Polish Journal of Medical Physics and Engineering 2017;23(3):67-71 September 2017
doi: 10.1515/pjmpe-2017-0012
ISSN 1898-0309

Scientific Paper

Patient dose measurement in common medical X-ray examinations and propose the first local dose reference levels to diagnostic radiology in Iran

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(received 4 April 2017; revised 7 July 2017; accepted 12 July 2017)

Abstract

Introduction: The main purpose of this study was to investigate patient dose in pelvic and abdomen x-ray examinations. This work also provided the LDRLs (local diagnostic reference levels) in Khuzestan region, southwest of Iran to help establish the NDRLs (national diagnostic reference levels).

Methods: Patient doses were assessed from patient's anatomical data and exposure parameters based on the IAEA indirect dosimetry method. With regard to this method, exposure parameters such as tube output, kVp, mAs, FFD and patient anatomical data were used for calculating ESD (entrance skin dose) of patients. This study was conducted on 250 standard patients (50% men and 50% women) at eight high-patient-load imaging centers.

Results: The results indicate that mean ESDs for the both pelvic and abdomen examinations were lower than the IAEA and EC reference levels, 2.3 and 3.7 mGy, respectively. Mean applied kVps were 67 and 70 and mean FFDs were 103 and 109, respectively. Tube loadings obtained in this study for pelvic examination were lower than all the corresponding values in the reviewed literature. Likewise, the average annual patient load across all hospitals were more than 37000 patients, i.e. more than 100 patients a day.

Conclusions: The authors recommend that DRLs (diagnostic reference levels) obtained in this region, which are the first available data, can be used as local DRLs for pelvic and abdomen procedures. This work also provides that on-the-job training programs for staffs and close cross collaboration between physicists and physicians should be strongly considered.

Key words: diagnostic reference level; entrance skin dose; Iran; patient dose; radiographic examination.

Introduction

In recent years with the progress of medical sciences, the development rate of novel X-ray technologies in the clinical setting has increased and nowadays plays a pivotal role in the diagnostic decision making. These devices are the most common human-made source of ionizing radiation and the amount of radiation received by patients is gradually on the rise. Therefore, the received dose and their associated risks, including the probability of radiation-induced cancer as well as biological complication, should pay strict attention to ensure that it remains at the appropriate level.

Several patient dose surveys have been performed around the world during the past decades and comparison has been carried out on obtained results with DRLs (dose reference levels) reported by international legislative organizations like the IAEA (International Atomic Energy Agency) and EC (European Commission) [1-6]. Some developed countries have drawn up a comprehensive NDRLs (national dose reference levels) plan for X-ray examinations based on the ICRP (International Commission on Radiological Protection) recommendations [7,8] and try to update it regularly.

There is neither regulated radiation protection procedures nor established NDRLs in Iran. The challenges facing Iran are to build the healthcare infrastructures, to provide medical imaging equipment and try to attract qualified specialists with the limitation of financial resources [9,10]. Few patient dose assessments have been conducted in Iran [11-17]. Iran also did not participate in the IAEA international patient dose survey, which makes these types of studies more important [18]. This contribution is the first steps into establish dose audits and optimizations of patient dose in conventional radiology examinations, including pelvis and abdomen procedures in Khuzestan region, southwest of Iran. These procedures were selected based on their frequencies and contribution to the collective dose delivered to the public. This study also provides the LDRLs (local dose reference levels) in Khuzestan region, southwest of Iran to help establish the national dose reference levels across Iran.

Materials and Methods

This study was conducted from October to December 2015 at eight medical imaging centers (C1-C8) of public and educational hospitals in southwest of Iran. Abdomen and pelvis radiographic examinations were selected in AP (anterior-posterior) view. ESD (entrance skin dose) is a well-defined parameter that was considered in this work for patient dose evaluation. By definition, it is the entrance dose at the skin surface of an adult standard patient taking into account scattered X-rays. In this study, the indirect dosimetry approach has been adopted according to the IAEA Report Series No. 475 [19]. With regard to this sound approach, exposure parameters such as tube output, kVp, mAs, FFD and patient's anatomical data were used for calculating ESD, using a calibrated Barracuda X-ray MPD (multi-purpose detector) (RTI Electronics AB, Mölndal, Sweden) and pure Aluminum HVL filters. Prior to main experiments, quality control tests were performed on all the X-ray machines and darkroom equipment using the MPD and an Alpha test phantom (PEHA med. Geräte GmbH, Sulzbach, Germany), according to the IPEM (Institute of Physics and Engineering in Medicine) Report No.91 method [20].

