Evaluation of patients' Body Mass Index and weight as a simpler alternative method for calculating size-specific dose estimation in patients with lung computed tomography

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► ***Original article***

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ABSTRACT

Background**:* Evaluation of Size-Specific Dose Estimation (SSDE) by patient's weight and Body Mass Index (BMI) instead of Anterior-Posterior (AP) and Lateral (LAT) diameter measurements in patient's images for lung computed tomography (CT). ***Materials and Methods: Before the examination, the weight and BMI of all patients were measured and calculated. All AP and LAT diameters were measured from the axial images, and localizer and conversion factors (f_{size}) were calculated based on them. Volume Computed Tomography Dose Index ($CTDI_{vol}$) and Dose Length Product (DLP) values were also recorded from the patient's examination summary. In this way, different SSDEs based on effective diameter ($SSDE_{eff}$), water equivalent diameter ($SSDE_{w}$), AP diameter ($SSDE_{AP}$), LAT diameter ($SSDE_{LAT}$), sum of the AP and LAT diameters ($SSDE_{AP+LAT}$), AP diameter in scout view ($SSDE_{APscout}$) and LAT diameter in scout view ($SSDE_{LATscout}$) are obtained. By Pearson statistical test the correlation between patients' BMI and weight with all types of SSDE calculation methods was examined. ***Results:*** There was a statistically significant correlation between all measured and compared parameters, but the most correlation between BMI and weight with SSDEs was obtained with $SSDE_{eff}$ (R=0.825, P<0.05) and $SSDE_{w}$ (R=0.777, P<0.05), respectively. Also, the correlation between BMI and effective diameter (d_{eff}) (R=0913, P<0.05) is the highest among all types of diameters measured. The correlation of BMI with $SSDE_{w}$ and water equivalent diameter (d_{w}) was (R=0.807, P<0.05), (R=0.909, P<0.05), respectively. ***Conclusion:*** There seems to be a significant correlation between BMI andf_size so that we can estimate patients' SSDE without measuring AP and LAT diameters, even before a CT scan.

INTRODUCTION

Medical radiation Dose increased more than six-fold between 1980 and 2006, according to a study, while it decreased by 20% between 2006 and 2016 [1]. CT scan equipment is mostly to blame for the increase in population-wide radiation. According to the same study, CT scans account for 63 per cent of the population's exposure, whereas nuclear medicine accounts for only 15%, which is a significant disparity. Despite the fact that computed tomography is the most widely utilized imaging modality in medicine, it is also the source of the majority of radiation exposures. As a result, the risk of cancer from CT scans has become a major worry [2, 3]. Therefore, measuring and estimating radiation dose is critical in determining how much radiation a patient will receive and developing an optimization program for reducing radiation doses. Various strategies for estimating radiation exposure are currently in use, with the Size-Specific Dose Estimates SSDE method being the most recent. Almost every computed tomography modality displays dose, Volume Computed Tomography Dose Index ($CTDI_{vol}$, mGy) [4], and Dose Length Product (DLP, mGy.cm) [5]. Of course, this is a requirement that forces all manufacturers to display these two items [6]. $CTDI_{vol}$ is a way of comparing the radiation output from different CT scanners, although it is not affected by patient size. We can also compare patients' doses in different situations with different scan lengths using the DLP produced by $CTDI_{vol}$ and scan length. This measure, on the other hand, does not reveal the patient's real dose and may only be used to compare different CT scans and procedures [7]. $CTDI_{vol}$ and DLP fluctuate when different parameters such as kVp, Tube current, rotation time, and pitch are changed, but they are not affected by the patient's geometry. As a result, these two factors for calculating a patient's CT scan exposure have flaws. For an accurate estimate of the dose, all researchers strive to estimate dose based on the geometry and size of the patients. However, AAPM (Report No.204) suggested a new method called

