Technical Note

Evaluating the Utilization of the National Cancer Institute Computed Tomography Program for Calculating Size-specific Dose Estimate and Effective Dose in Computed Tomography in Thai Pediatric Patients

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Abstract

The objectives of this study were to assess the feasibility of utilizing computational calculations and the simulation of the National Cancer Institute computed tomography (NCICT) dosimetry system to obtain size-specific dose estimate (SSDE) and effective dose values resulting from the most common CT examinations in Thai pediatric patients and to evaluate age- and size-specific k conversion factor. For the calculation methods, SSDEs were calculated using the American Association of Physicists in Medicine Report No. 220 and 293 methodologies. The results revealed that SSDEs derived from CT scans of the body, obtained through the two different methods, varied by within 10%. The size of the patient and the scanning distance had an impact on the variability of E values derived from NCICT. Age- and size-specific k conversion factors may be used as a first line to estimate risk for the pediatric patients.

Keywords: Monte Carlo simulation, National Cancer Institute computed tomography, pediatric patient, size-specific dose estimate, size-specific effective dose

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Introduction

Currently, the radiation dose from computed tomography (CT) imaging is presented in the form of the volume-weighted CT dose index ($CTDI_{vol}$) and the dose length product (DLP).[1,2] However, $CTDI_{vol}$ values do not represent the actual radiation dose received by the patient's organs and tissues. The American Association of Physicists in Medicine (AAPM) Report No. 204[3] discusses size-specific dose estimates (SSDEs), which are estimated radiation dose values adjusted for the patient's body size. AAPM Reports No. 220[4] and No. 293[5] recommend converting body and head sizes to a water equivalent diameter (D_w) based on the cross-sectional area and the radiation attenuation coefficient in CT images and using this to derive a better assessment of patient tissue dose.

Pediatric patients are at a higher risk of developing biological effects from radiation than adults. Estimating radiation doses is thus crucial and affects the development and improvement of pediatric CT imaging protocols. Monte Carlo methods can simulate the interaction of radiation, calculate the absorbed doses in organs, and calculate the effective dose for a CT examination.[6-8] The National Cancer Institute CT (NCICT) dosimetry system (National Cancer Institute, Bethesda, USA)[9,10] is one such program that uses a hybrid phantom model that allows users to select patient size from newborns to adults, gender, age, body size, CT scan parameters, and scan distance. The program calculates the absorbed dose in

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each organ and the SSDE. Both $CTDI_{vol}$ and SSDE are helpful for comparing and optimizing radiation doses for specific procedures.

The effective dose (E) serves as a metric for comparison of radiation-induced risks associated with radiation dose. However, it is calculated based on the absorbed radiation dose by the organs of standard reference phantoms from CT imaging and weighted according to tissue type.[11-14] The ICRP in Publication 147 has derived coefficients that can be used to assess lifetime risks of cancer incidence based on values for the effective dose for CT scans of different parts of the body, which consider the age and sex of the patient.[15]

SSDE and effective dose values have not been systematically collected in Thailand. The computation of SSDE and effective dose involves intricate and complex processes, and this coupled with the ongoing technological advancements in the development of Monte Carlo simulation programs for radiology applications makes this an ever-evolving field. The present research aimed to (1) calculate SSDE and effective dose values obtained through the NCICT program and (2) evaluate the DLP to effective dose (k) conversion factors as functions of pediatric patient ages and body sizes. The study was conducted for Thai pediatric patients who had undergone CT imaging of the brain, chest, and chest abdomen and pelvis (CAP). Differences in SSDE values calculated using the NCICT and the AAPM method were also compared, ultimately leading to critical analysis of the drawbacks and limitations of both approaches; this will lead to insights for future clinical applications of the dosimetry system for Thai pediatric patients.

Materials and Methods

The research is ethically approved by the university research ethics authority. This is a study using CT images and exposure parameters for pediatric patients, obtained from the three standard protocols used for CT imaging of the brain (without contrast medium injection), chest (with contrast medium injection), and CAP (with contrast medium injection) using a GE Discovery CT machine,[16] as shown in Table 1. The data were collected from May 2021 to May 2023 and included CT images and radiation dose information of patients under 15 years old, divided into four age groups: under 1 year, 1 to 5 years, 5 to 10 years, and 10 to 15 years. The values of $CTDI_{vol}$ and DLP obtained from CT scans of the individual pediatric patients were collected from the picture archiving and communication system.

National Cancer Institute computed tomography software

The NCICT software version 3.0.20211123 (National Cancer Institute, Bethesda, USA) is licensed for noncommercial research use.[9,10] It was employed to calculate organ and effective doses for CT patients, as shown in Figure 1a. NCICT relies on organ dose coefficients derived from Monte Carlo simulations involving CT X-rays in conjunction with the ICRP reference phantoms.[17] Information on the height and weight of the standard ICRP pediatric phantoms used to calculate effective doses for the NCICT program and those for standard Thai children are compared in Table 2.

