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Technical Note

Determination of radiation dose during computed tomography examinations in southern Saudi Arabian hospitals using size-specific dose estimates

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Abstract: This study seeks to update the radiation exposure recommendations for patients undergoing computed tomography (CT) examinations in southern Saudi Arabia based on size-specific dose estimates (SSDEs) and to evaluate the relationship between CT dose and patient dimensions as measured from scout and transverse CT images of the chest, abdomen and pelvis. Patient data were retrospectively collected in the Digital Imaging and Communications in Medicine format. Then the correlation between radiation dose and patient size was assessed. The lateral diameter values measured from scout and transverse images in this study vary with factors ranging from 1.06 to 1.08. As such, scout images are associated with the overestimation of patient size and consequently the overestimation of SSDE values. In conclusion the estimation of SSDE values should be performed using transverse images encompassing the anteroposterior and lateral patient diameters since scout images generally overestimate the patient size.

Keywords: radiation dose, computed tomography, size-specific dose estimate, Saudi Arabia

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INTRODUCTION

Computed tomography (CT) is known to be an important diagnostic imaging modality marked by a significant risk of radiation exposure, with patients potentially experiencing relatively high doses administered to their organs [1-7]. The 2008 report of the United Nations Scientific Committee on the Effects of Atomic Radiation suggested that CT scanning accounts for 43% of the total collective dose [8].

At present the CT dose is estimated in terms of the dose length product (DLP) and the volume CT dose index ($CTDI_{vol}$) per complete examination [9]. The $CTDI_{vol}$ constitutes the dose within the scan volume gleaned from dose measurements made in a standard acrylic phantom with a diameter of 16 cm (head) or 32 cm (body). Therefore, it corresponds to the axially acquired weighted CT dose index ($CTDI_w$) divided by the helical pitch [9]. The DLP accounts for the length of radiation output along the axis of the patient and can also be defined as $CTDI_{vol}$ multiplied by the scan length [10]. In 2002 the International Electrotechnical Commission recommended all CT manufacturers to display both DLP and $CTDI_{vol}$ on the screen of the CT scanner console [10]. However, both $CTDI_{vol}$ and DLP as machine parameters do not represent the actual absorbed or effective dose experienced by the patient. The $CTDI_{vol}$ is independent of patient size and patients of different sizes who are subjected to similar imaging parameters will have the same $CTDI_{vol}$ values. Therefore, neither $CTDI_{vol}$ nor DLP can accurately reflect the size of the patient. Moreover, there is great uncertainty regarding the estimation of the CT radiation dose absorbed by patients who are smaller than the 32-cm diameter of body phantoms (11-13).

During the past few years numerous efforts have been made to accurately estimate the radiation doses received by patients during different CT examinations. In this context the American Association of Physicists in Medicine issued a report in 2011 that introduced size-dependent conversion factors to estimate the size-specific dose estimates (SSDEs) of patients undergoing CT examination [11]. The SSDE is currently considered a more reasonable metric parameter by which to estimate the radiation dose of a CT examination for a patient. Accordingly, several researchers report the SSDE for patients who undergo different computed tomography examinations [14-17].

In Saudi Arabia only a limited number of surveys concerning CT scans have been carried out [18-21]. The present study highlights the relationship between patient size, displayed scanner output radiation dose and SSDEs from CT transverse and scout images in Saudi Arabia. The purpose of this study is to update the radiation exposure for patients undergoing CT examinations based on SSDEs, while the secondary aims include evaluating the relationship between the CT dose and patient dimensions as measured from scout and transverse CT images of the chest, abdomen and pelvis.

MATERIALS AND METHODS

This study was carried out in southern Saudi Arabia to assess the radiation dose received by patients undergoing chest, abdomen and pelvis CT examinations. In January 2018 the study was ethically cleared by the Scientific Research Ethics Committee at Najran University (Registration number: 07-02-8-18EC). Radiation-dose measurements are regularly conducted in hospitals using head and body phantoms fabricated from acrylic. The body phantom used in this study was made locally from eight transverse slices of Perspex (Perspex International Ltd., England) joined by chloroform (Figure 1). The fabrication process has been described elsewhere in detail [21]. The phantom dimensions, as shown in Figure 1, are equivalent to those of the model T40016 body phantom provided by Physikalisch-Technische Werkstätten (Freiberg, Germany). Table 1 presents the details of the manufacturers, model details and dose-modulation techniques of the scanners used in this study along with the normalised $CTDI_w$ ($nCTDI_w$) calculated using the VirtualDose software program (Virtual Phantoms, USA) [22]. In most clinics CT scanners are equipped with a fixed-exposure setting instead of tube current modulation (TCM). Furthermore, most existing TCM scanners use only filtered back-projection reconstruction methods. In this study no attempt was made

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to assess the relationship between patient size, TCM and image quality. It was assumed that the images acquired using site protocols were confirmed as acceptable by the reporting radiologist.

