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Establishment of Diagnostic Reference Levels for Radiography in 10-year-old Pediatric Patients in Republic of Korea

Seung-Youl Lee* and Sang-Myeong Park

Medical Device Research Division, National Institute of Food and Drug Safety Evaluation, Chungbuk 28159, Republic of Korea

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The diagnostic reference levels (DRLs) for a 10-year-old patient were established for the most common types of general radiography in this study, using a glass dosimeter and a phantom corresponding to the international standards. The DRLs are set by measuring the entrance surface doses (ESD) at 211 medical institutions. The ESD of the skull posterior-anterior (PA) projection is between 0.11 and 5.59 mGy, with the average dose at 1.03 mGy, and the third quartile value at 1.17 mGy. The ESD of the skull lateral (LAT) projection is between 0.08 and 5.20 mGy, with the average dose at 0.78 mGy, and the third quartile value at 0.96 mGy. The ESD of the chest PA projection is between 0.01 and 1.38 mGy, with the average dose at 0.18 mGy, and the third quartile value at 0.20 mGy. The ESD of the chest LAT projection is between 0.04 and 3.36 mGy, with the average dose at 0.42 mGy, and the third quartile value at 0.46 mGy. The ESD of the abdomen AP projection is between 0.09 and 4.64 mGy, with the average dose at 0.85 mGy, and the third quartile value at 1.13 mGy. The ESD of the pelvis AP projection is between 0.1 and 5.26 mGy, with the average dose at 0.85 mGy, and the third quartile value at 1.06 mGy. Based on third quartile values and through clinical expert consultation, the DRLs for 10-year-olds in Korea were established at 1.1 mGy for skull PA, 0.9 mGy for skull LAT, 0.2 mGy for chest PA, 0.4 mGy for chest LAT, 1.1 mGy for abdomen AP, and 1.0 mGy for pelvis AP.

Keywords : diagnostic reference level, pediatric medical exposure, entrance surface dose, radiography

1. Introduction

According to UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) 2010 report, the annual frequency of all diagnostic radiation exposures is estimated to be 3.6 in 2008 and an approximately twofold increased, compared in 1988. 2/3 of these examinations were performed in health care level I nations, including Republic of Korea [1]. The total number of the diagnostic radiation examinations was 160 million in 2007 and 220 million in 2011, a 35 % increase in Republic of Korea. The total number of general radiographic examinations increased from 120 million in 2007 to 170 million in 2011, a 39 % increase and the annual per caput effective doses in the country was 0.93 mSv in 2007 and 1.4 mSv in 2011, a 51 % increase [2, 3]. The recent increase in medical radiation dose is a part of the global trend, and many people are concerned about the dangers of radiation exposure and its side effects [4]. Accordingly, six international agencies, including the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA), came together to try to reduce medical radiation exposure by establishing a guidance level recommending the dose a patient should receive when undergoing diagnostic radiography, publishing Basic Safety Standard No. 115 in 1996 [5]. The International Commission on Radiological Protection (ICRP) recommended that each country establish a diagnostic reference level (DRL) appropriate for their own circumstances in order to optimize patient protection from medical radiation [6].

Especially children are more sensitive to radiation exposure than adults, and exposure during childhood can increase the lifelong risk of cancer [7]. According to the Biological Effects of Ionizing Radiation (BEIR) VII report, a 10-year-old child exposed to radiation has a 3-4 times greater chance of developing cancer than a 30’s and 40’s adult exposed to the same amount of radiation [8]. Thus, the European Commission (EC) and the National Radiological Protection Board (NRPB) of the UK established the DRLs for chest, skull, pelvis, and abdomen examinations according to age [9, 10]. Also, the Korean

*Corresponding author: Tel: +82-43-719-4927
Fax: +82-43-719-4900, e-mail: dasom1022@gmail.com

Ministry of Food and Drug Safety (MFDS, former KFDA) established the DRLs for only 5-year-old child and adult. Because the more specific DRLs are required to optimize pediatric medical exposure on various body parts, through measurement of pediatric doses at Korean medical institutions, this research aims to establish the pediatric DRLs for the skull, chest, abdomen, and pelvis and recommend them to medical institutions in order to reduce exposure to medical radiation in pediatric patients.

