Evaluation of Size-Specific Dose Estimates (SSDE) in paediatric body imaging using 320-detector CT

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Abstract

The radiation dose from CT is considered a high risk measure in diagnostic radiology. The American Association of Physicists in Medicine (AAPM) Report No. 204 has concerned the CT dose which depends on the patient size especially in the paediatric patients. We therefore used the conversion factor in AAPM 204 to evaluate size-specific dose estimates (SSDE) of the volumetric computed tomography dose index ($CTDI_{vol}$) for paediatric body CT imaging with 320 slice CT which is used for routinely in paediatric cases at Ramathibodi Hospital. Purpose of the study was to evaluate and compare SSDEs to displayed CT scanner output in paediatric chest and abdomen examinations acquired on 320-detector CT. Quality control was performed prior to data collection. A retrospective analysis categorized 525 paediatric CT examinations (224 chest, 92 abdomen, and 209 chest including abdomen) into four age groups. SSDE conversion factors were used as a function of effective diameter for 32-cm-diameter PMMA phantom to estimate the patient dose, based on scanner output index (displayed $CTDI_{vol}$) and patient sizes. Results showed that the highest percentage difference between the displayed and SSDE $CTDI_{vol}$ was found in the youngest age group (0-<1 year old). In conclusion, we found that size-specific dose estimation for CT results in dose estimates different to those displayed on the CT scanner, especially in a small-sized paediatric population. The percentage differences of size-specific dose estimation $CTDI_{vol}$ values from displayed values in each age group for chest, abdomen and chest including abdomen CT were 133/117/85/103, 124/100/83/65 and 112/105/91/68, respectively. Radiologists should be concerned about these differences, and diagnostic technologists should estimate the SSDE dose and adjust scanning parameters appropriately before performing the CT scan. To ensure that radiation dose does not exceed diagnostic reference levels.

Keywords: 320-detector CT, size-specific dose estimates (SSDE), volume computed tomography dose index ($CTDI_{vol}$), paediatric CT, diagnostic reference levels (DRLs).

Introduction

The risks associated with radiation dose are one of the major concerns with the use of computed tomography (CT) as an imaging modality (Khawaja et al., 2015). This radiation dose is usually presented as two parameters, the volume computed tomography dose index ($CTDI_{Vol}$) and the dose length product (DLP), with these being provided by the scanner. The $CTDI_{Vol}$ is defined as the ratio of the weighted computed tomography dose index ($CTDI_w$) to pitch, and $CTDI_w$ can be assessed using an ionization chamber to measure $CTDI_{100}$ in a 16- or 32-cm diameter cylindrical polymethyl methacrylate (PMMA) reference phantom, with these phantoms often being referred to as head or body CTDI phantoms, respectively (American Association of Physicists in Medicine., 2011). Both $CTDI_{vol}$ and DLP values depend on scanning parameters such as tube voltage, tube current, gantry rotation time, pitch, and bowtie filter; however, all of these parameters are independent of patient size. At present, some manufacturers use a 32-cm diameter phantom as a reference for calculating $CTDI_{vol}$ and DLP in paediatric patients, and this could therefore result in underestimation of the radiation dose to this age group. The American Association of Physicists in Medicine (AAPM) Report No. 204 introduced the idea of size specific dose estimates (SSDE), with the use of conversion factors for different torso dimensions, to translate the displayed $\mathrm{CTDI_{vol}}$ to a true $\mathrm{CTDI_{vol}}$ with respect to patient size. There were many researchers studied the correlation among patient size and size-specific dose estimates (SSDEs). Christner et al. (2012) studied in adult patients at CT of the torso. They found that $\mathrm{CTDI_{vol}}$ was significantly correlated with patient size, but SSDE was independent of size. While Tsujiguchi, Obara, Ono, Saito, and Kashiwakura (2018) studied in paediatric CT examination and found that there was a large correlation between the SSDE conversion factor and patient size, with a larger exposure dose in small patients size. Patient dimensions can be determined using electronic measuring tools to measure physical dimensions on either the CT localizer radiograph or an axial CT image. Purpose of the study was to evaluate and compare SSDEs to displayed CT scanner output in paediatric chest and abdomen examinations acquired on 320-detector CT.

Materials and Methods

This study consists of a retrospective review of paediatric chest, abdomen, and chest including abdomen CT scans, taken from June 2014 to June 2016 on a Toshiba Aquilion ONE 320-detector CT scanner, version 6. Quality control following the IAEA Human Health Series No.19 quality assurance programme was performed to verify the scanner output prior to patient data retrieval. This study was approved by the institutional review board, and the patient data parameters were collected from the hospital picture archiving and communications in medicine (PACS) system.

