Development of size-specific dose estimates for common computed tomography examinations: A study in Ghana

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Abstract

Purpose: This study determined the size-specific dose estimate (SSDE) of computed tomography (CT) examinations and derived mathematical expressions for dose output estimation and optimization in a teaching hospital in Ghana.

Methods: Demographic and scanner output indices including $CTDI_{vol}$ and DLP for adult head, chest and abdominopelvic (ABP) CT examinations carried out at the hospital from 2018 to 2020 were retrieved from its Picture Archiving and Communication System of the CT scanner machine. Other indices such as antero-posterior (AP) diameter (D_{AP}), lateral diameter (D_L) and diagonal diameter (D_{dia}) of the patients' bodies were measured on the mid-slice axial image using a digital caliper. The effective diameter (D_{eff}) was then calculated as the square root of the product of the D_{AP} and D_L. The SSDEs were calculated as the product of the $CTDI_{vol}$ and the size-specific conversion factors obtained from the American Association of Physicists in Medicine's (AAPM)

Report 204. Regression analyses were performed to find the relationship between SSDE and the various parameters to derive mathematical equations for the dose estimations.

Results: There were more female samples (*n* = 468, 56.3%) than males (*n* = 364, 43.7%) for each CT procedure. The SSDEs and size-specific diagnostic reference levels (SSDRLs) were: head (83.9 mGy; 86.9 mGy), chest (8.1 mGy; 8.7 mGy) and ABP (8.4 mGy; 9.2 mGy). The variations between $CTDI_{vol}$ and SSDEs for head (2.50%), chest (25.9%), and and ABP (26.2%) showed underestimation of radiation dose to patients especially in chest and ABP examinations if $CTDI_{vol}$ is used to report patient doses. The SSDEs of the chest and ABP CT examinations showed linear correlations with the $CTDI_{vol}$. The estimated values could be used to optimize radiation doses in the CT facility.

Conclusion: The SSDE and SSDRLs for head, chest and ABP CT examinations have been developed at a teaching hospital in Ghana. The SSDEs of chest and ABP examinations showed linear correlations with the $CTDI_{vol}$ and hence, can be calculated using the mathematically derived equations in the study.

Keywords: Computed tomography, dose index, size-specific dose estimate, antero-posterior diameter, lateral diameter, effective diameter.

Introduction

The volume-weighted CT dose index ($CTDI_{vol}$) and dose length product (DLP) are CT dose descriptors displayed on the CT scanner to measure and report radiation doses of patients during CT examinations [1-3]. The $CTDI_{vol}$ and DLP are based on measurements in polymethyl methacrylate (PMMA) phantoms for the head and body which are available in 16 cm and 32 cm diameters [2]. The $CTDI_{vol}$ descriptor is primarily useful for dose optimizations purposes, and also as a quality assurance tool in comparing doses, and scanner outputs from different protocols and from different manufacturers [3]. The dose within the scan volume from a specific scan protocol for a standardized phantom is represented by $CTDI_{vol}$, which measures the average x-ray output quantified by taking measurements in regular plastic (polymethyl methacrylate) 16-cm head or 32-cm body phantoms [1,2]. The $CTDI_{vol}$ is the pitch-corrected weighted CT dose index ($CTDI_w$) and expressed as

$$CTDI_{vol} = \frac{CTDI_w}{p} = \frac{1}{p}\left[\frac{1}{3} CTDI_{100,centre} + \frac{2}{3} CTDI_{100,periphery}\right] \quad (1)$$

where p is the scan pitch. Despite the fact that $CTDI_{vol}$ is highly accurate in describing radiation output from the scanner, it does not represent patient dose [1,4] and it does not consider the size of the patient [1,5]. Therefore, the interpretation of $CTDI_{vol}$ as patient dose could lead to overestimation or underestimation of patient doses [5].

The DLP represents the total exposure for the examination [4], and reflects the integrated radiation output (and thus, the potential biological effect) attributable to the complete scan acquisition [2]. DLP is the average x-ray tube output, describing the amount of radiation given off for all the slices in the entire scan, which is calculated by multiplying $CTDI_{vol}$ by the patient's scanned length in centimeters [1-3] as expressed in equation (2)

$$DLP = L(CTDI_{vol}) \quad (2)$$

where L is the scan length for the examinations.

According to the American Association of Medical Physicists (AAMP) Report 204 [1], the CT scan dose received by a patient is not only dependent on the scanner output but also the patient's size. In the AAMP Report 204, a new parameter called the "size-specific dose estimate (SSDE)" was presented as a more accurate patient dose estimator by considering the patient size. The SSDE is defined as a patient dose estimate which takes into consideration, corrections based on the size of the patient, using linear dimensions measured on the patient or patient images [6-8].