2. Materials and Methods

2.1. Selecting medical institutions to measure pediatric patient dose

This study aimed to establish DRLs for the most common types of pediatric radiographic examinations. The DRLs were established for the skull, chest, abdomen, and pelvis in this study. 211 medical institutions specializing in pediatric examinations were selected for the study. Fig. 1 shows the distribution of the institutions by the regions (provinces or metropolitan city). In addition.

2.2. Phantoms and dose reading systems for evaluating pediatric dose

To obtain the entrance surface dose (ESD) for imaging conditions by each body part in a 10-year-old child, we used the CIRS ATOM dosimetry phantom (Model 706-D, Height: 140 cm, Weight: 32 kg, Thorax dimensions: 17 × 20 cm^2) by CIRS. A GD-352M glass dosimeter and FGD-1000 dosimeter reader manufactured by ASAHI Techno Glass were used for this experiment, as shown in Fig. 2. To calibrate a low effective energy of less than 150 keV and to stabilize the dose of the glass dosimeter with a tin filter and to adjust the dose reader system, the standard X-ray system was used with 6 mGy at 1 m. pre-heating was carried out at 70 °C for 30 min. The fluctuation rate in the resulting glass dosimeter device was below 1 %, and the total error rate of the whole reading system was maintained within 5 % through standard irradiation.

