



Multi-slice CT examinations of adult patients at Sudanese hospitals: radiation exposure based on size-specific dose estimates (SSDE)

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Abstract

The aim of this study was to update the radiation exposure for adult patients undergoing multi-slice CT (MSCT) examinations using size-specific dose estimates (SSDE). Console, displayed $CTDI_{vol}$ and scan parameters were retrospectively recorded for 423 adult patients in seven Sudanese hospitals. Patient torso diameters were measured using digital calipers on the scanner console. SSDE was determined based on transverse images ($SSDE_{trans}$) and scout radiographs ($SSDE_{sco}$). Size-specific conversion factors were used to translate the recorded $CTDI_{vol}$ into SSDE according to the procedure described in the American Association of Physicists in Medicine (AAPM) Report 204. In chest CT, mean $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{sco}$ ranged: from 4.3 to 47.5 mGy (average: 12.8), 5.5 to 70.3 mGy (average: 18.6) and 5.8 to 63.5 mGy (average: 18.7), respectively. In abdominal CT, mean $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{sco}$ ranged: from 4.0 to 74.5 mGy (average: 16), 5.5 to 152.8 mGy (average: 23.9) and 6.0 to 151.3 mGy (average: 25.21), respectively. Our study highlights the relationships between CT dose and patient dimensions measured from scout and transverse CT images. The correlations between the patient size and dose based on scout images were less significant than that based on transverse images. High dose levels and dose variations among hospitals reveal the need for standardization of scanning protocols and staff training on adoption of scanners' dose reduction techniques.

Keywords Size-specific dose estimates (SSDE) · Computed tomography · Volume CT air kerma index

Introduction

According to UNSCEAR Global Survey of Medical Radiation Usage and Exposures, CT scanning accounts for 43% of the total collective effective dose due to diagnostic medical radiology [1]. CT scanning accounts for 7.9% of the total number of diagnostic medical examinations in health-care level I countries, just over 2.0% in health-care level II countries and just under 14% in health-care level III/IV countries

[1]. The development of multi-slice CT (MSCT) has led to a noticeable improvement in clinical CT performance, enabling faster and accurate diagnosis of diseases. Its contribution to radiation dose for the general population has become significantly higher. For this reason, low-dose CT has become the subject of numerous research publications. Epidemiological studies have failed to answer the various questions regarding cancer risk related to low radiation levels; nonetheless, the data were robust and the topic is challenging [2]. Nevertheless, the associated high radiation dose and the associated risk of carcinogenicity are of concern. Accurate dose estimates are, therefore, essential for better protection of the patient receiving CT examination as well as other medical procedures utilizing ionizing radiation.

In the European Guidelines for CT, two quantities are proposed for setting diagnostic reference levels: CT dose index ($CTDI_{vol}$) per slice (serial scanning) or per rotation (helical scanning) and the dose length product (DLP) per complete examination [3]. The $CTDI_{vol}$ estimates the average dose within a scan volume from dose measurements made in a standard 16-cm (head) or 32-cm (body) CT phantom. DLP

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accounts for the total radiation dose delivered to the scanned region of the body, defined as the product of $CTDI_{vol}$ and the scan length [3, 4].

The recommendations by the International Electrotechnical Commission (IEC) in 2002 made it mandatory for all manufacturers to display both $CTDI_{vol}$ and DLP on the screens of their CT devices [4]. However, because patients vary in size and shape, $CTDI_{vol}$ is an insufficient patient dose metric [5, 6]. In fact, $CTDI_{vol}$ is size independent, and patients with different sizes have the same $CTDI_{vol}$ value if scanned using the same imaging parameters. Moreover, using $CTDI_{vol}$, the dose to patients smaller than the acrylic CT body phantoms (32 cm) is underestimated by as much as a factor of three [7–9].

Concerns over using $CTDI_{vol}$ as a dose metric has led the American Association of Physicist in Medicine to develop and recommend size-dependent conversion factors, which can be used to determine size-specific dose estimate (SSDE) values from $CTDI_{vol}$ values [10]. The SSDE corrects for the difference between the patient size and the acrylic CT phantom and offers an improved metric for expressing the average absorbed dose.