To calculate dose output values, the ICRP category, gender, and age groups were selected as follows: for infants, pediatric patients aged 1 to <5 years, aged 5 to <10 years, and aged 10 to <15 years, patient age was chosen as 0 years, 1 year, 5 years, and 10 years, respectively. These weight and height values were based on the ICRP reference values and were not subject to modification. The parameters related to the entire scan, such as type of dosimetry phantom (head phantom or body phantom), tube voltage (kV), $CTDI_{vol}$, and scan range were input into the software.

The scan coverage for each body part is recommended as the default value for program utilization. However, in cases of the present study, the scan length in pediatric Thai patients tends to exceed the predefined default boundaries; therefore, adjustments were made by the user in accordance with the coverage set by the hospital, as mentioned in Table 1.

The organ and effective doses were estimated, incorporating tissue weighting factors as defined and derived from ICRP Publication 103.[18] The SSDE is determined by utilizing the effective diameter of the phantom for each age group. Subsequently, this value is used to derive conversion factors based on the phantom's diameter for $CTDI_{vol}$, which are then multiplied by the $CTDI_{vol}$ value.

Table 1: Parameters used in computed tomography imaging

Parameter	Brain NC	Chest CE	CAP CE
Tube voltage (kV)	100 and 120	100	100
Tube current (mA)	200–300	180–300	180–300
Rotation time (s)	0.5	0.6	0.6
Pitch	0.531	0.992	0.992
Collimation width (mm)	20	20	20
Slice thickness (mm)	5	5	5
Reconstruction algorithm	ASiRV 20%	ASiRV 20%	ASiRV 20%
Scan coverage	Vertex to base of skull	Above lung apex to costophrenic angle	Above lung apex to symphysis pubis
CTDI phantom (cm)	16	32	32

NC: Noncontrast, CE: Contrast enhancement, CAP: Chest abdomen and pelvis, ASiRV: Adaptive statistical iterative reconstruction V, CTDI: Computed tomography dose index

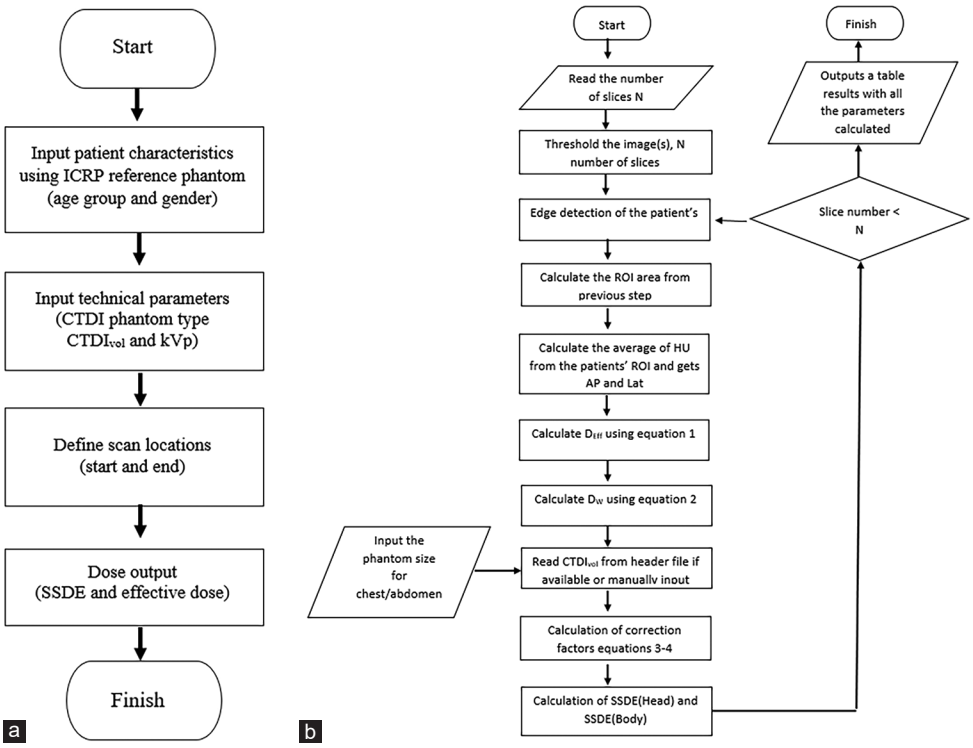

Figure 1: The flowchart for (a) the automated calculations of size-specific dose estimate (SSDE) and effective dose using National Cancer Institute computed tomography software and (b) the automated calculations of SSDE using the American Association of Physicists in Medicine method

Table 2: Information on height and weight of International Commission on Radiological Protection phantoms and standard Thai children

Age group (years)	Height (cm)				Weight (kg)			
	ICRP phantom		Standard Thai children		ICRP phantom		Standard Thai children	
	Male	Female	Male	Female	Male	Female	Male	Female
Newborn	51	51	53	53	3.5	3.5	3.9	3.7
1	76	76	80	80	10	10	11	11
5	109	109	109	108	19	19	18.5	18
10	138	138	135	137	32	32	30	30

ICRP: International Commission on Radiological Protection

To ascertain whether the measured absorbed radiation dose aligned closely with the simulated dose estimation, prior to the study, optically stimulated luminescence nanoDot dosimeters (Landauer, Inc., Greenwood, IL),[19,20] which were calibrated for the energy spectrum, were affixed to the surface of a Rando Phantom at both the right and left eye lenses for the CT brain and at the thyroid position for the CT chest as per the prescribed protocol, after which scanning was conducted. The radiation quantity values were then read out using a microStar reader (Landauer, Inc., Greenwood, IL) and compared with those from the NCICT program, with parameter values being entered in accordance with the scanned protocol. Percentage differences were calculated as within ± 4.5%.