The AAPM also stated that in using size-dependent conversion factors (*f*), patient doses can be estimated using $CTDI_{vol}$ values which represent scanner output [1].

The AP diameter (D_{AP}), lateral diameter (D_L), sum of D_{AP} and D_L, and effective diameter (D_{eff}) are four sets of conversion factors for determining SSDE based on the mode of measuring patient size. In particular, the D_L and D_{AP} respectively define the left to right (side-side), and the thickness of the body part being scanned in the AP dimension, while D_{eff} describes patient diameter at given locations in the craniocaudal dimension (along the patient's z-axis), as stated by the AAPM [1]. Hence, depending on the adopted methodology, and the diameter of the specific PMMA reference phantom used for $CTDI_{vol}$, (16cm for head or 32cm for body), the corresponding AAPM conversion factors ($f_{size}^{`16X}$ and f_{size}^{32X}) could be identified and the SSDE calculated for the respective 16 cm and 32 cm diameter $CTDI_{vol}$ reference phantoms via

$$SSDE_{16,X} = f_{size}^{16X} x CTDI_{vol}^{16}$$

$$SSDE_{32,X} = f_{size}^{32X} x CTDI_{vol}^{32} \quad (3)$$

for a specific dimension *X* of the size used.

In general, patient size does not absolutely correlate with age. Therefore, patient size-dependent factors are useful for the estimation of doses for patients of varying sizes obtained from CT scanner outputs such as the $CTDI_{vol}$ parameter which is displayed on the monitor and stored on PACS. For this reason, the SSDE for a given dimension is a product of the size-dependent correction factor normalized with a phantom whose dimensions are the same diameter as 16 cm and 32 cm $CTDI_{vol}$, as several methods for estimating patient doses have conventionally relied on normalization by the $CTDI_{vol}$ using 16 cm and 32 cm phantoms [1]. Accordingly, the AAPM [1] has indicated SSDE as a more accurate parameter for estimating patient dose, while Brady and

Kaufman [8] suggested that the combination of AP and lateral measurements, either as the sum or

D_{eff} (the square root of the product of D_{AP} *and* D_L) should be used to determine SSDE, as it produces less variability than other methods do. Thus,

$$D_{eff} = \sqrt{(D_{AP} x D_L)} \qquad (4)$$

Hence, substituting Eqn.(4) into Eqn.(3), the calculated SSDEs can be expressed with respect to D_{eff} as Eqn. (5)

$$SSDE_{16,X} = f_{size}^{16D_{eff}} x CTDI_{vol}^{16}$$

$$SSDE_{32,X} = f_{size}^{32D_{eff}} x CTDI_{vol}^{32} \qquad (5)$$

From Eqn. (4), the conversion factors stated in Eqn. (3) are > 1 if D_{eff} is smaller than the reference phantom dimensions, and < 1 for D_{eff} values larger than the reference phantom (i.e. larger patients). An extensive study on diagnostic reference levels (DRLs) for examination-specific CT procedures was recently conducted in several CT operating imaging facilities and hospitals in Ghana [9]. These DRLs, however, do not reflect patient exposure or dose values determined by the SSDE approach. In particular, no studies have assessed SSDEs for characterization of patient dose with respect to size in order to enhance optimization in Ghana presently. This study was therefore conducted to estimate patient dose using the SSDE parameter taking into account, patient size, scanner output parameter, and SSDE conversion factors.

Methods

The study was conducted at the Radiology Department of a public referral and teaching hospital in Ghana over a 2-year period from January 2018 to January 2020. The study was retrospective and so no direct contacts with patients were made. Management of the facility ensured patient confidentiality and anonymity in accordance with ethical requirements by fully anonymizing the data before access was made. Since the patients presented themselves to the study sites for CT on their own accord, the requirement for informed consent was waived by the Ethics and Protocols Committee of the University of Ghana School of Biomedical and Allied Health Sciences which approved the study (SBAHS/AA/RAD/10700009/2020-2021) in accordance with the Helsinki declaration. A non-probability purposive sampling was used in this study as it provided for a convenient way of obtaining the required number of patients' CT data within the study period.

