dose (µSv) and ratio of effective dose from ICRP103 and ICRP60 reports for each digital radiology examination.

X-ray examination	Age	Effective dose (ICRP60, µSv)	Effective dose (ICRP103, µSv)	Ratio (EDICRP103/ EDICRP60)
Skull (AP/PA)	0 - 1 year	1.82	2.42	1.33
	1 - 5 years	4.15	5.53	1.33
	5 - 10 years	5.51	7.36	1.34
	10 - 15 years	8.13	10.82	1.33
	Adult	10.23	13.67	1.34
Skull (Lat)	0 - 1 year	3.77	4.75	1.26
	1 - 5 years	9.61	12.01	1.25
	5 - 10 years	12.65	15.89	1.26
	10 - 15 years	15.32	19.26	1.26
	Adult	16.96	21.31	1.26
Cervical spine (AP)	0 - 1 year	6.94	8.30	1.20
	1 - 5 years	15.56	18.69	1.20
	5 - 10 years	21.03	25.17	1.20
	10 - 15 years	28.54	34.22	1.20
	Adult	31.06	37.22	1.13
Cervical spine (Lat)	0 - 1 year	3.88	4.05	1.04
	1 - 5 years	8.93	9.34	1.05
	5 - 10 years	11.12	11.61	1.04
	10 - 15 years	14.82	15.49	1.04
	Adult	17.82	18.62	1.10
Chest (PA)	0 - 1 year	19.58	21.64	1.10
	1 - 5 years	41.19	45.43	1.10
	5 - 10 years	52.95	58.46	1.10
	10 - 15 years	67.81	74.79	1.10
	Adult	73.76	81.36	1.11
Chest (Lat)	0 - 1 year	13.68	15.06	1.10
	1 - 5 years	34.87	38.36	1.10
	5 - 10 years	41.86	46.09	1.10
	10 - 15 years	56.93	62.62	1.10
	Adult	62.08	68.28	1.10
Thoracic spine (AP)	0 - 1 year	28.12	29.44	1.05
	1 - 5 years	67.11	70.26	1.05
	5 - 10 years	89.18	93.37	1.05
	10 - 15 years	112.07	117.34	1.05
	Adult	125.57	131.84	1.05
Thoracic spine (Lat)	0 - 1 year	27.45	28.60	1.04
	1 - 5 years	61.62	64.21	1.04
	5 - 10 years	87.62	91.30	1.04
	10 - 15 years	108.48	113.04	1.04
	Adult	123.32	128.48	1.04
Lumbar spine (AP)	0 - 1 year	71.89	66.35	0.92
	1 - 5 years	104.76	96.69	0.92
	5 - 10 years	198.74	183.04	0.92
	10 - 15 years	267.46	247.13	0.92
	Adult	323.52	298.56	0.92
Lumbar spine (Lat)	0 - 1 year	38.88	35.38	0.91
	1 - 5 years	86.62	78.91	0.91
	5 - 10 years	104.73	95.30	0.91
	10 - 15 years	176.21	160.70	0.91
	Adult	221.92	201.94	0.91
Pelvis (AP)	0 - 1 year	74.57	46.23	0.62
	1 - 5 years	109.41	67.94	0.62
	5 - 10 years	202.62	126.03	0.62
	10 - 15 years	284.27	177.67	0.62
	Adult	336.84	208.80	0.62
Abdomen (AP)	0 - 1 year	90.53	82.38	0.91
	1 - 5 years	203.22	184.93	0.91
	5 - 10 years	281.02	256.29	0.91
	10 - 15 years	364.83	332.36	0.91
	Adult	416.44	378.96	0.91