At the national level, CT patient dose data are available in Sudan in terms of $CTDI_{vol}$ and DLP dose indices [11, 12]. Thus, it was the aim of this study to update the radiation exposure for adult patients undergoing multi-detector CT examinations at Sudanese hospitals using size-specific dose estimates (SSDE). It was also the aim of this study to investigate the effect of body dimensions on SSDE calculated from transverse and scout images.

Materials and method

Study design

A total of 423 adult patients who underwent chest and abdominal CT examinations in seven MSCT CT facilities. The hospitals were in Khartoum and Medani states, representing the largest states in terms of population density and provide diagnostic services for a wide area around them. These hospitals were selected because these are among the largest in terms of workload. Patients were selected consecutively, and the relevant dose information was retrieved from the archive of examinations performed between May 2015 and December 2016. In each hospital, data on a minimum number of ten patients per examination, considered as a statistically significant number in radiological dose surveys, were collected. Survey data were collected from the following hospitals: Advance Diagnostic Center (ADC); Al-Amal Hospital (AMH); Antalia private Clinic (APC); Medani Hospital (MH); Ribat University Hospital (RUH); National Armed Force

Hospital (AFH); Royal Care Hospital (RCH). Our institution ethics approved the study. Due to the retrospective nature of the study, formal consents from the examined individuals were waived.

Dose determination

Dose information and scan parameters pertaining to the studied patients were retrospectively collected from the DICOM header, including patient information (age, gender), tube voltage, tube current, rotation time(s), pitch value and $CTDI_{vol}$.

For SSDE calculations, we measured the diameter of the patient's images using digital calipers on the scanner console. Measurements were done for anterior–posterior diameter (hereafter, D_{AP}) and lateral diameter (hereafter, D_{LAT}) from the mid-slice location on the transverse CT image and D_{LAT} on scout images. Measured dimensions, D_{AP+LAT} and D_{LAT} were used as patient's size indicators [10]. Next, the SSDE was calculated by multiplying the console-displayed $CTDI_{vol}$ with the size-specific conversion factors (f) given in the AAPM report 204 [10]:

$$SSDE = CTDI_{vol} \times f.$$

Descriptive statistics was used to analyze the study results. Pearson test was used to evaluate the correlations between $CTDI_{vol}$, SSDE and patient diameter in chest and abdominal CT. The correlation was considered statistically significant at P value less than 0.05.

Quality control measurements

The parameters, which best characterize the image quality, were assessed by CATPHAN 504 CT quality assurance phantom (The Phantom Laboratory Ltd, NY, USA). Parameters tested included slice width, linearity, uniformity, high and low contrast resolution and noise. The results were compared with recommended tolerance levels given in International Electrotechnical Commission [4].

Results

From 423 adult patients who underwent MSCT CT examinations, there were 84 females (mean age = 51 ± 17 , range 19–90, 3rd quartile 65) and 105 males (mean age = 54 ± 16 , range 22–82, 3rd quartile 66) in chest examinations, and 98 females (mean age = 51 ± 16 , range 17–85, 3rd quartile 65) and 93 males (mean age = 52 ± 17 , range 18–85, 3rd quartile 70) in abdominal examinations.

Table 1 summarizes the characteristic performance parameters for the CT systems included in the study. Four scanners were from Toshiba (three 64-slice and one

Table 1 The characteristic performance parameters for the CT systems included in the study

Center	CT device (make/model)	Number of slices	Normalized output ($nCTDI_w$)	
			Body phantom (32 cm)	Head phantom (16 cm)
ADC	Neusoft/NeuViz	16	a	a
AMH	Toshiba/Aquilion	64	0.117	0.198
APC	GE/Bright speed	8	0.096	0.182
MEH	Toshiba/Activion	16	0.108	0.245
RUH	Neusoft/NeuViz	128	a	a
AFH	Toshiba/Aquilion	64	0.117	0.198
RCH	Toshiba/Aquilion	64	0.117	0.198

^a $nCTDI_w$ values were calculated using CT-Expo Version 2.1 software tool for all the scanners except for Neusoft 16 and 128 slices which were not included in the software library

16 scanners), two scanners from Neusoft (128-slice and 16-slice) and one scanner from General Electric (8-slice). Image quality tests of the CT systems are shown in Table 2.