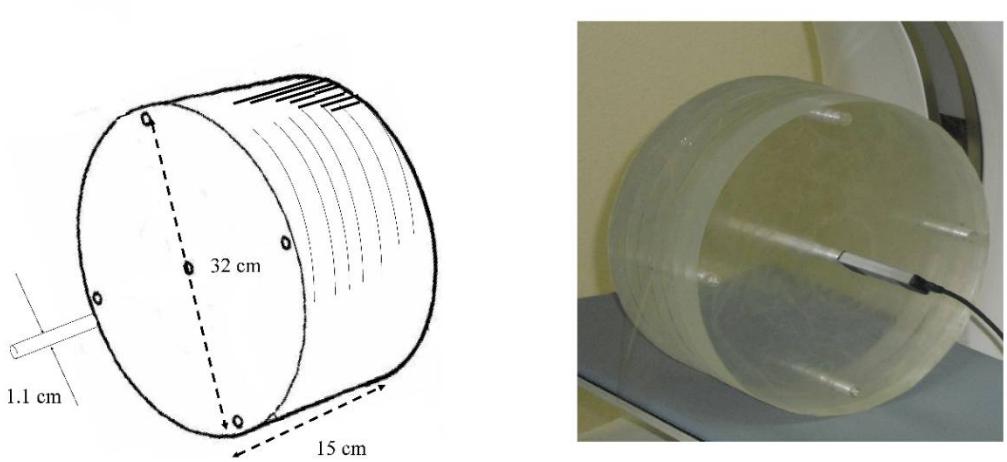

Figure 1. Fabricated adult body phantom measuring 32 cm in diameter used in regular assessment of radiation dose

Table 1. Specifications of CT scanners used in hospitals of southern Saudi Arabia

Hospital code	Manufacturer	Scanner Model	Number of slices	TCM	$nCTDI_w$ (32-cm body)
H1	Siemens	Somatom Definition Edge	128	Yes	8.88
	General Electric	Discovery	16	No	13.58
H2	Siemens	Sensation 16	16	Yes	8.61
	Toshiba	Activion™	16	No	10.46
H3	Siemens	Somatom Definition Edge	128	Yes	8.88
	Toshiba	Aquilion Prime	40	Yes	18.04
H4	General Electric	HiSpeed Dual	2	No	6.51
	General Electric	BrightSpeed Elite	16	No	14.10
	General Electric	Discovery	16	No	13.58
H5	Siemens	Sensation 16	16	Yes	8.61
	Toshiba	Aquilion Prime	40	No	18.04
	Siemens	Emotion Duo	2	No	10.02

The CT scanners used in the study met the quality assurance criteria for tube current, tube voltage, filtration, time and radiation output as specified by the American College of Radiology [23]. All patient data were retrospectively collected in the Digital Imaging and Communications in Medicine (DICOM) format, including those for tube voltage, tube current and $CTDI_{vol}$ value. A total of 543 patients underwent chest, abdomen and pelvis CT scans. Patients were selected consecutively and dose data were collected from the archive of examinations performed between March 2018 - May 2019. Patients' age and weight ranged between 18-87 years and 72-98 kg respectively. For each scanner, only 10 patients per examination were selected, which is considered to be a statistically significant number for a dose survey. The $CTDI_{vol}$ values recorded with DICOM images were collected. Subsequently, the median $CTDI_{vol}$ value per examination was calculated for each scanner used in this study.

The DICOM images were used to measure the diameter of the lateral (LAT) width and anteroposterior (AP) width from the LAT width on scout images and the mid-slice location on transverse CT images respectively. The SSDE was estimated from transverse images ($SSDE_{trans}$) using the diameter of the LAT and AP widths and from scout images ($SSDE_{scout}$) using LAT width as the patient size. The effective diameter (D_E) of the patient was evaluated from the average LAT and AP widths using the following formula:

$$D_E = \sqrt{\text{AP width } \times \text{LAT width}} \; .$$

Subsequently, the SSDE was calculated by multiplying the $CTDI_{vol}$ recorded in the picture archive and communication system with the size-specific conversion factor (f) provided by the American Association of Physicists in Medicine (AAPM) report no. 204 [11]:

$$\text{SSDE} = \text{CTDI}_{vol} \times f \; .$$

A t-test and coefficient of determination (R^2) were used to analyse the study results and evaluate the correlations between SSDE, $CTDI_{vol}$ and patient diameter in chest, abdomen and pelvis examinations. Statistically the correlation was considered significant at $P < 0.05$ (95% confidence).