Size-specific dose estimate calculation using the American Association of Physicists in Medicine method

CT images were analyzed using an ImageJ[21] algorithm, written by the authors following AAPM Report No. 204, No. 220, and No. 293. The flowchart for the automated calculations is presented in Figure 1b. The image datasets were imported into ImageJ as a stack of single image (s) in DICOM (Digital Imaging and Communications in Medicine) format; a threshold of -140 HU was set to detect the body surface contour for each pediatric patient, as shown in Figure 2. The patients' contours were selected as regions of interest (ROIs) in the axial images and were automatically detected using the analyze particle function, in ImageJ by specifying the size (5000-infinity) and circularity (0.2–1), resulting in only the patient's contour, avoiding peripheral objects such as the patient's couch. D_{Eff} was calculated as an approximation using the anteroposterior and lateral dimensions of each ROI, taken between the two widest points, as shown in equation 1. The area of the ROI (A_{ROI}) was measured and D_w was calculated per slice using equation 2.

$$D_{Eff} = \sqrt{AP \times Lat} \quad \text{Eq. 1}$$

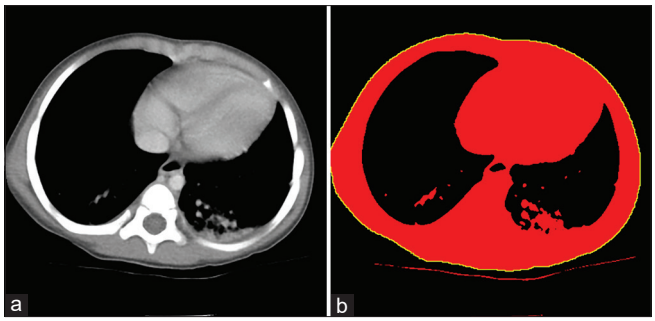

Figure 2: Steps of the segmentation process (a) original axial image (b) result of thresholding by − 140 HU and regions of interest selection

Then, calculate the water equivalent diameter (D_w) using the formula shown in equation 2 below.

$$D_w = 2\sqrt{\left[\frac{1}{1000}\overline{CT(x,y)_{ROI}} + 1\right]\frac{A_{ROI}}{\pi}} \quad \text{Eq. 2}$$

where $\overline{CT(x,y)_{ROI}}$ is average CT number within the area of interest

$\overline{A_{ROI}}$ is the area of ROI (cm^2)

Next, the D_w value was used to calculate the correction factor for CT brain, chest, and abdomen regions based on the phantom size, as shown in equations 3-4. These values were then multiplied by the $CTDI_{vol}$ value displayed on the CT scanner screen.

$$f^{H16} = 1.9852e^{(-0.0486D_w)} \quad \text{Eq. 3}$$

$$f^{B32} = 3.7055e^{(-0.0367D_w)} \quad \text{Eq. 4}$$

where H16 and B32 nomenclature are used in the superscript of the conversion factor f when the 16 cm or 32-cm PMMA CTDI phantom was used for the head (H) or body (B) $CTDI_{vol}$ measurements and D_w is the water equivalent diameter.

The algorithm reads the DICOM header file to obtain the DICOM tags for the local $CTDI_{vol}$ (0018,9345) for each slice, if not available it asks the user to manually enter the value. SSDE is calculated as the product of the local $CTDI_{vol}$ ($CTDI_{vol,\ 32}$) and the corresponding correction factor for the 32 cm phantom for the chest and CAP calculations, equations 3-4 depending on the acquisition. In the case of the head calculations, SSDE is calculated as the product of the local $CTDI_{vol}$ ($CTDI_{vol,\ 16}$) and the 16 cm phantom equation and the conversion factor using equation 2. All the parameters generated and calculated were output in a results table that could be saved as a spreadsheet.

Data analysis

The SSDE values obtained from the use of the NCICT program were compared with the AAPM calculation methods to derive the percentage differences. Descriptive statistics were utilized to summarize the quantitative data. The Wilcoxon signed-rank test was employed to compare the SSDE values between the AAPM calculation method and the NCICT program. P <0.05 was considered statistically significant.

The values of $CTDI_{vol,}$ SSDE, and effective dose for CT imaging of the brain, chest, and CAP are presented in the form of tables. The ratio between the effective dose obtained from NCICT and the DLP from the CT scan's radiation dose display, known as k-factors, was established in equation 5.

$$k = \frac{E}{DLP} \quad \text{Eq. 5}$$

where the k is k-factor ($mSv.\ mGy^{-1}cm^{-1}$), E is effective dose (mSv), and DLP is DLP (mGy.cm).