Size-Specific Dose Estimates (SSDE) [8]. A size-dependent factor is added to $CTDI_{vol}$ in this novel approach until dosage values are affected by patient size. The diameters of the Anterior-Posterior (AP) and Lateral (LAT) patients must be manually determined in localizer or axial computed tomography images for the computation of size-dependent variables, in fact, a method of correcting the patient's dose in a CT scan depends on the patient's size and geometry and getting closer to the actual patient dose estimate [9, 10], or, according to AAPM Report 220 [11], we can utilize the water-equivalent diameter by computing the CT attenuations in the axial images. This is a step forward for estimating patient dose in computed tomography by paying attention to patient body size, because the water-equivalent diameter is a more appropriate quantity to characterize the patient's size according to its information, which includes the absorption and transmission and attenuation of radiation in patient's body [12, 13]. However, in clinical and practical situations, this method can be time-consuming, reliant on human precision, and monotonous. The study's main goal is to determine whether it is possible to estimate SSDE without measuring body diameter only by body mass index (BMI) instead. So that we may have a good estimate of patient dosage in the shortest time possible before completing a CT scan for a patient, just by knowing the patient's height and weight, as well as detailed research of the link between the many parameters on which the SSDE can be computed. Also, due to the fact that in other studies, the main organ was mainly the abdomen and pelvis, but in this study, the lung region was selected due to the fact that the presence of trapped air increases the possibility of error. On the other hand, it has been tried to perform all possible methods for calculating SSDE and compare their dependence on the weight of patients.

MATERIALS AND METHODS

This study consists of three parts. First, the height and weight of all patients were measured before the scan, and then they were scanned with a completely similar protocol. The second part includes the collection of all patients' information, including the information related to the amount of dose received, as well as the measurement of the patient's body diameters in the CT images. In the last stage, we tried to analyze the relationship between the received dose and the BMI of the patients with statistical analysis.

Patients' population

Patients were assessed with a lung CT scan between July and November 2020. Patients who had artifacts or anything else that made their CT images unappealing were, of course, excluded from the study. The total number of patients investigated in this study is 86, with 50 males and 36 women ranging in age from 41.5±11.4 years (range 21-74). The investigated patients' height and weight were measured before the CT scan, depending on the type of investigation. Thus, the mean weight of patients is 82.3±18.3 kg (45-131), and the mean height of patients is 171.4±9.2 cm (154-193). Furthermore, the mean BMI was calculated to be 27.7±4.6 (17.2-37.8), and to make it easier to analyze and conclude, they were divided into four groups [14], according to the WHO classification: Underweight, Normal weight, Overweight and Obese. The number of patients in each group according to the BMI range is shown in table 1. Also, all the patients belong to the West Asian population and have no history of any particular disease. In figures 1-A, 1-B and 1-C distribution charts are shown for comparison and a better understanding of the physical condition of the studied population.

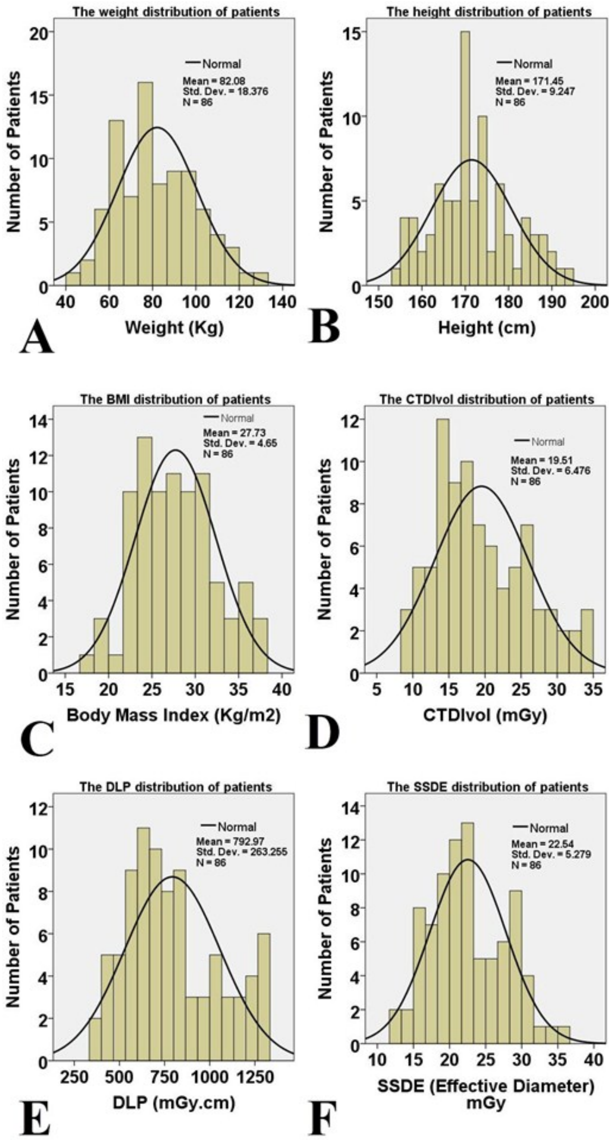

Figure 1. Distribution charts of all patients based on patient's weight **(A)**, height **(B)**, BMI **(C)**, CTDIvol **(D)**, DLP **(E)**, and SSDE **(F)**. Also, normal distribution and mean quantity are calculated in each graph for comparison with each other.