RESULTS AND DISCUSSION

Table 2 presents scan parameters together with $CTDI_{vol}$, $SSDE_{trans}$ and $SSDE_{scout}$ values estimated from different CT scanners for chest, abdomen and pelvis examinations. Considering a complete study sample, the $SSDE_{scout}$ values are lower than $SSDE_{trans}$ values, which could be due to the variation of LAT width measured from scout and transverse images. On average, the CT scan started from 119 cm and ended at 146 cm for chest examinations. For abdomen and pelvis examinations, the mean values of scan ranges applied were 108-124 cm and 91-108 cm respectively.

Table 2. Median scan parameters and estimated SSDE values from different CT scanners used for chest, abdomen and pelvis examinations using the conversion coefficient derived from AAPM [11]

Examination	D_{AP+LAT} (cm)[a]	D_{LAT} (cm)[b]	$CTDI_{vol}$ (mGy)	kVp[c]	mAs[d]	CC[e] (LAT+ AP)	CC[e] (LAT)	$SSDE_{trans}$ (mGy)[f]	$SSDE_{scout}$ (mGy)[f]
Chest	52.6	32.7	14.48	119	149.2	1.43	1.34	20.71	19.40
Abdomen	46.9	28.8	16.15	119	163.0	1.59	1.56	25.68	25.19
Pelvis	49.1	31.4	17.35	119	165.3	1.53	1.43	26.55	24.81

[a]Diameter of LAT and AP widths; [b]Diameter of the lateral; [c]Tube voltage; [d]Tube current; [e]Conversion coefficient; [f] mGy = milligray

Figures 2, 3 and 4 show the correlation between radiation doses (i.e. $SSDE_{trans}$, $SSDE_{scout}$ and $CTDI_{vol}$) and patient size for chest, abdomen and pelvis examinations respectively. Regarding transverse images (Figure 2a), insignificant correlations are apparent between $CTDI_{vol}$ ($R^2 = 0.316$) and patient size, and between $SSDE_{trans}$ ($R^2 = 0.077$) and patient size. Likewise, when using scout images (Figure 2b), we note insignificant correlations between $CTDI_{vol}$ ($R^2 = 0.299$) and patient size, and between $SSDE_{scout}$ (R^2 =0.075) and patient size. Both correlations in Figures 2a and 2b are statistically significant at $p = 0.05$.

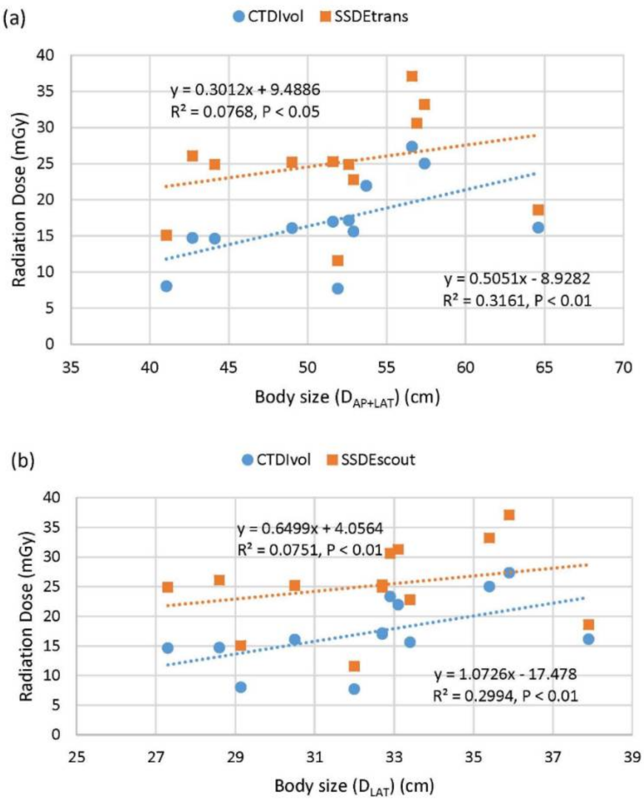

Figure 2. Correlations between patient size with radiation doses, i.e. (a) $CTDI_{vol}$ and $SSDE_{trans}$ and (b) $CTDI_{vol}$ and $SSDE_{scout}$ during chest examinations