Data acquisition

With reference to the IAEA method, at least ten standard patients (weight 70±10 kilograms (Kg)) including male and female should be assessed for any procedure. Therefore, 250 patients (125 men and 125 women) were entered into the study. Patients were asked to declare their weight, then the thickness of abdomen and pelvis were measured if the weight was in accordance with the standard patient. Obese patients (BMI ≥ 30 kg/m^2) and infants were excluded from the process. Full technical information of X-ray machines was recorded in each imaging centers as shown in **Table 1**. Also, patient information including weight, abdomen and pelvis thickness, age and gender as well as exposure setting (kVp, mAs and FFD) were recorded for any procedure by trained technologists in a pre-designed datasheet. Written informed consent were obtained from all participants prior to their inclusion in the study.

Indirect dosimetry

As illustrated in **Figure 1**, thickness of the patient under examination (abdomen and pelvis) was measured at the center of the radiation field with respect to the orientation of radiation field (AP), from the tabletop to the skin surface by a typical measuring tape.

ESD can be obtained for any examination using the following formula:

$$ESD = Tube\ output \times mAs \times \left(\frac{d}{d_{FTD}-t_p}\right)^2 \times BSF \qquad \text{Eq. 1}$$

Tube output was measured by placing MPD at distance d from the X-ray tube, mAs is the tube loading, d_{FTD} is the distance between the X-ray tube and tabletop and t_p is the thickness of abdomen or pelvis. BSF (has no unit) stands for backscatter factor that depends on HVL, kVp and field size and can be obtained according to the IAEA Technical Reports Series No. 457 appendix VIII [19]. It is noteworthy that measurement of tube output was performed in the quality control phase prior to main experiments. There are not any real patients during dosimetry and tube output measurements.

Results

Table 1 presents technical characteristics of X-ray units, image receptors, tube output (at 80 kVp) and HVL (at 70 kVp) for all imaging centers. The average annual patient load across all centers are more than 37000 patients. The average age of devices was 15 years. There has been frequent repairs on devices and replacement of accessories except C3 unit. Based on the IEC 1223 (International Electrotechnical Commission) and the IPEM Report No. 91, X-ray tube output in the range between 43-52 μGy/mAs is known as "Good", 26-43 μGy/mAs and 52-69 μGy/mAs are "Normal" and < 26 and > 69 μGy/mAs is "Poor" criteria [20]. Therefore, C2 and C3 units met "poor" tube outputs, 72.7 and 104.3 μGy/mAs, respectively. Likewise, the minimum HVL at 70 kVp should be at least 2.1 mm of Al, so all the X-ray machines met the minimum required HVL at 70 kVp except the C3 unit (1.9 mm of Al). The AEC (automatic exposure control) system either did not exist or could not be used, consequently manual exposure setting was common. As shown in **Table 1**, all centers had conventional radiology devices and were using SF (screen-film) with 400 speed classes. Also, anti-scatter grids (ratio 12:1) were used in all the centers.

