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Establishment of Local Diagnostic Reference Levels of Pediatric Abdominopelvic and Chest CT Examinations Based on the Body Weight and Size in Korea

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Objective: The purposes of this study were to analyze the radiation doses for pediatric abdominopelvic and chest CT examinations from university hospitals in Korea and to establish the local diagnostic reference levels (DRLs) based on the body weight and size.

Materials and Methods: At seven university hospitals in Korea, 2494 CT examinations of patients aged 15 years or younger (1625 abdominopelvic and 869 chest CT examinations) between January and December 2017 were analyzed in this study. CT scans were transferred to commercial automated dose management software for the analysis after being de-identified. DRLs were calculated after grouping the patients according to the body weight and effective diameter. DRLs were set at the 75th percentile of the distribution of each institution's typical values.

Results: For body weights of 5, 15, 30, 50, and 80 kg, DRLs (volume CT dose index [$CTDI_{vol}$]) were 1.4, 2.2, 2.7, 4.0, and 4.7 mGy, respectively, for abdominopelvic CT and 1.2, 1.5, 2.3, 3.7, and 5.8 mGy, respectively, for chest CT. For effective diameters of < 13 cm, 14–16 cm, 17–20 cm, 21–24 cm, and > 24 cm, DRLs (size-specific dose estimates [SSDE]) were 4.1, 5.0, 5.7, 7.1, and 7.2 mGy, respectively, for abdominopelvic CT and 2.8, 4.6, 4.3, 5.3, and 7.5 mGy, respectively, for chest CT. SSDE was greater than $CTDI_{vol}$ in all age groups. Overall, the local DRL was lower than DRLs in previously conducted dose surveys and other countries.

Conclusion: Our study set local DRLs in pediatric abdominopelvic and chest CT examinations for the body weight and size. Further research involving more facilities and CT examinations is required to develop national DRLs and update the current DRLs.

Keywords: *Diagnostic reference level; Computed tomography; Child; Radiation dose; Radiation protection*

INTRODUCTION

CT is an essential diagnostic modality for medical imaging, and its use has increased dramatically over the past several decades [1-6]. In the United States, according to the Organization for Economic Cooperation

and Development [1], the number of CT examinations was 78.9 per 1000 people in 1995 and 270.5 per 1000 people in 2018. Furthermore, CT examinations in Republic of Korea have dramatically increased from 74.6 per 1000 people in 2007 to 204.6 per 1000 people in 2017. This trend is also apparent in pediatric CT scans [2,4-6]. According to a recent study analyzing the American College of Radiology dose index registry [5], approximately 126000 single-phase abdominopelvic and 17000 single-phase chest CT scans were performed for pediatric patients between 2011 and 2016, with the number of CT scans increasing annually.

The radiation dose for pediatric CT scans merits special concern. Children have a greater risk for stochastic effects of radiation compared to adults [7] because of their smaller body habitus, growing body organs that are more radiosensitive than adult tissue, and a longer lifetime of exposure [3]. Therefore, optimization of the pediatric CT examination is crucial in pediatric imaging to achieve an acceptable image quality with appropriate minimal radiation exposure.

The diagnostic reference level (DRL) is a tool for the optimization of X-ray procedures. It was introduced by the International Commission on Radiological Protection (ICRP) in 1996 [8]. Traditionally, age bands have been used to establish DRLs for pediatric X-ray procedures because of their ease of applicability. However, even within each age group, there are considerable variations in the body weight and size, which are more appropriate grouping bases for pediatric CT examinations [9-11].

Before this study, no dose surveys for pediatric body CT examinations had been conducted using CT data from multiple hospitals in Korea. The purposes of this study were to analyze the radiation dose of pediatric body CT examinations from several university hospitals in Korea, to assess the feasibility of using an automated dose management system for the analysis of radiation dosages from multiple hospitals, and to establish the local DRLs for pediatric abdominopelvic and chest CT examinations by grouping patients according to the body weight and size.

MATERIALS AND METHODS

The Institutional Review Board of each hospital from where CT scans were collected approved this retrospective study (IRB No. 04-2018-018). The requirement for informed consent was waived, as this study showed minimal risk.

Data Collection

We collected pediatric abdominopelvic and chest CT scans at nine university hospitals from January to December 2017. At least one pediatric radiologist was employed at each hospital. Inclusion criteria were as follows: 1) age of 15 years or less; 2) single-phase contrast-enhanced abdominopelvic and chest CT examinations; and 3) CT scans with clinically acceptable image quality, as assessed by the pediatric radiologist at each institution. CT angiography examinations, multiphase CT examinations, CT scans with inadequate image quality for daily practice, and CT examinations performed for research were not included for this study. Exclusion criteria were a lack of information on the body weight, body weight > 80 kg, and dual-energy CT examinations.

The scout image, a set of axial images, and dosage reports were stored in the Digital Imaging and Communications in Medicine (DICOM) format after being de-identified, and data were transferred to the hospitals. Patients' body weights were collected manually by reviewing electronic medical records and radiology information systems or calculated from the amount of contrast medial used for the CT scans. The application of the iterative reconstruction and its strength and use of the automatic kilovoltage control protocols for pediatric CT examinations were surveyed per institution.

Data Processing and Data Retrieving

CT scans were transferred to commercial dose management software (Radimetrics, Bayer Healthcare, Leverkusen, Germany) to retrieve the institution name, CT scanner model, scan region, age, sex, weight, peak kilovoltage (kVp), effective diameter, and DRL quantities, including volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP). The effective dose was automatically calculated with Radimetrics software, with tissue weighting factors from ICRP publication 103 [12]. In our study, the reference phantom size of DRL quantities of abdominopelvic and chest CT examinations was 32 cm; therefore, dose metrics based on the 16-cm phantom size were converted to 32-cm phantom-based values by multiplying with a factor of 0.5. The measurement of the effective diameter, calculation of size-specific dose estimates (SSDE), and outlier detection are described in Supplementary Materials.