The study population consisted of adult head, chest and ABP CT examination data of patients. This decision was necessitated by that fact that adult patients more frequently undergo CT examinations [8], and head, chest and ABP regions are the most commonly scanned body parts [9,10]. Therefore, only scan data of adult head, chest and ABP CT procedures during this period were included in the study, while those of adult CT images with poor quality and patients aged below 18 years were excluded. Based on these inclusion and non-inclusion criteria, the scan data of 832 adult male and female patients were therefore retrospectively retrieved from the Picture Archiving and Communication System (PACS) of the hospital's advanced 640 multislice Toshiba Aquilon ONE TSX-301A CT scanner (Table 1). The data included the scanned images, scanning parameters (tube voltage, tube current-time product, number of sequences, pitch, rotation time, number of images, and slice thickness) and the $CTDI_{vol}$ and DLP dose descriptors [9-11]. Prior to using the data, quality control (QC) records of the equipment were assessed to ensure its functionability within the acceptable operating limits. These included CT dose output delivery accuracy, geometric efficiency, kilovolt accuracy, half-value layer (HVL), CT number, homogeneity, noise and signal-to-noise (SNR) of images and modulation transfer function (MTF). These were all found to be within their acceptable limits.

Table 1: Technical specifications of Toshiba Aquilon ONE TSX -301A CT scanner

Design Parameter	Value (quantity, volume, etc)
CT scanner mode	Multislice
Slices per rotation	16-cm volume (320 x 0.5mm)
Other rotation speed options (sec)	0.35, 0.375, 0.4, 0.45, 0.5, 0.6, 0.75, 1
Minimum rotation speed	35 msec
Minimum temporal resolution (msec)	16-cm full volume 350msec
Maximum beam width/Gantry diameter	16 cm/72 cm
Table weight limit	660 lb. (272.16 kg)
X-ray generator kV range	80-135 kVp
Maximum scan range	200 cm
X-ray tube heat capacity	7.5 MHU
Power requirement	480 VAC, 135kVA

To generate the SSDE, the first process involved the measurement of the D_{AP} and D_L on the middle slice of each set of images. Figure 1 shows how the D_{AP} and D_L measurements were taken on the retrieved images.

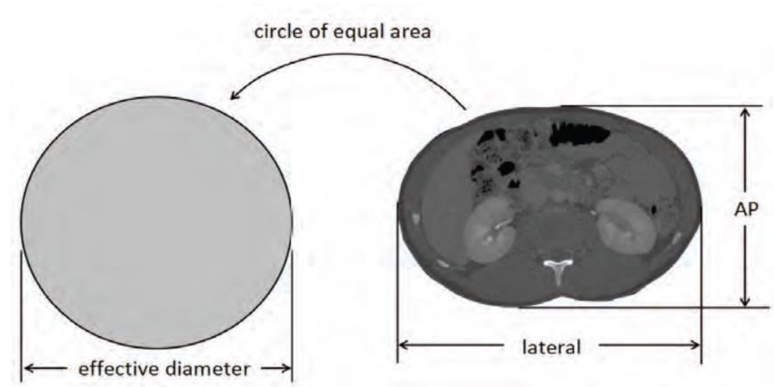

Figure 1: Measurement of anter-oposterior diameter and lateral diameter

The D_{eff} was then calculated via Eqn (4). The SSDEs were subsequently calculated as the product of the $CTDI_{vol}$ and corresponding conversion factors provided in the AAPM Report 204 as indicated via Eqn. (3).

Statistical Analysis

The data were analyzed with the Statistical Package for Social Sciences (SPSS) version 23 (IBM Inc., NY, USA) software. Inferential and descriptive analyses were performed and *p*-values < 0.05 were considered statistically significant. Inclusive in the descriptive analysis were frequencies, standard deviations, means, range and 75th percentiles. Regression analyses were performed to test the relationship between SSDE and the various diameters (D_{eff}, D_{AP}, D_L, D_{dia}), $CTDI_{vol}$, and also between $CTDI_{vol}$ and D_{eff}.

Results

The patient characteristics, CT scanning parameters, size measurements and the SSDE dosimetry results are shown in Tables 2-5 respectively.

Table 2: Gender

Gender	Body region							
	Head		Chest		ABP		Total	
	n	%	*n*	%	*N*	%	*n*	%
Male	192	47.8	80	39.4	92	40.5	364	43.8
Female	210	52.2	123	60.6	135	59.5	468	56.2
Total	402	48.3	203	24.4	227	27.3	832	100.0
Mean age (yrs)	51.8 ± 17		53.9 ± 16.5		52.4 ± 15.4			

