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Background : *CT is a standard imaging tool for assessing a variety of pediatric disorders. However, a major drawback of these scans is the use of ionizing radiation which potentially increases radiation-related malignancy risk. There has been no available data of pediatric radiation dose from chest and abdomen CT at KCMH.*

Objective : *To assess radiation dose parameters and image quality of our pediatric multi-slice chest and abdomen CT examinations, and compare them to the diagnostic reference levels (DRLs) in order to minimize or eliminate the amount of unnecessary radiation exposure.*

Design : *Retrospective descriptive data.*

Setting : *Department of Radiology, Faculty of Medicine, Chulalongkorn University.*

Materials and Methods : *Of the total 49 examinations of chest CT and 25 examinations of abdomen CT during Jan 2010 - June 2010, volume CT dose index ($CTDI_{vol}$), dose length product (DLP) and image noises were collected. Effective dose was accomplished by multiply adjusted DLP with region- and age-specific conversion coefficients. Third quartile values of $CTDI_{vol}$ and DLP were compared to the DRLs.*

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Results : *None of the patients aged below 5 years received* $CTDI_{vol}$ *and DLP greater than those of the DRLs in chest and abdomen CT examinations, while, a significant number of the patients aged older than 5 years did. Thirteen out of 49 patients (27%) received* $CTDI_{vol}$ *and DLP greater than those of the DRLs from chest CT, 8 out of 25 patients (32%) received* $CTDI_{vol}$ *greater than that of the DRLs from whole abdomen CT and almost all of them were not performed following the department protocol. Image quality (image noise and image quality score) seemed to be greater among patients aged above 5 years in both protocols.*

Conclusion : *Our radiation dose parameters were within the DRLs range in patients aged below 5 years but not in those above 5 years. Being stringent to CT protocol seems to be a good solution. The percentage of the studies not done following the protocol should be solved and monitored.*

Keywords : $CTDI_{vol}$, *DLP, effective dose, image qualitly.*

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เหตุผลของการทำวิจัย : *เอ็กซเรย์คอมพิวเตอร์เป็นเครื่องมือที่จำเป็นในการวินิจฉัยโรคในเด็ก แต่ข้อเสียที่สำคัญคือปริมาณรังสีที่ได้รับ และยังไม่มีข้อมูลเกี่ยวกับปริมาณรังสีที่ได้รับในการตรวจเอ็กซเรย์คอมพิวเตอร์ทรวงอกและช่องท้อง*

วัตถุประสงค์ : *เพื่อศึกษาหาปริมาณรังสีที่ผู้ป่วยเด็กได้รับจากการทำเอ็กซเรย์คอมพิวเตอร์ทรวงอกและช่องท้องในแต่ละครั้ง และเปรียบเทียบกับค่าอ้างอิงของต่างประเทศ เพื่อช่วยในการปรับตั้งค่าให้เหมาะสมมากยิ่งขึ้น และสามารถช่วยลดปริมาณรังสีลงได้*

รูปแบบการวิจัย : *การศึกษาแบบย้อนหลังเชิงพรรณนา*

สถานที่ทำวิจัย : *ภาควิชารังสีวิทยา คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย*

ตัวอย่างและวิธีการศึกษา : *ในช่วงเวลาตั้งแต่เดือนมกราคมถึงมิถุนายน ปีพ.ศ. 2553 มีการตรวจเอ็กซเรย์คอมพิวเตอร์ทรวงอก 49 การตรวจ การตรวจเอ็กซเรย์คอมพิวเตอร์ช่องท้อง 25 การตรวจ ค่า* $CTDI_{vol}$*, DLP, image noise และค่า effective dose จึงได้มาจากการนำ region- and age-specific conversion coefficients มาคูณกับค่า DLP ที่ปรับแล้ว จะถูกเก็บรวบรวม และทำการเปรียบเทียบค่าที่ได้เหล่านี้กับค่ามาตรฐาน โดยใช้ค่าควอไทล์ที่ 3*

