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Appraisal of radiation dose with 64-slice computed tomography perfusion in lung cancer patients with special reference to SSDE: An initial experience in a tertiary care hospital

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Abstract

Context: Computed tomography perfusion (CTP) is an important functional tool for lung cancer. It is expected to deliver high radiation dose, making its accurate estimation important. Size-specific dose estimate (SSDE) is a new dose metric, which includes the scanner output as well as the patient size. **Aims:** To determine radiation dose [CT dose index ($CTDI_{vol}$), dose length product (DLP), effective dose (ED), and SSDE] for CTP in lung cancer and the correlation of $CTDI_{vol}$, DLP, and SSDE with effective diameter and SSDE with weight, body mass index (BMI), and the scan length. **Settings and Design:** Cross-sectional study in the Department of Radio-diagnosis from October 2015 to March 2016. **Patients and Methods:** Due ethical approval and informed consent was taken. Thirty consecutive adult patients of lung cancer undergoing CTP study were included; various radiation dose parameters were determined and presented as mean ± SD. **Statistical Analysis Used:** Paired Student's *t*-test and Pearson correlation using Statistical Package for the Social Sciences, Version 16. **Results:** Mean radiation dose was $CTDI_{vol}$ = 270.138 ± 1.627 mGy, DLP = 681 ± 53.496 mGy.cm, ED = 12.501 ± 0.923 mSv, SSDE = 388.90 ± 81.27 mGy. The $CTDI_{vol}$ and DLP had significant positive correlation (r = 0.556, P = 0.000 and r = 0.522, P = 0.003, respectively) with effective diameter. SSDE had strong negative correlation (r = −0.997, P = 0.000) with effective diameter, significant negative correlation with the BMI (r = −0.889; P = 0.000) and weight (r = −0.910, P = 0.000) of patients. Scan length was not significantly correlated in SSDE (r = −0.012, P = 0.951). **Conclusions:** Smaller sized patients had greater SSDE.

Key words: Lung cancer; multidetector computed tomography; patient safety; perfusion imaging; radiometry

Introduction

Computed tomography (CT) in medical diagnostics is the largest contributor to low-dose radiation exposure of the population.[1] In recent times, constant technological advancements leading to increased applications have tremendously expanded the clinical use of CT in medical

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diagnostics, especially oncology; and with it the concern for radiation.

Lung cancer is a major public health problem and the leading cause of cancer death worldwide,[2] and CT is a gold standard imaging investigation for its morphological assessment.[3] Presently, CT perfusion (CTP) is also being used as a functional tool for mapping the tumoral angiogenesis that represents an indirect criterion of the tissue's metabolic activity. Advances in radiation oncology, such as gated radiotherapy for moving lung tumors and adjunct chemotherapy for nonsmall cell lung cancer, also require information on lesion's metabolism in terms of quantitative data.[4] This is provided by CTP through estimation of various perfusion parameters representing blood flow kinetics through the lesion. The usefulness of CTP has been proved in diagnosis, stratifying the risk and following patients to monitor the response of various tumors[5] and is, thus, gradually becoming a part of the initial contrast-enhanced CT (CECT) assessment in such patients.

CTP is a dynamic CECT examination done for the region of interest over a timeframe to determine the contrast kinetics through the region of interest, thus, indicating the amount of blood that passes through each unit volume of tissue. As in a CT scan, the estimated dose depends upon the exposure factors – kilovoltage (kV), the milli-ampere (mA), the beam thickness, the *z*-axis coverage, the radio-sensitivity of body part irradiated, and the total time of scanning; higher radiation dose is expected with perfusion CT studies as the selected slice [of varying thickness depending upon the type of multidetector CT (MDCT) scanner used] is continuously irradiated for almost a minute. Further escalation of the dose due to the relative higher radio-sensitivity of organs in thorax mandates a responsible use of this technique. Also, as serial CTP studies are required to monitor response to treatment (targeted radiotherapy and/or chemotherapy), the possibility of radiation exposure is further enhanced.[6-8] Deleterious effects of radiation are already known to occur due to serial CT head perfusion studies conducted in stroke patients.[1] No such data are available on CTP study done with the commonly available 64-slice CT scanner in lung cancer patients. A study using 128-slice single-source scanner estimated the effective dose (ED) of perfusion CT protocols of lung, liver, and pelvis using a phantom to be between 2.9 and 12 mSv.[9]

