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The effective dose and image noise in pediatric CT brain at King Chulalongkorn Memorial Hospital

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Background : *CT is the standard equipment for assessing a variety of disorder in children. More than half of pediatric CT examinations at King Chulalongkorn Memorial Hospital (KCMH) are related to the brain. Nevertheless, there is no available data of pediatric radiation dose from CT brain at KCMH.*

Objective : *To investigate the radiation dose when CT brain is performed and compare with the previously published dose 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 349 examinations in 2009, volume CT dose index ($CTDI_{vol}$), dose length product (DLP) and image noise were collected. Effective dose was accomplished by multiply DLP with age-specific conversion coefficients. Third quartile values of these parameters were compared with the German and UK DRL.*

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Results : *$CTDI_{vol}$ were lower than DRL from the UK and German in most pediatric age groups. Only 4 patients aged below 5 years old (2.3%) received higher $CTDI_{vol}$. Two out of four age groups showed greater DLP than DRL from the UK but still lower than the German value. Approximately, 21% (75/349) performed scanning more than twice in the same study. Effective dose in patients younger than 10 years demonstrated greater value which reflects overall higher DLP. Image noise displayed no difference in each age group and comparable with previous studies.*

Conclusion : *Most of our radiation dose parameters are within the appropriate range. However, there is a little problem with rescanning and over scan length. Stringent to CT protocol and proper pre-scanning evaluation may be a good solution.*

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

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บัณฑิต นวนพรัตน์สกุล, ปานฤทัย ตรีนวรัตน์, อัญชลี กฤษณจินดา. ค่า effective dose และ image noise ในผู้ป่วยเด็กที่ได้รับการทำเอ็กซเรย์คอมพิวเตอร์สมอง ในโรงพยาบาลจุฬาลงกรณ์. จุฬาลงกรณ์เวชสาร 2555 ก.ย. – ต.ค.; 56(5): 585 – 96

เหตุผลของการทำวิจัย : *เอ็กซเรย์คอมพิวเตอร์เป็นเครื่องมือที่จำเป็นในการวินิจฉัยโรคในเด็ก พบว่ามากกว่าครึ่งหนึ่งของผู้ป่วยเด็กในโรงพยาบาลจุฬาลงกรณ์นั้นเกี่ยวข้องกับการตรวจเอ็กซเรย์คอมพิวเตอร์สมอง อย่างไรก็ตามยังไม่มีข้อมูลเกี่ยวกับปริมาณรังสีที่ได้รับในการตรวจแต่ละครั้ง*

วัตถุประสงค์ : *เพื่อศึกษาหาปริมาณรังสีที่ผู้ป่วยเด็กได้รับจากการทำเอ็กซเรย์คอมพิวเตอร์สมองในแต่ละครั้ง และเปรียบเทียบกับค่ามาตรฐานของต่างประเทศ เพื่อช่วยในการปรับตั้งค่าให้เหมาะสมมากยิ่งขึ้น และสามารถช่วยลดปริมาณรังสีลงได้*

รูปแบบการวิจัย : *การศึกษาแบบย้อนหลังเชิงพรรณนา*

สถานที่ทำวิจัย : *ภาควิชารังสีวิทยา คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย*

ตัวอย่างและวิธีการศึกษา : *ในปีพ.ศ.2553 มีการตรวจเอ็กซเรย์คอมพิวเตอร์สมองในเด็กทั้งหมด 349 การตรวจ ค่า* $CTDI_{vol}$*, DLP และ image noise รวมถึง effective dose ซึ่งได้มาจากการนำ age-specific conversion coefficients มาคูณกับค่า DLP จะถูกเก็บรวบรวม และทำการเปรียบเทียบค่าที่ได้เหล่านี้กับการศึกษาก่อนหน้า ในประเทศอังกฤษและเยอรมัน โดยใช้ค่าควอไทล์ที่ 3*