Quality control was performed on the multi detector CT scanner before data collection, to assure the accuracy of the system in terms of image quality and radiation dosimetry. The calculated $\mathrm{CTDI_{vol}}$ was estimated from the measured $\mathrm{CTDI_{100}}$ obtained from cylindrical PMMA head (16 cm) and body (32 cm) phantoms, integrated the dose over a 100 mm pencil ion chamber, and using head and body protocols at all $\mathrm{kV_p}$ settings; the monitor displayed and measured values were within tolerance range (±10%) (International Atomic Energy Agency., 2012).

The paediatric CT examinations were categorized into four age groups based on International Atomic Energy Agency (IAEA) classification: (A) 0-<1, (B) 1-<5, (C) 5-<10, and (D) 10-15 years-of-age. The AAPM 204 report describes four measurement methods to find the conversion factors. Brady and Kaufman (2012) demonstrated that a summation or effective diameter calculation is more useful than an individually applied measurement, and that the approach of using age to determine the effective diameter, and ultimately to calculate the SSDE, is most effective for pre-adolescent patients (up to 13 years), whilst it is less accurate for teenage and young adult patients (Brady & Kaufman, 2012). Using digital callipers on the PACS system, the anteroposterior (AP) and lateral dimensions were measured at the same anatomic landmarks on the patients' CT radiographs: through the tracheal bifurcation for chest, and through the centre of the scan range for abdomen, and chest including abdomen. The patients' effective diameters (defined as the square root of the product of AP and lateral measurements) were then calculated using the average AP and lateral diameters of each group and each examination. Using the conversion factor from the look-up table in AAPM 204, the SSDE $\mathrm{CTDI_{vol}}$ values were calculated by multiply displayed $\mathrm{CTDI_{vol}}$ values with the conversion factor. Then compared the SSDE CTDI$_{vol}$ values to the displayed CTDI$_{vol}$ values. The correlation between an average CTDI$_{vol}$ and the paediatric age group of the monitor displayed value and the calculated SSDE values were plotted, and the statistical analysis was the percentage differences following the equation:

$$percentage\ difference = \frac{(SSDE\ CTDI_{vol} - displayed\ CTDI_{vol})}{displayed\ CTDI_{vol}} \times 100$$

The percentage differences between the displayed and calculated SSDE CTDI$_{vol}$ values were calculated for paediatric chest, abdomen, and chest including abdomen CT.

Diagnostic reference levels (DRLs) have been recommended by the International Commission on Radiological Protection (ICRP) as an advisory measure to improve optimization of patient protection, by identifying high patient dose levels which might not be justified on the basis of image quality requirements. DRLs should be set for common examinations using easily measurable dose quantities. DRLs are typically using a percentile point (most commonly 75th percentile or the third quartile) of the observed distribution of patient doses (European Commission., 2016).

Results

Five hundred and twenty five examinations including 224 chest, 92 abdomen and 209 chest including abdomen CT scans were categorized into four age groups: (A) 0-<1, (B) 1-<5, (C) 5-<10 and (D) 10-15 years old. The patient parameters were collected from the Picture Archiving and Communication System (PACS) of Ramathibodi Hospital from June 2014 to June 2016. These, together with the mean effective diameter, are displayed in Table 1 (A-C). The results showed that the effective diameter increased with age group.

Table 1 (A-C) Data from the 525 paediatric patients who underwent chest, abdomen, or chest including abdomen CT examinations. Values are mean ± SD and (range).

Age group (Years)	Chest CT (N=224)				
	Mean Age (year)	Gender (M/F)	Mean Weight (kg)	Mean Height (cm)	Mean Effective Diameter (cm)
0 - < 1	0.48±3.2	13/12	4.6±2.1	55.2±8.6	11±2.0
	(1-11Months)	(n=25)	(1.7-9.0)	(41-82)	(8-15)
1 - < 5	2.5±1.1	34/17	13.3±3.3	95.9±11.0	15±1.3
	(1-4)	(n=51)	(7.6-20.0)	(65-111)	(13-18)
5 - < 10	7.0±1.5	46/27	21.7±6.6	120.1±8.4	18±2.0
	(5-9)	(n=73)	(5-43)	(98-140)	(15-24)
10 - 15	12.7±1.4	49/26	48.2±15.2	151.2±12.9	25±4.1
	(10-15)	(n=75)	(23-100)	(127-176)	(17-36)

(A)

Table 1 (Cont.)