Grouping of Patients

First, we adopted weight bands from previously published

guidelines for establishing DRLs for pediatric CT scans [10,13]. Weight bands were grouped as follows: 5 kg, < 5 kg; 15 kg, 5 to < 15 kg; 30 kg, 15 to < 30 kg, 50 kg, 30 to < 50 kg; and 80 kg, 50 to < 80 kg. Second, data were grouped by using effective diameter as follows: < 13 cm; 14–16 cm; 17–20 cm; 21–24 cm; and > 24 cm. Since previously published DRLs with grouping of data by the body size used the lateral dimensions, 15, 19, 24, and 29 cm, the equivalent effective diameter was approximated from the American Association of Physicists in Medicine (AAPM) 204 report [14-17]. Third, age was used for grouping of dose data for comparison with other DRLs as follows: 0, < 1 month; 1 year, 1 month to < 1 year; 5 years, 1 to < 5 years; 10 years, 5 to < 10 years; and 15 years, 10 to < 15 years.

Setting of DRL

The median values of each DRL quantity for each group and hospital were calculated and defined as typical values [10]. Subsequently, the local DRL was set at the 75% value of the distribution of each hospital's typical values. This approach was recommended by both the ICRP and European guidelines [10,13]. Typical values were excluded if the number of examinations was fewer than five in each group for calculation of the DRL. Moreover, the DRL was set at the 75% value of the pooled distribution of entire institutions when the number of typical values in a group was less than five. $CTDI_{vol}$, SSDE, and DLP were used for DRL quantities. Distribution of the effective dose was modeled for pooled distribution after removing the upper and lower 5% values in each weight and age band.

Table 1. Patient Groups

|	Age				Effective Diameter			SSDE Conversion Factor		
	Count	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum
Abdomen										
Weight, kg										
5	17	0.1	0	0.7	11	9	14	2.47	2.22	2.66
15	259	2	0.2	7	15	12	18	2.14	1.91	2.38
30	520	6.4	1.9	15.9	17	13	22	1.98	1.65	2.30
50	496	11.1	3.9	16	21	12	28	1.71	1.32	2.38
80	333	13.7	9	17	24	19	30	1.53	1.23	1.84
Chest										
Weight, kg										
5	28	0.1	0	0.4	11	9	13	2.47	2.3	2.66
15	245	1.7	0.1	8.3	14	11	17	2.22	1.98	2.47
30	292	6	1.4	15.5	17	13	29	1.98	1.28	2.30
50	221	11.3	5.8	15.8	22	14	26	1.65	1.43	2.22
80	83	14	9.7	15.9	25	22	34	1.48	1.06	1.65

SSDE = size-specific dose estimates
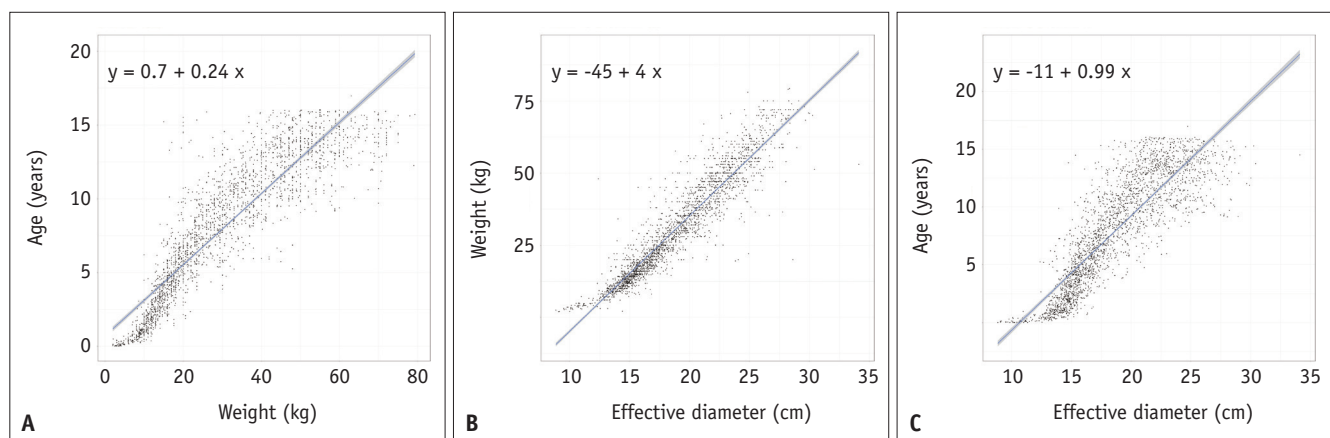
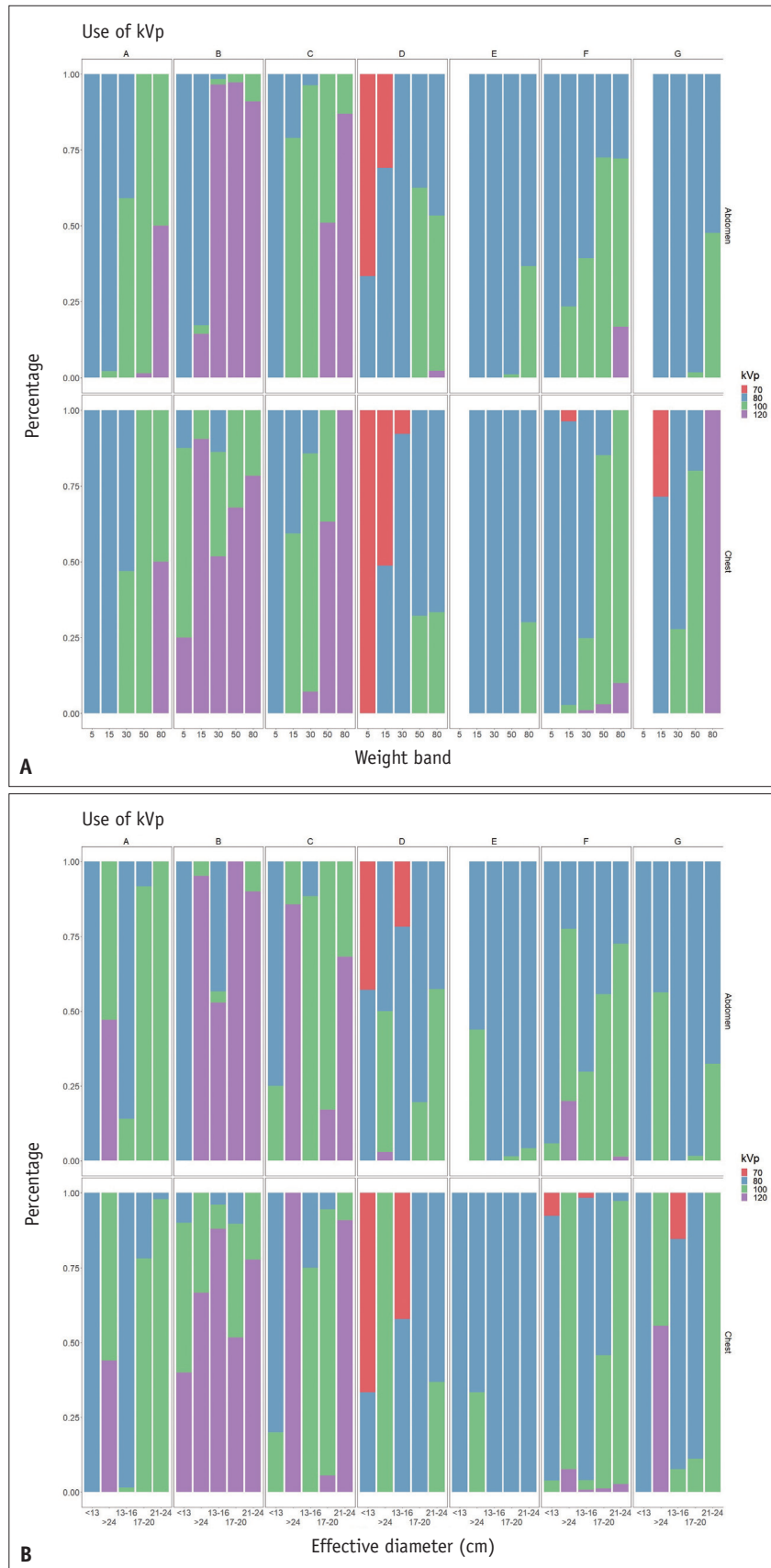Fig. 1. Scatter plots of weight by age (A), effective diameter by weight (B), and effective diameter by age (C).