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Table 1. Grouping of patients according to BMI and the number of patients in each group.

BMI Group	Underweight	Normal Weight	Overweight	Obese
BMI Range	BMI<18.5	24.99<BMI<18.5	29.99<BMI<25	BMI>30
Patients Num.	1	27	29	29

CT scan protocol

A 128-slice CT scanner (Ingenuity Core 128, Philips Medical Systems, Best, and The Netherlands) was used in the imaging center where these individuals were studied. Before the CT scan, the height and weight of all patients were measured. The patients were placed in the supine position with their hands stretched above the head and then The Dual Scout technique was used to perform lung CT scans from the apex of the lungs to the lower ribs and the ends of the lungs. The dual scout was performed in two anterior-posterior and lateral views and with 120 kVp. The CT scan of the patients was performed in the state of a deep breath holding under the following conditions: 120 kVp tube voltage, 1-second rotation time, 1.425 pitch factor, and 64 × 0.625 collimation. Automatic Exposure Control (AEC) is used to lower the dose of the patient. The Philips CT scanner AEC system is DoseRight (Philips Medical Systems, Best, The Netherlands) and automatic current selection (ACS) was activated. In addition, all patients' images were reconstructed in the following parameters: 512×512 matrix, 5mm thickness, 5mm increments, 500×500mm field of view, and iDose level 3. Due to the importance of measuring the diameter of the patient's body, the entire skin surface of the patient's body should be in the field of view, so, all images were reconstructed with the largest field of view.

Measurements and calculations

First, the Exam Summary was used to collect and record the $CTDI_{vol}$ and DLP values of all patients. The AP and LAT diameters of patients in the axial and central slice were measured with WW=3500 and WL=900 and recorded as AP_{in} and LAT_{in}, respectively, using Phillips WorkStation (IntelliSpace Portal 11.1, Philips Medical Systems, Best, The Netherlands) as shown in figures 2-C and 2-D.choosing the central slice over other slices produces equivalent findings when calculating the effective diameter [15, 16], hence the central slice has been chosen as a measuring reference. The effective diameter, d_{eff}, will be determined using the approach described in AAPM report 204 [8], with special attention to the AP and LAT diameters According to equation 1:

$$D_{eff} = \sqrt{AP \times LAT} \quad (1)$$

AP: Anteroposterior diameter (cm)
LAT: Lateral diameter (cm)
D_{eff}: Effective diameter (cm)

Furthermore, the AP diameter in the Lateral scout view and the LAT diameter in the AP scout view were measured at WW= 3500 and WL= 900, respectively, and recorded as AP_{scout} and $APLAT_{scout}$. The measuring method diameters on the scout views are shown in figures 2-A and 2-B. Because it has been claimed in a number of prior works that the amount of X-ray attenuation in the patient's body can be equivalent to a cylindrical water phantom (equal to the amount of X-ray absorption) [17,18], the water equivalent diameter was also measured and computed in this study. We can use the mean CT numbers area according to equation 2 in the axial section to calculate the water equivalent diameter according to AAPM report 220, which $\overline{CT(x.y)}_{ROI}$ is the mean CT number in the ROI and A_{ROI} is the total area of the ROI, and the central slice has been selected as a reference [19], as with other measurements. The central slice of each patient was entered into the ImageJ1.53c freeware (National Institutes of Health, USA) [20] program to calculate the mean CT numbers and perform ROI, and the result was termed d_w. According to the setting of WW and WL and the thresholding method, the edge of the contour direction was determined (yellow contour in figure 3). This means CT numbers should include the entire axial section of the CT, so the contours of the edge of the lungs (figure 3-A), which causes the information of the lung region to be removed, should be deleted. Figure 3-B shows the correct contouring that includes the entire axial area.