ผลการศึกษา : *ในกลุ่มอายุน้อยกว่า 5 ปี ค่า* $CTDI_{vol}$ *และ DLP จากการตรวจเอ็กซเรย์คอมพิวเตอร์ทรวงอกและช่องท้องมีค่าไม่เกินค่ามาตรฐาน ในกลุ่มอายุมากกว่า 5 ปี 27% ของการตรวจเอ็กซเรย์คอมพิวเตอร์ทรวงอก และ 32% ของการตรวจเอ็กซเรย์คอมพิวเตอร์ช่องท้อง มีค่า* $CTDI_{vol}$ *และ DLP เกินค่ามาตรฐาน โดยที่เกือบทั้งหมดของการตรวจที่มีค่า* $CTDI_{vol}$ *และ DLP เกินค่ามาตรฐาน มีการตั้งค่าพารามิเตอร์ของการตรวจที่ไม่เป็นไปตามที่สถาบันกำหนด ในส่วนของคุณภาพของภาพ พบว่าคุณภาพของภาพดีกว่าในกลุ่มอายุมากกว่า 5 ปี*

สรุป : *ปริมาณรังสีที่ผู้ป่วยเด็กในโรงพยาบาลจุฬาลงกรณ์ได้รับจากการตรวจเอ็กซเรย์คอมพิวเตอร์ทรวงอกและช่องท้อง สำหรับกลุ่มอายุน้อยกว่า 5 ปี พบว่าอยู่ในเกณฑ์ที่เหมาะสม ในขณะที่ในกลุ่มอายุมากกว่า 5 ปี มีผู้ป่วยบางส่วนได้รับปริมาณรังสีมากกว่าค่าอ้างอิงของต่างประเทศ เกิดจากการใช้ค่าพารามิเตอร์ที่ไม่เป็นไปตามที่สถาบันกำหนด ดังนั้นแนวทางการแก้ไขคือ การเข้มงวดในวิธีตั้งค่าการตรวจ*

คำสำคัญ : *$CTDI_{vol}$, DLP, effective dose, image quality.*

Computed tomography (CT) is a standard imaging tool for assessing a variety of pediatric disorders. [1-5] However, a major drawback of these scans is the use of ionizing radiation which potentially increases radiation-related malignancy risk, the most important side effect in both adults and children. There are three major considerations in children. First, children are considerably more sensitive to radiation than the adult, particularly in their infancy.[6] Second, small children will receive a greater radiation dose than larger children or adults from the same CT parameter settings.[7] Third, children have a longer time span in which to manifest radiation-related cancer which will be evident after decades.[8-10]

Thus, particular emphasis has been posed on the reduction of radiation dose for pediatric CT. Only with justification, CT will be performed. To optimize a CT protocol, radiologist, technician and (if any) medical physicist should balance dose reduction and image quality because adjusting each parameter represents a trade-off.

At King Chulalongkorn Memorial Hospital (KCMH), there was baseline data of radiation dose in pediatric brain CT. [10] We carried out this study to assess radiation dose and image quality in pediatric chest CT and abdomen CT which are the 2nd and 3rd commonly performed pediatric CT at our hospital.

Materials and Methods

Data from a retrospective review of all pediatric patients who underwent chest CT (either non-contrast enhanced studies or contrast enhanced studies) or whole abdomen CT (venous-phased contrast enhanced studies) on our somatom sensation-16 (Siemens Healthcare, Forchheim, Germany) from January 2010 to June 2010 were collected. Inform consent was waived under the suggestion of the ethics committee of the institution.

The patients were classified according to age into four groups: <1 year, 1-5 years (1 year to 4 years 11 months), 5 - 10 years (5 years to 9 years 11 months), and 10 - 15 years (10 years to 14 years 11 months). For each type of examination and each age group, the age, gender, body weight, CT scanning parameters (tube potential, tube current, slice collimation, gantry rotation time), volume CT dose index ($CTDI_{vol}$) and dose length product (DLP) were reviewed from PACS system. The scan lengths and image noises were collected by reviewing the image sets. Examinations were excluded when absent data or inappropriately recorded data due to summation of $CTDI_{vol}$ and DLP across the body regions such as chest including neck CT study or chest and abdomen CT study in continuous scan.