Fig. 2. Distributions of kVp by the (A) weight band and (B) effective diameter. kVp = peak kilovoltage

Statistical Analysis

Descriptive statistics included the median, minimum, maximum, 25th percentile, and 75th percentile for each DRL quantity. These descriptive statistics were analyzed for each variable according to the institution, scan region, weight, effective diameter, and age. The linear-by-linear association test was performed to evaluate the relationship between the kVp and the body weight and between the kVp and the effective diameter. Statistical analyses were performed using MedCalc Statistical Software version 19.2.1 (MedCalc Software Ltd.) and IBM SPSS Statistics for Windows version 25.0 (IBM Corp.). A p value < 0.05 was considered statistically significant.

RESULTS

A total of 2909 CT examinations were collected retrospectively from nine university hospitals and uploaded to the automatic dose management system. Automatic analyses of the radiation dose failed in 64 CT examinations for the following reasons: 35 CT examinations from five hospitals were not recognized by the automated dose management system, and 29 CT examinations from five hospitals had insufficient CT images. Finally, a total of 2845 CT examinations were valid for the dose analysis. Although the effective diameter was not automatically retrieved in 215 examinations from one hospital, it was measured manually.

Among the 2845 valid CT examinations, 226 from two institutions without information on the body weight, 35 with body weight > 80 kg, and 24 dual-energy ones were excluded. Twelve CT examinations with an inappropriate age for the weight band and 54 CT examinations with extreme DRL quantities were excluded during the outlier detection.
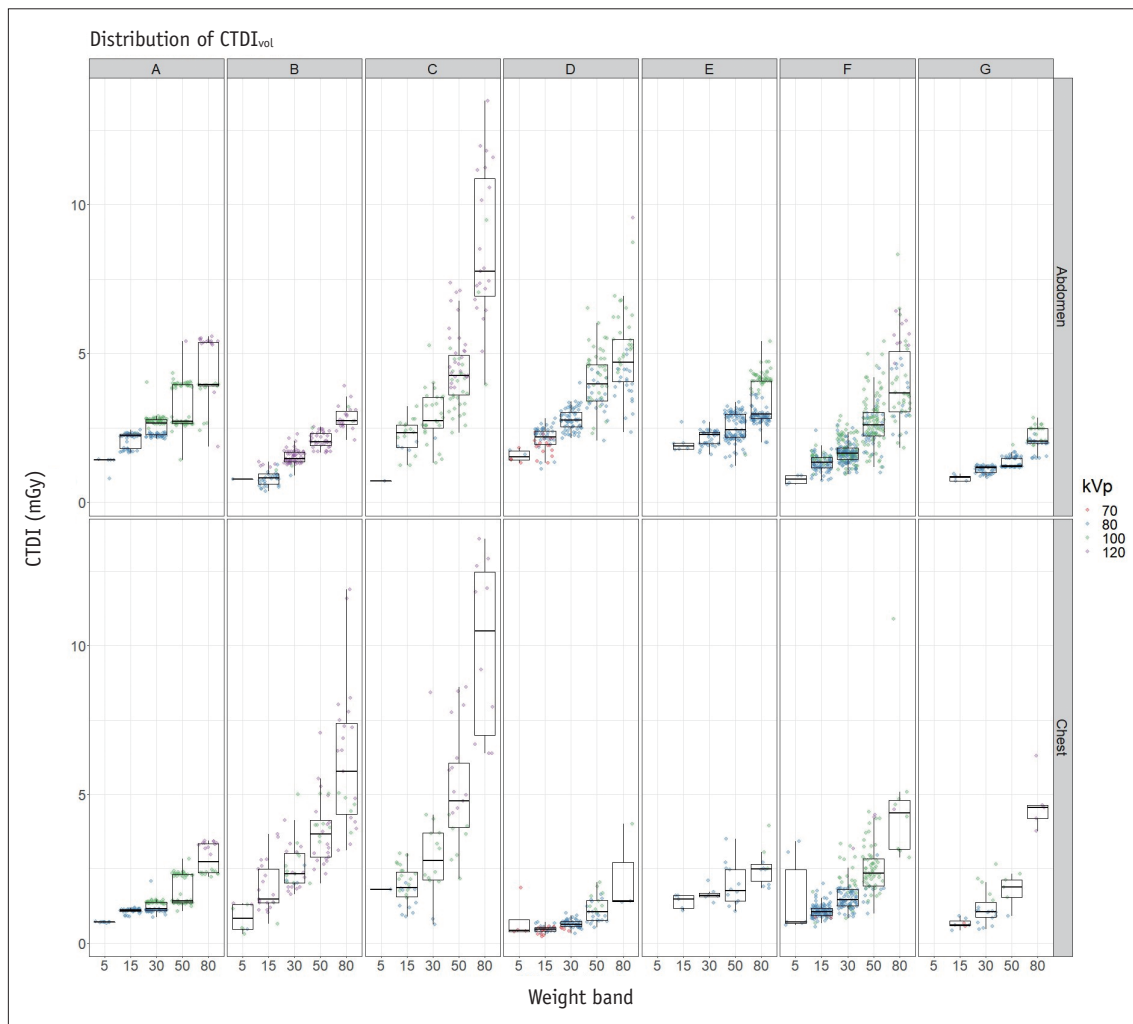