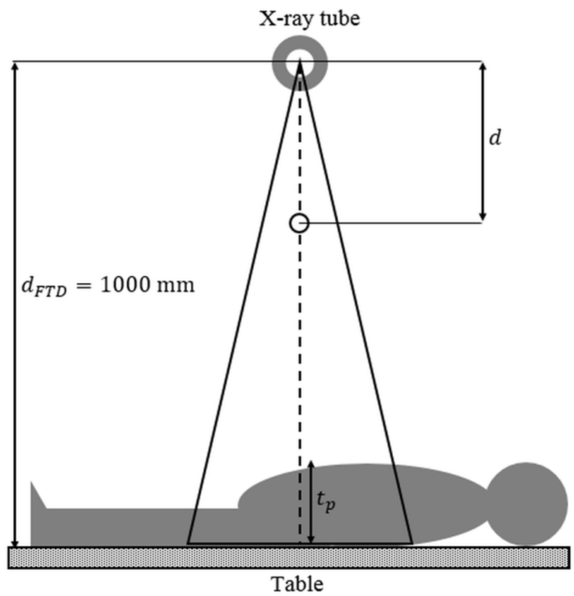

Figure 1. Geometry used for calculation of the entrance dose at the skin surface of a standard patient.

Table 1. Information of the imaging centers and technical data of the x-ray machines.

Center code	Manufacturer	Year of production	kVp max	Exposure setting	Generator type	Film type	Annual workload (patient)	Output (μGy/mAs) at 80 kVp	HVL (mm Al) at 70 kVp	Image receptor (type-speed)
C1	Shimadzu	1994	150	Manual	1-phase	AGFA	27000	41.8	2.2	SF-400
C2	Varian	1997	150	Manual	3ph-12pu	CEA	57600	72.7	2.8	SF-400
C3	Varian	2011	150	Manual	3ph-12pu	Fujifilm, KODAK	36000	104.3	1.9	SF-400
C4	Varian	2000	150	Manual	3ph-12pu	AGFA	13200	58.8	3.5	SF-400
C5	Shimadzu	1999	150	Manual	3ph-12pu	AGFA, CEA, Fujifilm	36000	62.3	2.9	SF-400
C6	Villa Medical Systems	1990	150	Manual	1-phase	Retina, Fujifilm, CEA	36000	20.2	2.7	SF-400
C7	Varian	2003	150	Manual	3ph-12pu	AGFA	36000	-	3	SF-400
C8	Toshiba	1999	150	AEC	1-phase	Kodak	54000	35	3.2	SF-400

Table 2. Patient weight and exposure parameters data across all imaging centers (mean (± SD) and min-max range).

Center code	Exam	Patient data		Exposure parameters		
		Number	Weight	kVp	mAs	FFD (cm)
C1	Pelvic	18	67.3±12.7	68.8 (60-75)	55.3 (30-75)	113.4 (68-120)
	Abdomen	17	65.4±9.2	69.8 (63-76)	58.2 (44-90)	115.9 (100-120)
C2	Pelvic	11	69.9±10.4	70.1 (66-80)	22.2 (14-32)	107.3 (100-115)
	Abdomen	15	67.4±9.5	68.9 (60-84)	22.5 (15-90)	100.3 (100-105)
C3	Pelvic	27	69.9±9	74 (65-86)	12.7 (2.56-32)	99.8 (80-122)
	Abdomen	20	67.7±12	76 (65-99)	22.5 (10.2-40)	99.9 (70-120)
C4	Pelvic	22	68.5±11.5	63.3 (55-70)	27.1 (20-40)	107.5 (95-120)
	Abdomen	17	73.2±9.2	70.1 (60-75)	37.6 (32-51.2)	134.1 (80-180)
C5	Pelvic	22	67.2±7.4	61.1 (54-68)	41.5 (15.6-62.5)	107 (85-120)
	Abdomen	7	67.6±9.2	63.8 (56-72)	51.7 (32-62.5)	118.3 (103-120)
C6	Pelvic	7	71.7±11.4	72.9 (55-103)	32.3 (16-50)	84.5 (75-100)
	Abdomen	6	76±12	76.5 (66-84)	47.2 (24-75)	74.2 (65-100)
C7	Pelvic	22	73.6±9.1	65.2 (55-83)	25.2 (2.5-40)	94.7 (80-126)
	Abdomen	10	70.5±6.5	66.7 (62-73)	36.1 (25-40)	102.2 (84-126)
C8	Pelvic	20	65.1±12.1	65.7 (56-76)	38.6 (16-120)	100 (100-100)
	Abdomen	9	67.1±10.8	67 (60-74)	41.3 (19.2-61)	102.2 (100-120)

Table 3. Patients parameters data across all imaging centers (mean value, SD and min-max range).