ผลการศึกษา : *ค่า* $CTDI_{vol}$ *ของผู้ป่วยเด็กส่วนใหญ่นั้นต่ำกว่าค่ามาตรฐานในทุกกลุ่มอายุ พบว่ามีเพียง 4 รายเท่านั้นในเด็กที่อายุน้อยกว่า 5 ปี (2.3%) มีค่า* $CTDI_{vol}$ *เกินมาตรฐาน ส่วนค่า DLP นั้นพบว่าสูงกว่าค่ามาตรฐานของประเทศอังกฤษใน 2 กลุ่มช่วงอายุ แต่ยังไม่เกินค่ามาตรฐานของประเทศเยอรมัน ซึ่งมีสาเหตุมาจากการตรวจซ้ำมากกว่า 2 ครั้งในแต่ละการศึกษา โดยพบมากถึง 75 การตรวจ (21%) ส่วน effective dose นั้นเป็นไปในทิศทางเดียวกันกับ DLP ในส่วนของ image noise นั้นพบว่าไม่มีความแตกต่างกันในแต่ละกลุ่มช่วงอายุ และพบว่าค่าที่ได้ใกล้เคียงกับการศึกษาก่อนหน้านี้*

สรุป : *ปริมาณรังสีที่ผู้ป่วยเด็กในโรงพยาบาลจุฬาลงกรณ์ได้รับจากการตรวจเอ็กซเรย์คอมพิวเตอร์สมองแต่ละครั้ง อยู่ในเกณฑ์ที่เหมาะสม ซึ่งพบปัญหาเพียงเล็กน้อยเกี่ยวกับการตรวจซ้ำและการตรวจในช่วงที่ยาวเกินความจำเป็น เป็นผลให้ได้รับปริมาณรังสีเกินมาตรฐาน โดยแนวทางการแก้ไขได้แก่ การเข้มงวดในวิธีตั้งค่าการตรวจและการเตรียมผู้ป่วยให้พร้อมก่อนการตรวจ*

คำสำคัญ : $CTDI_{vol}$, *DLP, Effective dose, Image noise*

Computed tomography (CT) is the standard equipment for assessing a variety of disorders in children. (1-5) More than 65% of all CT examinations in pediatric patients at King Chulalongkorn Memorial Hospital (KCMH) are related to the brain either with or without contrast studies.

The most concern relevant to CT modality is radiation exposure. Three major reasons should be considered for the pediatric population. First, increased radiosensitivity of certain tissues, particularly in infancy, and a longer lifetime for radiation-related cancer may occur, and a lack of size-based adjustments in technique. (6) Second, small children have a chance to receive greater radiation doses than larger children or adults from the same CT settings. (7) It is owing to more for smaller in body diameter and shorter in length. Third, children have a longer lifetime in which to manifest radiation-related cancer because many radiation-induced cancers, particularly solid malignancies, will not be evident for decades. (8-10)

Nevertheless, at our hospital, there is no available data of pediatric radiation dose from CT of the brain. Therefore, we investigate the radiation dose that pediatric patients received when CT of the brain is performed and compare with dose reference levels (DRLs) in previously published studies. To this end, strategies should be developed that minimizes or eliminates the amount of unnecessary radiation exposure.

Materials and Methods

Data from a retrospective review of all pediatric patients whom performed sequential CT of the brain on our Somatom Sensation 4 and Somatom Sensation 16 (Siemens Healthcare, Forchheim, Germany) from January 2009 to December 2009 were collected. Inform consent was omitted by permission of the director of KCMH.

Scanning parameters were reviewed on the PACS system. Examinations were excluded when absent data or inappropriately recorded, either summation across the body regions or across individual protocol.