Fig. 3. Distribution of the CTDI$_{vol}$ by the weight band in each institution. The reference phantom size is 32 cm. CTDI$_{vol}$ = volume CT dose index, kVp = peak kilovoltage

Finally, 2494 CT examinations (1625 abdominopelvic and 869 chest CT examinations) from seven institutions were enrolled for the dose analysis.

Table 1 shows the patient age, effective diameter, and conversion factor for SSDE categorized with weight bands. Figure 1A represents a scatter plot for the body weight by age. The body weight strongly correlated with age (Kendall's tau-b; 0.77, $p < 0.01$). Figure 1B and C show a scatter plot of the effective diameter for the body weight and age, respectively. The effective diameter strongly correlated with the body weight (Kendall's tau-b; 0.82, $p < 0.01$) and moderately correlated with age (Kendall's tau-b; 0.7, $p < 0.01$).

All institutions used iterative reconstruction for both abdominopelvic and chest CT scans. The strengths of the iterative reconstruction were low, medium, and high at one, five, and one institution, respectively. Tube current modulation was applied for 88% of abdominopelvic CT scans and 93% of chest CT scans. All CT examinations were performed using multi-detector row CT scanners equipped with more than 64 channels.

Figure 2 shows the distribution of kVp in each weight and effective diameter band. The range of kVp was from 70 to 120; institutions D, F, and G used 70 kVp for small children. The kVp showed statistically significant linear-by-linear associations with the both weight and effective diameter in both abdominopelvic and chest CT examinations ($p < 0.01$). Institutions D, F, and G used the automatic kV control for pediatric body CT examinations.

Supplementary Tables 1 and 2 summarize the CTDI$_{vol}$, DLP, and SSDE of the abdominopelvic and chest CT examinations with weight bands. Figures 3, 4, and 5 represent the distributions of the CTDI$_{vol}$, SSDE, and DLP in each weight band.
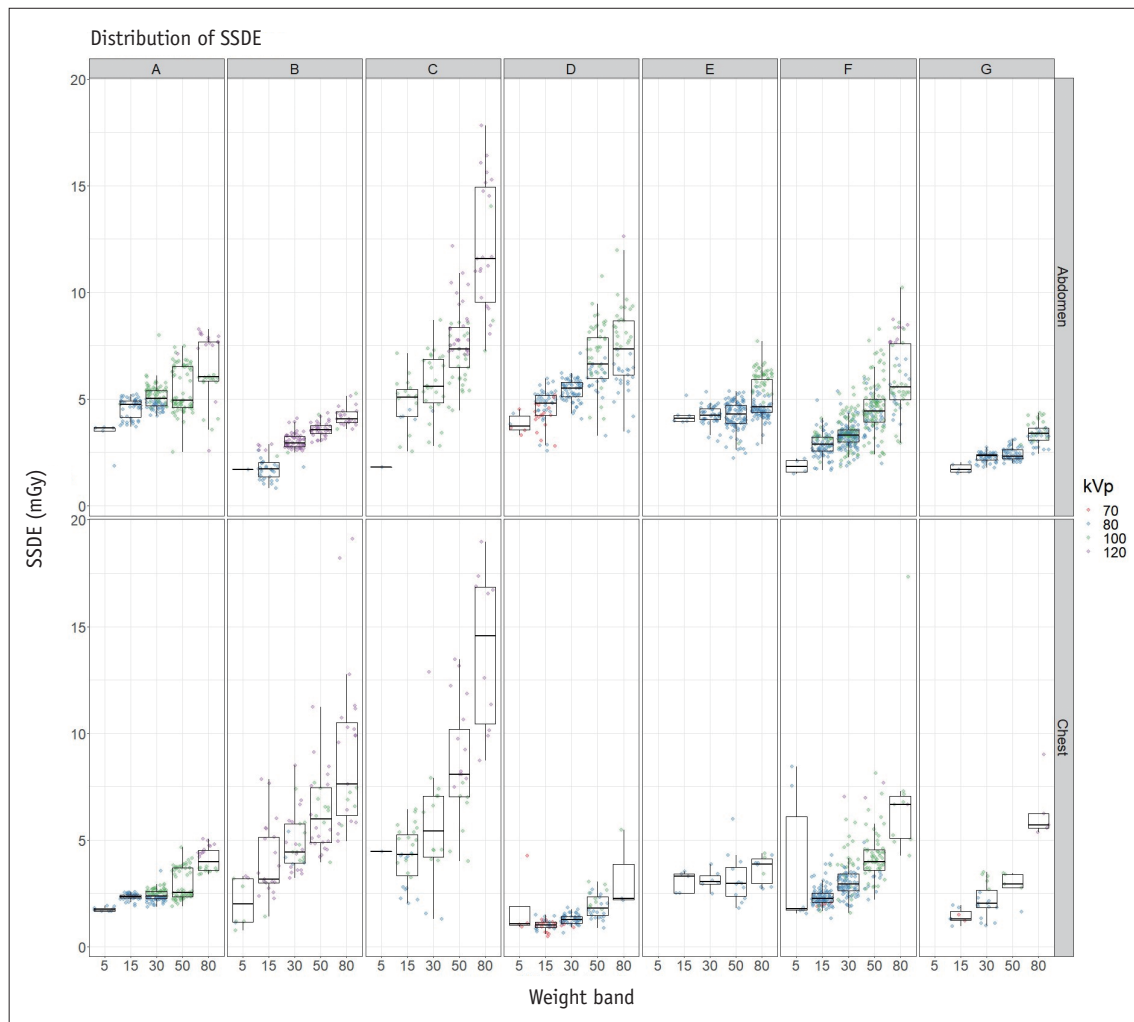