Key: *n*=number, ABP= Abdominopelvic

Table 3: CT scanning parameters

Scan parameters	Body region for CT procedure		
	Head (*n* ± SD)	Chest (*n* ± SD)	Abdominopelvic (*n* ± SD)
Tube voltage (kVp)	120.0 ± 0.0	119.3 ± 18.7	115.7 ± 8.4
Tube load (mAs)	300.0 ± 0.0	126.6 ± 77.0	110.5 ± 50.2
Pitch	0.66 ± 0.0	0.99 ± 0.0	0.81 ± 0.0
Rotation (s)	0.75 ± 0.0	0.50 ± 0.0	0.50 ± 0.0
Slice thickness (mm)	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
$CTDI_{vol}$ (mGy)	86.0 ± 0.0	6.0 ± 3.2	6.2 ± 2.6
Total DLP (single sequence)	1559.6 ± 197.1	255.3 ± 138.8	234.5 ± 183.4

Key: n=number, SD =standard deviation; ABP= Abdominopelvic

Table 4: Size measurements

Measured diameters	Size measurement (cm)					
	Head		Chest		ABP	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
D_{AP}, cm	18.7 ± 0.9	16.2 -21.8	22.0 ± 3.1	15.6 - 32.5	22.5 ± 4.2	13.3 - 36.4
D_L, cm	15.3 ± 1.0	12.3 -18.0	32.0 ± 3.5	18.4 - 40.0	30.9 ± 4.5	15.0 - 41.3
D_{eff}, cm	16.9 ± 0.9	14.2 -19.3	26.5 ± 2.9	19.1- 36.0	26.3 ± 3.9	16.7 - 35.5

Key: SD =standard deviation; ABP= Abdominopelvic, D_{AP} = antero-posterior, diameter D_L = lateral diameter D_{eff} = effective diameter

Table 5: Dosimetry: $CTDI_{vol}$ vs SSDE

Dose descriptor and estimates	Body region					
	Head		Chest		ABP	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
$CTDI_{vol}$ (mGy)	86.0 ± 0.0	85.0 - 86.0	6.0 ± 3.2	2.9 -19.4	6.2 ± 2.6	2.1-20.1
SSDE (mGy)	83.9 ± 3.2	77.4 - 94.6	8.1 ± 3.5	3.3 - 22.6	8.4 ±2.8	2.1-21.1
% VRT	2.50		-25.9		-26.2	

Key: SD=standard deviation; %VRT=% variation between $CTDI_{vol}$ and SSDE, ABP= Abdominopelvic

A total of 832 CT data sets of head (n = 402, 48.3%), chest (n = 203, 24.4%) and ABP (n = 227, 27.3%) examinations were used in this study (Table 2). There were more females (n = 468, 56.3%) than males (n = 364, 43.7%) for each CT procedure. The mean ages of the patients ranged from 51.8 ± 17 years (head) to 53.9 ± 16.5 years (chest).

Fixed values of the various scan parameters were used for all the head examinations irrespective of patient size, except the scan length which resulted in changes in DLP values (mean: 1559.6±197.1 mGy.cm), while the automatic exposure control (AEC) was used for chest and ABP examinations only. From Table 3, higher mean tube voltage (119.3 ± 18.7 kV) and tube current-time-product (26.6 ± 77.0 mAs) were used for chest examinations compared to ABP examinations (tube voltage; 115.7 ± 8.4 kV; tube current-time-product: 110.5 ± 50.2 mAs).

The recorded mean (±SD), and range values of D_{AP} for the three procedures were [head: (mean:18.7±0.9 cm; range: 16.2 -21.8 cm), chest: (mean: 22.0 ± 3.1 cm; range: 15.6-32.5 cm), and ABP (mean: 22.5 ± 4.2 cm; range: 13.3 -36.4cm)] respectively. Similarly, the D_L values were [head: (mean: 15.3 ± 1.0 cm; range: 12.3 -18.0 cm, chest (mean: 32.0 ± 3.5 cm; range: 18.4-40.0cm) and ABP (mean: 30.9±4.5cm; range: 15.0-41.3cm). The lowest mean D_{eff} of 16.9 ± 0.9 cm was recorded for head examinations (Table 4).

A fixed $CTDI_{vol}$ value of 86.0 mGy was observed for head examinations and this corresponded to a mean SSDE value of 83.9 ± 3.2 mGy. The mean $CTDI_{vol}$ values used for chest (6.0 ± 3.2 mGy) and ABP (6.2 ± 2.6 mGy) examinations corresponded to SSDE values 8.1 ± 3.5 mGy and 8.4 ±2.8 mGy respectively. The % VRT represents the percentage change between $CTDI_{vol}$ and SSDE with respect to the various anatomical parts. These were minimum (2.50%) for head and maximum (-26.2%) for ABP procedures (Table 5).

