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Estimation of doses for all types of patients in common diagnostic X-ray examinations

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ABSTRACT

Objectives: Today, medical imaging is essential in any medical diagnosis. In 1990, the International Commission on Radiological Protection recommended the diagnostic reference level (DRL) to optimize the X-ray examinations according to the principle of optimization to ensure the patient radiation dose in diagnostic imaging centers was not ignored.

Methods: Twelve common radiography examinations were conducted for all types of patients in all Ilam hospitals and imaging centers. A quality control check was performed on the equipment and the solid state dosimeters were used for estimating the Entrance Surface Air Kerma. Then Entrance Skin Dose of each patient was estimated. Finally, its third quartile (75%) was presented as the DRL.

Results: The range of Entrance Skin Dose (ESD) is from 18 mGy to 0.001 mGy in the lumbosacral lateral (LAT) in fat adult and chest of an infant, respectively. Also, the range of DRL is from 4.62 mGy to as low as 0.07 mGy in the lumbosacral of an adult and infant chest, respectively.

Conclusion: All DRLs obtained in this study were compared to other reference countries and other cities in Iran. Almost all DRLs in Ilam are comparatively lower. One of the reasons may be due to the execution of the QA program. Establishing DRL in a province and encouraging radiographers to follow these values and to carry out QA programs regularly in all radiology departments will cause more effective radiation protection in the population and patient dose.

Keywords: Entrance skin dose, Diagnostic reference level, Radiography examination, Quality control

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Introduction

Today, as imaging techniques have improved, correct detection seems to be impossible in many injuries and diseases without the application of these techniques. The most common sources of artificial human exposure to X-ray are medical application of this radiation. On the other hand, biologically harmful effects of these radiations have been proved and all of the related national and international organizations insist on minimizing use of these radiations. The International Commission on Radiological Protection (ICRP) has placed emphasis on justification and optimization as well as on dose limitation(1). The National Radiological Protection Board (NRPB), in 'Guidelines on patient dose to promote the optimization of protection for diagnostic medical exposures', emphasizes regular measurement of patient's dose in the entire radiology department and detection of Diagnostic Reference Levels (DRLs)(2). DRLs are detected based on the third quarter of patient's average dose (75%), which refers to the radiography performance. Entrance Skin Dose (ESD) is a suitable physical parameter for patient dose evaluation in general radiography and its measurement methods are mentioned in the European Commission (EC) Instructions. In 1997, the EC introduced DRL usage as a useful standard for optimizing patient's radiation protection(3). Also, in 2001, ICRP reported the DRL values which were set by organizations in different countries and recommended that the DRL can be planned for each country based on actual conditions (economic status, social, etc.)(4).

Any studied hospitals should measure dose of referred patients after the detection of these levels as DRLs. If these measurements are more than the DRLs, further causes should be discovered and all of them should be explained. If all imaging centers perform the detection of patient dose, the comparison of patient dose with DRLs and resolving of the probable factors leading to dose enhancement, all of these will lead to decreasing dose in new measurements. The control of this process is done every five years. This process is useful for increasing patients' health and decreasing the radiation damages (cancer, genetic effects, etc.)(5). This work is a follow up of the other studies in other regions using the same methodology. In this study, an effort has been made for the first time to suggest DRLs by carrying out measurements of Entrance Surface Air Kerma (ESAK) free in air by setting actual exposure factors used for 12 radiographic examinations in all hospitals in Ilam. The aim of this paper is to describe the current levels of patient radiation dose in hospital, to compare them with data previously published and with our NDRLs and finally, to show how possible LDRLs could be proposed in order to obtain a more fully optimized radiation protection of patients. DRL evaluation in Iran has been performed in cities such as Mashhad, Sabzehvar and Tehran, however, so far it has not been conducted in Ilam province. The difference between this study and other studies is that in this study the DRL values were obtained separately depending on the type of patient (fat-standard-thin adults, children and infants), while in other studies, values only for standard-sized adult patients were obtained, so this study is much more comprehensive.