Correlations between k factors and the age of pediatric patients known as age-specific k conversion factors and those with the diameter measured at the midpoint of the scan termed size-specific k conversion factor were evaluated using a simple regression model to find the best fit model and level of the relationship. The size-specific k-factors are used for the calculation of size-specific effective doses for individuals undergoing CT scans that is based on organ and tissue doses derived using phantoms matched to the size of the patient's body.[11] Values of age-specific k conversion factors were calculated and compared with ones recommended by other studies.[22,23]

Results

Pediatric patients' information

The number of sample groups and the average D_w and D_{Eff} values for each age group of pediatric patients who underwent CT of the brain, chest, and CAP are presented in Table 3. The average size of the diameter in the head region of the NCICT program's ICRP reference pediatric phantoms is smaller than that in real Thai pediatric patients across all age groups. Similarly, the average size in the torso region of the model phantoms is smaller than that in real patients in the age group of <1 year. However, in the age group of 1 year and above, it is found that the average size of the diameter in the torso region of the model phantoms is larger than that in real Thai patients.

Values of $CTDI_{vol}$ and size-specific dose estimate

The values $CTDI_{vol}$, DLP, and SSDE are shown in Table 4. Values of $CTDI_{vol}$ for CT imaging increased with age. CT brain imaging had the highest $CTDI_{vol}$ values, ranging from 21.3 to 36.8 mGy, while CT chest and CAP imaging had lower values, approximately 5 to 6 times lower and 4 to 5 times lower, respectively, compared to CT brain. The SSDE values obtained from CT brain imaging for newborn patients were higher than the $CTDI_{vol}$. However, for pediatric patients aged 1 year and older, SSDE values were lower than the $CTDI_{vol}$, with SSDE values for CT chest and CAP imaging being approximately twice as high as $CTDI_{vol}$. Comparison of SSDE values from the AAPM method and the NCICT program revealed that SSDE values from the NCICT program were higher than the

Table 3: Average water equivalent diameter and effective diameter values at each age group

Examination	Age group (years)	*n*	CT images		NCICT D_{eff} (cm)	%diff* (D_{eff})	%diff** D_w versus D_{eff}
			D_w (cm)	D_{eff} (cm)			
Brain NC (*n*=189)	Newborn	50	12.9±1.6 (9.4–15.4)	12.5±1.5 (9.4–15.0)	9.9	−21	−23
	1	50	15.7±0.8 (14.2–17.3)	15.1±0.7 (13.9–16.7)	14.4	−5	−8
	5	50	16.69±0.69 (15.0–19.2)	16.1±0.7 (14.0–18.9)	15.9	−1	−5
	10	39	17.44±0.87 (15.4–19.0)	16.8±0.9 (14.7–18.6)	16.2	−4	−7
Chest CE (*n*=76)	Newborn	12	11.8±1.0 (10.5–13.5)	12.2±0.8 (11.1–13.6)	10.5	−14	−11
	1	20	15.0±1.3 (12.4–17.7)	15.1±1.3 (12.9–17.4)	15.2	1	1
	5	21	16.8±1.7 (14.2–20.0)	17.4±1.5 (14.3–20.4)	19.2	10	14
	10	23	20.6±2.9 (13.0–20.7	21.3±3.2 (14.9–29.6)	24.5	15	19
CAP CE (*n*=71)	Newborn	8	12.4±1.3 (10.7–14.8)	12.4±1.3 (10.6–14.4)	11.1	−10	−10
	1	17	15.1±2.5 (12.4–22.7)	15.3±2.8 (11.9–24.1)	16.3	7	8
	5	18	16.7±2.5 (13.2–21.6)	16.6±2.5 (12.3–21.6)	17.8	7	6
	10	28	22.3±5.2 (16.9–42.1)	21.9±5.2 (16.6–42.3)	22.1	1	−1

*The differences between the values of D_{eff} obtained from the CT imaging and those derived from the NCICT software program,***The differences between the values of D_w obtained from the CT imaging and the values of Deff derived from the NCICT software program. D_w: Water equivalent diameter, D_{eff}: Effective diameter, CAP: Chest abdomen and pelvis, CE: Contrast enhancement, CT: Computed tomography, NCICT: National Cancer Institute CT, NC: Noncontrast

Table 4: Values of $CTDI_{vol}$, dose length product, and size-specific dose estimates obtained from computed tomography imaging of the brain, chest, and chest abdomen and pelvis