Fig. 4. Distribution of the SSDE by the weight band in each institution. kVp = peak kilovoltage, SSDE = size-specific dose estimates

Summaries of SSDE in effective diameters are shown in Supplementary Tables 3 and 4. Figure 6 represents a scatter plot of the $CTDI_{vol}$ by SSDE. The SSDE in all weight bands was greater than the $CTDI_{vol}$ for both abdominopelvic and chest CT. Supplementary Tables 5 and 6 show the distribution of DRL quantities in age bands.

Tables 2 and 3 represent the local DRL for each weight band and effective diameter for both abdominopelvic and chest CT. The DRLs based on the age bands are shown in Supplementary Table 7. Since the sample sizes of the weight band in weight of 5 kg, effective diameter < 13 cm, and age band of 0 years were insufficient to set DRLs from the typical values, those DRLs were set from the pooled distribution of entire institutions.

Table 4 shows the distribution of effective doses.

A comparison of DRLs obtained from this study with published DRLs is shown in Table 5 [9,14-16,18-21]. In our study, for the body weight of 5, 15, 30, 50, and 80 kg, $CTDI_{vol}$ of DRLs were 1.4, 2.2, 2.7, 4.0, and 4.7 mGy, respectively, for abdominopelvic CT and 1.2, 1.5, 2.3, 3.7, and 5.8 mGy, respectively, for chest CT. In European DRL, for the body weight of 5, 15, 30, 50, and 80 kg, $CTDI_{vol}$ of DRLs were 3.5, 5.4, 7.3, and 18 mGy, respectively, for abdominopelvic CT and 1.4, 1.8, 2.7, 3.7, and 5.4, respectively, for chest CT [9]. DRLs were generally lower than those from other countries for abdominopelvic CT. However, DRLs of chest CT were slightly higher than those of the United States and Europe.

DISCUSSION

Our study was aimed at establishing local DRLs for pediatric body CT examinations from several university hospitals in South Korea. This is the first multicenter dose
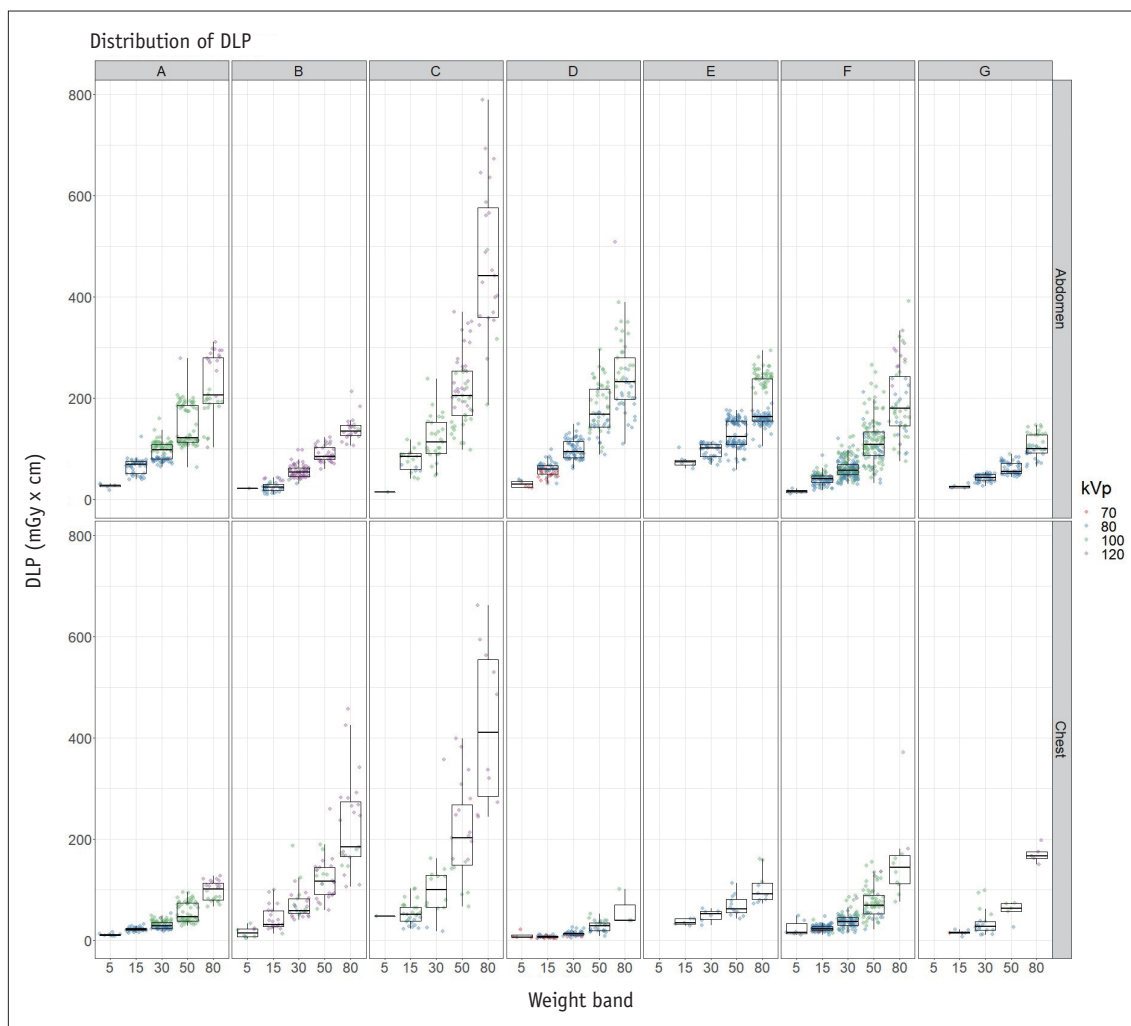