Material and Methods

In the first step, the annual number of radiography examinations has been estimated based on information obtained from questionnaires distributed to all imaging centers in Ilam. In this study, 21 imaging centers evaluated. Before conducting any measurement, radiation dose processes and quality control tests were done on X-ray machines. This is because, based on the acquired experience, physical parameters of the radiation exposure in X-ray equipment may not have adequate quality and if this does not improve with a systematic regular program of quality control and quality assurance, it will increase the patients' doses and also will maximize the exposure risk in all population as well as leading to some errors in ESD measurement. In this study, six quality control examinations of X-ray equipment were implemented, which have more influence on patient dose content, kVp accuracy, time accuracy, radiation output linearity, radiation output linearity than mA, radiation output linearity than time and evaluating Half Value Layer (HVL); and existing fault was resolved if necessary. Twelve radiography examinations consisted of Chest posterior-anterior (PA) and Lateral (LAT), Skull PA, anterior-posterior (AP) and LAT, Pelvis, Lumbar Spine AP and LAT, Abdomen, Cervical Spine AP and LAT, Thoracic Spine AP and LAT. In fact, there were two reasons for the choice of these examinations: first, they have a major contribution in the cumulative dose for society and second, these X-ray examinations are conducted in most radiology centres. In general radiology, ESD and ESAK are used in mGy to express the amount of the dose. For record exposure factors and other effective factors in ESAK, those forms that were completed by personnel were provided. The form consisted of data such as the number of radiography rooms, equipment types and models, the utilisation period of X-ray equipment, kVp (kiloelectron-Volt peak), mAs (miliampere-second), FSD (Film-Screen Distance), FOV (Field Of View) and type of patient (fat adult upper than 80 kg, moderate adult between 60–80 kg and thin adult less than 60 kg–child–infant). Simultaneously with registration of radiation factor by personnel, X-ray equipment output was measured by one of the modern solid state dosimeters. In this case, we performed an exposure and gained output. This action was conducted differently for kVp (constant mAs, constant FSD and FOV). Actually, it gained tube output for different kVp with a Barracuda dosimeter that is produced in the RTI electronic company. This device can measure mAs, kVp, dose, dose rate and Half Value Layer in one exposure. Then, ESAK was estimated based on these data. The formula used for ESAK calculation is as follows:

$$\mathrm{ESAK} = \frac{\mathrm{H} \times \mathrm{mAs}}{\mathrm{d}^2} \qquad \text{Eq.1}$$

where H is tube output, mAs is tube current and d is film for source distance.

ESAK is not included in the back-scatter factor (BSF) and it cannot be used for correct patient dose estimation. For this estimation, the multiplying sign BSF (BSF represented by ICRP and other international organisations(6)) in ESAK resulted in ESD. ESD is a correct estimation of patient dose.

$$ESD = \frac{H \times mAs}{d^2} \times BSF \qquad \text{Eq.2}$$

All data were transferred to computer and were analyzed by SPSS software ver. 21. Finally, the ESD third quartile (75%) was calculated as the DRL.

Results

Data analysis in this study showed that more than 158,200 patients were referred to 21 radiology centres in Ilam for more than 236,104 radiography examinations in 2014. Table 1 shows the annual number of different types of radiography examinations in 2014.

Table 1. Annual number of X-ray examinations in Ilam (2014)

Examination	Number
Chest PA & AP	35,416
Chest LAT	10,860
Thoracic Spine	11,404
Lumbosacral	10,720
Cervical Spine	15,513
Pelvic	21,910
Abdomen	10,413
Skull	11,570
Other	108,298
Total	236,104

Table 2 compares the annual number of radiography examinations per 1,000 population resulting from this study, with established values from Kuwait, United Arab Emirates (UAE), United Kingdom (UK), Iran and the mean values from Healthcare Level II countries(7).

Table 2. Comparison of the annual number of X-ray examinations per 1,000 population of this survey with some established values

Radiography Examination	Annual number of X-ray examinations per 1,000 population					
	This Survey	Healthcare Level II Countries	UK	Kuwait	UAE	Iran
Chest PA & AP	61.06	24	141	323	111	90.12
Chest LAT	18.72	-	-	-	-	-
Thoracic Spine	19.66	2.4	5	-	2.1	7.61
Lumbosacral	18.48	5.3	19	35	28	24.90
Cervical Spine	26.74	25	14	31	2.7	16.12
Pelvic	37.77	14	31	19	9.2	14.91
Abdomen	17.95	13	21	63	26	11.28
Skull	19.94	30	28	71	23	25.77
Other	186.72	-	-	-	-	-
Total	407.04	150	423	734	288	300.45

Table 3 compares the kVp, mAs and ESD mean values for a standard adult patient of this study with the UK (2000)(8), Malaysia (1998)(9), Iran(2008)(10) and Korea (2007)(11). The dispensation and mean value ESD are presented for all type of patients in Tables 4 and 5. The maximum/minimum ratio of ESDs for all types of patients ranged from 18 mGy for lateral lumbosacral in fat adult to 0.001 mGy for AP Chest in infant. Tables 4 and 5 show ESD and its diffusion indexes such as third quartile. This data was classified based on type of patient. Tables 6 and 7 compare DRL in this study with results of other studies.