Examination	Age group (years)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	SSDE (AAPM) (mGy)	SSDE (NCICT) (mGy)	%diff of SSDE**
CT brain	Newborn	21.3±3.8 (11.2–32.8)	333±94 (180–618)	22.6±4.1 (10.7–33.8)	27.1±4.8 (14.3–42.0)	19.9*
	1	24.8±7.0 (9.3–43.5)	478±156 (211–838)	23.0±6.4 (8.3–41.5)	26.6±7.6 (10.0–47.0)	15.7*
	5	27.8±7.1 (20.8–49.2)	576±155 (253–1012)	24.5±6.2 (10.7–42.8)	27.8±7.4 (12.5–49.8)	13.5*
	10	36.8±7.9 (15.0–44.0)	775±187 (283–1059)	31.3±6.4 (13.0–41.8)	37.0±8.0 (15.0–50.1)	18.2*
CT chest	Newborn	3.0±0.9 (1.9–4.6)	64±21 (29–98)	7.3±2.0 (4.9–10.8)	7.6±2.2 (4.9–11.7)	4.1*
	1	3.9±0.8 (2.1–4.9)	93±23 (44–128)	8.3±1.9 (4.5–11.0)	8.1±1.8 (4.4–10.8)	−2.4
	5	4.8±0.9 (3.4–6.3)	133±27 (89–184)	9.5±1.7 (6.9–13.9)	8.8±1.6 (6.3–11.8)	−7.4*
	10	7.1±2.6 (5.4–14.3)	233±116 (124–551)	12.2±3.7 (7.0–20.5)	11.0±4.1 (6.5–21.6)	−9.8*
CT CAP	Newborn	5.0±1.0 (4.1–6.8)	146±25 (102–174)	11.8±2.3 (9.6–15.8)	12.4±2.5 (9.9–16.8)	5.1*
	1	5.5±0.7 (3.8–7.1)	201±35 (121–286)	11.7±1.3 (8.9–13.4)	11.3±1.4 (8.7–14.4)	−3.4
	5	6.8±1.2 (5.2–9.3)	276±67 (197–434)	13.3±2.0 (10.6–18.0)	13.3±2.2 (10.4–18.7)	0
	10	10.0±3.1 (5.0–20.4)	505±190 (207–1156)	15.9±2.7 (8.7–21.8)	17.2±5.4 (8.7–35.6)	8.2

*P<0.05 statistically significant differences between both methods, **The differences between the values of SSDE (mGy) obtained from the AAPM protocol and those derived from the NCICT program. DLP: Dose length product, CT: Computed tomography, CAP: Chest abdomen and pelvis, AAPM: American Association of Physicists in Medicine, SSDE: Size-specific dose estimate, $CTDI_{vol}$: Volume-weighted CT dose index, NCICT: National Cancer Institute CT

AAPM method by up to 20% for CT brain imaging, while for CT chest and CAP imaging, differences ranged within ± 10%.

The comparison of $CTDI_{vol}$ and SSDE found that, in the context of CT brain imaging for newborn patients, SSDE values were higher than the $CTDI_{vol}$. However, for pediatric patients of 1 year and older, the SSDE values were lower than $CTDI_{vol}$. This discrepancy is attributed to the head size, which is larger than the standard size of the model phantoms with a 16 cm central axis, resulting in a lower correction factor. In the case of CT torso imaging, it was observed that SSDE values were higher than $CTDI_{vol}$ for all age groups. This is primarily due to the same reason, where the average body size of pediatric patients is smaller than 32 cm, which is the standard size of the model phantoms in the torso region, resulting in a higher correction factor.

Age-specific k conversion factor

Age-specific k conversion factor (mSv. $mGy^{-1}cm^{-1}$) obtained from this study and comparisons to those from the ICRP reference pediatric phantoms[17] and Deak *et al*.[22] are shown in Table 5 for CT brain, chest, and CAP scans.

The effective dose values obtained from the age-specific k conversion factor obtained from this study are shown in Table 5. The effective dose from CT brain ranged from 1.6 to 3.4 mSv, with a decreasing trend with age. The effective doses from chest and CAP imaging were 4.6–6.7 mSv and 10.4–13.5 mSv, respectively. The effective dose values obtained for CT chest and CAP were generally comparable among pediatric patients across all age groups, except for pediatric patients aged 10 years, who exhibited significantly

Table 5: The age-specific k conversion factors and calculated effective dose for computed tomography brain, chest, and chest abdomen and pelvis obtained from various studies

	Age group (years)	The age-specific k conversion factor ($mSv.mGy^{-1}.cm^{-1}$)			Effective dose (mSv)		
		This study	Deak *et al*.[22]	Romanyukha *et al*.[23]	This study	Deak *et al*.[22]	Romanyukha *et al*.[23]
Brain	Newborn	0.010	0.0088	0.009	3.4±1.1 (1.4–6.4)	2.9±0.8 (1.3–5.3)	3.0±0.9 (1.6–5.6)
	1	0.004	0.0054	0.006	2.0±0.8 (0.8–3.4)	2.6±0.8 (1.1–4.4)	2.9±0.9 (1.3–5.0)
	5	0.003	0.0035	0.004	1.8±0.8 (0.8–5.6)	2.0±0.5 (0.9–5.7)	2.3±0.6 (1.0–4.1)
	10	0.002	0.0027	0.003	1.6±0.5 (0.5–2.7)	2.1±0.5 (0.8–2.9)	2.3±0.6 (0.9–3.2)
Chest	Newborn	0.074	0.074	0.099	4.8±1.4 (2.5–7.0)	4.8±1.4 (2.5–7.0)	6.4±2.1 (2.9–9.7)
	1	0.050	0.048	0.064	4.6±1.1 (2.6–6.6)	4.6±1.0 (2.1–6.2)	5.9±1.4 (2.8–8.2)
	5	0.037	0.032	0.047	4.9±1.0 (3.3–6.6)	4.4±0.8 (3.0–5.9)	6.3±1.3 (4.2–8.7)
	10	0.027	0.024	0.033	6.7±3.2 (3.3–14.8)	5.6±2.6 (3.1–12.9)	8.1±3.8 (4.1–18.2)
CAP	Newborn	0.072	0.0838	0.088	10.5±2.0 (8.3–13.5)	12.3±1.9 (8.6–14.6)	12.8±2.2 (9.0–15.3)
	1	0.052	0.053	0.063	10.4±1.5 (6.9–14.0)	10.7±1.8 (6.9–15.2)	12.6±2.2 (7.6–18.1)
	5	0.038	0.0355	0.043	10.4±2.0 (7.7–15.0)	9.8±2.4 (7.0–15.0)	11.9±2.9 (8.5–18.7)
	10	0.027	0.0247	0.032	13.5±5.0 (5.5–29.0)	12.4±4.7 (5.1–28.5)	15.4±6.1 (6.6–23.9)