Study protocol

Routine chest and whole abdomen protocols at the time of this study are given in Table 1. The tube current and tube potential were adjusted depending on body-weight groups. All CT images were performed with a spiral scan with gantry rotation time, pitch, beam collimation, reconstruction section thickness and reconstruction kernel are summarized in Table 2.

Radiation dose parameters

A volume CT dose index ($CTDI_{vol}$), dose length product (DLP) and effective dose were described in this study as three important radiation dose parameters.

Table 1. Tube potential and tube current adjusted depending on patient's weight.

	Chest		Abdomen	
	Tube potential (kVp)	Tube current (mAs)	Tube potential (kVp)	Tube current (mAs)
BW < 10 kg	80	60	80	80
BW 10 - 20 kg	80	80	100	90
BW 20 - 40 kg	100	90	100	100
BW > 40 kg	100	100	120	120

Table 2. CT imaging parameters.

CT protocol	Beam collimation (mm)	Reconstructed Section Thickness (mm)	Reconstruction Kernel	Pitch	Gantry rotation time (sec)
Chest	0.75 × 16	3-5	B30f*	1.15	0.5
Abdomen	0.75 × 16	3-5	B30f*	1.15	0.5

B30f* = Medium smooth kernel in body mode

$CTDI_{vol}$ is a radiation exposure measurement (mGy), calculated for the center location as well the peripheral locations when performed with one axial scan and divided by pitch ratio. DLP is simply the $CTDI_{vol}$ multiplied by the length of the scan (in centimeters) and is given in units of mGy•cm.

The $CTDI_{vol}$ and DLP were adjusted by multiplying the console-displayed $CTDI_{vol}$ and DLP values by a factor of two, to compensate the underestimation of radiation dose calculated from using 32-cm phantom in the calculation system for chest CT and abdomen CT by somatom sensation-16.[12 - 14]

The calculated effective dose in each age group was accomplished by multiplying the adjusted DLP by age and region-specific conversion coefficient ($mSv \cdot mGy^{-1}, \cdot cm^{-1}$) as summarized in Table 3.[14]

Table 3. Age and region-specific conversion coefficient.[14]

Region of body	Effective dose per DLP (msv(mGy cm)$^{-1}$) by age			
	< 1 year	1 - 5 years	5 -10 years	10 - 15 years
Chest	0.039	0.026	0.018	0.013
Abdomen	0.049	0.030	0.020	0.015

Image quality assessment

The image noise was expressed as standard deviation (SD) of CT numbers (Hounsfield Units, HU). The image noise was done in two organs and in background air for each protocol by placing 1.0-cm^2 circular region of interests (ROIs) (Table 4.) The SD from the ROI was recorded and interpreted as the image noise. In order to minimize the potential influence of window settings, image noise was measured under a fixed window setting (width/level) for each organ and for background air: the thoracic aorta (350/45), liver and muscles (300/35), and background air (1500/-500).

The visual image quality was evaluated by a board-certificated radiologist with 2 years of post-training experience who was unaware of CT parameters. CT studies were reviewed under clinical viewing conditions at a PACS system. The reader did not review previous or subsequent studies of any patient regardless of indication or the presence or absence of pathologic condition. The radiologist graded the CT images for image quality on a 5-point scale: grade 5 (excellent) was assigned when the soft tissue contrast, sharpness of tissue interfaces, lesion conspicuity, and image degradation (caused by streaking noise or beam-hardening artifacts) were deemed superb; grade 3 (satisfactory) when image quality was fair and did not hamper image interpretation; and grade 1 (non-diagnostic) when they were considerably deteriorated and hampered image interpretation. Grade 4 corresponded to the intermediate quality between grades 5 and 3, and grade 2 corresponded to that between 1 and 3. Examples of diagnostic acceptability scores correlated with CT images are shown in Figure 1-2.