Regression analyses were performed to investigate any relationship between SSDE and the various diameters (D_{eff}, D_{AP}, D_L, D_{dia}), and $CTDI_{vol}$, and also between $CTDI_{vol}$ and D_{eff} for chest and ABP examinations (Figures 2 and 3). From Figure 2, there were statistically significant relationships between SSDE and D_{eff} (R^2 =0.110, p =0.001), D_{AP} (R^2 =0.057, p=0.018), D_L (R^2 =0.110, p=0.0016), and D_{dia} (R^2 =0.168, p=0.0001) for chest CT procedures. The relationship between SSDE and $CTDI_{vol}$ was linear and stronger (R^2=0.938, p=<0.0001). Figure 2 further shows that the D_{eff} accounted for about 30% (R^2 =0.308, p=<0.0001) of the variation in $CTDI_{vol}$ in the model. Similar results were found for the relationship between SSDE and D_{eff} (R^2 =0.113, p =0.0001), D_{AP} (R^2 =0.1048, p=0.0001), and D_{dia} (R^2 =0.09119, p=0.0001) for ABP examinations.

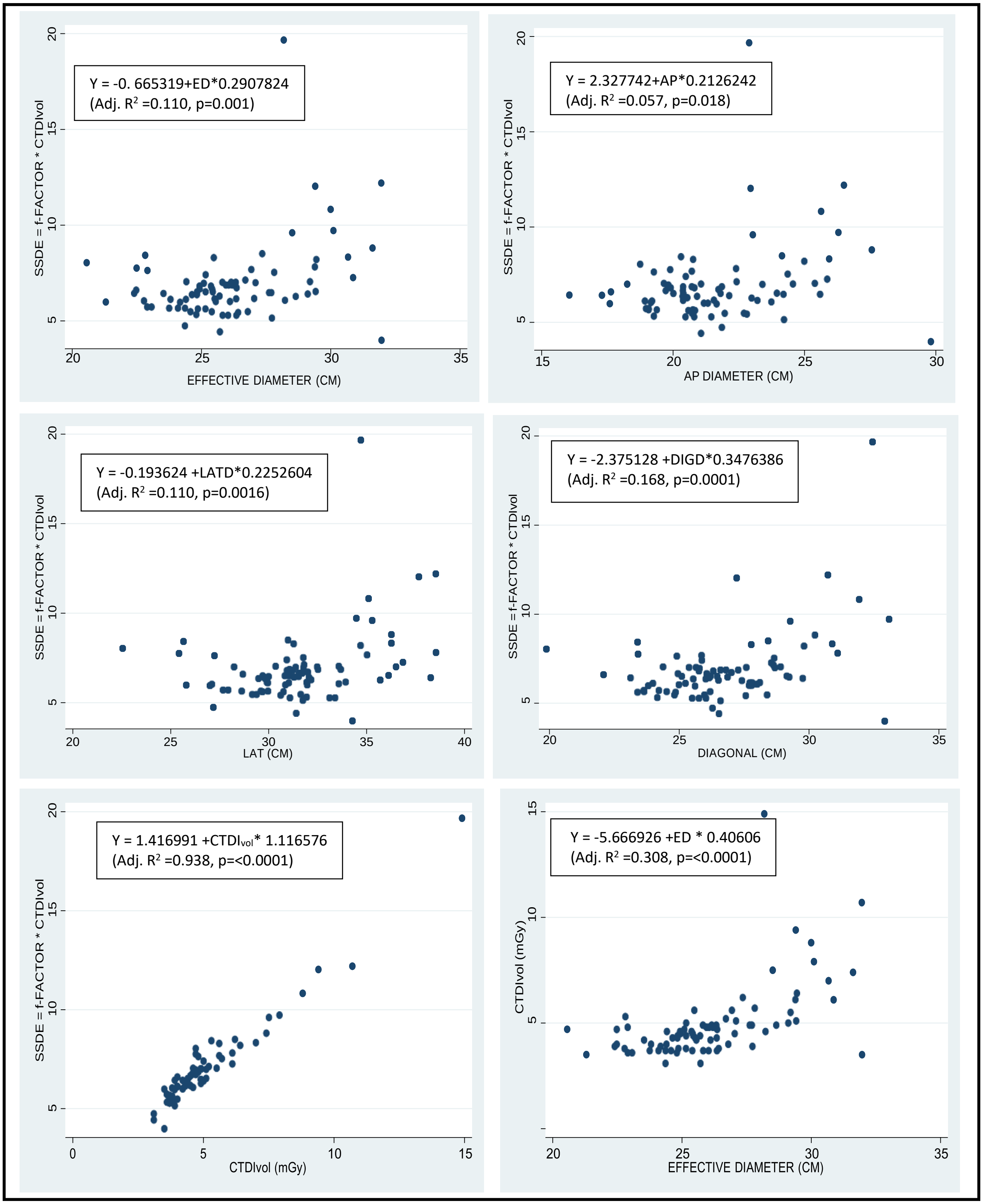

Figure. 2: Relationships between SSDE and effective diameter, AP diameter, diagonal

diameter and $CTDI_{vol}$ as well as $CTDI_{vol}$ and effective diameter for chest examinations.