Modern multi-slice CT scanners are equipped with tube current modulation features where the radiation dose is

adjusted according to patient attenuation. The survey showed that some centers use the protocols provided by the vendors and others use manual settings for the examinations, which could explain the variation in mAs values recorded in the study (Table 3). Also, it appeared that radiographers lacked training on how to deal with dose reduction techniques of the scanners.

As detailed above, SSDE was estimated via two ways: (1) from transverse images (hereafter, $SSDE_{trans}$) using D_{AP+LAT} as patient size; (2) from scout images (hereafter, $SSDE_{sco}$) using D_{LAT} as patient size. The relations between $CTDI_{vol}$, $SSDE_{trans}$, $SSDE_{sco}$ and body size were studied for multi-slice CT examinations of 423 adult patients.

Tables 3 and 4 present patient information (age and size), scan parameters (kV, mAs), $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{sco}$ for chest and abdominal CT.

In chest CT scanning, mean $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{sco}$ ranged: from 4.3 to 47.5 mGy (average: 12.8), 5.5 to 70.3 mGy (average: 18.6) and 5.8 to 63.5 mGy (average: 18.7), respectively. The relationships between patient size and CT doses, $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{sco}$, are shown in Fig. 1a, b.

Based on transverse images (Fig. 1a), weak correlations were shown between patient size and $CTDI_{vol}$ ($r^2 = 0.003$)

Table 2 Image quality tests for the CT systems included in the study

	Slice width	Spatial resolution	Linearity	Uniformity	Noise	Low contrast resolution @		
						0.3%	0.5%	1%
Limit	Base-line $\pm 20\%$ or ± 1 mm	Base-line $\pm 20\% \geq 5$ LP/cm	≥ 0.99	± 5 HU	Base-line $\pm 10\%$ or ≤ 5 HU	2 mm		
ADC	P	P	P	P	P	P	P	F
AMH	–	–	–	–	–	–	–	–
APC	P	P	P	F	P	P	P	F
MEH	P	P	P	P	P	P	P	F
RUH	–	–	–	–	–	–	–	–
AFH	P	P	P	P	P	P	P	F
RCH	P	P	P	P	P	P	P	F

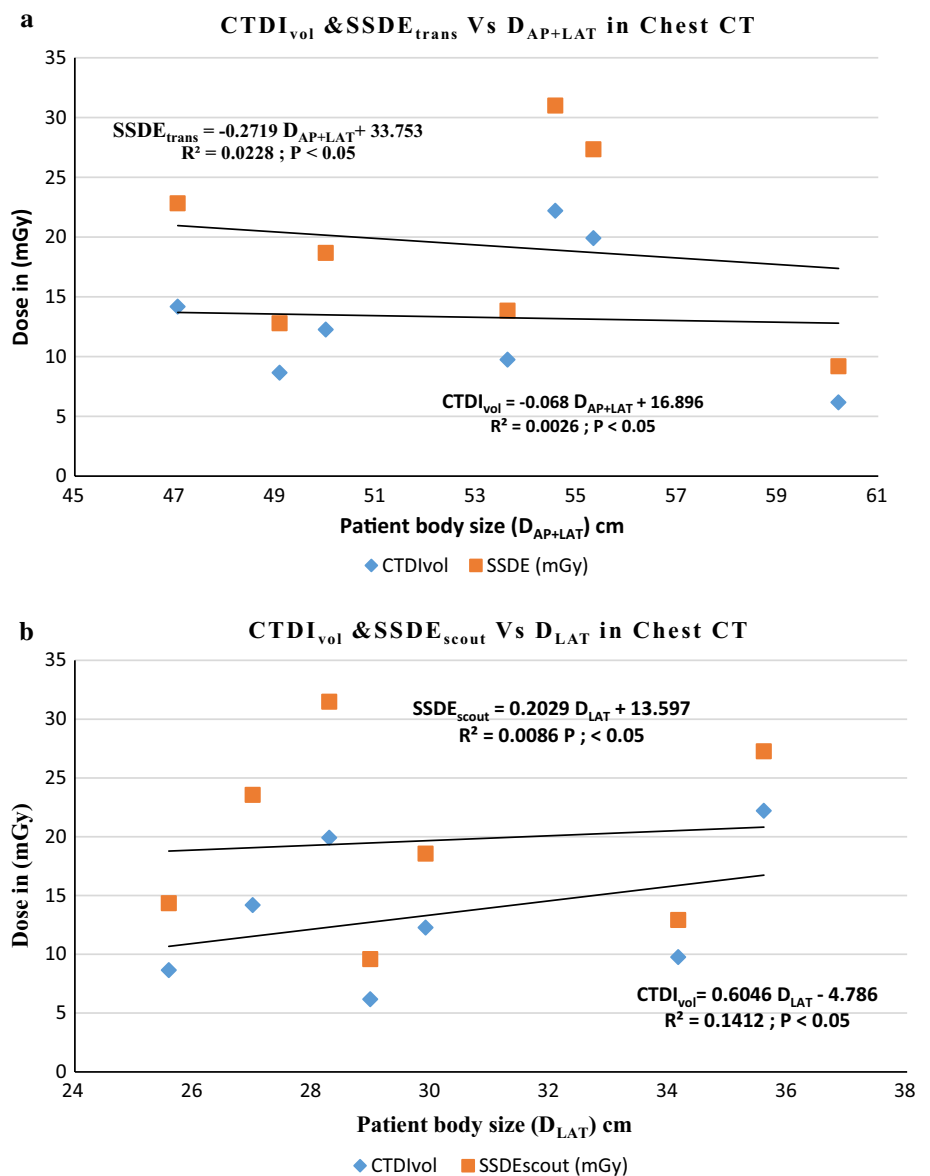
Table 3 Mean scan parameters and estimated SSDE from different scanners in different hospitals for chest examination