CAP: Chest abdomen and pelvis

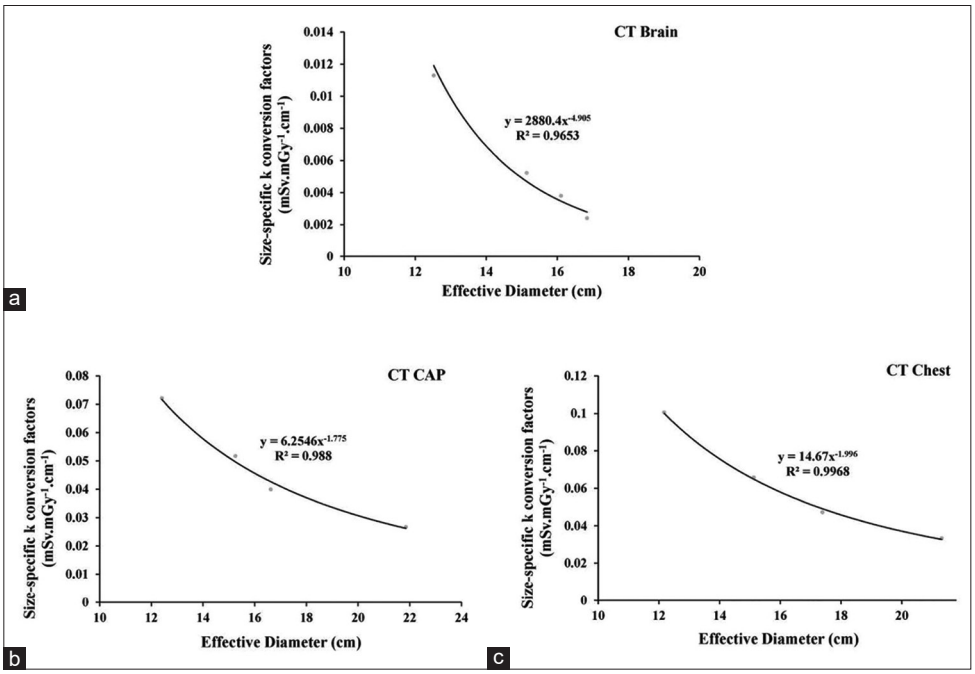

Figure 3: The size-specific k conversion factors for assessment of a size-specific effective dose, which uses organ doses derived from phantoms matched to the patient size, obtained from the study for computed tomography (a) brain, (b) chest and (c) chest abdomen and pelvis. CAP: Chest abdomen and pelvis, CT: Computed tomography

higher effective dose values. In performing CT brain scans on older individuals or those with larger head sizes, the resulting impact leads to a decreased effective dose. This is attributed to a lower proportion of absorbed radiation in the brain and pituitary gland compared to newborns. Additionally, the longer scanning length in older children covers organs with lower tissue weighting factors. Consequently, the overall risk is diminished. Values of the effective dose were compared for those using the age-specific k conversion factor recommended by Deak *et al*.[22] and Romanyukha *et al*.[23] [Table 5]. The maximum differences are 31% and 45%, 16% and 33%, and 17% and 22% between other studies and the present work for CT brain, chest, and CAP, respectively.

Size-specific k conversion factor

Size-specific k conversion factors ($mSv \cdot mGy^{-1} \cdot cm^{-1}$) as a function of effective diameter measurements (cm) for CT brain, chest, and CAP scans are shown in Figure 3a–c, with the relationship best described by power functions. Based on the fits of regression models, a set of lookup tables were generated using the simple measurements of

effective diameter, as shown in equation 6 and summarized in Table 6.

$$X = (a \times D_{Eff})^{-b} \quad \text{Eq. 6}$$

where X is the size-specific k conversion factor in units of $mSv \cdot mGy^{-1} \cdot cm^{-1}$, and DEff is the effective diameter in units of cm.