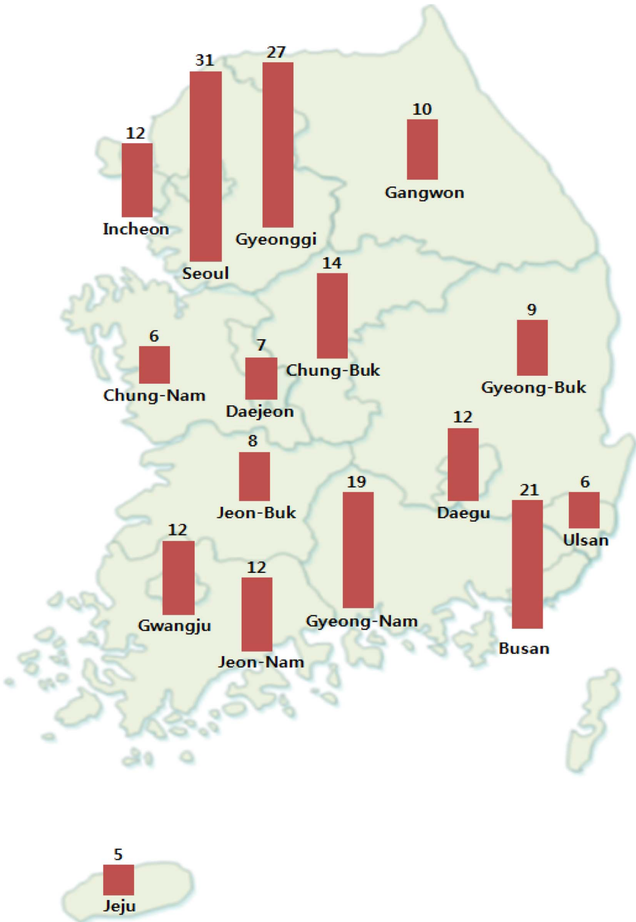


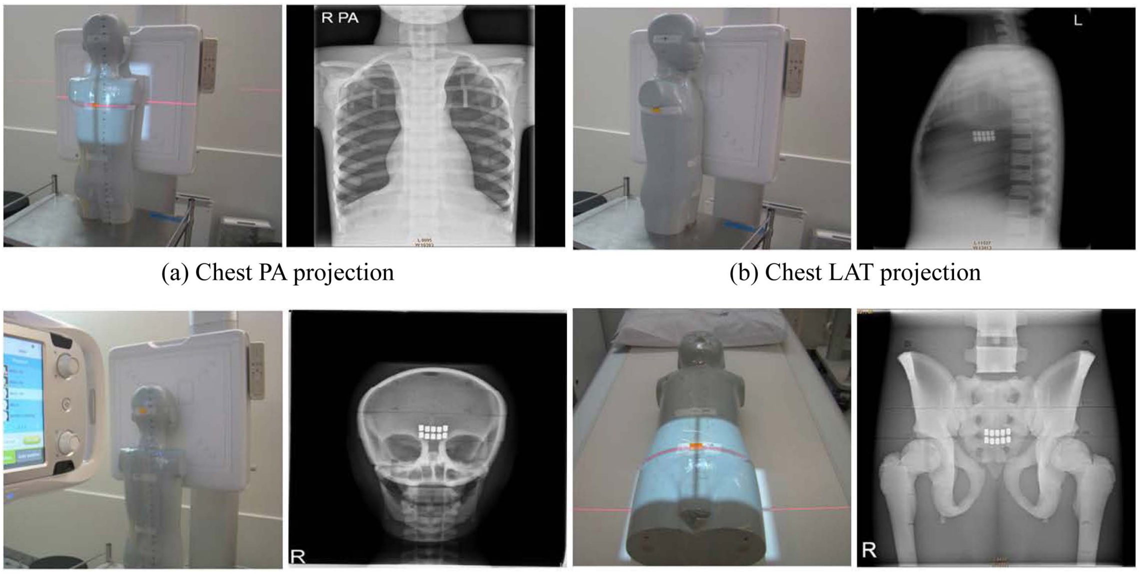
Fig. 1. (Color online) Distribution of medical institutions for patient dose measurement.

2.3. Method to measure pediatric patient dose

Our researchers personally visited the medical institutions and measured the pediatric patient dose. The human-shaped ATOM dosimetry phantom was used instead of an actual patient, and imaging conditions used at the medical

(a) human-shaped phantom (706-D) (b) glass dosimeter (GD-352M) (c) Reader (FGD-1000) (d) Standard system for X-ray

Fig. 2. (Color online) Material and measuring equipment.



(a) Chest PA projection (b) Chest LAT projection

(c) Skull PA projection (d) Pelvis AP projection

Fig. 3. (Color online) Example for the patient dosimetry of Chest PA/LAT, Skull PA, Pelvis AP and the X-ray image.

institution were employed to conduct measurements. Five GD-352M glass dosimeters were affixed along the central line of the beam radiation, and the entrance surface dose (ESD) for a 10-year-old child was measured at 6 projections of 4 body parts, including the skull posterior-anterior (PA) projection or the skull anterior-posterior (AP) projection, skull lateral (LAT) projection, Chest PA and LAT projections, abdomen AP, and the pelvis AP, as shown in Fig. 3.

2.4. Collection of information of diagnostic radiation equipment and imaging conditions

We collected the manufacturer, model, type, high-voltage stoppage system, and manufacture date of the diagnostic radiation equipment. We also collected and performed statistical analysis on the imaging conditions for an actual 10-year-old child; the conditions include kVp, mA, exposure time, and mAs, as well as technical aspects such as additional filters, grid ratio, image acquisition method type (digital radiography, computed radiography and film/screen system), focus-film distance (FFD), and collimation field size. In addition, each diagnostic image was saved as a DICOM file for image evaluation.

2.5. Analysis and statistical processing

SPSS 20.0 was used in this research. Linear regression was used to compare the conditions for each examination, and an independent t-test was used to compare the exposure methods. One-way ANOVA and a Scheffe post-hoc test were performed to compare the types of medical institutions and image acquisition methods.

3. Results

3.1. Distribution of patient doses in 10-year-old patient according to body parts

We evaluated the patient doses when imaging each body part of a 10-year-old patient at 211 Korean medical institutions; the following results were obtained and shown in Table 1 and Fig. 4. The ESD of the skull PA projection is between 0.11 and 5.59 mGy, with the average dose at 1.03 mGy, and the third quartile value at 1.17. The ESD of the skull LAT projection is between 0.08 and 5.2 mGy, with the average dose at 0.78 mGy, and the third quartile value at 0.96. The ESD of the chest PA projection is between 0.01 and 1.38 mGy, with the average dose at 0.18 mGy, and the third quartile value at 0.20. The ESD of the chest LAT projection is between 0.04 and 3.36 mGy, with the average dose at 0.42 mGy, and the third quartile value at 0.46. The ESD of the abdomen AP projection is between 0.09 and 4.64 mGy, with the average dose at 0.85 mGy, and the third quartile value at 1.13. The ESD of the pelvis AP projection is between 0.1 and 5.26 mGy, with the average dose at 0.85 mGy, and the third quartile value at 1.06.