Hospital	N	Mean age	D_{AP+LAT} (cm)	D_{LAT} (Cm)	kVp	mAs	$CTDI_{vol}$ (mGy)	SSDE (mGy)	
								Transverse	Scout
ADC	18	58.17	55.33	28.28	120.0	246.67	19.91	27.35	31.48
AMH	23	49.13	47.05	26.99	120.0	128.00	14.18	22.83	23.55
APC	26	50.81	49.08	25.58	120.0	145.92	8.65	12.79	14.34
MEH	30	53.60	60.21	28.97	120.0	91.23	6.17	9.20	9.58
RUH	38	53.05	53.62	34.15	120.0	167.08	9.75	13.85	12.91
AFH	26	53.23	50.00	29.90	120.0	131.27	12.27	18.68	18.55
RCH	28	55.68	54.57	35.59	120.0	157.64	22.20	31.01	27.26

Table 4 Mean scan parameters and estimated SSDE from different scanners in different hospitals for abdomen CT

Hospital	N	Mean age	D_{AP+LAT} (cm)	D_{LAT} (Cm)	kVp	mAs	CTDI _{vol} (mGy)	SSDE (mGy)	
								Transverse	Scout
ADC	16	47.88	52.65	31.75	120.0	263.81	23.29	35.75	35.03
AMH	29	51.24	49.30	28.15	120.0	173.45	20.99	32.56	33.69
APC	43	53.74	52.63	28.75	115.0	163.01	9.77	13.62	14.55
MEH	30	59.09	53.17	29.45	120.0	80.43	6.50	9.11	9.60
RUH	43	51.23	51.03	33.06	120.0	151.00	9.60	13.83	12.06
AFH	37	49.89	50.67	30.16	120.0	152.03	22.19	33.21	33.39
RCH	36	56.00	49.31	32.85	120.0	187.22	25.62	39.08	35.12

Fig. 1 **a** CTDI_{vol} and SSDE_{scout} as a function of patient size (anterior–posterior + lateral diameter, (D_{AP+LAT}) in chest CT. **b** CTDI_{vol} and SSDE_{scout} as a function of patient lateral diameter (D_{LAT}) in chest CT



and between patient size and SSDE_{trans} ($r^2 = 0.023$). Similarly, when patient dimensions were taken from scout radiographs (Fig. 1b), the correlations between patient size and

CTDI_{vol} ($r^2 = 0.14$) and between patient size and SSDE_{scout} ($r^2 = 0.009$) were weak. These correlations were statistically significant at $P = 0.05$.