The worldwide accepted dose metrics for characterizing CT scanner exposure output is CT dose index (CTDI), which was originally proposed by Jucius and Kambic and established by Shope *et al*.[6] It represents the average absorbed dose, along the *z*-axis from a series of contiguous irradiations. It is measured from one-axial CT scan, and is calculated by dividing the integrated absorbed dose by the nominal total beam collimation.[6] However, as CTDI is measured by using a standardized, homogeneous, cylindrical phantom, it questionably represents the dose for objects of substantially different size, shape, or attenuation, such as the human body. Hence, the limitation of CTDI is that it is a measurement of scanner output only that does not represent the actual patient absorbed doses as it does not include any patient information (the heterogeneous attenuation and size of individual patients).[10,11]

Moreover, CTDI does not indicate the dose to a specific point in the scan volume when the patient table remains stationary for multiple scans, such as for interventional or perfusion CT, thus, disqualifying it as a patient dose indicator in these situations. Hence, there was a need of a radiation descriptor that takes patient size into account while estimating the radiation dose. American Association of Physicist in Medicine (AAPM) Report Number 204[12] introduced a new radiation dose descriptor known as "Size-Specific Dose Estimates" (SSDE). In all cases, the SSDE should correspond to tissue doses and not the air kerma making f-factor (air kerma to tissue dose correction value) a part of the SSDE metric. As the size-dependent factors are pertinent to the 32 cm diameter CT dose index volume ($CTDI_{vol}$) reference phantom, these factors can be represented as f 32 X size, where X refers to the specific measure of patient size. Different methodologies have been proposed to determine the size of the patient and we used the effective diameter technique in our study. The term "f-s coefficients" refers to the conversion factor as per the determined size of the patient.[6]

The International Electrochemical Commission requires display of the radiation output with dose descriptors for the purpose of monitoring the radiation doses in CT.[13] The radiation dose delivered by the CT examination is represented by standard dose descriptors representing the absorbed dose such as $CTDI_{vol}$ or dose length product (DLP). SSDE calculates the radiation dose using a correction factor based on the size of the patient unlike $CTDI_{vol}$ and DLP. As SSDE is influenced more by the patient and not by the scanning parameters, it is a more sensitive indicator of patient dose in scanning protocols/techniques involving repeated exposure of a limited thickness of the tissue like the perfusion CT.

In a study investigating the effect of the body dimension on the patient dose, SSDE values were significantly different (32% lower to 72% greater) than $CTDI_{vol}$.[14] Thus, the most accurate dose descriptor can be utilized to estimate the ED taking into account the radio-sensitivity of the exposed organs.

With this background in mind, we conducted a pilot study on CTP in lung cancer patients using a 64-slice MDCT with the aim (1) to determine the various dose descriptors – $CTDI_{vol}$, DLP, and SSDE and the ED in CTP; (2) to show the correlation of $CTDI_{vol}$, DLP, and SSDE in CTP

with a patient size parameter, the effective diameter; (3) to determine the correlation of SSDE with the patient size in terms of weight and body mass index (BMI) and also with the scan length.

This will help to provide a fair idea of the radiation dose being delivered to the patient through a particular CTP protocol and guide to reduce the exposure factors with respect to the size of the patient in order to limit the use of excess radiation during the CT examination. This information can also be used to assess the efficacy of the automatic exposure control systems.

Patients and Methods

After obtaining institutional Ethical Committee clearance and written informed consent from the patients, a cross-sectional study was conducted in the Department of Radio-diagnosis, over a 6-month period from October 2015 to March 2016. Patients with age >18 years of either sex with clinical/radiological suspicion or diagnosed cases of lung cancer sent for a CTP study were included. Nonconsenting, age <18 years, patients giving history of contrast allergy, deranged creatinine (S. creatinine >1.5 mg%), and pregnant patients were excluded. A sample size of 30 was considered for the study.

Equipment: The perfusion CT and CECT examination of the chest for patients was conducted on 64-slice MDCT Somatom Definition AS (M/s Siemens AG Healthcare Sector, Erlangen, Germany) equipment.