3.2. Distribution of kVp by body part in examinations of 10-year-old patient

As shown in Table 1 and Fig. 5, the kVp of the skull PA projection was between 60.00 and 95.00; the average kVp

Table 1. Distribution of ESD (Unit : mGy), kVp, mAs in pediatric (10-year-old) radiographic examinations according to type of radiography.

Type of radiography		N	Min	1st quartile	Median	3rd quartile	Max	Ave
Skull PA	kVp	190	60.00	66.00	70.00	73.75	95.00	70.46
	mAs	190	3.20	10.02	14.00	18.00	60.00	15.49
	mGy	190	0.11	0.54	0.80	1.17	5.59	1.03
Skull LAT	kVp	181	50.00	65.00	68.00	70.00	92.00	68.51
	mAs	181	1.00	10.00	12.50	16.00	90.00	13.80
	mGy	181	0.08	0.42	0.66	0.96	5.20	0.78
Chest PA	kVp	209	50.00	75.00	90.00	100.00	125.00	87.62
	mAs	209	0.40	2.22	3.20	6.13	200.00	6.15
	mGy	209	0.01	0.07	0.12	0.20	1.38	0.18
Chest LAT	kVp	182	54.00	80.00	90.00	100.00	125.00	92.13
	mAs	182	0.75	3.20	6.30	11.21	60.00	8.76
	mGy	182	0.04	0.12	0.26	0.46	3.36	0.42
Abdomen AP	kVp	205	54.00	65.00	68.00	72.00	92.00	68.60
	mAs	205	1.61	7.90	12.50	16.00	76.00	14.13
	mGy	205	0.09	0.36	0.66	1.13	4.64	0.85
Pelvis AP	kVp	174	46.00	65.00	70.00	72.00	86.00	68.46
	mAs	174	2.30	8.00	12.50	16.00	90.00	13.82
	mGy	174	0.10	0.42	0.70	1.06	5.26	0.85