Table 3. Comparison of kVp, mAs and ESD mean values for radiography examinations in standard adult patient in

Some studies	Projection	Parameter	This Study	UK (2000)	Malaysia (1998)	Korea (2007)	Iran (2008)
Chest	PA	kVp	61.8	85	79	106	66
		mAs	12.58	5	9	9	18
		ESD	0.28	0.15	0.28	0.21	0.35
	LAT	kVp	67.84	98	88	104	72
		mAs	19.27	15	19	25	41
		ESD	0.52	0.85	1.40	1.56	1.58
Thoracic Spine	AP	kVp	68.68	76	72	74	65
		mAs	23.03	31	48	30	49
		ESD	1.81	2.9	7.03	2.10	2.23
	LAT	kVp	71.9	73	81	79	73
		mAs	38.64	66	62	47	66
		ESD	2.37	8	16.54	6.17	5.20
Lumbosacral	AP	kVp	69.26	77	77	76	70
		mAs	34.18	42	51	35	50
		ESD	2.02	5	10.56	2.80	3.05
	LAT	kVp	78.32	88	89	84	80
		mAs	42.2	72	72	68	73
		ESD	3.44	11.17	18.60	16.42	7.38
Cervical Spine	AP	kVp	58.52	-	66	68	61
		mAs	10.78	-	16	19	28
		ESD	0.36	-	1.02	1.09	1.36
	LAT	kVp	59.61	-	69	74	59
		mAs	11.85	-	20	25	21
		ESD	0.34	-	1.60	0.48	0.82
Pelvic	AP	kVp	67.6	74	70	72	66
		mAs	31.87	35	40	31	48
		ESD	1.9	3.6	8.41	2.44	2.32
Abdomen	AP	kVp	70.71	74	71	74	68
		mAs	34.28	46	57	33	54
		ESD	1.97	4.70	10	2.33	3.27
Skull	PA	kVp	62.76	72	71	72	63
		mAs	28	30	38	28	41
		ESD	1.24	2.3	4.78	2.04	2.32
	LAT	kVp	61.43	66	68	69	59
		mAs	23.85	19	32	25	32
		ESD	0.95	1.20	3.34	1.50	1.47

Table 4. ESD statistical indices for all types of patients.

	ESD (mGy)							
Radiograph	**Type of patient**	**Mean**	**Fashion**	**Minimum**	**Maximum**	**First quartile**	**Second quartile**	**Third quartile**
Chest PA	Fat adult	0.41	0.017	0.02	2.53	0.15	0.29	0.52
	Standard adult	0.28	0.015	0.008	2.26	0.09	0.19	0.37
	Thin adult	0.21	0.03	0.007	2.01	0.07	0.12	0.31
	Children	0.16	0.064	0.002	1.78	0.057	0.086	0.17
	Infants	0.075	0.041	0.001	0.71	0.03	0.043	0.071
Chest LAT	Fat adult	0.65	0.03	0.03	2.16	0.26	0.52	0.91
	Standard adult	0.52	0.22	0.02	1.62	0.2	0.41	0.78
	Thin adult	0.38	0.17	0.02	1.44	0.15	0.29	0.59
	Children	0.19	0.01	0.01	0.78	0.09	0.16	0.23
	Infants	0.08	0.006	0.006	0.65	0.05	0.07	0.11
Thoracic spine AP	Fat adult	2.62	1.9	0.69	11.77	1.25	1.9	3.29
	Standard adult	1.81	0.63	0.5	6.41	0.97	1.35	1.32
	Thin adult	1.24	0.52	0.21	4.94	0.65	0.99	1.7
	Children	0.42	0.59	0.09	1.8	0.17	0.27	0.59
	Infants	0.16	0.09	0.03	0.63	0.07	0.09	0.21
Thoracic spine LAT	Fat adult	3.33	2.86	0.67	12.56	1.65	2.86	4.19
	Standard adult	2.37	1.89	0.51	9.4	1.13	1.89	3.11
	Thin adult	1.78	1.5	0.42	5.67	0.95	1.5	2.28
	Children	0.52	0.43	0.11	1.79	0.28	0.43	0.66
	Infants	0.19	0.13	0.04	0.92	0.09	0.12	0.19
Lumbosacral AP	Fat adult	3.17	0.67	0.67	15.63	1.61	2.47	3.64
	Standard adult	2.02	2.7	0.62	8.3	1.04	1.65	2.4
	Thin adult	1.46	0.45	0.45	4.28	0.9	1.29	1.75
	Children	0.54	0.12	0.12	1.81	0.25	0.43	0.75
	Infants	0.19	0.04	0.04	1.12	0.07	0.1	0.27
Lumbosacral LAT	Fat adult	4.58	3.6	1.11	18	2.29	3.73	7.1
	Standard adult	3.44	2.32	1.07	11.98	1.76	2.82	4.63
	Thin adult	2.61	1.42	0.72	13.66	1.41	2.04	3.19
	Children	0.81	0.14	0.05	3.81	0.28	0.57	1.13
	Infants	0.26	0.1	0.04	0.95	0.1	0.16	0.35
Abdomen	Fat adult	3.24	0.61	0.57	16.05	1.63	2.36	4.18
	Standard adult	1.97	0.46	0.43	11.7	1.16	1.63	1.26
	Thin adult	1.42	1.18	0.35	6.8	0.89	1.18	1.65
	Children	0.43	0.23	0.05	2.36	0.17	0.26	0.54
	Infants	0.18	0.07	0.03	0.89	0.07	0.1	0.21
Pelvic	Fat adult	2.46	0.73	0.43	13.5	1.27	1.98	3.17
	Standard adult	1.9	0.63	0.26	11.64	0.95	1.39	2.3
	Thin adult	1.39	1.5	0.27	6.6	0.67	1.03	1.7
	Children	0.42	0.18	0.07	2.2	0.18	0.31	0.51
	Infants	0.19	0.44	0.03	1.05	0.07	0.11	0.25