Based on transverse images (Figure 3a) collected during abdomen examinations, a strong correlation is observed between $SSDE_{trans}$ (R^2 = 0.691) and patient size. Conversely, when patient dimensions are taken from scout radiographs (Figure 3b), a weak correlation is recorded between $SSDE_{scout}$ (R^2 = 0.278) and patient size; notably, the latter correlation is statistically insignificant at $p = 0.05$. Meanwhile, the R^2 values obtained from transverse and scout images for the relationship between $CTDI_{vol}$ and patient size are 0.317 and 0.128 respectively. This means that the $CTDI_{vol}$ is insignificantly correlated with patient size. Both correlations in Figures 3a and 2b are statistically significant at $p = 0.05$.

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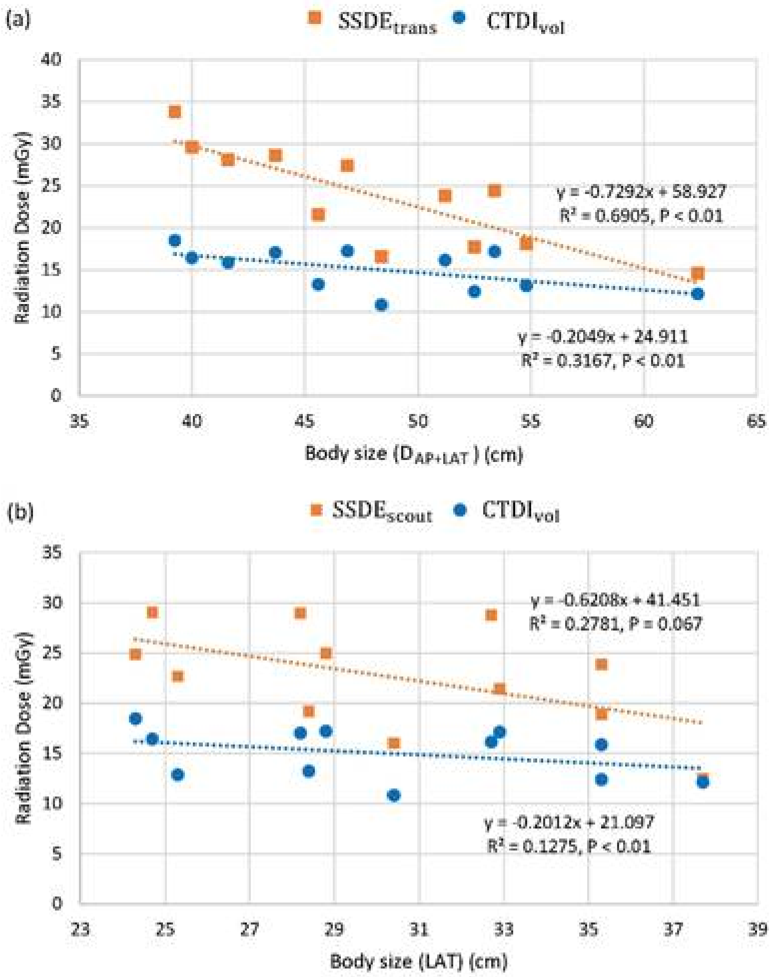

Figure 3. Correlations between patient size with radiation doses, i.e. (a) $CTDI_{vol}$ and $SSDE_{trans}$ and (b) $CTDI_{vol}$ and $SSDE_{scout}$ during abdomen examinations

In the transverse images from pelvis examinations (Figure 4a), the correlation between $CTDI_{vol}$ ($R^2 = 0.441$) and patient size is weaker than that between $SSDE_{trans}$ ($R^2 = 0.612$) and patient size, and the latter correlation is statistically insignificant at $p = 0.05$. In addition, a significant correlation between $SSDE_{scout}$ ($R^2 = 0.480$) and patient size and an insignificant correlation between $CTDI_{vol}$ ($R^2 = 0.314$) and patient size are obtained (Figure 4b). The latter correlation is statistically insignificant at $p = 0.05$.