Scanning technique: The entire examination of patient consisted of a topogram, noncontrast CT (NCCT), dynamic chest CT examination of the mass lesion in the lung, and lastly, the postcontrast CT acquisition was done. Standard protocols were used for NCCT and postcontrast scanning – kVp of 120, effective mAs of 110, detector collimation of 64 × 0.6 mm, table feed 46 mm, pitch of 1.2, and gantry rotation time of 0.5 s. Dynamic acquisition was done at 100 kV, effective mAs of 150, collimation 64 × 0.6 mm, and gantry rotation time of 1 s. As a default setting, automatic tube current modulation (ATCM) was used during the acquisitions of CT scan of the chest for all the protocols. Following the NCCT acquisition, a dynamic chest CT examination was done using intravenous (IV) administration of 60 ml of low osmolar contrast media (300–350 mg/ml) at a rate of 6 ml/s, followed by a saline bolus at the same rate, using a dual-head pressure injector; after a delay of 5 s. The dynamic study had a total scan acquisition time of 40 s. This was followed by a postcontrast CT examination of thorax from the level of lower neck to the upper abdomen by giving additional IV contrast (2 ml/sec) with a delay of 35 s. After the completion of the study, the patient was kept under observation for half an hour to watch for any delayed contrast reaction.

All the CTP studies were of diagnostic quality and the perfusion parameters could be determined in all 30 patients.

CT dose descriptors

CT Dose Index ($CTDI_{vol}$)

The CTDI is the primary dose measurement concept in CT. It is measured using one-axial CT scan (one rotation of the X-ray tube), and is calculated by dividing the integrated absorbed dose by the nominal total beam collimation.[15]

CTDI is represented as follows:

$$\text{CTDI} = \frac{1}{NT}\int_{-\infty}^{+\infty} D(z)\,\mathrm{d}z \qquad (1)$$

where $D(z)$ = the radiation dose profile along the z-axis.

N = the number of tomographic sections imaged in a single axial scan.

T = width of the tomographic section along the z-axis imaged by one data channel.

$CTDI_{100}$ represents the accumulated multiple scan dose at the center of a 100-mm scan.

$$\text{CTDI100} = \frac{1}{NT}\int_{z=-50\text{mm}}^{+50\text{mm}} D(z)\mathrm{d}z \qquad (2)$$

$CTDI_{100}$ is acquired using 100-mm long, 3-cc active volume CT pencil ionization chamber using standard CTDI phantom measured at the center of rotation of the beam. CTDI measured at the center of a polymethylmethacrylate (PMMA) body phantom (32 cm for body scans) is "$CTDI_c$," and at the phantom periphery (1 cm depth) is "$CTDI_p$." $CTDI_w$, a weighted version of CTDI, is defined as:

$$CTDI_w = 1/3\ (CTDI_c) + 2/3\ (CTDI_p) \qquad (3)$$

The clinical scanning mode scans the entire volume in patients in contrast to CTDI where measurements are based on a single-axial scan mode. Therefore, the average dose will also depend on table feed in between axial scan or the feed per rotation in spiral scanning. The dose, expressed as the $CTDI_w$, must therefore be corrected by the pitch of the spiral scan or an axial scan series to describe the average dose in the scanned volume represented by $CTDI_{vol}$.

$$CTDI_{vol} = CTDI_w/\text{Pitch} \qquad (4)$$

Where Pitch is defined as a table distance traveled in one or 360° rotation/total collimated width of the X-ray beam. Thus, $CTDI_{vol}$ represents the average absorbed dose over x, y, and z direction.[6]

The unit of CTDI, $CTDI_w$, and $CTDI_{vol}$ is milligray (mGy)

Dose Length Product (DLP)

DLP is another dose descriptor that is related to $CTDI_{vol}$ and the length of scanning, and is commonly used to represent the dose in a CT examination. Its value is simply the $CTDI_{vol}$ multiplied by the length of the scan (in cm) and is given in units of milligray-centimeters (mGy.cm)

$$DLP = CTDI_{vol} \times \text{Scan Length} \quad (5)$$

The DLP reflects the total energy absorbed (and thus the potential biological effect) attributable to the complete scan acquisition. DLP depends on the length of the imaged body region.

Effective Dose (ED)

ED is calculated as

$$\text{Effective dose} = DLP \times k \text{ mSv} \quad (6)$$

Where "*k*" is a conversion factor depending on region of the body and is 0.019 for ED estimates in our study.[16] The unit of ED is milli Sieverts (mSv).