Discussion

When considering the differences in SSDE between the two methods [Table 4], it is observed that the SSDE value is influenced by two primary factors: $CTDI_{vol}$ and the size of the patient/phantom, which has an impact on the $CTDI_{vol}$ to SSDE conversion factor. This is another aspect that users must be mindful of when utilizing the NCICT program, as discrepancies arise from the patient's diameter not matching the size of the phantom, as depicted in Table 3, resulting in outcomes presented in Table 4. As for the size correction factor, this study compared the patient body sizes, as shown in Table 3, indicating that the head size of the phantom in the program is smaller than that of actual patients and is less than 16 cm. Consequently, this leads to higher correction values. When combined with the $CTDI_{vol}$ values as discussed earlier, it results in the SSDE value obtained from the NCICT program being higher than the calculation method of the AAPM. Moreover, the AAPM method applies D_w for SSDE calculations, while the NCICT program employed D_{Eff} as explained in the method section. For CT scans of the torso, it was observed that SSDE values for CT chest obtained from the NCICT program were lower than those obtained from the AAPM method. This disparity may be attributed to the presence of low-density air-filled spaces within the pulmonary region, resulting in smaller central axis dimensions and subsequently leading to higher correction factors. Consequently, values derived from the AAPM calculation method were found to be greater.

The selection of the scan coverage, which includes the start and end positions in the NCICT program, is another aspect that users must be mindful of when utilizing the NCICT program since it significantly impacts the effective dose. This is from the fact that absorbed radiation doses of various organs within the primary radiation field have distinct tissue weighting factors. The researcher conducted a study on the influence of adjusting the start and end positions of scanning in a phantom model. This was done by using the average scan length values from real patients and moving the scanning coverage (with the same length) up and down by 10%. The goal was to observe changes in effective dose values over the course of these adjustments, and the results are displayed in Table 7, showing that the effective dose can change by up to 33%, 7%, and 8% for CT brain, chest, and CAP, respectively. These primary factors arise from variations in the absorbed radiation dose to the salivary glands, oral cavity, spinal cord, and thyroid gland that can be increased by up to twofold when they are within or outside the primary beam. In CT chest with manually selected scan coverage, a downward movement of scan coverage will result in an increase in the effective dose due to the heightened

Table 6: Coefficients to derive values for size-specific k conversion factors from effective diameter

	Size-specific k conversion factors ($mSv.mGy^{-1}.cm^{-1}$)		
	a	b	R^2
Brain	2880.4	−4.905	0.9653
Chest	14.67	−1.996	0.9968
CAP	6.2546	−1.775	0.988

CAP: Chest abdomen pelvis

Table 7: Changes in effective dose values from computed tomography brain, chest, and chest abdomen pelvis with 10% adjustments of the start and end positions of scanning the International Commission on Radiological Protection reference phantoms, as compared to the reference scan positions

	Age group (years)	Average scan length (cm)	Start-end positions (reference position)	Percentage change of E (mSv)			
				Move up*		Move down**	
				Male	Female	Male	Female
Brain	Newborn	11	Vertex - base of Skull	N/A	N/A	23.1	23.1
	1	15		N/A	N/A	33.3	33.3
	5	18		N/A	N/A	20.5	20.5
	10	19		N/A	N/A	18.8	18.8
Chest	Newborn	9	Lung apex - mid of liver	−4.1	−4.1	6.8	7.2
	1	14		−4.4	−4.4	3.0	3.4
	5	19		−5.5	−5.8	0.3	0.3
	10	24		−6.6	−6.6	0.8	0.8
CAP	Newborn	24	Lung apex - symphysis pubis	5.5	6.7	−5.1	−5.3
	1	32		5.9	1.4	−4.8	−6.4
	5	43		4.5	2.8	−7.4	−8.4
	10	53		3.7	0.8	−2.6	−7.4

*The starting position of the scan is higher than the reference position, **The starting position of the scan is lower than the reference position. Since the head region begins at a distance of 0 cm, there are only starting positions lower than the reference position. CAP: Chest abdomen pelvis, N/A: Not available, ICRP: International Commission on Radiological Protection

Table 8: Comparisons of effective dose from using age- and size-specific k conversion factor obtained from this study for average size of Thai pediatric patient

	Age group (years)	DLP (mGy.cm)	D_{eff} (cm)	Effective dose (mSv)		Ratio
				Age-specific effective dose k conversion factor	Size-specific effective dose k conversion factor	
Brain	Newborn	333	12.5	3.3	4.0	1.2
	1	478	15.1	1.9	2.3	1.2
	5	576	16.1	1.7	2.0	1.2
	10	775	16.8	1.6	2.2	1.4
Chest	Newborn	64	12.2	4.7	6.4	1.3
	1	93	15.1	4.7	6.0	1.3
	5	133	17.4	4.9	6.5	1.3
	10	233	21.3	6.3	7.6	1.2
CAP	Newborn	146	12.2	10.5	10.8	1.0
	1	201	15.1	10.5	10.2	1.0
	5	276	17.4	10.5	10.8	1.0
	10	505	21.3	13.6	13.9	1.0

CAP: Chest abdomen pelvis, DLP: Dose length product

absorption of radiation in the breast tissue and the intestines. For the same reason, an elevation in scan coverage has a more significant impact, primarily because of the substantial increase in the absorbed radiation in the salivary glands, oral cavity, spinal cord, and thyroid. This increase is consistent for both male and female subjects.