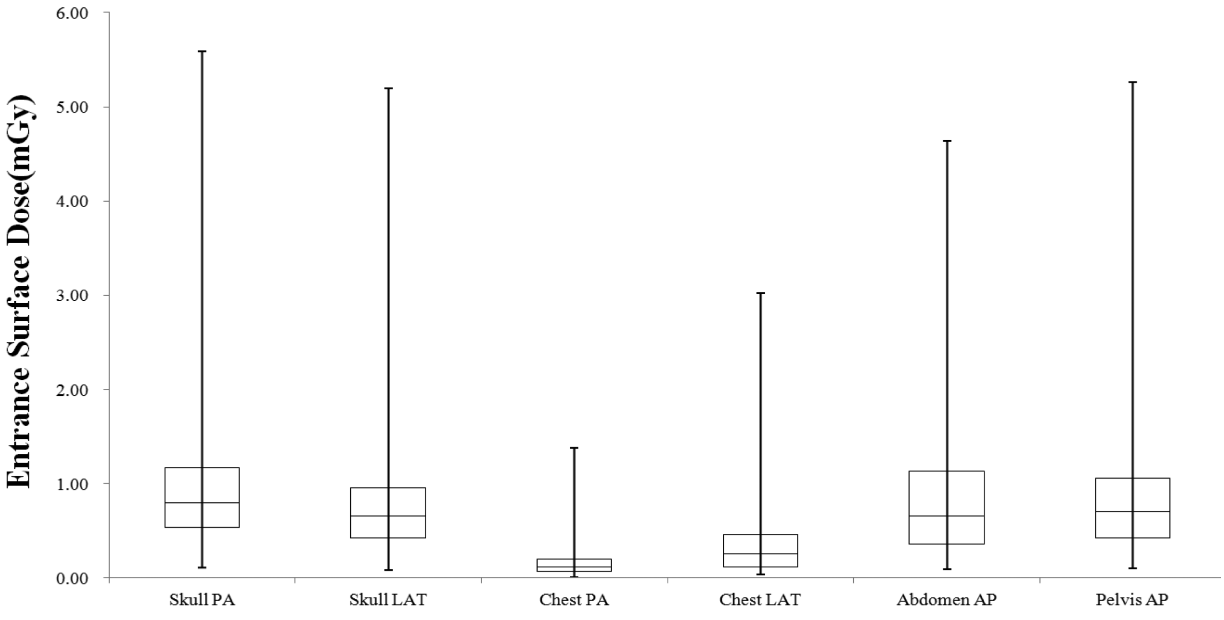


Fig. 4. Distribution of the entrance surface dose(ESD) for 10-year-old patient 6 projection of 4 body parts in Republic of Korea.

was 70.46, and the third quartile value was 73.75. The kVp of the skull LAT projection was between 50.00 and 92.00; the average kVp was 68.51, and the third quartile value was 70.00. The kVp of the chest PA projection was between 50.00 and 125.00; the average kVp was 87.62 and the third quartile value was 100.00. The kVp of the chest LAT projection was between 54.00 and 125.00; the average kVp was 92.13 and the third quartile value was 100.00. The kVp of the abdomen AP projection was between 54.00 and 92.00; the average kVp was 68.60 and the third quartile value was 72.00. The kVp of the pelvis AP projection was between 46.00 and 86.00; the average kVp was 68.46, and the third quartile value was 72.00 .

3.3. Distribution of mAs by body part in imaging of 10-year-old patient

As shown in Table 1 and Fig. 6, the mAs of the skull PA projection was between 3.20 and 60.00; the average

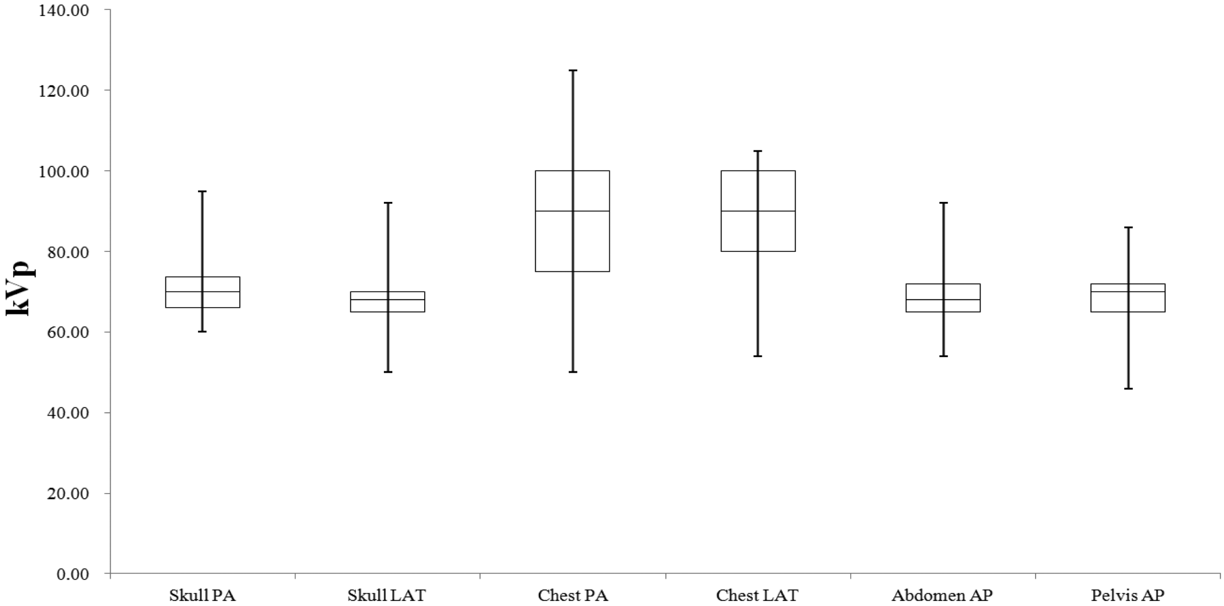


Fig. 5. Distribution of the kVp for 10-year-old patient 6 projection of 4 body parts in Republic of Korea.