Concerning abdominal CT, mean $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{scout}$ ranged from 4.0 to 74.5 mGy (average: 16), 5.5 to 152.8 mGy (average: 23.9) and 6.0 to 151.3 mGy (average: 25.21), respectively. The relationships between patient size and CT doses, $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{scout}$, are shown in Fig. 2a, b.

Based on transverse images (Fig. 2a), strong correlation was shown between patient size and $CTDI_{vol}$ ($r^2 = 0.39$) and between patient size and $SSDE_{trans}$ ($r^2 = 0.39$). Both correlations were statistically significant at $P = 0.05$. On the contrary, when patient dimensions were taken from scout radiographs (Fig. 2b), weak correlation was shown between patient size and $CTDI_{vol}$ ($r^2 = 0.05$) and between the patient size and $SSDE_{scout}$ ($r^2 = 0.01$). The later correlation was statistically insignificant at $P = 0.05$.

In Table 5, a statistical summary is given for the studied CT doses [mean, σ , range (min–max), third quartile] and max/min ratios.

Significant dose variations were presented, reflected by the maximum to minimum ratio of 11.04 (chest CT) and 18.62 (abdominal CT), which is a clear indication that scan protocols were not standardized.

Discussion

$CTDI_{vol}$ provides a useful way to compare radiation output levels among different scanners. $CTDI_{vol}$ depends on scan parameters (kV and mAs), but does not consider the physical characteristics of the patient. This is of concern because the dose received depends on both the patient size and the scanner radiation output [5–10, 13]. $SSDE$ is determined

Fig. 2 a $CTDI_{vol}$ and $SSDE_{scout}$ as a function of diameter (anterior–posterior + lateral diameter, D_{AP+LAT}) in abdominal CT. b $CTDI_{vol}$ and $SSDE_{scout}$ as a function of patient lateral diameter (D_{LAT}) in abdominal CT