The patients were classified 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 CT scanning parameters, volume CT dose index ($CTDI_{vol}$), dose length product (DLP), head diameter, skull thickness and image noise were collected. $CTDI_{vol}$ is a radiation exposure measurement (mGy), calculated for the center location as well as at least one of the peripheral positions 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 calculated effective dose in each age group was accomplished by applied the DLP multiply by age-specific conversion coefficient ($mSv \cdot mGy^{-1} \cdot cm^{-1}$); newborn to 3 months = 0.011, 4 months to 2 years 11 months = 0.0067, 3 years to 7 years 11 months = 0.004, 8 years to 14 years 11 months = 0.0032. (11)

The image noise evaluation was expressed as standard deviation (SD) of CT numbers (Hounsfield Units, HU). These values were measured only in single phase non-contrast study at two structures (the gray matter and CSF) and background air by placing a square region of interest (ROI). The ROI measurement was performed at three predefined levels (cerebellum, thalamus and centrum semiovale level) using our PACS workstation. Following the measurement, three measured values of three levels were averaged. The ROI was drawn as large as possible within a homogenous area of each organ (for organs, ROI up to 100 mm^2; for background air, ROI fixed at 100 mm^2). Noise measurement was normalized by the factors for noise dependence on kVp. The reference settings were 120 kV and the standard reconstruction kernel was C30s medium smooth. Finally, minimizing the potential influence of window settings, image noise was measured under a fixed window setting (width/level) for brain (100/30) and background air (1500/-700) (Fig.1).

Head diameter measurement was performed by measuring the anterior to posterior and transverse diameters at the level of the center of thalamus on PACS workstation. The mean value represented the head diameter of patients. The calvarial thickness was also averaged by bilateral parietal, frontal and occipital bones at the level of thalamus.

Mean, range and standard deviation of CTDI$_{vol}$, DLP, effective dose and image noise for each age group were expressed. Additionally, the third quartiles of these values were compared with two published German and UK CT dose surveys in each age group. The correlation between image noise with measured head diameter, skull thickness and other CT parameters were performed using multivariate linear regression by a statistical software package