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

$\overline{CT(x.y)}_{ROI}$: mean CT number in the ROI in axial image
A_{ROI}: Total area of the ROI (mm^3)
d_w: Water equivalent diameter

SSDE calculation

Because the patient's dose is dependent on X-ray output and patient size, the SSDE technique was proposed in AAPM report 204 to account for the influence of the patient size parameter's reliance on the estimated dose for the patients. According to the same study, AAPM has proposed a patient size-dependent factor termed conversion factor "f_{size}" based on the use of the 16cm or 32cm diameter PMMA phantom for $CTDI_{vol}$, which can be determined based on the patient's measured AP and LAT diameters. As a result, SSDE can be determined by using equation 3:

$$SSDE = f_{size} \times CTDI_{vol} \quad (3)$$

SSDE: Size Specific Dose Estimation
f_{size}: Correction Factor
$CTDI_{vol}$: Volume Computed Tomography Dose Index

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AAPM report 204 provides f_{size} as a function of AP, lateral, sum of the lateral and AP ,and effective diameter separately. Also, AAPM report 220 shows the use of f_{size} based on water equivalent diameter for calculating SSDE. So, various SSDEs calculated based on f_{size} the following SSDEs were calculated and recorded:

$SSDE_{eff}$: Calculated from f_{size} based on effective diameter
$SSDE_{w}$: Calculated from f_{size} based on the water equivalent diameter
$SSDE_{AP}$: Calculated from f_{size} based on the AP diameter in the axial section
$SSDE_{LAT}$: Calculated from f_{size} based on the LAT diameter in the axial section
$SSDE_{AP+LAT}$: Calculated from f_{size} based on the sum of AP and LAT diameters
$SSDE_{APscout}$: Calculated from f_{size} based on AP diameter in the Scout view
$SSDE_{LATscout}$: Calculated from f_{size} based on LAT diameter in the Scout view

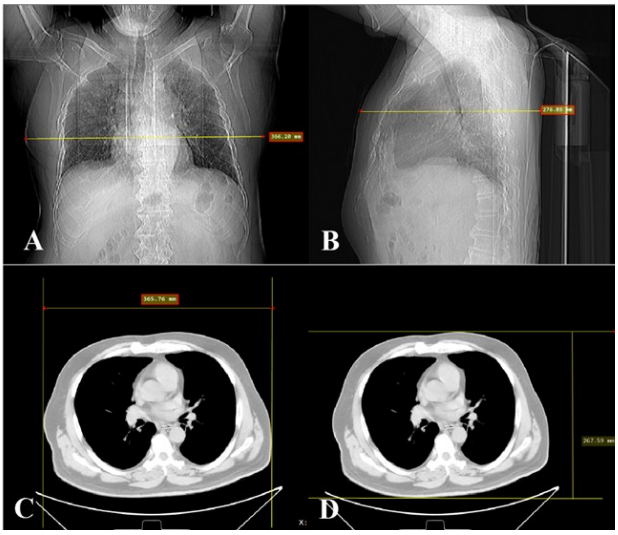

Figure 2. The measuring method for Lateral (LAT) diameter is based on AP scout view **(A)** or axial image **(C)**. Also, the Anterior-Posterior (AP) diameter is based on lateral scout view **(B)** or axial image **(D)**. In this study, LAT diameter was measured on AP scout view and the axial image shown with symbols and , respectively. Also, the AP diameter was computed from the lateral scout view and the axial image shown with symbols and , respectively.

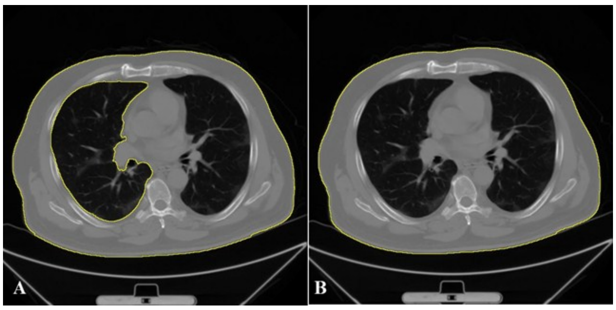

Figure 3. Measuring of the mean CT number and total area in the axial CT image to calculate water equivalent diameter (d_w) using ImageJ based on equation 2.

Statistical analysis

All statistical analyses in this study were performed by IBM SPSS Statistics for Windows, Version 8 (IBM Corp., Armonk, N.Y., USA). The normality of continuous variables was checked using the Shapiro-Wilk test. All variables were with normal distribution reported as mean ± Standard deviation. Pearson's test was used to check the correlation between measured and calculated variables. In this study, the correlation between BMI and weight with all diameter variables, all conversion factors, and all calculated SSDEs was investigated. A p-value of less than 0.05 was considered to indicate a significant statistical difference.