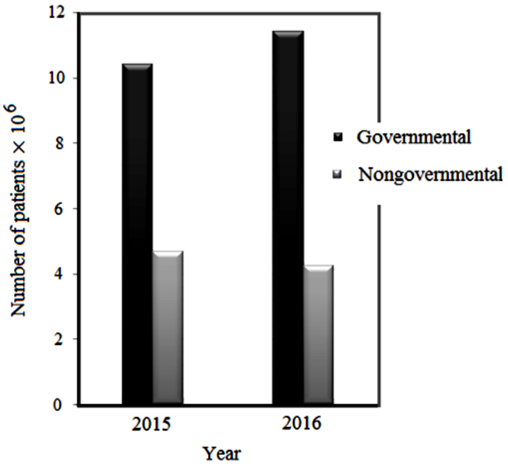

Figure 2. Total number of patients referred to governmental and nongovernmental radiology departments in 2015 and 2016.

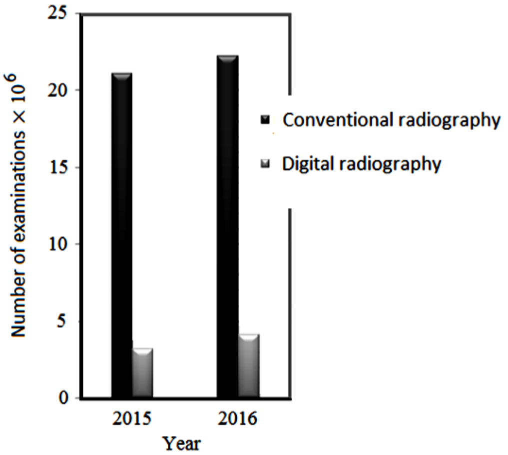

Figure 3. Contribution of radiology examinations performed with conventional and digital radiology units in 2015 and 2016.

Figure 4 shows contributions of digital radiology examinations which were referred to the Iranian governmental and nongovernmental centers in 2015 and 2016. Percentages of patients who were referred to radiology departments for X-ray examinations in 2015 and 2016 are presented in figure 5. This data indicate the frequency of various examinations, based on distinguished years, figure 6 shows the contribution of the effective dose for different examinations in the years 2015 and 2016, respectively. This data were obtained considering the total numbers of patients who were referred to the examinations.

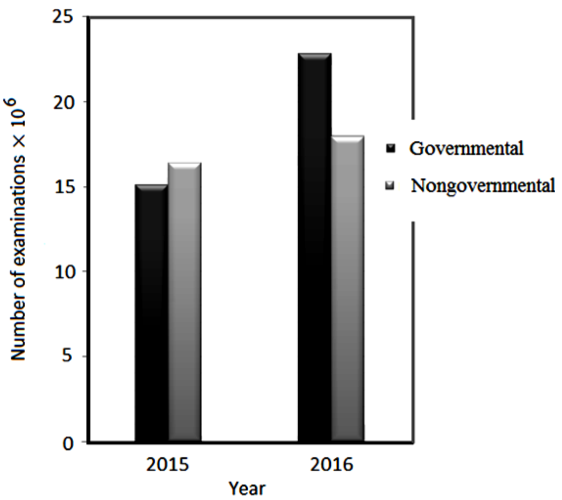

Figure 4. Contribution of digital radiology examinations referred to governmental and nongovernmental departments in 2015 and 2016.

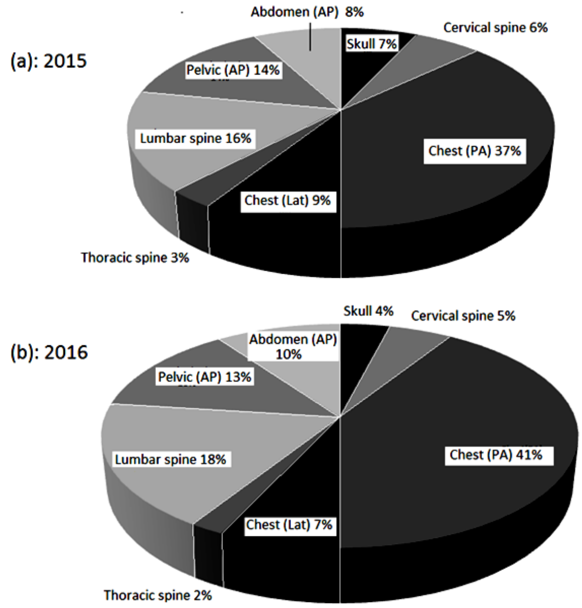

Figure 5. Percentages of patients referred to radiology departments for X-ray examinations in 2015 and 2016.