Data analysis

Radiation dose parameters and image quality (image noise and image quality score) were summarized for each protocol and for each age group. All parameters were expressed as the mean ± standard deviation. Additionally, the third quartiles of $CTDI_{vol}$ and DLP were compared to those of diagnostic reference levels (DRLs).[15]

Results

As for chest CT studies, during a 6-month period, there were a total of 58 examinations from 49 children (26 males, 23 females; mean age 6.8 years); 55 studies were performed either non-contrast enhanced CT (3/55) or contrast enhanced CT (52/55) and 3 studies were performed with both non-contrast enhanced and contrast enhanced CT. Six studies were excluded due to no available radiation dose data on PACS system (3/6), and summation of doses across other regions (3/6). Numbers of examinations in each age group were 20.4% (10/49) for <1 year, 24.5% (12/49) for 1 - 5 years, 28.6% (14/

Table 4. Region of interest location for each scan region.

CT protocol	Organ 1	Organ 2	Level
Chest	Thoracic aorta	Paraspinal muscle	Carina
Abdomen	Liver	Paraspinal muscle	Hilum

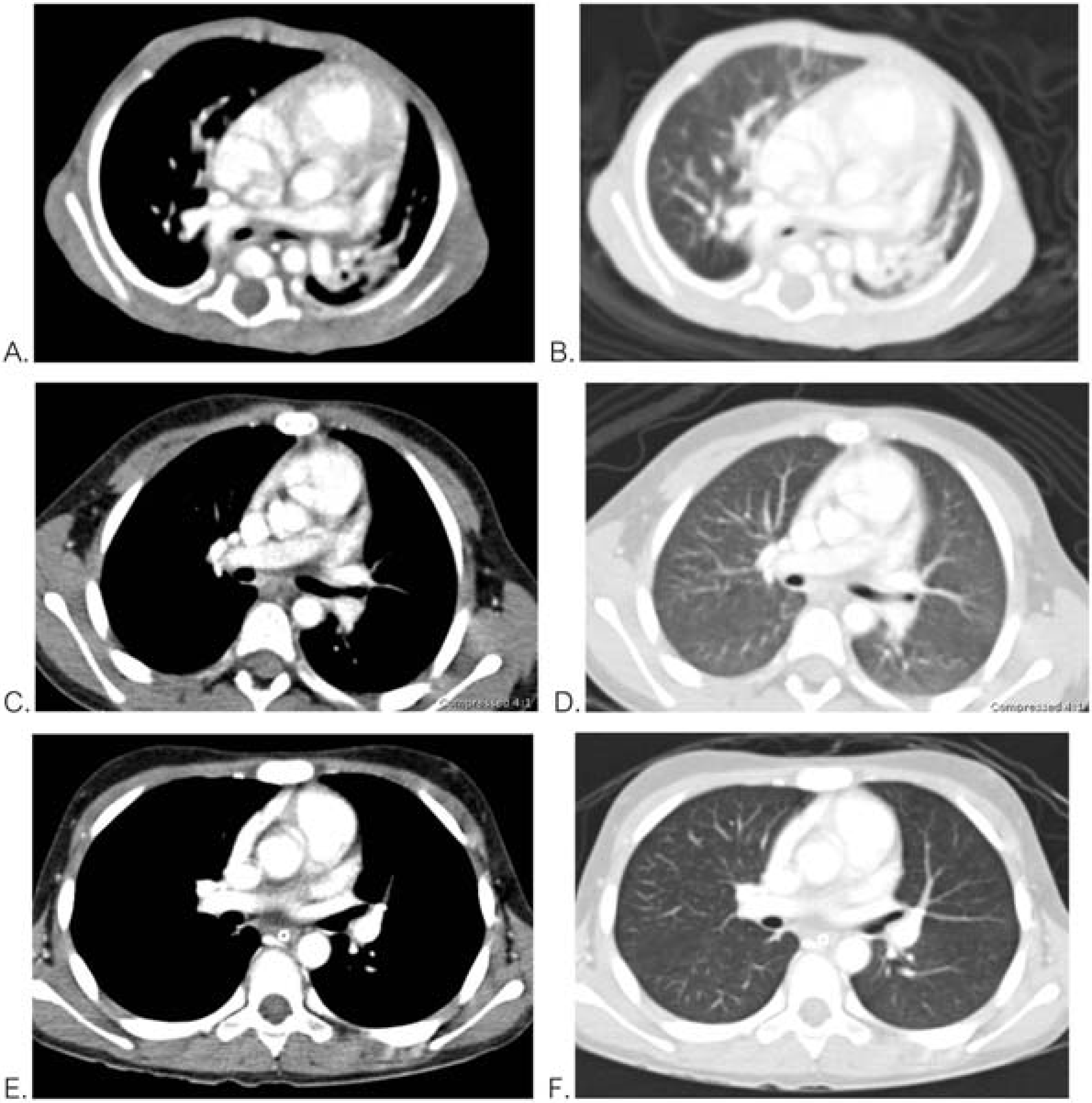

Figure 1. Chest CT at mediastinal window and lung window
A, B image quality score = 3
C, D image quality score =4
E, F image quality score =5

49) for 5 - 10 years and 29% (13/49) for 10 - 15 years. About 6% (3/49) of the examinations were performed with non-contrast enhanced CT, and the remaining (46/49) were contrast enhanced studies. The indications for chest CT were arranged in descending order as follows: neoplasm detection and surveillance (43%), infectious and inflammatory evaluation (27%), congenital malformation evaluation (12%), pre- and post operative evaluation (8%), assessment for trauma (7%), and others (3%).