Age group (Years)	Abdomen CT (N=92)				
	Mean Age (year)	Gender (M/F)	Mean Weight (kg)	Mean Height (cm)	Mean Effective Diameter (cm)
0 - < 1	0.54±3.21 (1-11Months)	5/14 (n=19)	6.5±1.8 (3-9)	64.1±6.4 (50-74)	15±2.3 (11-19)
1 - < 5	2.5±1.1 (1-4)	8/16 (n=24)	12.7±5.7 (6-30)	89.1±15.4 (63-112)	17±1.8 (15-22)
5 - < 10	6.6±1.6 (5-9)	16/7 (n=23)	20.6±7.2 (6-33)	117.6±14.9 (66-137)	18±2.7 (13-22)
10 - 15	12.0±1.6 (10-14)	19/7 (n=26)	43.1±15.3 (12-72)	144.5±16.0 (110-169)	23±3.4 (17-30)

(B)

Age group (Years)	Chest including abdomen CT (N=209)				
	Mean Age (year)	Gender (M/F)	Mean Weight (kg)	Mean Height (cm)	Mean Effective Diameter (cm)
0 - < 1	0.49±2.9 (1-9Months)	7/4 (n=11)	6.5±2.2 (4.8-9.7)	51.4±25.2 (7-65)	14±1.9 (12-18)
1 - < 5	2.7±1.0 (1-4)	30/52 (n=82)	13.7±5.2 (3-30)	92.2±12.4 (65-125)	17±2.3 (12-24)
5 - < 10	5.9±1.1 (5-9)	36/32 (n=68)	21.6±7.9 (13-44)	115.6±12.2 (94-137)	18±2.3 (14-23)
10 - 15	12.3±1.6 (10-15)	33/15 (n=48)	41.5±13.0 (19-65)	149.8±13.1 (120-169)	22±2.8 (17-26)

(C)

Table 2 The displayed and size specific dose estimate (SSDE) volume CT dose index ($CTDI_{vol}$) for paediatric chest, abdomen, and chest including abdomen CT examinations in each age group. Values are mean ± SD and (range).

Part of CT examinations	$CTDI_{vol}$ (mGy)	Age group (years)			
		0 - < 1	1 - < 5	5 - < 10	10 - 15
Chest	Displayed	1.8±1.3 (0.6-5.7)	2.4±1.3 (1.6-7.5)	3.3±2.3 (1.7-14.6)	3.1±3.6 (1.0-20.0)
	Calculated SSDE	4.2±2.8 (1.5-12.7)	5.2±2.7 (3.4-14.9)	6.1±4.0 (3.2-24.)	6.3 ±5.3 (1.78-31.0)
Abdomen	Displayed	1.7±0.2 (1.3-2.1)	2.3±0.9 (1.5-4.7)	3.0±1.8 (1.7-9.4)	3.7±1.3 (2.4-8.4)
	Calculated SSDE	3.8±0.4 (3.1-4.8)	4.6±1.9 (3-9.8)	5.5±3.0 (2.9-16.1)	6.1±2.6 (4.1-15.5)
Chest including abdomen	Displayed	1.7±0.1 (1.6-1.8)	1.9±0.5 (1.2-3.3)	2.3±0.5 (1.7-3.9)	3.1±1.0 (2.1-7.4)
	Calculated SSDE	3.6±0.3 (3.2-4.3)	3.9±0.7 (2.4-5.4)	4.4±0.8 (3.44-6.2)	5.2±1.4 (3.6-11.8)

The SSDE conversion factors for calculating the volume CT dose index ($CTDI_{vol}$) as a function of effective diameter were based on the use of a 32-cm diameter PMMA phantom, as in AAPM report 204. These conversion factors were used to calculate the SSDE $CTDI_{vol}$ values, which were the size-specific patient doses derived from the scanner output indices ($CTDI_{vol}$). Table 2 shows the mean ± standard deviation (SD) of the displayed and calculated SSDE $CTDI_{vol}$ values for chest, abdomen, and chest including abdomen CT examinations in each age group. It can be seen that the calculated SSDE $CTDI_{vol}$ for patients of less than 5 years was over twice that of the displayed $CTDI_{vol}$ in all CT examinations. As patient age increases, the difference between the calculated SSDE $CTDI_{vol}$ and displayed $CTDI_{vol}$ reduced by less than half. This demonstrates that if the displayed $CTDI_{vol}$ was used to calculate the dose received by the patient, the value for the received dose could be incorrect.