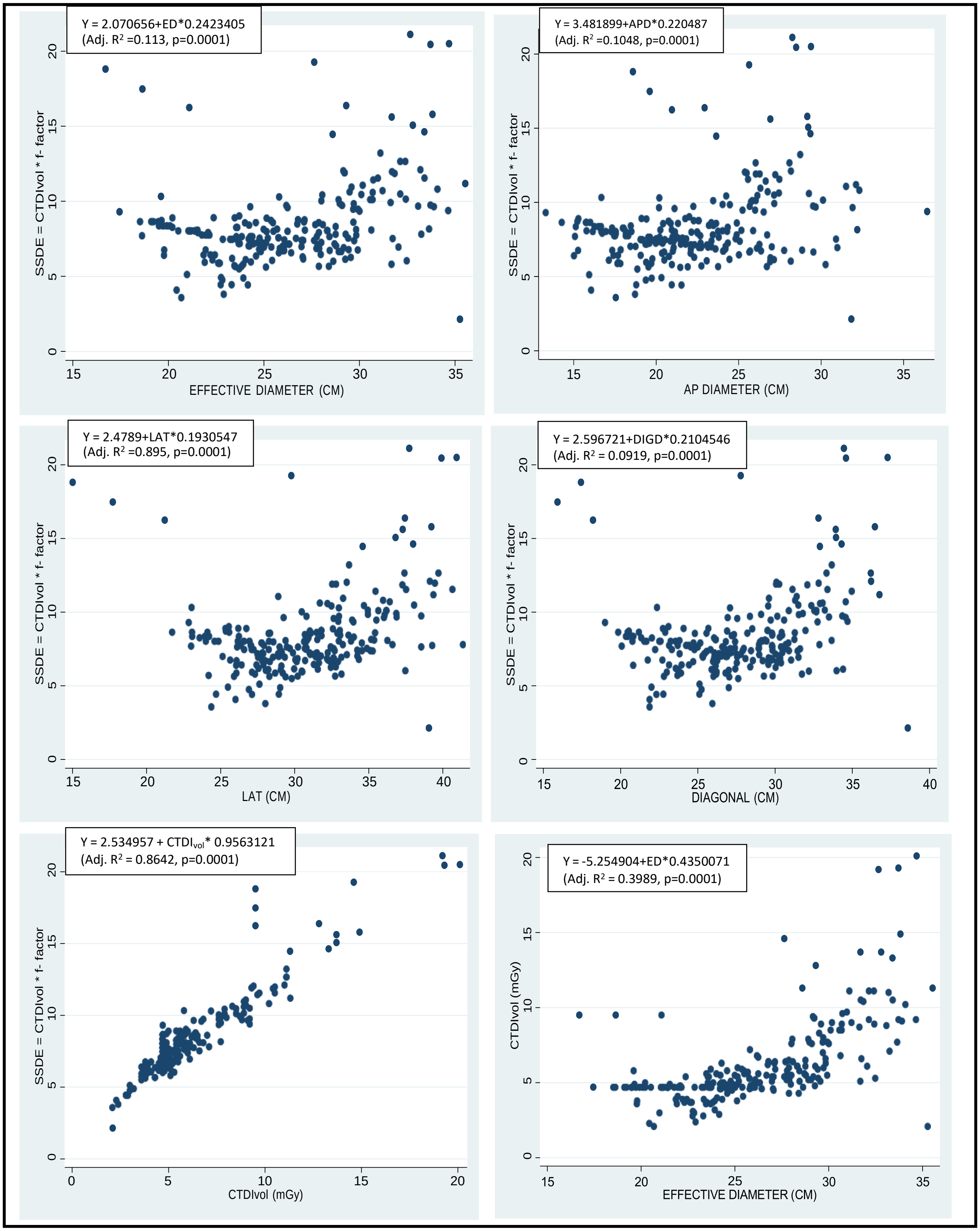

Figure 3: Relationship between SSDE and D_{eff}, D_{AP}, D_{dia} and CTDI$_{vol}$ as well as CTDI$_{vol}$ and

effective diameter for ABP examinations.