RESULTS

According to extracting information from the patient's CT exam summary page, the mean $CTDI_{vol}$ and DLP in this study population are equal to 19.51±6.47 mGy and 792.97±97 mGy.cm, respectively. All types of SSDEs and conversion factors calculated in table 2 are summarized. The mean $SSDE_{w}$ has the greatest mean among SSDEs, while the mean $SSDE_{APscout}$ has the lowest. Nevertheless, the mean $SSDE_{w}$ has the highest mean difference when compared to other SSDEs. The highest mean difference among the mean conversion coefficients is related to the mean f_{w}. Table 3 shows the correlation between BMI and weight in patients with all diameters measured, SSDEs calculated, and f_{size} conversion coefficients assessed using Pearson's correlation. In the evaluation correlation between BMI and weight with seven different diameters (d_{eff}. d_{AP}. d_{w}. AP_{in}. LAT_{in}. AP_{scout}. LAT_{scout}. AP+LAT) strongest correlation was found with d_{eff}, followed by d_{w}, and finally AP+LAT. As a result, BMI (R= 0913, P<0.05) and patient weight (R= 0.877, P <0.05) have a substantial correlation with d_{eff}, while the correlation is stronger with BMI. The lowest correlation BMI was observed with AP_{in} (R= 0.787, P< 0.05) However, there is a statistical correlation between all the items listed in Table 3. We also calculated SSDE in seven different ways, confirming the strong correlation between BMI and SSDE calculated by the d_{eff} method ($SSDE_{eff}$ R=0.825, P<0.05) and then SSDE calculated by the AP+LAT method ($SSDE_{AP+LAT}$ R=0.823, P<0.05) and SSDE calculated by the water equivalent diameter d_{w} method ($SSDE_{w}$ R=0.807, P<0.05). When compared to other estimated SSDEs, $SSDE_{APscout}$ (R=0.759, P<0.05) and $SSDE_{LATscout}$ (R=0.774, P<0.05) had the smallest correlation with BMI and weight.

The correlation between the patient's weight with $CTDI_{vol}$ and DLP according to the Pearson correlation is equal to (R=0.849, P<0.05) and (R=0.869, P<0.05), respectively. Moreover, The correlation between the patient's BMI with $CTDI_{vol}$ and DLP according to the Pearson correlation is equal to (R=0.905, P<0.05) and

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(R=0.853, P<0.05), respectively, showing that the highest correlation was related to BMI with $CTDI_{vol}$ (R = 0.905, P <0.05).The correlation linear regression based on Pearson statistical test between patient's weight and BMI with various SSDE calculation techniques and d_w and d_{eff} diameters was calculated and shown in Figure 4 to present an appropriate model, which is the major goal of our study. An equation has been obtained for each of these graphs (equation 4-10) these represent regression equations obtained from linear regression graphs. By using these equations can estimate SSDE from different variables such as effective or water equivalent diameter. Equations 4, 6, and 7 are linear regression equations between BMI and SSDE calculated based on d_{eff}, d_w and AP diameter, respectively. The equation of linear regression SSDE computed from d_{eff} as a function of the patient's weight is equation 5.

$$SSDE_{eff}^{BMI}(mGy) = \left[0.94 \times BMI\left({}^{Kg}/_{m^2}\right)\right] - 3.44 \qquad (4)$$

$$SSDE_{eff}^{Weight}(mGy) = [0.22 \times Weight(Kg)] + 4.33 \qquad (5)$$

$$SSDE_{w}^{BMI}(mGy) = \left[1.14 \times BMI\left({}^{Kg}/_{m^2}\right)\right] - 4.79 \qquad (6)$$

$$SSDE_{AP}^{BMI}(mGy) = \left[1.03 \times BMI\left({}^{Kg}/_{m^2}\right)\right] - 5.88 \qquad (7)$$

The BMI index was separated into four groups to better evaluate the relationship between patient demographics and dose, with the mean $CTDI_{vol}$, DLP, and SSDEs determined in table 4. Due to the small number of patients in this class, the underweight (n = 1) will not be analyzed in this section. Among all BMI groups, the highest and lowest SSDEs were $SSDE_w$ and $SSDE_{APscout}$, respectively.

Table 2. Mean SSDE and Conversion Factor of all patients in different methods based on: Effective Diameter, Water Equivalent Diameter, AP Diameter, Lateral Diameter, AP+LAT diameter, AP and LAT diameter in Scout View.