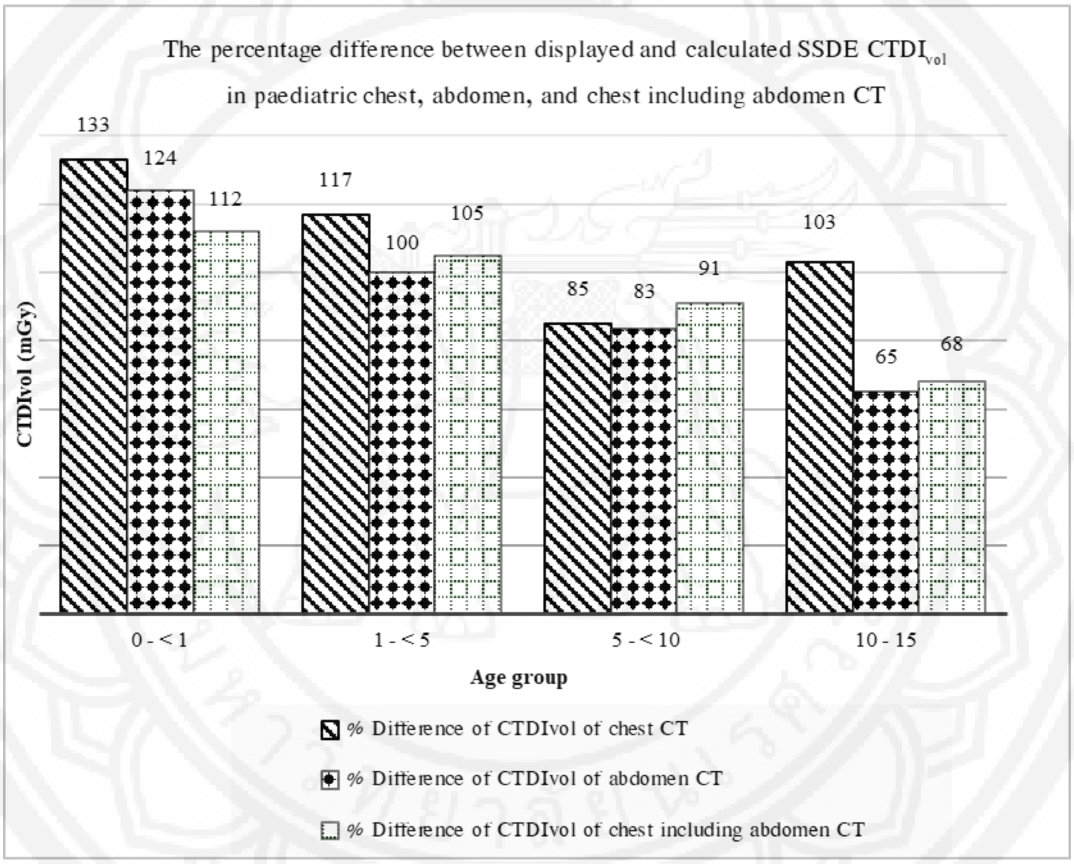

Figure 2 The percentage differences between displayed and calculated SSDE of $CTDI_{vol}$.

The percentage differences between the displayed and calculated SSDE $CTDI_{vol}$ for chest, abdomen, and chest including abdomen CT examinations in each age group are shown in Figure 2. The result demonstrated that size-specific dose estimates following AAPM 204 had more effect to increase $CTDI_{vol}$ in the paediatric with age 0-<1.

The diagnostic reference levels (DRLs) or the third quartile or 75th percentile of the displayed and calculated SSDE $CTDI_{vol}$ (mGy) for the chest, abdomen, and chest including abdomen CT examinations in each age group in this study are compared with published values in Table 3. We found that DRLs reported from Italy (European Commission., 2016), Portugal, and Australia (Australian Radiation Protection and

Nuclear Safety Agency., 2013) have similar dosimetry phantom size references (32-cm PMMA body phantom) to those found in our study.

Table 3 The 75th percentile of displayed and calculated SSDE $CTDI_{vol}$ in paediatric chest, abdomen, and chest including abdomen CT examinations in each age group in this study compared with published values.