However, the correlation between SSDE and D_L was stronger (R^2=0.895, p=0.0001). The results also established a strong linear relationship between SSDE and $CTDI_{vol}$ (R^2=0.8642, p=0.0001).

Figure 3 also showed that the D_{eff} accounted for about 40.0% (R^2 =0.3989, p=<0.0001) of the variation in $CTDI_{vol}$ in the model. Since fixed exposure parameters were used for head examinations and a constant $CTDI_{vol}$ value was obtained, head procedures were excluded from the inferential analysis.

From Figure 3, the mathematical expressions derived to calculate the SSDE of the chest and ABP CT procedures are

$$SSDE_{ch} = 1.4167 + 1.1166 CTDI_{vol} \quad (6)$$

$$SSDE_{ABP} = 2.5350 + 0.9563 CTDI_{vol} \quad (7)$$

where $SSDE_{Ch}$ and $SSDE_{ABP}$ are the chest and ABP SSDEs. These expressions demonstrate a linear relationship between SSDE and the $CTDI_{vol}$. Variations in body sizes and patients' BMIs resulting from some pathologies may have effects on the $CTDI_{vol}$, and hence, these equations may not be applicable everywhere.

Discussion

Dosimetry

The estimated mean values of the CT dose descriptors were comparable with the literature. The results of this study are consistent with the findings in a Ghanaian study in which Anim-Sampong et al. [12] reported CT doses comparable with the International Commission on Radiological Protection (ICRP) DRLs. The reason for the similarity could be attributed to the fact that there is no significant change in the adult head dimensions between different people in one population. The estimated mean $CTDI_{vol}$ (86.0± 0.0 mGy) and DLP (1559.6±197.1 mGy.cm) values of head examinations were higher than the corresponding ACR and EC $CTDI_{vol}$ (60.0 mGy)

and DLP (1050.0 mGy.cm) values respectively. In a Nigerian study among a different cohort of patients, Adejoh et al. [13] recorded mean $CTDI_{vol}$ and DLP values of 57.0 mGy and 1336.0 mGy.cm respectively.

The measured $CTDI_{vol}$ (6.0 ± 3.2 mGy) and DLP (255.3 ±138.8 mGy.cm) values for chest examination were similar to other studies. In particular, Anim-Sampong et al. [12] recorded mean $CTDI_{vol}$ and DLP values of 5.9 mGy and 282.2 mGy.cm respectively in a previous study. Rajaraman et al.,[15] reported a mean $CTDI_{vol}$ of 7.3 mGy, while Moifo et al.,[16] recorded mean $CTDI_{vol}$ and DLP values of 14.8 mGy and 531.0 mGy.cm, respectively. The measured $CTDI_{vol}$ was comparatively lower than the ICRP reported value of 30.0 mGy for the same procedure [14]. For ABP examinations, the measured $CTDI_{vol}$ (6.2 ± 2.6 mGy) and DLP (234.5 ± 183.4 mGy.cm) were similar to the reported $CTDI_{vol}$ (6.8 ± 3.0 mGy), and DLP (353.5 ± 178. 4 mGy.cm) values by Anim-Sampong et al. [12]. In a Cameroonian study, Moifo et al., [16] recorded lower $CTDI_{vol}$ (13.7 mGy) but higher DLP (620.0 mGy.cm).

A reason for the observed differences in the dose indexes may result from differences of the body sizes of the surveyed patient cohorts in the different studies. The different sizes affect the work of the tube current modulation (TCM) system, and the choice of different tube current values. In particular, different nations have varying body sizes: some nations have bigger body sizes, while some have smaller, or taller or shorter sizes. The body mass indices (BMIs) therefore vary. Some pathologies also lead to heavier or lighter patients, and this could lead to the differences in the dose indexes.

In general, the radiation dose changes almost as the square of the tube voltage, and hence, higher tube voltages for head CT in particular, would lead to higher $CTDI_{vol}$. Appropriate minimization of the tube voltage can therefore be a very effective means of reducing radiation exposure. As done in most hospitals, a fixed tube potential of 120 kVp was used for all head examinations. However, a combination of this voltage with high tube current-time product presents another challenge. Specifically, corrective actions are needed to reduce head CT doses by lowering the tube current-time product. Varying scan ranges also account for the differences in the dosimetry values for chest and ABP scans. These findings, therefore, necessitate dose optimization measurements of radiation exposures at the study facility.