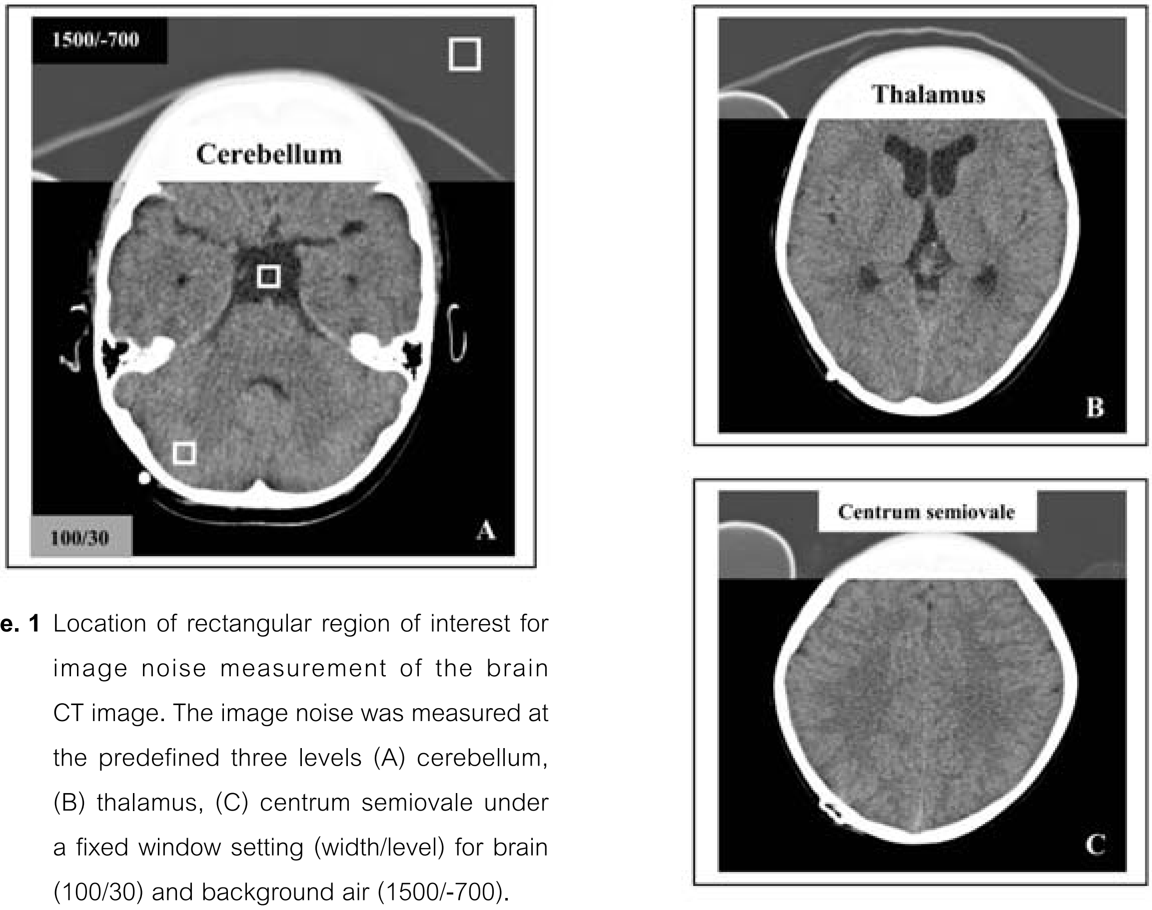

Figure. 1 Location of rectangular region of interest for image noise measurement of the brain CT image. The image noise was measured at the predefined three levels (A) cerebellum, (B) thalamus, (C) centrum semiovale under a fixed window setting (width/level) for brain (100/30) and background air (1500/-700).

(SPSS 17.0). A *p*-value of <0.05 was considered statistically significant difference.

Results

During one year period of all pediatric CT brain, there were a total of 468 examinations from 210 children (118 males, 92 females; mean age 5.7 years), most of them were performed more than once a year (maximum 11 times per year). There were 119 studies excluded due to the helical instead of sequential mode of scanning, radiation dose parameter not sending to PACS system, and summation dose across the brain and neck. Number of examination in each age group were comparable as shown in Table 1: 22% (79/349) for <1 year, 27% (93/349) for 1 - 5 years, 22% (76/349) for 5 - 10 years and 29% (101/349) for 10 - 15 years. The examinations were performed about 50% in non-contrast study only, and the remaining were both non-contrast and contrast studies.

According to KCMH protocols, the same technique was executed for both the posterior fossa and cerebrum in children's age <6 years old which beam collimation ranged from 1-1.5 mm and gantry rotation time was 0.75 second. Whereas, children whose age $\geq$ 6 years old, the protocol technique was separated into the posterior fossa and cerebrum which beam collimation were 1 mm and 8 mm, respectively, and gantry rotation time was 1 second for both regions. The tube potential was set unadjustable at 120 kVp. The maximum value of tube current was 300 mAs while the lowest was 110 mAs. The scan length had a tendency to increase with age group. Orbits and eye lens were included in all pediatric CT of the brain, only in one case that the eye lens was not exposed. Maxillary sinus and hard palate were covered in some numbers.

The radiation dose parameters are displayed in Table 2 for $\mathrm{CTDI}_{\mathrm{vol}}$, DLP, effective dose and image noise. The amount values of double series are approximately two times in single series. Image noise values show not much different in each age group. The average image noise is about 2.7 HU.

As shown in Table 3, by comparison, DRL in terms of $\mathrm{CTDI}_{\mathrm{vol}}$, DLP and effective dose are expressed as third quartile, compatible with the values reported from Germany and the UK(12,13). Most data of both non-contrast and contrast studies were comparable, therefore assembled data to one set was demonstrated.

Table 1. Number of examination classified as single and double series in each age group.

Age group / Protocol	< 1 year	1 - 5 years	5 - 10 years	10 - 15 years	Total
NC only	40	53	42	43	178
NC + C	39	40	34	58	171
Total	79	93	76	101	349

Note: NC referred to non-contrast study and C referred to contrast study.

Table 2. Summary of CT dose parameters expressed by mean, standard deviation and range; CTDI$_{vol}$, DLP, effective dose and image noise.