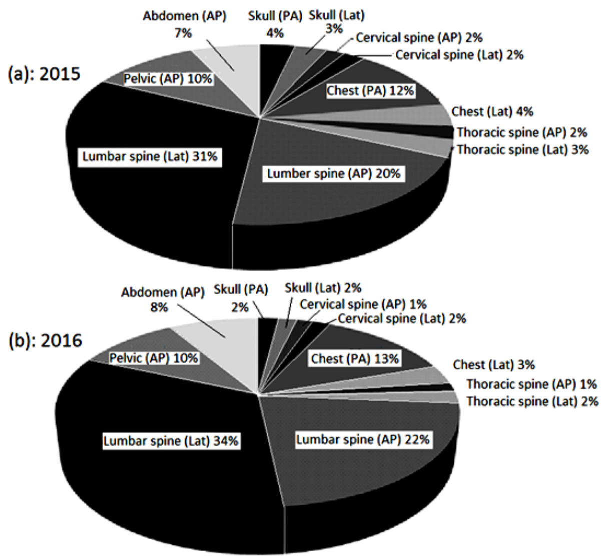

Figure 6. Percentages of received total doses from different examinations in 2015 and 2016.

DISCUSSION

The present study is the first comprehensive national plan, which was designed with cooperation of national authorities to determine patient dose in digital X-ray examinations that were carried out in radiology centers of Iran. The investigators tried to collect data for a sample including a large number of patients and X-ray imaging centers throughout the country within the limited time. The survey results indicated large variations in radiological practices in the evaluated centers due to different factors. Exposure parameters of examinations were normally set by radiologic technologists, which use different exposure conditions. To this end, considerable variations in ESD were observed between different imaging centers. These variations can be seen even from one X-ray room to another or for the same model of digital radiography unit in the same center or hospital. Based on obtained results of evaluated medical centers, it can be concluded that these variations were results of differences in actual radiation energies and fluences, radiation scattering from large fields, types of the detectors, performance of equipment and processors, filtration, patient setup from one hospital to another for the same examination as well as due to employed exposure settings such as kVp, mAs and field size, the use of grids and skills of radiology staff.

Based on presented results in table 7, these considerable variations in exposure parameters led to great differences in mean values of ESD for the same procedures by up to a factor of 7.46 for pelvis (AP) (for 10-15 years of age) at all hospitals. The maximum to minimum ratios in chest (PA) (for 10-15 years of age) and abdomen (AP) (for 10-15 years of age) procedures among all hospitals showed extremely large differences of 9.82 and 7.25 respectively. These results imply that the same exposure conditions were utilized for children in the 10-15 years age group and adults in large number of centers. This can be result to higher radiation exposure for this group. Due to the higher sensitivity of children to radiation, it is suggested that special performance of protection measures and optimization of exposure techniques for children in this age group be performed, independent to the adult group. The presence of a physicist in imaging departments in large centers is proposed and is important for optimization of exposure techniques, updating the exposure conditions, and special care to patients to adopt the radiation protection and safety principals.

The results (table 7) indicate that the dose received for age group 1-5 years (after the 0-1 year age group) significantly increased due to a significant increase in exposure parameters especially mAs. The value of effective dose for AP projection was more than the lateral (Lat) projection except for the skull digital radiography. The results also indicate that the highest value of ESD is related to the lumbar spine (Lat) radiography, but the highest effective dose belonged to the abdomen (AP) projection. Therefore, due to the sensitivity of children compared to adults and sensitive organs in this technique, adequate considerations should be taken into account when such technique is performed.