The study also showed variations of 2.50%, -25.9% and -26.2% between the SSDE and scanner-reported $CTDI_{vol}$ values for head, chest and ABP CT examinations respectively (Table 5). Choudhary et al., [17] also obtained a high variation of SSDE from $CTDI_{vol}$. This means that the use of $CTDI_{vol}$ to report patient doses for CT examinations of these body regions results in an underestimation of actual doses received by patients. This is supported by McCullough's [5] claim that, the interpretation of $CTDI_{vol}$ as patient dose could lead to either underestimation or overestimation of patient doses

Comparison of Estimated SSDEs with Other Examinations

Table 6 shows a comparison of the SSDE with some reported literature values. From Table 3, the estimated mean and median SSDE for adult head examinations were higher than values reported by Choudhary et al. [17] (median SSDE=54.1 mGy) and Kayun et al. [19] (mean SSDE=47.89 mGy). In general, the SSDE is directly proportional to the $CTDI_{vol}$. Hence, higher $CTDI_{vol}$ values result in higher SSDE. The differences in the measured SSDE may be explained by the fact that higher $CTDI_{vol}$ were used in image acquisition in this study and hence, higher SSDEs were measured. The impact of higher $CTDI_{vol}$ and SSDE in medical radiation protection and patient safety is huge as the probability of stochastic effect increases with dose.

Table 6: Comparison of estimated SSDE with literature values

	SSDE (mGy): Head			SSDE (mGy): Chest			SSDE (mGy): ABP		
	Mean	Median	75th P.	Mean	Median	75th P.	Mean	Median	75th P.
Current study	83.9	83.4	86.9	8.1	6.9	8.7	8.4	7.8	9.2
Rajaraman et al. [15]	-	-	-	10.6	-	-	-	-	-
Choudhary et al.[17]	-	54.1	-	-	23.1	-	-	20.1	-
Kayun et al. [19]	47.9	-	-	-	-	-	-	-	-
Hu et al. [20]	-	-	-	4.6	-	16		-	-
Christner et al. [21]	-	-	-	21.8	-	-	-	21.8	-

-=*No available data given in the publication; 75th P. = 75th percentile*

On the other hand, the estimated median SSDE (6.9 mGy) for chest CT examination was lower than the median value of 23.1 mGy reported by Choudhary et al. [17]. This difference may be due to the fact that the AAPM Report 204 conversion factors were used in this study, whereas Choudhary et al. [17] utilized different normalized dose conversion coefficients which were comparatively higher for smaller phantoms relative to larger-dimensioned one. This implied that higher conversion coefficients applied to small patients would result in higher $CTDI_{vol}$, and hence higher SSDE. According to Choudhary et al, [17], their SSDE values were 4 – 8% lower than reported AAPM values. Elsewhere in the literature, contrasting values of the mean and median SSDE values have also been reported. In particular, Hu et al. [20] obtained a lower mean value of 4.6 mGy, while Christner et al. [21] and Rajaraman et al. [15] recorded higher mean SSDE values of 21.8 mGy and 10.6 mGy respectively, compared to 8.1mGy in this study.

For adult ABP examinations, the estimated median (7.8 mGy) SSDE was lower than 20.1 mGy and 21.8 mGy indicated by Choudhary et al., [17] and Christner et al., [21] respectively. In the case of Christner et al., [21], the study was conducted in the chest and abdominal regions, while this study focused on the ABP region only. So, this could have accounted for the observed variation of their findings.

According to the ICRP [7] and International Atomic Energy Agency ([IAEA], 22), the 75th percentile should be used in the establishment of DRLs. Although there are very limited reported studies on the establishment of size-specific DRLs (SSDRLs) in the literature, the observed value for head CT, in particular, appears to be high (Table 5). This study calls for further optimization actions in CT facilities to ensure patients' protection, as previously suggested by Botwe et al., [9, 23]. A lesson can also be leant from the results of a recent study [24] that evaluated dose optimization options of adult head CT examinations.

The regression analysis and derived mathematical expressions showed linear relationships between SSDE, and the four sets of different measurements, and $CTDI_{vol}$ for the chest and ABP regions. Since differences in body sizes affect the $CTDI_{vol}$, and some pathologies also lead to variations in patients' BMI (heavier or lighter patients) which could lead to the differences in the dose indexes, the derived expressions may not be suitable for patients everywhere. Similar expressions describing the relationships between SSDE and the $CTDI_{vol}$ can be establish for patients of different races or in different geographical locations or nations.

Conclusion

The SSDE method developed in this study could be adopted to estimate the actual doses to patients during CT examinations. The estimated values (mean and DRLs) could be used to optimize radiation doses in CT facilities. Moreover, the SSDEs of chest and ABP CT examinations showed linear correlations with the $CTDI_{vol}$ and hence, can be mathematically calculated using the $CTDI_{vol}$ values.

Conflict of Interest

None declared.

Acknowledgement

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