Size-Specific Dose Estimate (SSDE)

The effective diameter method was used to calculate the patient size for the purpose of calculating the SSDE in this study. The effective diameter for the patient was obtained, which was used to find the factor based on size (*f*-size). This factor when multiplied by $CTDI_{vol}$ yielded the SSDE for the patient.[9]

$$\text{Effective Diameter} = \sqrt{AP \times LAT} \quad (7)$$

Where AP is antero-posterior and LAT is the lateral diameter of the patient part scanned for CTP study.

The specific formula to estimate patient dose for a specific patient size is given by:

$$\text{Size-Specific Dose Estimates} = SSDE = f^{32D}_{size} \times CTDI^{32}_{vol} \quad (8)$$

SSDE was calculated by using conversion factors (*f*-size) based on the effective diameter published in AAPM Report No. 204[6] (which is based on the use of 32 cm diameter PMMA phantom for $CTDI_{vol}$).

Recording of Data and Calculation of the Dose

The weight and the height of the patient was recorded. The BMI was calculated by the formula BMI = Weight (kg)/Height^2 (m). The weight and BMI were expressed as mean ± SD. The kVp, mAs, scan time, scan length were noted [Table 1]. The scan length for NCCT varied from 214 to 424 mm, whereas it was fixed at 19 mm for the dynamic scan. The $CTDI_{vol}$ and DLP were also recorded for the CT console after acquisition of the NCCT and the dynamic scans for all 30 patients on a predesigned pro forma.

The ED was calculated for both NCCT and dynamic scans using Equation 6. To determine the ED for CTP study, ED for both NCCT and the dynamic scans were summed up. The SSDE was also calculated for the CTP study, as shown in Equations 7 and 8. For determination of the effective diameter, the AP and LAT diameters were measured from outer to outer surface on the axial CT section of the dynamic scan on the CT console, as shown in Figure 1. The conversion factor was determined from the AAPM Report Number 204[12] used for PMMA phantom of 32 cm diameter.

The CTP study consisted of NCCT and dynamic scans only, and the dose from the topogram was not included in the calculation of the CTP dose. Thus, the calculation of $CTDI_{vol}$, DLP, SSDE, and ED for CTP was achieved by adding the respective values for NCCT and the dynamic scans [Tables 2 and 3].

Statistical analysis

The various parameters – $CTDI_{vol}$, DLP, SSDE, and ED – determined for CTP for 30 patients of lung cancer were represented as minimum, maximum, range, median, and mean ± SD values [Table 4].

The data were analyzed by the statistical analysis software SPSS version 16. The data were tested with Shapiro–Wilks method and found to be normal in distribution. Correlation of DLP, $CTDI_{vol}$, and SSDE with the effective diameter was determined in CTP. Correlation of SSDE with the weight and BMI was also determined. Pearson correlation was applied to find the strength of association between the patient factors (effective diameter, weight, and BMI) with SSDE values in CTP.

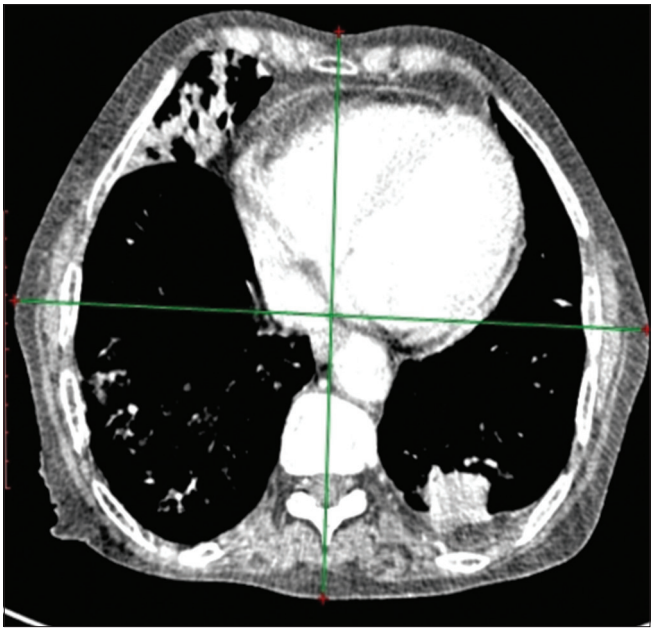

Figure 1: The AP and LAT diameters taken from the axial slice of dynamic/CTP study. The peripheral lung cancer is also evident in the image