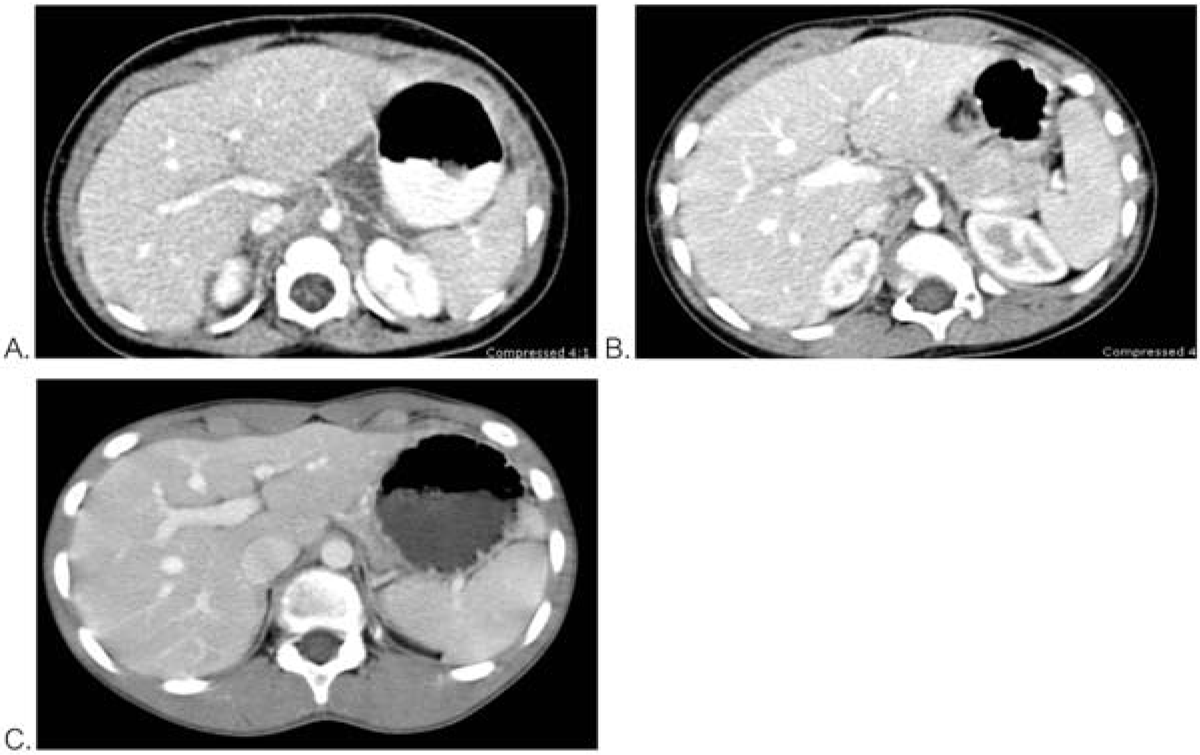

Figure 2. Whole abdomen CT
A. Image quality score = 3
B. Image quality score = 4
C. Image quality score = 5

As for abdomen CT studies, there were a total of 47 CT performed in 42 children (27 males, 15 females; mean age 6.6 years); 39 whole abdomen studies, 7 upper abdomen studies and 1 lower abdomen study. Twenty-seven studies were venous-phased contrast enhanced whole abdomen CT. Two studies were excluded due to summation of doses across other regions. Thus, 25 studies were included. Numbers of examinations in each age group were 8% (2/25) for <1 year, 28% (7/25) for 1 - 5 years, 40% (10/25) for 5 - 10 years and 24% (6/25) for 10 - 15 years. The indications for abdomen CT were arranged in descending order as follows: neoplasm detection and surveillance (84%), infectious and inflammatory evaluation (4%), pre- and post operative evaluation (4%), assessment for trauma (4%), and others (4%).

Table-5 lists the median and range values for tube potential, tube current and scan length for each age group. In both chest and whole abdomen CT studies : for age <1 year and 1-5 years, most of the examination were done at 80 kVp, for age 5-10 years, the examinations were done at 80-120 kVp and for 10 - 15 years, more than the majority of examinations were done at 120 kVp. The tube current and scan length had a tendency to increase with age group. The radiation dose parameters, image noise (quantitative image quality) and diagnostic acceptability score (visual image quality) are displayed in Table 6.

Table 5. The median and range values for tube potential, tube current and scan length for each age group.

CT protocol	N	Tube potential (kVp)	Tube current (mAs)	Scan length (cm)
Chest				
< 1 year	10	80 (80-80)	80 (35/30-80)	13.1 (7.6-16.5)
1-5 years	12	80 (80-80)	80 (60-90)	17.6 (10.3-12.6)
5-10 years	14	90 (80-120)	90 (70-139/80)	21.0 (16.6-25.0)
10-15 years	13	120 (80-140)	100 (80-120)	29.5 (20.3-36.8)
Abdomen				
< 1 year	2	80 (80-80)	75 (70-80)	24.7 (22.5-26.9)
1-5 years	7	80 (80-100)	80 (70-90)	27.5 (22.7-33.2)
5-10 years	10	110 (80-120)	120 (90-200)	35.5 (29.3-43.0)
10-15 years	6	120 (100-120)	150 (100-150)	45.2 (37.5-51.5)

Note-Data are expressed as median and range values. The number in the parentheses indicated minimum-maximum in each age group. The number with "/" indicated using AEC.

Table 6. Summary of radiation dose parameters, Image noise and image quality scores.