Fig. 5. Distribution of the DLP by the weight band in each institution. DLP = dose–length product, kVp = peak kilovoltage
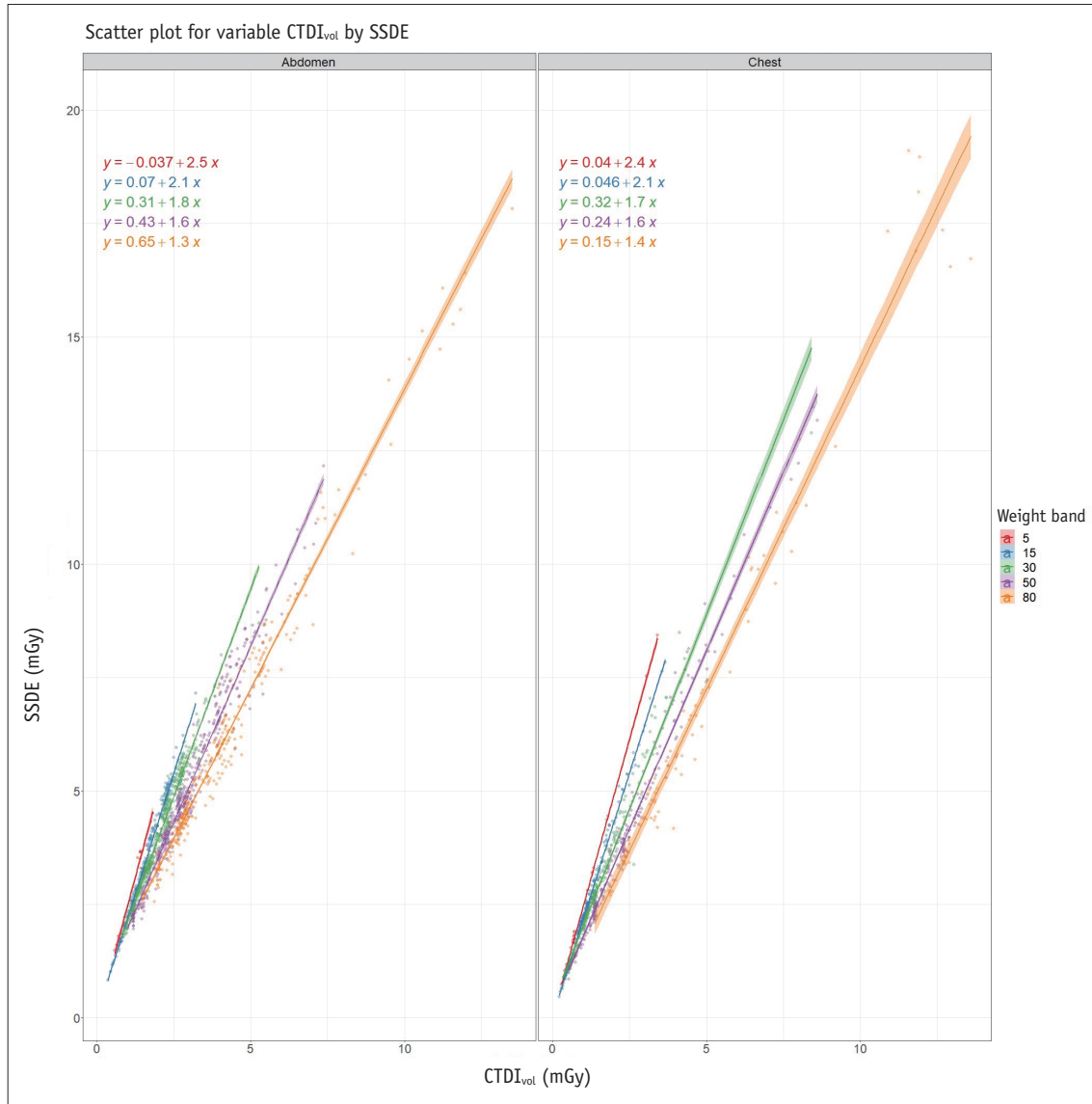
Fig. 6. Scatter plot of the CTDI_vol by the SSDE. CTDI_vol = volume CT dose index, SSDE = size-specific dose estimates

survey of pediatric CT examinations in South Korea, with grouping of patients by the body weight and size. There are various classes of DRL according to the target group of the dose survey, including typical, local, national, and regional DRLs [10]. Typical values represent the median value of the distribution in a healthcare facility or X-ray unit that is used to identify X-ray units requiring further optimization. The local DRL is typically set at the third quartile of the typical values of several healthcare facilities or X-ray units; thus, the DRL value in our study was a local DRL for a pediatric body CT examination. The national DRL should be based on most healthcare facilities across an entire country, and regional DRL is based on the DRL values of several countries within one geographic region or continent.

This study was an update of a previously published dose survey conducted in 2015 [21]. DRL values for both abdominopelvic and chest CT examinations were lower than the previous dose survey. Moreover, DRL values in this study were generally lower than those of other countries. Nevertheless, DRL values for chest CT examinations of larger patients were slightly higher than those in the United States and Europe, indicating the need for reviewing and optimizing CT protocols.