CT Protocol	References		DRLs of $CTDI_{vol}$ (mGy) in Category				Dosimetry Phantom size
			0 - < 1	1 - < 5	5 - < 10	10- 15	
Chest	This study	Displayed	1.7	1.9	3.3	4.4	32 cm
		SSDE	3.8	5.7	6.2	6.1	32 cm
	Granata et al. (Italy)		NA	2.5	3.8	6.6	32 cm
	Santos et al. (Portugal)		2.4	5.6	5.7	7.2	32 cm
	Australia		2.0 (0-4 years)		5.0 (5-14 years)		32 cm
	United Kingdom (Shrimpton, 2004)		12	13	20	14	16 cm
	(Kritsaneepaiboon, Trinavarat, & Visrutaratna, 2012)		4.5	5.7	10	15.6	16 cm
	Switzerland		5	8	10	12	16 cm
	Germany		3.5	5.5	8.5	14	16 cm
Abdomen	This study	Displayed	1.8	2.7	3.2	4	32 cm
		SSDE	4.1	5.4	5.7	5.7	32 cm
	Granata et al. (Italy)		NA	5.7	7.0	14.0	32cm
	Australia		7 (0-4 years)		10 (5-14 years)		32 cm
	United Kingdom (2003)		20	25	30	14	16 cm
	Kritsaneepaiboon et al. (2012)		7.7	9	14	17	16 cm
	Switzerland		7	9	13	16	16 cm
	Germany		5	8	13	20	16 cm
Chest including abdomen	This study	Displayed	1.7	1.8	2.6	3.3	32 cm
		SSDE	3.8	3.8	5.0	5.6	32 cm

Discussion

By firstly implementing SSDE as radiation dose indices, instead of the scanner report ($CTDI_{vol}$), it was found that most of the mean weights in each age group corresponded with the European guidelines on DRLs for paediatric imaging. From the Figure 1 and 2, the percentage differences between the displayed and calculated SSDE $CTDI_{vol}$ values in all of the paediatric CT examinations were more than 60%. The maximum value of each CT examination found in the youngest age group of 0-<1 years-of-age were 133, 124 and

112 in the chest, abdomen, and chest including abdomen CT examinations, respectively. It corresponded to Tsujiguchi's study which mentioned that there was a large correlation between SSDE calculation and paediatric size. The results demonstrate that the percentage differences decrease with increasing age group or increasing patient size, and therefore the SSDE should be calculated, to account for the effect of the paediatric patient size on the estimated radiation dose from the displayed $\mathrm{CTDI}_{\mathrm{vol}}$, and to ensure that the scanning parameters are appropriately adjusted before the CT scan.

The DRLs of the displayed $\mathrm{CTDI}_{\mathrm{vol}}$ (mGy) values of the paediatric chest CT examination in each age group were lower than those reported in studies using the same phantom size from Italy, Portugal, and Australia, while the DRLs of the SSDE $\mathrm{CTDI}_{\mathrm{vol}}$ (mGy) were slightly higher (shown in Table 3). These differences could possibly be because the scanning protocols were based on paediatric weight range, and there may have been different patient sizes, especially in the youngest age group. The DRLs of the displayed and SSDE $\mathrm{CTDI}_{\mathrm{vol}}$ of the paediatric abdomen CT examinations in each age group are lower than those of studies form Italy and Australia , while comparisons could not be made for DRLs of paediatric chest including abdomen, as there are no published values available.

This was a pilot study of my hospital to evaluate the size-specific dose estimates following AAPM 204 to evaluate the patient dose especially in paediatric patient. It is useful to aware the CT dose and adjust the scan parameters before the examination. There were several limitations to our study. First, there was variability in the selection of boundary diameters at midslices of the scan range. Second, errors in radiograph dimensions occurred due to patient positions not being aligned with the centre of the gantry. Third, the concept of water equivalent diameter (Dw) with automatic software that can directly extract the cross-sectional area to calculate patient size and SSDE has been recommended, although it was not used in this study.

Conclusion

In conclusion, this study found that size-specific dose estimation for CT results in dose estimates different to those displayed on the CT scanner, especially in a small-sized paediatric population. It demonstrates that the SSDE $\mathrm{CTDI}_{\mathrm{vol}}$ is higher than the displayed value in all of paediatric age and CT examinations. Radiologists should be concerned about these differences, and technologists should estimate the SSDE dose and adjust the scanning parameters appropriately before performing the CT scan. To ensure that the radiation dose does not exceed the DRL.

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