Table 5. ESD statistical indices for all types of patients in Cervical and Skull

Radiograph	Type of patient	ESD (mGy) Mean	Mode	Minimum	Maximum	First quartile(Q1)	Second quartile(Q2)	Third quartile(Q3)
Cervical spine AP	Fat adult	0.47	0.02	0.02	1.58	0.19	0.41	0.67
	Standard adult	0.36	0.01	0.008	1.32	0.16	0.29	0.5
	Thin adult	0.27	0.01	0.01	1.23	0.14	0.23	0.31
	Children	0.15	0.001	0.001	1.18	0.07	0.11	0.18
	Infants	0.09	0.001	0.001	0.68	0.05	0.07	0.11
Cervical spine LAT	Fat adult	0.43	0.16	0.02	2.23	0.19	0.32	0.56
	Standard adult	0.34	0.26	0.02	2.14	0.16	0.27	0.37
	Thin adult	0.28	0.29	0.01	1.83	0.13	0.19	0.29
	Children	0.19	0.05	0.005	1.56	0.08	0.11	0.2
	Infants	0.12	0.001	0.001	0.81	0.05	0.07	0.16
Skull AP	Fat adult	1.53	1.17	0.41	5.31	0.96	1.26	1.89
	Standard adult	1.24	0.52	0.38	5.41	0.78	1.05	1.43
	Thin adult	1.03	1.47	0.34	4.47	0.55	0.92	1.28
	Children	0.51	0.78	0.05	2.57	0.22	0.43	0.64
	Infants	0.28	0.08	0.04	1.19	0.08	0.16	0.4
Skull LAT	Fat adult	1.28	1.7	0.28	4.14	0.72	1.03	1.71
	Standard adult	0.95	1	0.75	1.1	0.9	0.95	1
	Thin adult	0.83	0.2	0.18	3.32	0.47	0.69	1.03
	Children	0.47	0.32	0.09	1.8	0.24	0.4	0.57
	Infants	0.26	0.08	0.04	1.44	0.08	0.16	0.28

Table 6. Comparison of DRLs in this study with references and with other studies for standard adult patient

Radiograph	Projection	DRL (mGy) This study	IAEA (1996)	EC (1999)	NRPB (2002)	Iran (2008)	Korea (2007)	Brazil (2009)	Lithuania (2010)	Montenegro (2011)	Latin America (2013)	Korea (2014)
Chest	PA	0.37	0.4	0.3	0.2	0.41	0.28	0.35	0.3	0.3	0.28	0.46
	LAT	0.78	1.5	-	1	2.07	1.61	0.96	1.7	1.5	-	1.69
Thoracic Spine	AP	1.32	7	-	3.5	2.72	2.58	2.91	6	4.5	-	2.01
	LAT	3.11	20	-	10	5.29	8.85	6.24	10	6.6	-	4.18
Lumbosacral	AP	2.4	10	10	6	3.43	3.56	6.6	10	6	-	2.39
	LAT	4.63	30	30	14	8.41	11.45	16.2	20	10	4.76	6.91
Abdomen	AP	1.26	10	10	6	4.06	2.87	-	10	4.39	10.49	2.09
Pelvic	AP	2.3	10	-	4	3.18	2.9	-	10	6.3	-	2.26
Cervical Spine	AP	0.5	-	-	-	-	1.44	0.72	-	1.9	-	1.07
	LAT	0.37	-	-	-	-	0.57	1.20	-	1.3	-	0.98
Skull	PA	1.43	5	5	3	2.85	2.76	3.28	4	3.9	-	1.68
	LAT	1	3	3	1.5	1.93	1.78	2.14	3	3.1	-	1.87

Table 7. Comparison between DRL of child and infant in this study and the other patients in different studies (19,20).