A different sampling of dose data may primarily affect differences in DRL values between the present and previous studies conducted in Korea. This study collected CT scans from several university hospitals where pediatric CT scans are performed frequently. It is more likely that designing

and optimizing CT protocols are well managed by pediatric radiologists in these university hospitals. In our study, all institutions routinely applied iterative reconstruction and modern technologies, such as automatic tube current modulation. Moreover, several hospitals used the automatic kV control to optimize their CT protocols. However, the previous study sampled dose data from various hospitals that referred to a single tertiary hospital [21]. Thus, CT examinations from many hospitals where pediatric X-ray procedures are performed infrequently or with suboptimal pediatric CT scan protocols might have been included. Furthermore, CT examinations were performed with modern CT scanners equipped with more than 64 channels, while the previous study included examinations performed with

Table 2. Local Diagnostic Reference Levels of Abdominopelvic and Chest CT for Weight Bands

		CTDI$_{vol}$			SSDE			DLP		
	Count	Percentile 75	Median	Percentile 25	Percentile 75	Median	Percentile 25	Percentile 75	Median	Percentile 25
Scan										
Abdominopelvic										
Weight, kg										
5	17*	1.4	1.4	0.8	3.7	3.5	1.8	30.0	24.1	17.7
15	7	2.2	1.9	0.8	4.8	4.1	1.7	73.8	59.9	25.6
30	7	2.7	2.3	1.5	5.5	4.2	2.9	101.2	94.1	54.3
50	7	4.0	2.6	2.0	6.6	4.4	3.6	168.8	121.5	84.5
80	7	4.7	3.7	2.7	7.3	5.6	4.1	233.0	179.8	135.5
Chest										
Weight, kg										
5	28*	1.2	0.7	0.6	3.0	1.7	1.4	21.5	12.1	8.9
15	7	1.5	1.1	0.6	3.3	2.3	1.3	34.6	23.4	14.0
30	7	2.3	1.5	1.1	4.4	2.9	2.0	59.0	37.5	28.0
50	7	3.7	1.9	1.4	6.0	2.9	2.5	117.4	63.0	46.5
80	6	5.8	4.5	2.7	7.6	6.2	4.0	184.4	155.6	101.1

*Numbers represents count of pooled distribution of each age band. Other counts represent number of institutions. CTDI$_{vol}$ = volume CT dose index, DLP = dose–length product, SSDE = size-specific dose estimates

Table 3. Local Diagnostic Reference Levels of Abdominopelvic and Chest CT for Effective Diameter Bands

		SSDE			CTDI$_{vol}$			DLP		
	Count	Percentile 75	Median	Percentile 25	Percentile 75	Median	Percentile 25	Percentile 75	Median	Percentile 25
Scan										
Abdomen										
Effective diameter, cm										
< 13	61*	4.1	3.5	2.1	1.8	1.4	0.9	46.2	32.0	21.5
14–16	7	5.0	4.0	2.6	2.3	1.9	1.3	79.0	66.5	41.9
17–20	7	5.7	4.1	3.2	3.0	2.2	1.7	112.6	107.6	66.2
21–24	7	7.1	4.8	3.8	4.3	2.9	2.3	190.5	153.9	104.2
> 24	7	7.2	6.0	4.1	5.0	3.9	2.7	238.2	201.4	132.4
Chest										
Effective diameter, cm										
< 13	73*	2.8	2.0	1.6	1.2	0.9	0.6	23.6	17.9	9.3
14–16	7	4.6	2.4	1.8	2.2	1.1	0.8	50.0	25.9	20.0
17–20	7	4.3	3.0	1.9	2.3	1.6	1.0	62.0	45.2	27.0
21–24	7	5.3	3.5	3.0	3.3	2.1	1.8	111.4	71.3	55.9
> 24	7	7.5	5.4	3.4	5.0	3.8	2.4	180.0	119.7	85.4

*Numbers represents count of pooled distribution of each age band. Other counts represent number of institutions. CTDI$_{vol}$ = volume CT dose index, DLP = dose–length product, SSDE = size-specific dose estimates

Table 4. Distribution of the Effective Dose for Each Weight and Age Band

	Effective Dose					
	Count	Mean	Standard Deviation	Median	Percentile 25	Percentile 75
Scan						
Abdominopelvic						
Weight, kg						
5	17	2.4	0.9	2.6	1.4	3.0
15	259	2.7	1.1	2.6	1.8	3.7
30	520	2.7	1.0	2.5	2.0	3.4
50	496	3.2	1.3	3.0	2.4	3.9
80	333	4.1	2.0	3.4	2.9	4.8
Chest						
Weight, kg						
5	28	1.7	1.3	1.2	1.0	2.3
15	245	1.6	1.0	1.4	1.1	1.8
30	292	1.6	1.1	1.4	1.0	1.9
50	221	2.3	1.7	1.9	1.2	2.7
80	83	4.2	2.8	3.1	2.3	5.4
Scan						
Abdominopelvic						
Age, years						
0	9	2.4	0.9	2.6	1.4	3.0
1	75	2.8	1.2	2.9	1.6	3.8
5	348	2.7	1.0	2.4	1.9	3.4
10	484	2.9	1.2	2.8	2.0	3.5
15	709	3.6	1.7	3.1	2.7	4.2
Chest						
Age, years						
0	13	1.4	0.8	1.2	0.8	1.3
1	64	1.7	1.2	1.4	0.7	2.2
5	288	1.5	0.9	1.4	1.1	1.7
10	238	1.8	1.2	1.5	1.1	2.1
15	266	2.9	2.3	2.2	1.5	3.4

older CT scanners with less than 16 channels. Improvement in hardware with better dose efficiency, dedicated automatic exposure control, and development of iterative reconstruction may substantially contribute to radiation dose reduction [22]. Therefore, care should be taken when comparing the results of this study with that of the previous dose survey.

Estimating and managing the dose from X-ray procedures in pediatric patients are challenging. There is a wide variation because of the different body habitus with growth; thus, standardization of the patient in a single reference band is not possible, particularly for conventionally used age bands [15,16,23]. The patient's weight, cross-sectional area, or body dimension may be used as an alternative to age in optimizing CT protocols. In previous studies, the patient's individual size did not correlate with age; therefore, the authors

suggested that patient size is preferable to age bands when designing protocols for imaging procedures and managing radiation doses [10,24]. Furthermore, as modern radiography, fluoroscopy, and CT scanners have equipped automatic exposure control systems or tube current modulation based on the attenuation of the regions of interest [10,25,26], the grouping of the dose survey into the patient size or water-equivalent diameter should be considered for establishing DRLs in pediatric CT examinations.