Age group	CT protocols \ Radiation dose parameters			CTDI$_{vol}$ (mGy)	DLP (mGy·cm)	Effective dose (mSv)	Image noise (HU)		
							CSF	Gray matter	Background air
< 1 year	Single series	Non-contrast (n = 40)		25.1 ± 3.5 (20.1 - 38.3)	310.3 ± 63.5 (198.0 – 552.0)	2.8 ± 0.7 (1.5 - 4.2)	3.1 ± 0.5	3.0 ± 0.5	2.2 ± 1.3
	Double series	Non-contrast (n = 39)		23.7 ± 4.2 (8.4 - 28.8)	272.9 ± 66.6 (101.0 – 477.0)	2.5 ± 0.8 (0.7 – 5.3)			
		Contrast (n = 39)		25.0 ± 3.5 (16.4 - 28.8)	285.2 ± 64.2 (106.0 – 415.0)	2.7 ± 0.8 (0.7 – 4.4)		-	
		Total		48.7 ± 7.7 (24.8 - 57.6)	558.1 ± 130.8 (207.0 - 892.0)	5.2 ± 1.6 (1.4 - 9.7)			
1 - 5 years	Single series	Non-contrast (n = 53)	n = 3	49.0 ± 23.3 / 38.0 ± 14.2 (22.1 - 62.4) / (22.1 – 46.8)	312.0 ± 36.7 / 373.0 ± 151.5 (287.0 - 349.0) / (221.0 – 524.0)	2.3 ± 1.4 (0.9 - 8.4)	3.5 ± 0.5	3.2 ± 0.5	2.0 ± 0.4
			n = 50	27.8 ± 9.1 (17.3 - 48.1)	412.5 ± 203.4 (218.0 - 1249.0)				
	Double series	Non-contrast (n = 40)	n = 1	36.0 ± 0.0 / 46.8 ± 0.0	202.0 ± 0.0 / 379.0 ± 0.0	1.94 ± 0.7 (1.0 - 4.1)			
			n = 39	25.4 ± 7.7 (16.0 - 48.0)	330.1 ± 104.4 (187.0 – 614.0)				
		Contrast (n = 40)	n = 1	36.0 ± 0.0 / 27.0 ± 0.0	202.0 ± 0.0 / 216.0 ± 0.0	2.1 ± 0.8 (1.0 - 4.3)		-	
			n = 39	27.0 ± 8.3 (16.8 - 48.0)	360.9 ± 121.0 (187.0 - 634.0)				
		Total	n = 40	72.0 ± 0.0 / 73.8 ± 0.0	404.0 ± 0.0 / 590.0 ± 0.0	4 .0 ± 1.5 (2.0 - 8.4)			
				52.4 ± 15.3 (33.8 - 96.0)	691.0 ± 225.4 (374.0 - 1248.0)				

Note: Data are expressed as mean, standard deviation and range values. The numbers in the parentheses indicate minimum-maximum in each age group. The symbol " / " represents "posterior fossa / cerebrum" values.

Table 2. (Cont.) Summary of CT dose parameters expressed by mean, standard deviation and range; $CTDI_{vol}$, DLP, effective dose and image noise.