Exam	Patient data												
	Number	Age (yr)			Weight (kg)			BMI (kg/m^2)			Thickness (cm)		
		mean	SD	min-max	mean	SD	min-max	mean	SD	min-max	mean	SD	min-max
Pelvic	149	39.5	19.1	15-86	68.8	10.4	50-90	25.3	3.8	18.2-35.2	18.4	4.7	10-34
Abdomen	101	40.9	18.6	17-86	68.9	10.2	50-90	25	3.9	17.2-36	21.3	6.8	10-38
Total number of patients (male, female): 250 (125,125)													

Table 4. Exposure parameters and ESDs across all imaging centers for both examinations.

Exam	Exposure parameters												
	Number	kVp			mAs			FFD (cm)			ESD (mGy)		
		mean	SD	min-max	mean	SD	min-max	mean	SD	min-max	mean	SD	min-max
Pelvic	149	67.1	6.9	54-103	31.2	18.3	2.5-120	102.9	11.9	68-126	2.32	1.67	0.21 - 12.4
Abdomen	101	70.4	6.7	56-99	37.5	17.2	10.2-90	108.5	21	65-180	3.72	3.68	0.7 - 20
Total number of patients (male, female): 250 (125,125)													

Table 5. Obtained ESDs (mGy) and exposure parameters (mean value) across all imaging centers as well as literature and international DRLs.

Exam		This study	Previous studies (mean value)							HPA DRLs (mean value)			DRLs	
			Iran (2015)	Korea (2013)	Montenegro (2012)	Ghana (2012)	India (2010)	Iran (2007)	Korea (2007)	UK (2000)	UK (2005)	UK (2010)	EC (1996)	IAEA (1996)
Pelvic (AP)	kVp	67.1	68.8	75			68	68	72	74	75	75	75-90	
	mAs	31.2	34.8	42			69	66	31	35	32	33		
	ESD (mean , 3rd Q)	**(2.32, 2)**	**1.90**	**2.34**	**4.7**	**14.8**	**6.34**	**2.84**	**2.44**	**3.6**	**3.06**	**3.2**	**10**	**10**
Abdomen (AP)	kVp	70.4	71.1	76			67	67	74	74	76	76		
	mAs	37.5	35.8	42			67	65	33	46	31	41		
	ESD (mean , 3rd Q)	**(3.72, 10)**	**2.07**	**2.46**	**4**		**5.61**	**3.87**	**2.33**	**4.7**	**3.54**	**3.6**		**10**

Table 2 shows the mean and standard deviation of patient weight and exposure parameters for pelvis and abdomen examinations. The information provided in this table offers a convenient way to evaluate radiologic technologist working habits among imaging centers in order to compare exposure setting parameters for the same examination. Almost all centers received more than 15 patients per procedure on average, which is in full compliance with the IAEA minimum acceptance criteria, which is 10 patients for each examination [19]. **Tables 3-4** present the patient individual information and exposure conditions as well as obtained ESDs among imaging centers for both examinations. Exposure parameters, mean and 3rd quartile of ESDs are shown in **Table 5**. This important findings provided us with a comparable situation in our results with studies in other countries and international DRLs [21-23].

Discussion

In recent years, the growth rate of X-ray generating devices has increased and nowadays plays a critical role in the diagnosis of diseases. In Iran, 18,867,000 diagnostic X-ray imaging were carried out on 12,963,000 patients in 2003, i.e. 363 examinations per 1000 inhabitants [17].