The initial set of k-factors was formulated by Shrimpton *et al*.[24] utilizing stylized phantoms. Subsequent efforts by the European guidelines[25] and Deak *et al*.[22] resulted in updated sets of k-factors tailored for pediatric and adult patients. Several studies have recommended age-specific k conversion factor values. For this study, those obtained for each type of CT imaging were compared with the values recommended by Deak *et al*.[22] and Romanyukha *et al*.,[23] as shown in Table 5. It was observed that the values obtained from different methods exhibit a maximum difference of no more than 45%. Additionally, the study by Lee *et al*.[26] found that the conversion factors for CT brain imaging in pediatric groups aged less than 2 years, 4–6 years, 9–11 years, and 13–15 years were 0.0063, 0.0046, 0.0031, and 0.0024 mSv. $mGy^{-1}.cm^{-1}$, respectively, which are in close agreement with the findings of Romanyukha *et al*.[23]

Deak *et al*.[22] employed a sequence of stylized phantoms and performing Monte Carlo transport calculations, incorporating tissue weighting factors derived from ICRP Publication 103[18] while Romanyukha *et al*. have revised the age-specific k-factors using the ratio of the effective dose (mSv) calculated by NCICT program and the DLP (mGy.cm) of different scan types listed in European guidelines on quality criteria for CT.[25] A significant limitation of calculations based on the stylized phantoms is that they represent reference body sizes, where anatomical structures are described using mathematical equations. Consequently, the application of these k-factors to patients deviating in size from the reference phantom may lead to over- or underestimations of the effective dose.

As per the research conducted by Wall *et al*.[27] which updated effective dose values for common CT examinations employing the ICRP methodology for effective dose determination, the study incorporated new recommendations, specifically concerning tissue-weighting factors and the precise utilization of computational voxel reference adults. Consequently, the DLP to effective dose conversion factors calculated using the two distinct phantom methodologies can vary by 50%–80%.

The size-specific k conversion factors for CT brain, chest, and CAP are illustrated in Figure 3a-c. In this context, it is necessary to determine the effective diameter first, which is then used to calculate the k factor. Subsequently, this ratio is multiplied by the DLP obtained from the scans. The authors compared age-specific k conversion factors using average DLP and effective diameter data within each age group and size-specific conversion factors used to derive a size-specific effective dose, with organ doses assessed on phantoms with similar stature to the patients. The effective doses calculated by both methods are compared in Table 8. The results indicate that the Thai size-specific effective doses are 1.2–1.4 times the standard age-specific effective doses for CT brain and CT chest. However, no significant difference was observed in the two effective dose values for CT CAP when utilizing both conversion factors. The goal of this research is to present an approach for estimating effective dose, and users must consider the appropriateness of each method for their specific applications.

The study faced some limitations. First, only one scanner was studied, the results obtained may serve as preliminary guidelines, particularly in estimating effective dose values, and in the future, further studies may be conducted on CT machines from other vendors. Second, the number of pediatric patients meeting the selection criteria was small, primarily because of incomplete patient data. The GE DoseWatch program, used for patient data and parameter collection, only retained data for a limited period of 2 years, and due to limited pediatric patient data, gender-specific

analysis was not conducted for certain topics. Nevertheless, through random sampling, it was found that the effective dose in pediatric female and male patients did not exhibit significant differences. Third, the selection of scan boundaries significantly impacts the calculated effective dose values, particularly in the head region, and this research has not extensively investigated the effects of changes in scan length. Finally, this research is a retrospective study that does not specify the weight and height of the pediatric patients. Therefore, the ICRP mode of the NCICT program was chosen to determine the sizes of pediatric patients, which are dependent on their age. The inability to precisely select individual patient sizes may have led to discrepancies between the calculated SSDE and effective dose values and the actual values.

Conclusions

The SSDE and effective dose values obtained from CT scans are parameters related to the radiation risk associated with CT imaging and can guide the development of protocols for appropriate radiation dose management in the future. The calculation of SSDE using the NCICT program may yield values that differ from those obtained through the methodology recommended by the AAPM, primarily due to differences in their calculation principles. The effective dose is associated with the risk incurred from undergoing a CT scan. Values for the effective dose have been computed for anatomical phantoms from the NCI library representing the standard ICRP pediatric phantoms. These have been used to derive values for the k-factors that show slight differences from earlier values derived using more stylized phantoms. To integrate the impact of patient body size into effective dose computations, a series of size-specific k conversion factors have been devised to allow size-specific effective doses to be calculated. These factors can be applied to individual patients for clinical CT procedures and provide a more realistic assessment of differences in tissue doses. They suggest that when size is taken into account, the effective doses for the chest and head of Thai patients are 1.2–1.4 times higher.

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Conflicts of interest

There are no conflicts of interest.

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