Age group	CT protocols		Radiation dose parameters	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)	Effective dose (mSv)	Image noise (HU)		
							CSF	Gray matter	Background air
5 - 10 years	Single series	Non-contrast (n = 42)	n = 21	58.7 ± 5.5 / 45.4 ± 5.6 (48.0 - 62.4) / (36.0 - 57.6)	353.5 ± 64.1 / 382.9 ± 66.5 (294.0 - 524.0) / (288.0 - 524.0)	2.2 ± 0.7 (1.0 - 3.3)	3.3 ± 0.7	3.1 ± 0.6	1.7 ± 0.5
			n = 21	32.1 ± 12.3 (16.4 - 62.3)	461.0 ± 160.0 (249.0 - 797.0)				
	Double series	Non-contrast (n = 34)	n = 19	57.3 ± 6.3 / 46.2 ± 6.7 (48.0 - 62.4) / (33.9 - 57.6)	307.1 ± 44.4 / 400.7 ± 89.1 (230.0 - 399.0) / (288.0 - 614.0)	2.4 ± 0.6 (1.0 - 3.3)		-	
			n = 15	39.1 ± 9.4 (22.1 - 55.5)	532.5 ± 116.0 (299.0 - 724.0)				
		Contrast (n = 34)	n = 15	58.6 ± 6.0 / 47.3 ± 6.5 (48.0 - 62.4) / (36.0 - 57.6)	318.4 ± 49.6 / 396.4 ± 78.5 (230.0 - 400.0) / (288.0 - 518.0)	2.5 ± 0.6 (1.0 - 3.3)			
			n = 19	40.8 ± 10.3 (19.3 - 55.5)	607.6 ± 164.9 (243.0 - 827.0)				
		Total	n = 34	115.9 ± 12.3 / 93.5 ± 13.2 (96.0 - 124.8) / (69.9 - 115.2)	625.5 ± 94.0 / 797.1 ± 167.6 (460.0 - 799.0) / (576.0 - 1132.0)	4.9 ± 1.2 (2.0 - 6.6)			
				79.9 ± 19.7 (41.4 - 111.0)	1104.1 ± 280.9 (542.0 - 1551.0)				
10 - 15 years	Single series	Non-contrast (n = 43)	n = 30	59.7 ± 5.2 / 46.8 ± 4.5 (38.4 - 62.4) / (38.4 - 57.6)	352.9 ± 84.0 / 427.1 ± 82.2 (207.0 - 674.0) / (276.0 - 622.0)	2.3 ± 0.6 (0.9 - 3.5)	3.3 ± 0.6	3.1 ± 0.5	1.6 ± 0.4
			n = 13	40.1 ± 14.9 (22.1 - 62.4)	595.9 ± 244.5 (287.0 - 1082.0)				
	Double series	Non-contrast (n = 58)	n = 47	60.6 ± 4.1 / 46.6 ± 5.0 (48.0 - 67.2) / (36.0 - 57.6)	343.0 ± 54.7 / 394.6 ± 60.1 (269.0 - 549.0) / (288.0 - 518.0)	2.2 ± 0.5 (0.9 - 3.0)		-	
			n = 11	31.7 ± 11.1 (22.1 - 50.4)	422.7 ± 130.9 (290.0 - 655.0)				
		Contrast (n = 58)	n = 36	61.0 ± 3.6 / 47.6 ± 4.5 (48.1 - 67.2) / (38.4 - 57.6)	363.9 ± 83.3 / 395.4 ± 69.0 (275.0 - 694.0) / (163.0 - 518.0)	2.3 ± 0.5 (1.0 - 3.7)			
			n = 22	44.9 ± 13.6 (22.1 - 62.3)	674.6 ± 226.7 (304.0 - 972.0)				
		Total	n = 58	121.6 ± 7.7 / 94.2 ± 9.5 (96.1 - 134.4) / (74.4 - 115.2)	706.9 ± 138.0 / 790.0 ± 129.1 (544.0 - 1243.0) / (451.0 - 1036.0)	4.5 ± 1.0 (1.9 - 6.7)			
				76.6 ± 24.7 (44.2 - 112.7)	1097.3 ± 357.6 (594.0 - 1627.0)				

Note: Data are expressed as mean, standard deviation and range values. The numbers in the parentheses indicate minimum-maximum in each age group. The symbol " / " represents "posterior fossa / cerebrum" values.

Table 4 demonstrates the associated factors ($CTDI_{vol}$, DLP, gantry rotation time, beam collimation, head diameter and skull thickness) with image noise by multivariable linear regression. There are three significant factors, $CTDI_{vol}$, beam collimation and head diameter while the remaining factors are not significant. The measured head diameter showed direct variation with the image noise, whereas $CTDI_{vol}$ and beam collimation reveal inverse variation.

Discussion

Seventy-five percentile values of $CTDI_{vol}$, DLP and effective dose from CT scanning performed in the United Kingdom in 2003 and Germany in 2006 were reported.(12,13) DRLs from European group and from the UK are also recommended by IAEA for any CT unit to use as reference levels.