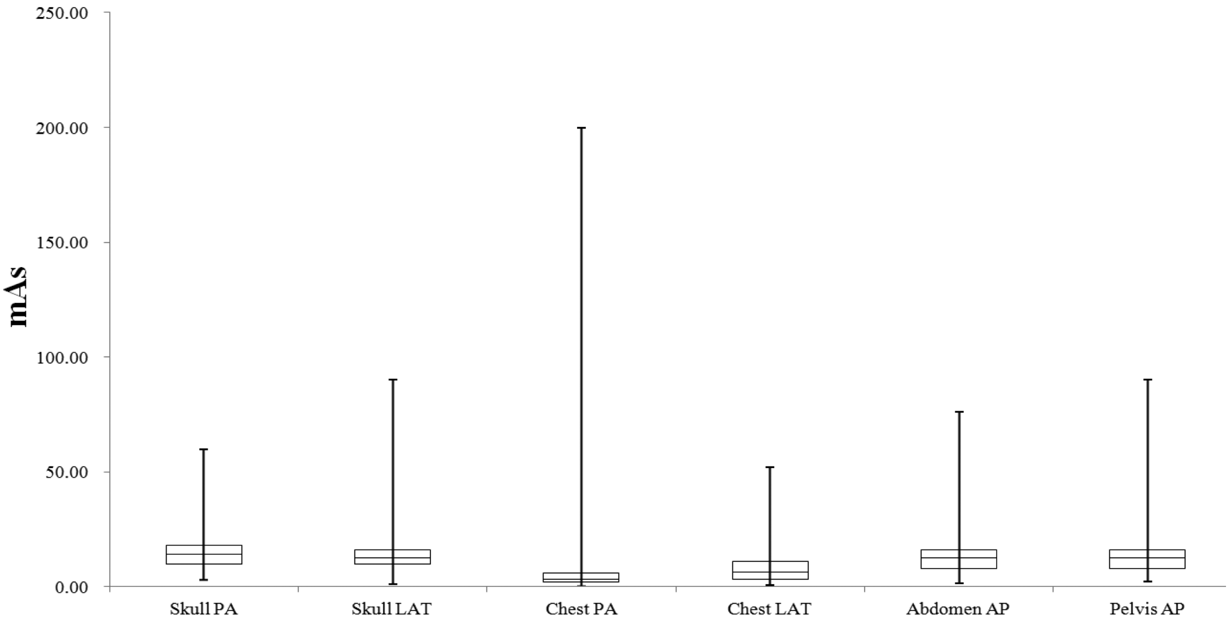


Fig. 6. Distribution of the mAs for 10-year-old patient 6 projection of 4 body parts in Republic of Korea.

mAs was 15.49, and the third quartile value was 18.00. The mAs of the skull LAT projection was between 1.00 and 90.00; the average mAs was 13.80, and the third quartile value was 16.00. The mAs of the chest PA projection was between 0.40 and 200.00; the average mAs was 6.15, and the third quartile value was 6.13. The mAs of the chest LAT projection was between 0.75 and 60.00; the average mAs was 8.76, and the third quartile value was 11.21. The mAs of the abdomen AP projection was between 1.61 and 76.00; the average mAs was 14.13, the third quartile value was 16.00. The mAs of the pelvis AP projection was between 2.30 and 90.00; the average mAs was 13.82, the third quartile value was 16.00.

3.4. Comparison of patient dose in 10-year-old patient according to exposure and acquisition types, etc.

Table 2 shows the distribution of ESD of 6 projections by the exposure type, the image acquisition method and institution type: In type of exposure modes, manual mode tended to have higher ESD than automatic mode in all

Table 2. Distribution of ESD according to exposure type, image acquisition method, medical institution, and high-voltage generators type for pediatric (10-year-old) radiographic examinations.