$SSDE_{eff}$	$SSDE_w$	$SSDE_{AP}$	$SSDE_{LAT}$	$SSDE_{AP+LAT}$	$SSDE_{APscout}$	$SSDE_{LATscout}$
22.54±5.28	26.79±6.56	22.79±5.89	22.27±5.03	22.56± 5.27	19.82± 4.14	21.92± 5.46
$ƒ_{eff}$	**$ƒ_w$**	**$ƒ_{AP}$**	**$ƒ_{LAT}$**	**$ƒ_{AP+LAT}$**	**$ƒ_{APscout}$**	**$ƒ_{LATscout}$**
1.19± 0.14	1.42± 0.17	1.20± 0.12	1.19± 0.19	1.20±0.14	1.07±0.19	1.16±0.16

Table 3. Correlation between Body Mass Index and Weight of all patients with different measured diameters, conversion factors and SSDEs by Pearson test.

	D_{eff}	D_w	AP_{in}	LAT_{in}	AP_{scout}	LAT_{scout}	AP+LAT
BMI (Kg/m^2)	R=0.913, P<0.05	R=0.909 P<0.05	R=0.787 P<0.05	R=0.789 P<0.05	R=0.862 P<0.05	R=0.844 P<0.05	R=0.912 P<0.05
Weight (Kg)	R=0.877 P<0.05	R=0.829 P<0.05	R=0.766 P<0.05	R=0.746 P<0.05	R=0.824 P<0.05	R=0.845 P<0.05	R=0.873 p<0.05
	$ƒ_{eff}$	**$ƒ_w$**	**$ƒ_{AP}$**	**$ƒ_{LAT}$**	**$ƒ_{APscout}$**	**$ƒ_{LATscout}$**	**$ƒ_{AP+LAT}$**
BMI (Kg/m^2)	R=-0.903 P<0.05	R=-0.881 P<0.05	R=-0.836 P<0.05	R=-0.776 P<0.05	R=-0.828 P<0.05	R=-0.812 P<0.05	R=-0.897 P<0.05
Weight (Kg)	R=-0.863 P<0.05	R=-0.796 P<0.05	R=-0.810 P<0.05	R=-0.724 P<0.05	R=-0.789 P<0.05	R=-0.796 P<0.05	R=-0.856 p<0.05
	$SSDE_{eff}$	**$SSDE_w$**	**$SSDE_{AP}$**	**$SSDE_{LAT}$**	**$SSDE_{APscout}$**	**$SSDE_{LATscout}$**	**$SSDE_{AP+LAT}$**
BMI (Kg/m^2)	R=0.825, P<0.05	R=0.807 P<0.05	R=0.816 P<0.05	R=0.772 P<0.05	R=0.759 P<0.05	R=0.774 P<0.05	R=0.823 P<0.05
Weight (Kg)	R=0.772 P<0.05	R=0.777 P<0.05	R=0.764 P<0.05	R=0.742 P<0.05	R=0.705 P<0.05	R=0.713 P<0.05	R=0.772 p<0.05

Table 4. Mean $CTDI_{vol}$, Dose Length Product and different SSDEs in different BMI groups.

BMI (Kg/m^2)	$SSDE_{eff}$	$SSDE_w$	$SSDE_{AP}$	$SSDE_{LAT}$	$SSDE_{AP+LAT}$	$SSDE_{APscout}$	$SSDE_{LATscout}$	$CTDI_{vol}$	DLP
Obese (n=29)	27.50 (±4.29)	33.06 (±5.36)	28.26 (±5.02)	26.80 (±4.66)	27.57 (±4.30)	23.70 (±3.89)	27.00 (±4.73)	26.33 (±4.96)	1060.45 (±196.36)
Overweight (n=29)	22.10 (±3.32)	26.13 (±3.87)	22.45 (±3.57)	21.51 (±3.20)	21.94 (±3.34)	18.96 (±2.37)	21.22 (±3.42)	18.63 (±3.23)	760.33 (±16.78)
Normal Weight (n=27)	18.05 (±2.60)	21.17 (±3.48)	17.68 (±2.74)	18.58 (±2.63)	18.22 (±2.60)	16.82 (±2.24)	17.56 (±2.90)	13.54 (±2.26)	555.03 (±103.18)