Our study shows that third quartile value of $CTDI_{vol}$ is lower than DRL of the UK in most of pediatric age group. In the age group between 5-10 years old, $CTDI_{vol}$ was about the same. Note that CT brain in 4 out of 172 patients aged below 5 years (2.3%) was not performed according to the department protocol for age. They received higher $CTDI_{vol}$ than the others in the same age group, and the $CTDI_{vol}$ in two of them were higher than the UK DRL. On the contrary, 55 out of 177 patients (31%) between 5-15 years old did not follow the department protocol, but mostly using the lower $CTDI_{vol}$. In this latter group, none was receiving $CTDI_{vol}$ higher than the UK DRL. The explanation of this phenomenon in older children is that we had two CT machines and protocols for older children were different, and technologists might mixed up the parameter settings. What we can conclude from our $CTDI_{vol}$ data are: (1) our $CTDI_{vol}$ was within the international-standard reference level; (2) only in small percentage (2.3%) with personal error and higher dose protocol was used; (3) high percentage of not following protocol should be solved and monitored.

Even our brain $CTDI_{vol}$ were within DRL in almost all cases, our DLP were not. Two out of four age groups showed higher DLP values than reference levels. This reflects longer scan length and/or repeated scanning area. Retrospective review of the CT studies from PACS confirmed that both happened. There were 75 out of 349 patients (21%) had been performed scanning more than twice in the same study. Repeated scanning from patient's motion gave an additional higher DLP in some patients, varying

Table 4. Associated factors with image noise by multivariate linear regression.

	Coefficients	Standard error	*p*-value
$CTDI_{vol}$	- 0.03	0.01	< 0.05
DLP	0.00	0.00	0.94
Gantry rotation	0.42	0.40	0.29
Beam collimation	- 0.35	0.07	< 0.05
Head diameter	0.19	0.03	< 0.05
Skull thickness	- 0.02	0.04	0.60

in degree from rescanning only a few slices to rescanning the entire brain. In the other two age groups where our DLP values were lower than the international reference levels, analysis of both $CTDI_{vol}$ and DLP clearly showed the same situation with long scan length and/or repeated scanning area. And the problem of rescanning should be prevented by proper immobilization and pre-scanning evaluation whether sedation is needed or not.

The effective dose of CT brain in children younger than 10 years of age at KCMH showed higher values than dose in the UK. Effective dose in both studies had been calculated in the same way by using the coefficient factors specific for different ages. So it reflects the overall higher DLP in our patients.

According to the previous mentioned study, Dong Hyun Yang and Hyun Woo Goo demonstrated that the average image noise for pediatric CT brain was 3.7 HU(14), whereas our data display the average image noise of 2.7 HU. Our image noises in different age groups had no statistical difference. 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. A point of view, our results of image noise seem to be helpful for future studies.

From the multivariate linear regression, we found an agreement with the recent published study(14) that the image noise was less in children with small head diameters than in those with large head diameters. Correlations between $CTDI_{vol}$, beam collimation and head diameter with image noise corresponded to the physical principles. Uncorrelated DLP values and gantry rotation time with image noise in this study may result from repeated scanning as described earlier.

There are some limitations in our study, however. First, the CT parameters including kVp, mAs, gantry rotation time and beam collimation do not necessarily convey as equal values among different models of CT scanner and each patient in the same age group. Second, the validation of radiation dose with dosimetric measurement was not performed directly, the fixed formula has been used instead. Lastly, image noise measurement was performed by only single technique, so clinical application may be troubled and prejudice is unavoidable.

Conclusions

KCMH is on the front line medical school and also has a great number of pediatric patients. Therefore, the collected data could be used as references for other hospitals and potentially national applied. Despite almost $CTDI_{vol}$ in all children are less than recent published DRL, the important concerns at KCMH are exceeding values of DLP and effective dose. In order to solve this problem, stringent CT parameter protocol should be followed.

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