Radiograph	Projection	Type of patient	DRL (mGy) This study	India (2010)	Kenia (2012)	Bulgaria (2008)
Chest	PA	child	0.17	0.2	0.1	0.45
		infant	0.071	-	0.065	0.13
	LAT	child	0.23	0.3	0.14	-
		infant	0.11	-	0.12	-
Thoracic Spine	AP	child	0.59	0.3	0.42	-
		infant	0.21	-	-	-
	LAT	child	0.66	0.6	0.44	-
		infant	0.19	-	-	-
Lumbosacral	AP	child	0.75	0.7	0.5	-
		infant	0.27	-	0.08	-
	LAT	child	1.13	1.3	0.31	-
		infant	0.35	-	0.08	-
Abdomen	AP	child	0.54	0.5	0.2	-
		infant	0.21	-	0.12	-
Pelvic	AP	child	0.51	0.7	0.43	1.08
		infant	0.25	-	0.13	0.43
Cervical Spine	AP	child	0.18	-	0.25	-
		infant	0.11	-	0.2	-
	LAT	child	0.2	-	0.16	-
		infant	0.16	-	0.1	-
Skull	PA	child	0.64	0.6	0.3	1.06
		infant	0.4	-	0.21	0.65
	LAT	child	0.57	0.5	0.28	-
		infant	0.28	-	0.17	-

Discussion

According to Table 1 that shows the annual number of different radiography examination types, Chest PA and Pelvic are the more frequent examinations with 15% and 9.28%, respectively. While in other studies performed in 2008 in Iran, Limbs & Joints and Chest were more frequent examinations, with 35.4% and 29.9%, respectively. The difference may be due to social and economic situations. Therefore, it is more important to obey DRL concerned with Chest X-ray. The comparison of this survey of the annual number of radiography examinations per 1,000 population with other studies demonstrates that the annual number of Chest PA & APs is lower than for other studies, except in the values of Healthcare Level II countries. Also, the annual number of Thoracic Spine and Pelvic are significantly more than in all of the other studies, while the annual number of Skull is lower than for other studies. Comparison of this study with other studies performed in 2008 in Iran shows that the total annual number of radiography examinations per 1,000 populations in our study is more by a factor of 1.35.

The comparison of results of this study with results of the surveys carried out in other studies shows that the range of applied tube potential of standard adult patient for all examinations is 66.53, which is smaller than the corresponding value in other surveys, which is 80.26 kVp. Also, to the contrary, in most examinations mAs values were lower than those used in other surveys. Additionally, the mean ESD values for all examinations included in this study were lower than the values reported by other studies.

The third quartile values for all types of patients in this survey are reported in Tables 4 and 5 as the first local DRLs in Ilam province and have been adapted in Table 6 in order to make comparisons with international reference dose values reported by the EC(3), the International Atomic Energy Agency (IAEA)(12) and the NRPB(13), Iran(10), Korea (2007)(11), Brazil(14), Lithuania(15), Montenegro(16), Latin America(17) and Korea (2013)(18). Almost all DRLs in this study were less than those of the EC, IAEA, NRPB and of other studies, except for that of the Chest examination, which in some cases was slightly higher than in some of these studies. Comparison between the DRLs for children and infants in this study and in other studies is presented in Table 7 and demonstrates that the values of this study are higher in more of the cases than in other studies. The main reason for the values being more than in other studies is likely the conquering use of a low-kVp technique. This is contradictory to the recommendation to use a high-kVp technique. Finally, this research to obtain DRLs in Ilam province shows that so far, all radiographic procedures are almost safe.

Conclusion

Diagnostic reference levels help to make standardisation and optimisation easier within departments and encourage the decrease of dose variations between imaging centres. The dose-reducing potential of introducing regular patient dose surveys and making comparisons with DRLs has been demonstrated by the NRPB. Establishing DRL in a province encourages radiographers to follow this value which makes radiation protection in the population more effective and reduces patient dose. Finally, a ‘culture’ of regular patient dose measurements needs to become a part of diagnostic radiology.

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