Classifications			Skull		Chest		Abdomen	Pelvis
			PA	LAT	PA	LAT	AP	AP
Type of exposure modes	Manual mode	n(%)	133(70%)	125(68.5%)	147(70.3%)	119(65.4%)	143(69.8%)	117(67.2%)
		mGy	1.09	0.83	0.20	0.51	0.90	0.90
	AEC mode	n(%)	57(30%)	56(31.5%)	62(29.7%)	63(34.6%)	62(30.2%)	57(32.8%)
		mGy	0.89	0.68	0.12	0.26	0.74	0.76
Type of image acquisition methods	Film	n(%)	13(6.8%)	8(4.4%)	26(12.4%)	7(3.8%)	22(10.7%)	7(4.0%)
		mGy	1.11	0.93	0.19	0.49	0.59	0.90
	CR	n(%)	33(17.4%)	33(18.2%)	39(18.7%)	35(19.2%)	40(19.5%)	31(17.8%)
		mGy	1.03	0.97	0.24	0.46	1.11	1.00
	DR	n(%)	144(75.8%)	140(77.3%)	144(68.9%)	140(76.9%)	143(69.8%)	136(78.2%)
		mGy	1.02	0.73	0.16	0.41	0.82	0.81
Type of medical institutions	Clinic	n(%)	23(12.1%)	16(8.8%)	37(17.7%)	14(7.7%)	33(16.1%)	14(8.0%)
		mGy	1.33	1.12	0.27	0.43	0.92	1.00
	Hospital	n(%)	45(23.7%)	43(23.8%)	50(23.9%)	47(25.8%)	50(24.4%)	38(21.8%)
		mGy	1.51	1.14	0.26	0.79	1.28	1.40
	Medical center	n(%)	122(64.2)	122(67.4%)	122(58.4%)	121(66.5%)	122(59.5%)	122(70.1%)
		mGy	0.80	0.62	0.12	0.28	0.65	0.66
Type of high-voltage generators	Three phase	n(%)	29(15.3%)	29(16.0%)	30(14.4%)	26(14.3%)	30(14.6%)	27(15.5%)
		mGy	0.85	0.72	0.14	0.50	0.67	0.75
	Single phase	n(%)	18(9.5%)	12(6.6%)	24(11.5%)	12(6.6%)	22(10.7%)	11(6.3%)
		mGy	1.63	1.37	0.26	0.79	1.09	0.85
	Inverter	n(%)	131(68.9%)	129(71.3%)	141(67.4%)	132(72.5%)	140(68.3%)	126(72.4%)
		mGy	0.98	0.75	0.17	0.39	0.83	0.86
	Condenser	n(%)	3(1.6%)	3(1.7%)	4(1.9%)	3(1.7%)	4(2.0%)	2(1.2%)
		mGy	1.55	0.47	0.22	0.37	1.52	1.41
	Unknowability	n(%)	9(4.7%)	8(4.4%)	10(4.8%)	9(4.9%)	9(4.4%)	8(4.6%)
		mGy	1.01	0.87	0.12	0.27	0.88	0.87

projections. In type of image acquisition methods, CR and F/S showed higher ESD than DR in all projections. In type of medical institutions, Medical center hospitals have the lowest ESD in all projections.

4. Discussion

Children are at greater risk of developing cancer through ionizing radiation exposure as compared to adults; therefore, children's exposure to radiation should be minimized and optimized [11]. In countries outside of Korea, research on the DRLs for various ages and body parts is actively being carried out. In this research, we visited 211 Korean medical institutions where examinations were performed on 6 body parts of 10-year-old children and measured ESD with respect to medical institution type, exposure type, and image acquisition method. In particular, this study is more meaningful because it is the real data obtained through the actual projections in the medical institution, while other countries establish DRL only as a survey analysis of shooting conditions. As a result, Chest PA's ESD was 65 times different. Of course, the shooting conditions may vary depending on the doctor's reading criteria or clinical point of view. It was considered to be sufficiently readable at low conditions. Therefore, to reduce the dose of pediatric patients, it is necessary to prepare a standard radiography condition and follow-up studies are required.