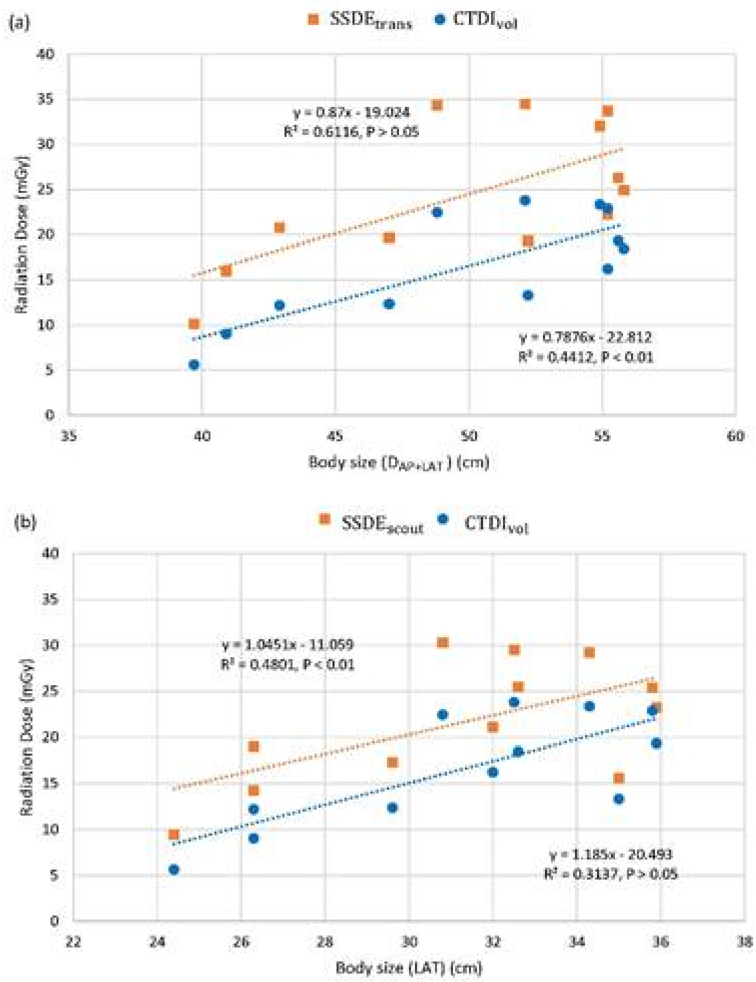

Figure 4. Correlations between patient size with radiation doses, i.e. (a) $CTDI_{vol}$ and $SSDE_{trans}$ and (b) $CTDI_{vol}$ and $SSDE_{scout}$ during pelvis examinations

For the sake of clarification, Table 3 presents a comparison of the median values of $CTDI_{vol}$ and $SSDE_{trans}$ obtained from this study with data reported from India [24] and Sudan [25]. To assess and compare patient sizes and radiation doses, values of diameter of LAT and AP width in this study were converted to their corresponding D_E values based on conversion factors provided by AAPM report no. 204 [11]. By comparison, we found that patient sizes are comparable to those reported by the aforementioned studies from India and Sudan. Besides, the SSDE and $CTDI_{vol}$ values in the present study are higher than those reported in the prior Indian study and lower than those reported by the prior Sudanese study recorded during abdomen examinations, whereas the values are higher than those in the same Sudanese study recorded during chest examinations.

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Table 3. Comparison of median $CTDI_{vol}$ and SSDE values obtained from this study with these reported in the literature

Examin-ation	This study				Sudan			India		
	$CTDI_{vol}$ (mGy)*	Max/ Min ratio	D_E (cm)	SSDE (mGy)	$CTDI_{vol}$ (mGy)	D_E (cm)	SSDE (mGy)	$CTDI_{vol}$ (mGy)	D_E (cm)	SSDE (mGy)
Chest	14.48 (7.71–27.36)	3.55	25.51	21.14	12.19	25.81	18.75	16.27	25.5	23.1
Abdomen	16.15 (10.84–17.24)	1.59	22.83	25.84	21.05	25.09	32.53	14.74	22.8	20.1
Pelvis	17.35 (5.63–23.79)	4.23	23.57	27.05	-	-	-	29.81	24.0	42.8

*Median (minimum-maximum)

Continuously, the $CTDI_{vol}$ and DLP are reported on the dose page of each patient's CT study. The need for these dose alerts may be associated with a high potential risk of radiation exposure during CT imaging. Several patients request radiation dose information, but unfortunately the readily available dose quantities are often misunderstood. The use of $CTDI_{vol}$, based on tube voltage, tube current, rotation time, pitch, beam collimation, field-of-view and tube filtration can constitute a useful approach by which to compare levels of scanner radiation output. However, it does not take into account the size of the patient to which the dose was delivered and therefore does not accurately reflect the dose absorbed by the patient [26]. To estimate the actual patient dose, the SSDE should be determined from $CTDI_{vol}$ using patient-size-specific conversion factors which correlate linearly with patient size [11].