As presented in **Table 5**, the findings of this research indicate that mean entrance skin doses for both examinations (pelvis: 2.3 mGy and abdomen: 3.7 mGy) are lower than the IAEA and EC dose reference levels (pelvis: 9 mGy and abdomen: 10 mGy) [18,22]. Care must be taken that the international dose reference levels are presented as 3rd quartile. As mentioned earlier, radiology technologists who participated in this study set exposure parameters (kVp and FFD) lower than the recommended range defined by EC that is 75-90 for kVp and 100-150 for FFD (cm) in a standard pelvis examination. Despite the fact that mean applied kVps for pelvis and abdomen examinations were 67 and 70 and mean applied FFDs were 103 and 109 cm, respectively, the images taken had acceptable quality. In respect of radiation physics fundamentals, using low kVp and FFD must result in more entrance skin dose due to high intensities of the X-ray field and this represents a stark contrast to our finding. The explanation for this disparity lies in some noteworthy points. It should not be expected that applying "good radiographic technique" parameters, as recommended in European Commission EUR 16260 EN, result in 10 mGy absorb dose to the patient's pelvis [22]. This is because other factors like mAs, BMI and thickness must also be considered. The amount of 10 mGy is a maximum level that is considered as the ultimate limit. Reported findings of other studies as shown in Table 5 also confirms this claim. A comparison of exposure parameters for abdomen with the EC criteria is not possible as there is no recommended "good radiographic technique" characteristics and DRLs.

As **Table 2** shows, nearly all centers received more than 10 patients per a procedure (pelvis or abdomen) except C6 that can be partly relate to limited ability of applying high kVp and mAs. As **Table 3** shows, mean value of physical parameters such as age, weight and BMI of patients who participated in this study are 40 year, 69 kg and 25 kg/m^2, respectively for both pelvis and abdomen examinations. This reported values are in good agreement with the previous Iranian studies and the IAEA Asian standard patient specifications. The average annual patient load across all centers are more than 37000 patients, i.e. more than 100 patients a day. C2 center had the maximum amount of annual patient load and C4 was an imaging center with minimum referred patients. There was no clear association between daily workload and patient doses.

As **Table 5** shows, the kVp values obtained in this study for pelvis examination were lower than those of obtained in the Korea (2007, 2013), India, three the UK studies, EC and the previous studies which have been done in Iran (2007 and 2015) [3,5,24]. This is also true for abdomen examination if India and Iran (2007) studies be ignored [1]. There are several reasons why Iranian radiology technologists did not set higher applied voltages. It was seen that, in the case of technical problems that are related to high-voltage burden to the radiology device-typically kVps higher than 85 or 90-service provider companies do not provide any support services. In other words, the radiology technologists are facing a major hurdle to set kVps higher than 85 to avoid damaging the tubes. This is mainly due to device aging as well as frequent repairs on X-ray tubes and generators. Another reason for applying low voltages is a wrong mindset of Iranian technologists toward scattered and leakage radiation level in a radiography control room, especially in the cases of high kVp X-ray examinations like procedures in this study. Particular attention should be paid for bridge the gap between theoretical and clinical knowledge of technologists in the form of on-the-job training programs to diminish this problem. Also, the tube loadings (mAs) reported in this work for pelvis examination are lower than the corresponding values in all the reviewed literature. The tube loadings obtained from abdomen examination are more than Korea (2007) and UK (2005) results, comparable to Iran (2015) and lower than the results of other studies. The main reason for low obtained ESDs in this study is due to low applied tube loadings. As shown in **Table 5**, it is fully clear that the relationship between radiation dose and mAs is linear.

Such studies should be carried out on a larger scale across the country, also covering digital radiography systems, CT scans and interventional radiology procedures to set up a valid national reference levels in the country.

Conclusions

This research is a regional patient dose survey for Khuzestan, southwest of Iran. Therefore, the authors recommend that DRLs obtained in this region, which is the first available data, can be used as local DRLs for pelvis and abdomen examinations. This work also provides evidence that dose reduction in the conventional X-ray examinations is feasible through adequate education of radiology technology undergraduate students by updated theoretical and clinical course materials, on-the-job training workshops for staffs, implementation of systematic QA and QC programs and close cross collaboration between physicists and physicians in medical imaging centers.

Acknowledgements

This research was supported by Behbahan Faculty of Medical Sciences (Research Project No. 9407).

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