By examining 6 body parts in 211 devices, a total of 1,141 projection conditions and additional factors were analysed statistically. As a result, mAs accounted for a statistically significant 28.1 % of the average ESD ($p < 0.001$), as shown in Table 3. In a comparison of the average ESD according to exposure type, the manual type had an average of 0.73 mGy, and the AEC type had an average of 0.56 mGy. The difference in dose between the manual and AEC modes was statistically significant ($p < 0.001$), as shown in Table 4. When comparing patient dose according to medical institution type, clinics were found to have higher doses than other institutions ($p <$

Table 3. Analysis of statistical influence of radiation imaging factors.

Variables	R Square	Adjusted R Square	B	Beta	F	t	VIF
kVp	0.050	0.049	-0.011	-0.223	59.669	-7.725*	1.000
mAs	0.281	0.280	0.034	0.530	443.461	21.059*	1.000
FFD	0.211	0.210	-0.010	-0.459	304.470	-17.449*	1.000

*: statistically significant at $p < 0.001$

Table 4. Comparison of average ESD value according to exposure type in pediatric (10-year-old) radiographic examinations.

	Mode	N	Mean	Std. Deviation	t
Type of exposure modes	Manual mode	784	0.73	0.71	3.753*
	Auto mode	357	0.56	0.64	

*: statistically significant at $p < 0.001$

Table 5. Mean ESD value of image acquisition methods, medical institutions, high-voltage generators to statistical analysis.

Classifications		N	Mean ESD	Std. Deviation	F	p
Type of image acquisition methods	Film	83	0.6	0.62	3.608	0.027
	CR	211	0.79	0.76		
	DR	847	0.66	0.68		
Type of medical institutions	Clinic	137	0.79	0.94	64.604	<0.001
	Hospital	273	1.04	0.92		
	Medical center	731	0.52	0.44		
Type of high-voltage generators	Three phase	171	0.6	0.47	5.309	<0.001
	Single phase	99	0.96	1.21		
	Inverter	799	0.66	0.64		
	Condenser	19	0.89	0.98		
	Unknown	53	0.65	0.53		

0.001. as shown in Table 5. Consequently, the DR devices with AEC show the lowest doses, and of projection conditions, ESDs according to mAs and FFD were statistically significant ($p < 0.001$).

When setting (DRLs), the total third quartile value of the ESD was set as the standard by international organizations such as NRPB (National Radiological Protection Board, UK) and EC (European Commission) [12]. Similarly, we have used the third quartile value and advice from experts to establish the following DRLs in this study. As shown in Table 6, this DRLs are similar or higher than NRPB (2000) which is available for direct comparison of 10-year-old DRL. It should be noted that NRPB has a continual interest in patient dose and is adjusting its values. We believe that as this is the first step in steadily working towards reducing patient dose in Republic of Korea, the patient dose will eventually become lower like UK.

Table 6. Comparison with other published foreign DRLs for 10 years old patient

[Unit : mGy]

Type of radiography		This study	MFDS 2013	NRPB 2000		EC 1999
			5-yr DRL	10-yr DRL	5-yr DRL	5-yr DRL
Skull	PA	1.1	1	1.1	1.1	1.5
	LAT	0.9	0.8	0.8	0.8	1
Chest	PA	0.2	0.1	0.12	0.07	0.1
	LAT	0.4	-	-	-	-
Abdomen	AP	1.1	0.8	0.8	0.5	1
Pelvis	AP	1.0	0.8	0.7	0.6	0.9

5. Conclusion

This research examined the conditions and dose distribution for the most common pediatric general radiography (skull PA and LAT, chest PA and LAT, abdomen AP, and pelvis AP) in 211 Korean medical institutions. We used a glass dosimeter to measure the ESD and analysed it statistically. As a result, we found the minimum, first quartile, median, third quartile, and average values for the imaging factors. The third quartile values were used to set the DRLs. The values were 1.1 mGy for skull PA, 0.9 mGy for skull lateral, 0.2 mGy for chest PA, 0.4 mGy for chest LAT, 1.1 mGy for abdomen AP, and 1.0 mGy for pelvis AP.

Acknowledgments

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