CT protocol	CTDIvol (mGy)	DLP (mGy cm)	Effective dose (mSv)	Image noise (HU)			Image quality score
				Organ 1	Organ 2	Air	
Chest							
< 1 year	3.7 ± 0.8	56.8 ± 15.8	1.9 ± 0.6	12.1 ± 2.6	8.3 ± 1.3	5.6 ± 0.7	3.4 ± 0.7
1-5 years	4.2 ± 0.5	89.3 ± 17.4	2.1 ± 0.5	12.2 ± 3.4	8.5 ± 0.6	5.4 ± 1.8	4.0 ± 0.0
5-10 years	9.8 ± 6.1	255.4 ± 169.4	3.8 ± 2.0	12.2 ± 3.8	8.1 ± 0.7	5.5 ±1.3	4.4 ± 0.6
10-15 years	13.4 ± 3.9	434.0 ± 148.5	5.7 ±1.9	9.8 ± 3.2	6.9 ± 1.6	4.7 ± 1.2	5.0 ± 0.0
Abdomen							
< 1 year	3.9 ± 0.4	106 ± 22.6	3.2 ± 0.7	10.8 ± 1.2	10.6 ± 1.3	4.1 ± 0.8	3.5 ± 0.7
1-5 years	4.7 ±1.5	158.6 ± 57.6	3.5 ± 1.0	10.2 ± 1.5	10.0 ± 1.7	4.2 ± 0.7	4.0 ± 0.0
5-10 years	15.3 ± 9.5	664.2 ± 462.8	16.6 ± 6.0	9.1 ± 2.0	9.2 ± 1.8	3.4 ± 2.0	4.7 ± 0.4
10-15 years	20.5 ± 6.2	1,055.6 ± 367.7	15.8 ± 5.5	9.0 ± 1.6	8.7 ± 0.8	3.5 ± 1.7	4.8 ± 0.4

The radiation dose parameters revealed a tendency to be less in younger-age groups in both chest and abdomen CT studies. The imaging quality seemed to better in older-age groups. As for chest CT studies, there was not much difference in mean values of image noise in <1 year, 1-5 years, and 5-10 years age groups which were relative higher than that of the group of 10 - 15 years old, corresponding with the mean value of image quality scores which was highest in group of 10-15 years old. As for whole abdomen CT studies, the mean values of image noise in 5-10 years and 10-15 years age groups were slightly lower than those of < 1 year and the age group of 1-5 years old, corresponding with the mean values of image quality scores which were higher in the older-age groups.

Our CT dose parameters in terms of third quartile values of $CTDI_{vol}$ and DLP were lower than those of the DRLs[15] in younger-age groups (<1 year and 1-5 years) in both chest and whole abdomen CT studies, whereas those values in older-age groups (5 -10 years and 10-15 years) were higher than those of DRLs. (Table 7)

Discussion

In this study, we described radiation dose parameters and image noises in our pediatric abdomen and chest multi-slice CT protocol. Our study groups of 49 chest CT examinations and 25 whole abdomen CT examinations encompassed nearly the entire range of children's age groups.

As expected, radiation dose parameters showed a tendency to be less in younger age groups. We found that our third quartile values of $CTDI_{vol}$ and DLP of younger age groups (<1year and 1 - 5 years) were lower than those of the DRLs, whereas, those of older age groups (5 - 10 and 10 - 15 years) were higher than those of the DRLs, much higher in 10 - 15 years age group, in both chest and whole abdomen CT protocols.

As for chest CT protocols, none of the patients in <1 year and 1 - 5 years age group received greater $CTDI_{vol}$ and DLP than those of the DRLs, while, 36% (5/14) of patients in 5 – 10 years age group and 69% (9/13) of patients in 10-15 years age group did. In 5 - 10 years age group, 4 (4/5) examinations which received greater $CTDI_{vol}$ and DLP than those of the DRLs were done at a tube potential of 120 kVp which

Table 7. Summary of radiation dose for current study and the diagnostic reference levels (DRLs).