The SSDEs estimated in this study were based on chest, abdomen and pelvis examinations only. These examinations were selected because the conversion factors provided in the AAPM report no. 204 [11] to calculate SSDEs were developed specifically for use with CT imaging of the abdomen and pelvis. In addition, the AAPM claimed that their pairing with CT scans for the thorax was acceptable since the errors were expected to be less than 20% [27].

On studying our results in Figures 2-4, we found that the SSDE values based on scout and transverse images are always higher than the $CTDI_{vol}$ values, consistent with the nature of the conversion factors provided by the AAPM report no. 204 [11]. As previously mentioned, a comparison between the results of scout and transverse radiographs indicates a strong correlation between $SSDE_{trans}$ and patient size in abdomen and pelvis examinations (Figures 3-4). Despite the existence of different approaches for obtaining patients' dimensions, a similar correlation was reported by Pourjabbare et al. when conducting abdominal CT examinations [28].

The results in Figure 3 suggest decreasing SSDE values with increasing patient size with no adaptation of $CTDI_{vol}$ according to the latter. The disparity in SSDE can be attributed to the use of fixed-exposure settings instead of TCM by most scanners. This implies that younger patients and thicker patients would both receive greater radiation doses. Several studies have examined the relation between $CTDI_{vol}$ and patient diameter while keepingradiographic techniques constant and agreed that the radiation dose decreases with increasing patient size because there is more attenuation of the incident X-ray beam by surrounding soft tissues, necessitating correction to offset the patient's size for appropriate CT dosimetry [29, 30]. The TCM methods automatically correct the tube current to calculate variations in patient size and regional thickness across individual cases [29]. In this respect several authors investigated the correlation between radiation dose and patient size [31-34]. Notably, the outcomes of these studies suggest that an increase is apparent in the dose administered to the patient's organs as a function of the patient's size, which is attributed to the automatic exposure control system [31, 33–34].

It is worth mentioning that the LAT diameter measurements from the scout and transverse images collected in this study present values varied with factors ranging from 1.06 to 1.08. Accordingly, the scout images are associated with the overestimation of patient size and thus, the overestimation of SSDE. The overestimation of patient size on the scout images can be attributed to image magnification given the two LAT projections or because the images do not include skin-to-skin coverage [28]. For example, 5% of CT examinations involved in this study do not include skin-to-skin coverage of the body region in the fields of view and this insufficient measurement of patient size may have triggered the overestimation of SSDE.

On the other hand, the relationship between dose and patient size during chest CT examinations shows a different trend (Figure 2). Specifically, the correlation between SSDEs from scout and transverse images is insignificant and this could be attributed to the patient table [35]. As the thorax includes the lungs, which have a density different from that of water, the absorbed dose could give an overestimation of SSDE due to density variation [36]. To address this issue, a water-equivalent diameter is proposed by AAPM and both the variable densities of tissues and the patient size are considered [11]. For example, a strong variation (a factor of 2) can be observed when comparing the results from Xu et al. [16] with the SSDE results obtained for chest examinations. Accordingly, further studies are needed to improve the current patient dose using the water-equivalent diameter.

It is worth mentioning that a strong correlation is observed between patients' AP and LAT diameters and patients' weights from transverse images. The values of R^2 range between 0.87-0.93 ($p < 0.001$) for all examinations involved in this study. Thus, if patient dimensions are not available, there is a possibility of using the patient's weight to estimate the SSDE.

It is evident from Table 3 that the $CTDI_{vol}$ and SSDE values from chest examinations are lower than the data reported in India [24] and higher than those reported in Sudan [25], indicating the need for further optimisation of the dosing protocol. Moreover, both the small sample size and the exclusion of pediatric patients can be considered as limitations of this study.

CONCLUSIONS

This study provides insight into the relationship between $CTDI_{vol}$, SSDE and patient diameter obtained from scout and transverse images collected during CT chest, abdomen and pelvis examinations in southern Saudi Arabia. As an overall trend, the medians of CT radiation doses for the abdomen and pelvis examinations are within the dose reference levels reported in the literature. For an estimation of SSDE, transverse images should be used to measure the AP and LAT patient diameters since scout images generally overestimate the patient size.

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