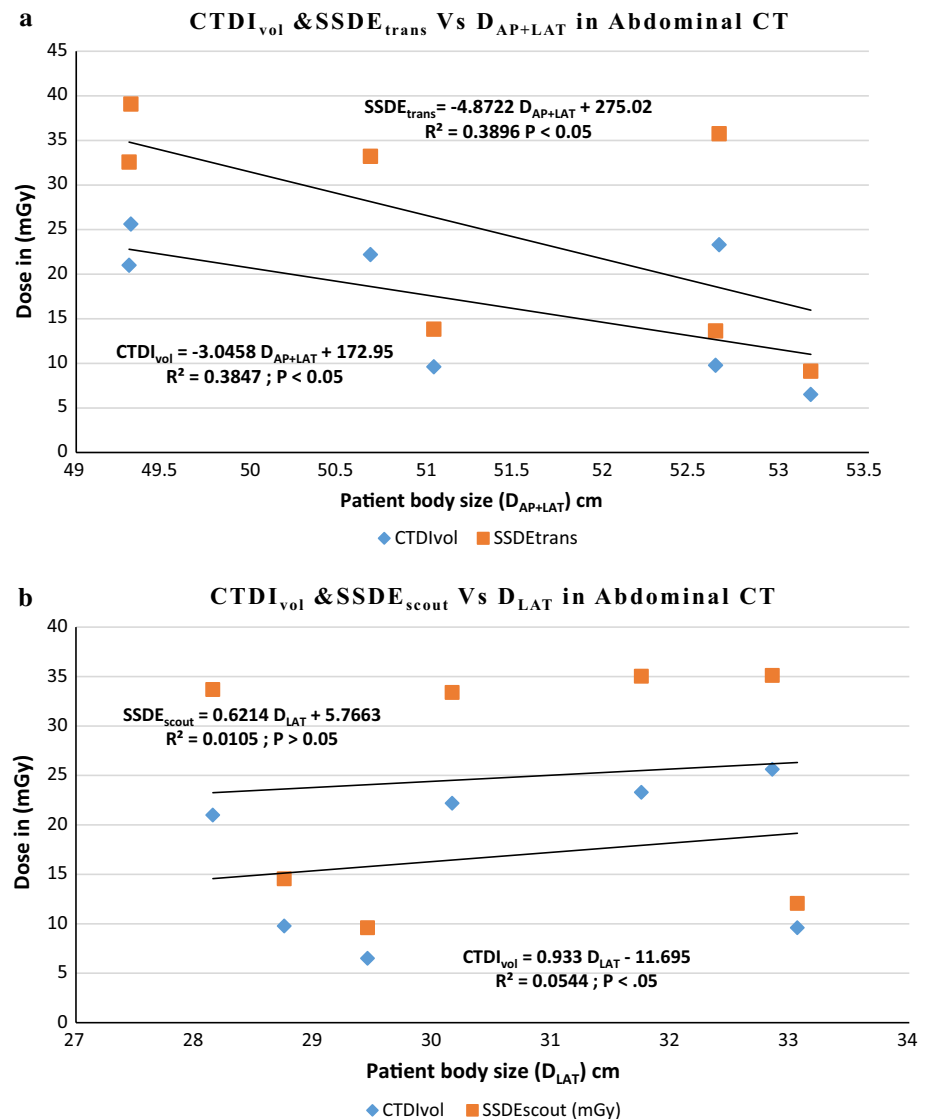


Table 5 Descriptive statistics mean, σ , range (min–max) and third quartile of patient estimated doses from the participating centers

Dose descriptor	Chest CT ($n = 189$)				Abdominal CT ($n = 234$)			
	Mean $\pm \sigma$	3rd quartile	Min–max	Max/min ratio	Mean $\pm \sigma$	3rd quartile	Min–max	Max/min ratio
CTDI _{vol}	12.75 \pm 6.9	15.20	4.3–47.5	11.04	16.02 \pm 8.85	22.8	4.0–74.5	18.62
SSDE _{trans}	18.58 \pm 10.4	22.66	5.5–70.3	12.78	23.92 \pm 15.14	33.32	5.5–152.8	27.78
SSDE _{sco}	18.57 \pm 9.80	24.10	5.8–63.5	10.94	23.33 \pm 15.09	32.88	6.0–151.3	25.21

from CTDI_{vol} using conversion coefficients that depend on patient effective diameter, which correlates linearly with patient weight. Both patient body characteristics and the radiation output are better described by the SSDE.

Performance of MSCT

Image quality assurance tests were performed, and the results were compared with the tolerance limits specified by the International Electrotechnical Commission [4]. With the exception of the low contrast resolution at 1%, the QA parameters tested fell within the recommended tolerance level indicating satisfactory performance. The equipment was not covered under regular QA program and thus baseline data for the tested QA parameters do not exist.

Concerning dose performance, CTDI_{vol} can be used as a suitable dose descriptor for CT scanner output. For instance in abdominal CT, a 16-slice CT scanner at the ADC hospital provides the highest CTDI_{vol} (23.3 mGy), followed by 64-slice CT at AMH (21.0 mGy) and AFH (22.2 mGy), followed by 128-slice CT at RUH (9.6 mGy). The low dose at 16-slice CT at APC is apparently due to the lower kV used. With the exception of 16-slice CT at RCH, one would conclude that multi-slice CT scanners tend to provide lower patient dose compared to the same type of CT with lower multi-detectors in a row. This is mainly due to the faster rotation which allow scanning larger volumes with less radiation dose. Definite conclusions on performance of different types of MSCT could not be feasible in this study due to the limited number of scanners per model studied.

CTDI_{vol} vs SSDE

As seen (Figs. 1, 2), SSDE values from transverse CT images and scout radiographs were significantly different compared to CTDI_{vol}. The correlation between the patient size and dose based on transverse images was stronger than that from scout radiographs. This agrees with the results of the study by Pourjabbar et al. [14], who reported that when patient dimensions were measured from scout radiographs, the obtained SSDE values overestimate the patient dose [14]. SSDE values (Figs. 1, 2) were always higher than CTDI_{vol}, and larger size patients—more than 32 cm—received lower doses than

smaller size patients, which was consistent with the nature of the conversion factors provided by the AAPM report 204 [10].