The ratios of effective dose values are close to 1 based on ICRP103 to ICRP60 reports (table 8) for all the examinations except for skull and pelvis techniques. It was due to modifications in tissue weighting factors according to ICRP103 report.

The utilization of a low kVp and high mAs is not recommended for imaging technique due to the decreased penetration of X-rays in such conditions. Therefore, the ideal way to decrease the relative dose is the utilization of a higher kV technique. On the other hand, the use of a low kVp procedure is appropriate for small-sized pediatric patients due to decreased radiation scattering and increased tissue contrast.

The use of digital units (figures 2, 3 and 4) was growth from 2015 to 2016. The increased number of radiology examinations in 2016 can be attributed to an increase in the Iranian population and radiological units in the same year compared to 2015. As shown in figures 5 and 6, the trends, based on which the highest number of examinations is related to chest (PA), is the remarkable effect, while the highest dose contribution is related to the examination of lumbar spine (Lat). This is due to very low exposure time in chest (PA) examinations. The reason for the short time period, which is applied in chest examinations, is to minimize the motion artifacts that are originated from the heart motion in this technique. Another reason is the high thickness in lumbar spine (Lat) examination compared to the chest (PA) radiography that requires high exposure parameters.

During the radiography, doses received by children patients from chest X-ray examination (Tables 7 and 8) are relatively low, however the optimization of chest X-ray examination for mentioned age group is important due to the high frequency of these techniques.

There was a reduction of 4% in the number of skull examinations based on the results of the present study. The reason for acquiring brain CT techniques instead of skull techniques in radiology is the fact that physicians do not have great desires for performing skull techniques, but they are more inclined to perform brain CT techniques for diagnosing patients leading to decreased patient doses in X-ray radiology skull examinations.

The effective dose for AP projection is more than one in a lateral projection except for the skull digital radiography (table 8). While Compagnone *et al.* (21) calculated effective dose and entrance skin dose of PA, AP and lateral projections for abdomen, chest, lumbar spine, pelvis, and skull in digital and conventional radiography modalities in a hospital of Italy by application of mathematical models. Their results indicated that an effective dose in PA and lateral chest digital radiography was less than the Italian national diagnostic reference level.

Diagnostic reference level (DRL) was established to avoid high doses in the exposure to diagnostic and interventional medical procedures (22,23); and it was then incorporated by the International Commission on Radiological Protection (ICRP) (23). DRL is a criterion for the assessment of medical examination performance; and hereupon can continuously improve imaging systems (24).

The present study had limitations including the limitation of accessibility of radiology units due to the large number of radiology centers and units throughout the country. Therefore, future studies are suggested using a sample including a larger number of digital radiography units. There were also large variations in patient doses in evaluated centers. This implies that there are patient doses higher than the DRL in some centers and there is not a consistency between techniques in various centers. Therefore, the following cases are proposed to minimize patient doses: radiology centers should have physicists; quality control should be performed based on specific standards; radiology technicians should be trained in proper manner; and much supervision of Iranian Atomic Energy Organization should be provided in radiology centers. It is possible to simulate a digital radiography unit by Monte Carlo codes; and an effective dose, a risk and organ dose from the simulation can be compared by corresponding values from the presented in the present study. This will be as a validation of obtained results in the present study.

CONCLUSION

The digital radiography examinations increased due to the increased trend of using digital radiology units. The average contributions of public exposure during 2015 ($n>$ $^{1\,1}8^{1}9^{3}85$) and 645^{0} ($n>$ $^{1\,2\,2}678^{0}9$) were equal to 60 μGy and 76.8 μGy respectively.

The established national dose reference levels (NDRL), which are in terms of effective dose, can be used as optimization criteria to reduce patients' doses. In addition, the following special considerations should be taken into account: adequate training of imaging staff; updating clinical audits; patient dose considerations; implementation of systematic and regular quality assurance; and quality control programs in medical imaging departments for optimization of radiological practices. The presence of a physicist in imaging departments in large centers is proposed.

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