CT protocol	CTDIvol (mGy)				DLP (mGy cm)			
	Switzerland	**Germany**	**UK**	**KCMH**	**Switzerland**	**Germany**	**UK**	**KCMH**
Chest								
<1 year	5	3.5	12	4.2	110	55	200	75.5
1-5 years	8	5.5	13	4.7	200	110	230	101.5
5-10 years	10	8.5	20	15.6	220	210	370	395.0
10-15 years	12	12	14	15.6	460	205	580	536.0
Abdomen								
<1 year	7	5	20	4	130	145	170	114
1-5 years	9	8	20	4.4	300	255	250	148
5-10 years	13	13	30	22	380	475	500	1,056.5
10-15 years	16	10	14	24.5	500	500	550	1,274.5

Note-Data are expressed as third quartile values.

was higher than that of the department protocol setting and the remainder (1/5) had no available data of patient's body weight. In age group of 10-15 years old, all 9 examinations which received higher $CTDI_{vol}$ and DLP than those of the DRLs were done at tube potential of 120-140 kVp, higher than that of setting of the department protocol.

According to IAEA suggestion, the DRLs of abdomen CT are derived from the third quartile values of $CTDI_{vol}$ and DLP of upper abdomen CT protocols. Thus, the DLP of our whole abdomen CT studies are expected to be higher than those of the DRLs and cannot be compared with them.

In younger age groups (<1 year, and 1-5 years) with all examinations done following the setting of the department protocol, our $CTDI_{vol}$ was much lower than that of the DRLs and was probably too low for these age groups resulting in higher mean values of image noise than expected. Forty percents (4/10) of examinations in 5-10 years age group and 67% (4/6) of examinations in 10 - 15 years age group were not done following the department protocol, using high tube current (140 - 200 mAs which was higher than that of the setting of the department protocol) and all of them received $CTDI_{vol}$ greater than that of the DRLs, whereas, the remainders done following the department protocol received $CTDI_{vol}$ within that of the DRLs. To reduce excessive radiation dose in older age groups (5 - 10 years and 10 - 15 years), the percentage of studies not following the protocol should be solved and monitored.

According to the previously mentioned study by Yang DH and Goo HW, the average image noise for pediatric chest CT (ROI at the thoracic aorta) and abdomen CT (ROI at liver) were 16.2 HU and 13.0 HU, respectively.[17] The average image noise of our study were 11.5 HU and 9.4 HU for chest and abdomen CT with ROI at the thoracic aorta and liver, respectively. However, the diagnostic level of image noise in clinical CT examinations is difficult to determine because the level must differ among the different diagnostic tasks or radiologists.[18] In addition, multiple factors, including radiation dose, image reconstruction kernel, and method of contrast enhancement influence the image noise. The results of visual image quality assessment (image quality scores) may help support the clinical acceptability of the image noise level. Because there are only a few studies regarding image quality in pediatric CT imaging studies, further work is needed to certify the standard diagnostic level of image quality for specific pediatric CT protocols. From this viewpoint, our results of image noise seem to be helpful for future studies.

In our study, image noises were relative less, corresponding to image quality scores in older-age groups in both chest and abdomen CT studies. This was attributed to the use of high tube voltage and/or high tube current in these age groups.

Some limitations existed in our study, however. First, some age groups had a small number of examinations, particularly in the less than 1 year age group. We believe that a paucity of CT examination in this small baby group has been a common problem in other studies.[17, 19] Secondly, there was a low percentage for available data of patient's body weight in each examination (30% for chest CT and 29% for abdomen CT) limiting us to determine whether or not each examination was done following the department protocol and prohibiting us from performing analysis of its impact on CT dose parameter and image quality. Lastly, for abdomen CT, we included only venous-phased contrast-enhanced whole abdomen CT examinations which were the majority of pediatric abdomen CT performed at KCMH. Thus, this could not reflect the radiation dose of whole abdomen CT for every patient. However, these data would be useful for further studies.

Conclusions

Our $CTDI_{vol}$ and DLP from pediatric chest or whole abdomen CT were within normal ranges in patients aged below 5 years but not in those aged above 5 years. The main reason was that those studies were not done following the setting of the protocol of the Department. Being stringent to CT protocol seems to be a good resolution. The percentage of studies not done following the protocol should be solved and monitored.

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