In most clinics, scanners used a fixed exposure setting instead of tube current modulation. This has the implication that small patients would receive unnecessarily high absorbed doses and risks, while in large patients there would be poor image quality. Many studies have examined the relation between CTDI_{vol} and patient diameter keeping radiographic techniques (mAs) constant. They agreed that for a given CT technique, patient dose decreases as patient size increases because there is more attenuation of the incident X-ray beam by surrounding soft tissues, necessitating adjustment according to patient size for appropriate CT dosimetry [15, 16]. AEC systems automatically adjust tube current to account for global variations in patient sizes and local thickness variations in individual patients [15]. In this regard, several authors studied the relationship between the radiation absorbed dose and patient size [17–20]. The result was an increase in patient organ dose as a function of patient size, which was ascribed to the AEC system that attempts to maintain constant image noise for all patient sizes [17, 19–21].

On the other hand, the relation between the patient size and dose in chest CT scanning showed a different trend. As seen (Fig. 1a), larger patients received higher (in case of SSDE) and lower (in case of CTDI_{vol}) doses than smaller ones. The correlation between CTDI_{vol}, SSDE_{sco} and D_{LAT} was insignificant at $P = 0.05$. In a study by Anam et al. [22], it was shown that among other factors, patient table can have significant effect on SSDE [22]. In chest CT scanning and generally when scanning tissues having different density from water or PMMA, SSDE considerably underestimates the absorbed dose due to the much lower density of lung tissues in chest [23].

To overcome this problem, the water equivalent diameter (D_w) has been proposed that considers both the geometrical size of the patient and the inhomogeneity of the patient's tissues [24]. Thus, further studies are needed to further improve current patient dose data using D_w .

Comparison with the literature and dose optimizations

To optimize the radiation dose delivered to patients during radiological procedures, estimated radiation doses should

be compared against established diagnostic reference levels (DRLs) [25, 26]. Examples of DRLs for abdominal CT are those recommended by the American College of Radiology in the USA (25.0 mGy), the Health Protection Agency in the UK (14.0 mGy) [25, 26] and the Italian nationwide survey (18 mGy) [27]. When our results (22.8 mGy) were compared with these DRLs, the current doses were comparable to the US DRLs.

As seen (Table 4), inter-hospital dose ratios—maximum to minimum—are as high as 11.04 (chest CT) and 18.62 (abdominal CT). All hospitals used almost 120 kV in exception to one APC hospital in chest CT, which reported using both 110 and 120 kV (median 115) during chest CT. There is wide variation in the mAs and therefore variations in the $CTDI_{vol}$ values, which are determined by the scan protocol of the specific CT scanner. Dose variations among hospitals are clear evidence that dose reduction is possible without losing the quality of diagnostic information. The most direct optimization measures are the standardization of CT protocols, either via using tube current modulation (TCM) or special dose-saving protocols provided by most of the modern MSCT CT scanners. TCM adjusts the mAs deployed according to the patient's body size and hence the dose. When TCM is used, larger patients receive higher doses that maintain the same image quality. Furthermore, $CTDI_{vol}$ also depends on the helical pitch that considers the consecutive scanning in helical CT. $CTDI_{vol}$ is inversely correlated with the pitch. Therefore, it is always advised to use high pitch values for lower patient dose. $CTDI_{vol}$ values vary due to the variation of the normalized output ($nCTDI_w$) among scanners. The latter depends on the inherent characteristics of the scanner such as bowtie filters used. Survey results revealed an important room for dose optimization; however, lack of proper training and inexperienced technologists are major obstacles to the full utilization of these features.

Conclusions

To provide more accurate estimations of patient doses, the SSDE metric was used in this study instead of $CTDI_{vol}$. This study highlights the relationships among scanner radiation output and SSDE measurement of patient dimensions from both scout radiographs and transverse CT images. The correlation between the patient size and dose based on scout images was less significant than that based on transverse images. The results will assist the medical physics community and the radiologist to choose proper indicators for patient size when determining SSDE. The study also highlights the need for dose optimization through CT protocol standardizations and staff training on adoption of scanners' dose reduction techniques. For more accurate patient dose

estimates, further studies are certainly needed to improve the patient dose data in CT using water equivalent diameter.

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Compliance with ethical standards

Conflict of interest We have no conflicts of interest to disclose.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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