DISCUSSION

The AAPM 204 report's major goal was to develop instruments that may strike the correct balance between the patient's dose and the exam quality. Prior to this report, since 2002, all CT scanners were required to disclose $CTDI_{vol}$ and DLP amounts before and after the CT scan, according to the IEC 2002 standard [6]. However, these two amounts are estimated independently of the patient's size, and estimating the real dose to patients is one of their fundamental flaws. As a result, the SSDE quantity was suggested in the AAPM report 204 to adapt the dose received based on the patient's size. The $CTDI_{vol}$ amount, on the other hand, frequently offers a lower estimate than the actual values since a 32cm phantom cannot adequately reflect a patient's actual dimensions [19, 21]. We can compare the output of different CT scans for an exam with $CTDI_{vol}$, but not the Dose a patient receives in this exam. As a result, the AAPM report 204 aims to combine the $CTDI_{vol}$ output of a CT scan device with a patient-sized conversion factor ($ƒ_{size}$) to provide an accurate assessment of the patient's dose, especially in children. The AAPM report 220 was provided as a result of these efforts to create more accurate patient

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-dependent results by using the equivalent water diameter (d_w) to determine the patient size and SSDE.

The presentation of this study was predicated on the fact that a patient's rate of attenuation can be deemed equivalent to a cylindrical water phantom with similar attenuations, based on earlier studies. The conversion factor will then be calculated depending on the patient's size using the same water equivalent diameter. Both systems, however, have a number of flaws. Both procedures will take time since they require additional software to quantify AP and LAT diameters, notably water-equivalent diameter calculations, which most CT equipment cannot perform. In addition, these procedures are almost harsh in clinical settings, with the likelihood of user measurement mistakes and tediousness.

As a result, because the patient's Body Mass Index reflects the patient's size, it may be a more acceptable option because it is more freely accessible. The main goal of our research is to investigate the correlation between BMI as a parameter related to patient size and water equivalent diameter, effective diameter, and other parameters useful in calculating and estimating SSDE, and to discover a relationship that makes estimating SSDE much easier and faster. Using the patient's BMI as a starting point. The patient's weight parameter was employed alone in this study, in addition to analyzing the correlation between BMI and SSDE. When compared to traditional methods of measuring the patient's body diameters and calculating the water equivalent diameter, the patient's BMI and weight can be a good alternative to measuring the patient's body diameters and calculating the water equivalent diameter for estimating SSDE.

Thus, an appropriate f_{size} may be selected using the table provided by the AAPM report 204, and the SSDE estimate can be performed utilizing this strong correlation. Of course, it should be noted that the lowest relationship between BMI and weight with the calculated types of SSDE was related to the estimated SSDE based on the diameters measured from the scout images, i.e., $SSDE_{APscout}$ ($R=0.759$, $P<0.05$) and f_{size} ($R=0.774$, $P<0.05$), which could be due to the patient's off-centering mistake, Readings of AP and LAT diameters that are excessive [22-24]. Also, by using the equations 4-7, BMI can be used for SSDE estimation based on linear regressions computed in Figure 4. To examine the results in terms of the magnitude of obese and underweight patients, BMI was separated into four groups (table 4). Given that the highest SSDE in all types of calculated SSDEs is related to obese patients and the lowest is related to underweight patients, as shown in figure 5, increasing the BMI lowers the f_{size} value (figure 5-A) while increasing the SSDE value (figure 5-B) using the d_{eff} technique. According to the Pearson correlation for BMI with f_{size} and $SSDE_{eff}$, equal to -0.903 and 0.825, respectively, it confirms the inverse correlation between BMI and these two parameters (figure 5). This result is in agreement with the study conducted by Alikhani *et al.* [25].