However, the application of the body size and X-ray attenuation characteristics require additional workload and dedicated software, hindering their use in routine practice and dose surveys. In our study, all hospitals used CT protocols designed according to the patient's body weight, and none of the hospitals used the body size or X-ray attenuation characteristics. Few studies conducted dose

Table 5. Comparison of Diagnostic Reference Levels

		Abdominopelvic					Chest				
Body Weight (kg)		< 5	5–< 15	15–< 30	30–< 50	50–< 80	< 5	5–< 15	15–< 30	30–< 50	50–< 80
Equivalent Age		< 1 m	1 m–< 4 y	4–< 10 y	10–< 14 y	14–< 18 y	< 1 m	1 m–< 4 y	4–< 10 y	10–< 14 y	14–< 18 y
Equivalent Body Width (cm)			< 18	18–23	24–30	31–35		< 18	18–23	24–30	31–35
This study	CTDI (mGy)	1.4	2.2	2.7	4	4.7	1.2	1.5	2.3	3.7	5.8
	SSDE (mGy)	3.7	4.8	5.5	6.6	7.3	3	3.3	4.4	6	7.6
	DLP (mGy x cm)	30	73.8	101.2	168.8	233	21.5	34.6	59	117.4	184.4
Korea (previous study) (2015) [21]	CTDI (mGy)	3.8	4.5	6.2	8.3	...	2.8	3.4	4.6	6.9	...
	SSDE (mGy)	5.6	6.7	10.1	13.1	...	3.6	5.3	7.2	11.4	...
	DLP (mGy x cm)	98	169	256.5	390	...	26.5	60.5	80	236.5	...
United States (2013, 2017) [15,16]	CTDI (mGy)	...	5	7.1	9.8	14	...	1.8	2	3.2	4.8
	SSDE (mGy)	...	12	13.4	16.4	19	...	3.9	4.5	5.1	6.6
	DLP (mGy x cm)	...	105.7	244.9	418	650.8	...	28	52	80	148
Europe (2018) [9]	CTDI (mGy)	...	3.5	5.4	7.3	13	1.4	1.8	2.7	3.7	5.4
	DLP (mGy x cm)	45	120	150	210	480	35	50	70	115	200
Japan (2015) [20]	CTDI (mGy)	...	5.5	8	8.5	...	...	5.5	7	7.5	...
	DLP (mGy x cm)	...	110	200	265	...	...	105	150	205	...
Australia (2015) [18]	CTDI (mGy)	...	7	10	...	...	...	2	5	...	...
	DLP (mGy x cm)	...	170	390	...	...	...	60	110	...	...
Australia and New Zealand (2015) [14]	SSDE (mGy)		11.5	15	15	16.2		7.9	9.4	12	12
Germany (2019) [19]	CTDI (mGy)	...	...	5	7	...	1	1.7	4	6.5	...
	DLP (mGy x cm)	...	...	185	310	...	15	25	110	200	...

CTDI = CT dose index, DLP = dose-length product, m = months, SSDE = size-specific dose estimates, y = years

surveys for pediatric CT examinations by grouping patients according to the body size [14-16].

Therefore, current guidelines on establishing DRLs in pediatric CT scans recommend grouping of dose surveys into body weight groups instead of the classically used age bands [10,13]. In a previous study, the authors suggested grouping the survey data based on patient weight when a smaller sample is used and using age groups when the patient's weight is not known or with large sample sizes, particularly in less-developed countries [11]. According to previous studies, which achieved similar results as our study, the weight well-correlated with the body size [20,27,28].

Our study had several limitations. First, data of neonates and infants are not sufficient to obtain typical values in some institutions, and therefore, DRLs were obtained from the pooled data. Although we collected data from one or two CT scanners that performed most pediatric CT examinations in a given period, some examinations in this age group were still challenging.

Second, patient weight was calculated from the amount of contrast agents used during the CT examination in six of seven hospitals because information on the body weight was not easily accessible in many hospitals. Although modern CT scanners can embed the body weight into the DICOM header, its current use seems limited in most institutions. Embedding of the variables that can be used for the analysis of the radiation dose, such as the weight, height, and X-ray attenuation characters into the DICOM header will facilitate automated, time-saving, and precise dose surveys in the future.

Third, care should be taken in interpreting the data of this study because this study was conducted based on university hospitals, which are likely to have well-optimized pediatric CT protocols. It is important to recognize that the DRL values of our study were local DRLs of several university hospitals and not the national DRLs.

Finally, we did not conduct structured image quality assessments for collected CT scans because of the large sample size. Pediatric radiologists confirmed that the CT scans we collected had clinically acceptable quality. Various factors, such as the age, clinical status, clinical indication, and the radiologist's personal preference, may affect determining acceptable image quality and optimizing CT protocols.

In conclusion, our study set local DRLs in pediatric abdominopelvic and chest CT examinations based on the weight and body size by using an automated dose collection system. The DRL values were decreased compared to the previous dose survey and values from other countries. Further studies with more facilities should be performed for the development of national DRLs and regular update of the current DRLs.

Supplement

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Conflicts of Interest
The authors have no potential conflicts of interest to disclose.

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Conceptualization: Jae-Yeon Hwang, Young Hun Choi. Data curation: Jae-Yeon Hwang, Young Hun Choi. Formal analysis: Jae-Yeon Hwang. Funding acquisition: Jae-Yeon Hwang. Investigation: Young Hun Choi, Hee Mang Yoon, Young Jin Ryu, Hyun Joo Shin, Hyun Gi Kim, So Mi Lee, Sun Kyung You, Ji Eun Park. Methodology: Young Hun Choi, Hee Mang Yoon. Project administration: Jae-Yeon Hwang. Visualization: Jae-Yeon Hwang. Writing—original draft: Jae-Yeon Hwang, Young Hun Choi. Writing—review & editing: Hee Mang Yoon, Young Jin Ryu, Hyun Joo Shin, Hyun Gi Kim, So Mi Lee, Sun Kyung You, Ji Eun Park.

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