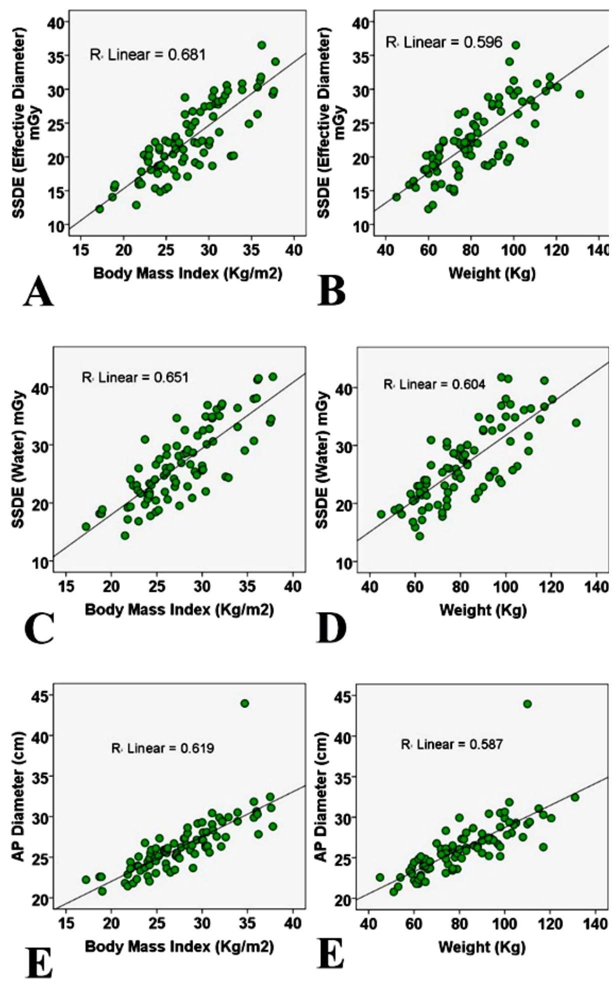

Figure 4. The correlation linear regression between patient's BMI with $SSDE_{eff}$ **(A)**, $SSDE_w$ **(C)**, and AP_{in} **(E)**, also a correlation between patient's weight with $SSDE_{eff}$ **(B)**, $SSDE_w$ **(D)** and AP_{in} **(F)**. R-squared (R^2) was calculated in each graph to compare the goodness of fit. The highest and lowest R^2 were to correlate linear regression Body Mass Index with SSDE (effective diameter) and Weight with AP diameter, respectively.

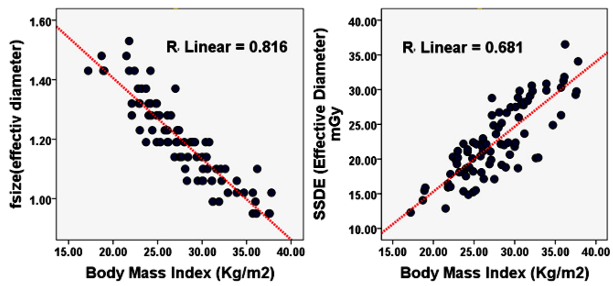

Figure 5. Correlation between BMI with f_{size} **(A)** and SSDE **(B)** based on effective diameter calculations. These diagrams show an inverse correlation between Body Mass Index with f_{size} and SSDE (based on effective diameter) and a decrease in R-squared for Body Mass Index with SSDE.

In the Boose *et al.* [26] study, a substantial correlation between weight and BMI and d_{eff} was

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seen in patients who had abdominal and pelvic CT scans as well as patients who had lung CT scans. In contrast to Boose *et al*. study, the correlation between BMI with d_{eff} was stronger than the correlation between weights with d_{eff} in patients with lung CT scans. Xu *et al.* [27] study explored the correlation between BMI and weight with d_{eff} in patients with abdominal, pelvic, and lung CT scans, and found a strong correlation. However, the correlation between BMI with d_{eff} was slightly stronger in our study than the correlation between BMI and d_w. The correlation between BMI with f_{size} was investigated in Alikhani *et al.* [25] study, which included the abdomen, head, and knee areas. In head and knee exams, f_{size} behaved practically independently of BMI, while in abdomen exams, the correlation between the two declined exponentially. The correlation between BMI with d_{eff} and SSDE was examined only in abdominal and pelvic exams in a study by O'Neill *et al*. [28], which confirmed a strong correlation and was proposed as a suitable alternative to SSDE estimation, and these findings were in agreement with our study.

As BMI increased, f_{size} values declined exponentially, and patients with higher BMI had a stronger correlation with SSDE than those with lower BMI. Fukunaga *et al.* [29] study on the correlation between weight with d_{eff}, Iriuchijima *et al.* [30] study on the correlation between weight with SSDE on abdominal and lung CT scans, and O'Neill *et al.* [28] study on the correlation between BMI and d_{eff} only on the abdominal exam, all found a strong correlation between these parameters. Even in the pediatric population, Kritsaneepaiboon *et al.* [31] studied the correlation between BMI with SSDE and Khawaja *et al.* [10] studied the correlation between weight with SSDE in the abdomen and lung CT scans, which revealed a substantial correlation between weight and BMI with SSDE. Our study has limits as well, the number of groups analyzed was modest, and statistical results from bigger populations would almost certainly be more accurate. The CT-scanned individuals in this study were evaluated by a single device, which may be more appropriate if the study was expanded to include multiple devices.

CONCLUSION

Given the foregoing correlations, it can be concluded that, as compared to traditional methods of measuring the diameter of the patient's body and computing the diameter equivalent of water, the patient's BMI and weight can be a good option for predicting SSDE.

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