Table 1: Patient factors (age, sex, weight, BMI) and technical factors (effective mAs, scan time, scan length) in NCCT and dynamic study for 30 patients

Age/Sex	Weight (kg)	BMI	Effective mAs		Scan time (s)		Scan length (mm)	
			NC	Dy	NC	Dy	NC	Dy
40/M	54	19.85	55	150	7.05	40	331	19
50/M	46	17.17	60	150	7.67	40	319	19
70/M	51	19.92	54	150	8.78	40	350	19
53/M	69	25.36	71	150	9.22	40	424	19
44/M	70	24.22	102	150	7.26	40	334	19
47/M	73	24.74	84	150	6.94	40	319	19
70/M	67	24.63	83	150	7.44	40	342	19
65/F	46	16.91	42	150	7.98	40	367	19
41/M	48	19.51	62	150	7.26	40	330	19
50/F	57	20.95	75	150	7.03	40	338.8	19
61/M	69	24.46	61	150	6.33	40	291	19
75/M	72	23.52	102	150	6.64	40	297	19
68/M	50	19.08	63	150	8.07	40	371	19
38/F	57	20.21	100	150	4.65	40	214	19
55/F	56	22.76	110	150	6.91	40	315	19
51/F	51	19.46	65	150	6.83	40	314	19
55/M	65	22.49	85	150	6.9	40	329	19
70/F	55	20.7	103	150	8.09	40	372	19
72/M	49	18.7	76	150	8.26	40	345	19
54/M	47	19.58	110	150	7.42	40	324	19
40/M	68	23.52	130	150	7.26	40	334	19
42/F	48	18.32	82	150	6.07	40	279	19
52/F	48	18.75	82	150	5.39	40	248	19
68/M	46	18.29	52	150	9.2	40	423	19
60/M	52	20.31	61	150	6.22	40	286	19
56/M	68	25	52	150	8.67	40	399	19
74/M	66	24.26	92	150	8.72	40	401	19
65/M	71	24.56	82	150	8	40	368	19
58/M	64	22.69	100	150	7.4	40	347	19
38/F	58	22.65	50	150	7.42	40	342	19

NC, Noncontrast; Dy, Dynamic acquisition; kVp was 120 in NCCT and 100 in dynamic study

Results

The CTP study was performed on 30 patients of lung cancer; all the studies were of diagnostic quality and the perfusion parameters could be determined in all.

Out of 30 patients, 21 were male and 9 female patients. The male to female ratio was 2.3:1. The age ranged from 38 to 75 years, with the mean age of 56 years. Majority of patients were in the age group of 50–59 years constituting 33.33% patients.

The weight of the patients varied from 46 to 73 kg and the BMI from 16.91 to 25. The mean weight was 58.03 ± 9.412 and the BMI was 21.66 ± 3.02. The effective diameter varied from 18 to 30 cm and was used to know the conversion factor required to calculate the SSDE for CTP study. The conversion factor varied from a maximum of 1.91 to a minimum of 1.23.

Scan length ranged from 214 to 424 mm in the NCCT scans with the mean length of 335.127 ± 75.46 mm, while it was fixed to 19 mm for the dynamic scan. Therefore, in CTP the scan length varied from 233 to 452 mm with the mean of 356.86 ± 73.706 mm.

The mean radiation doses in CTP study were $CTDI_{vol}$ = 270.138 ± 1.627 mGy, DLP = 681 ± 53.496 mGy.cm, ED = 12.501 ± 0.923 mSv, and SSDE = 388.90 ± 81.27 mGy.

The $CTDI_{vol}$ and DLP showed a positive correlation (r = 0.556, P = 0.000 and r = 0.522, P = 0.003, respectively) with the effective diameter. On the contrary, SSDE showed a strong negative correlation (r = −0.997, P = 0.000) with the effective diameter for the CTP study. The relationship of $CTDI_{vol}$, DLP, and SSDE with the effective diameter for CTP study is shown in Figure 2A–C. Comparison of SSDE in CTP was also done with the patient size with respect to the weight and BMI of the patients. SSDE was found to have

Table 2: $CTDI_{vol}$ and DLP in NCCT, dynamic, and CTP study for 30 patients

CTDI vol (mGy)			DLP (mGy.cm)			ED (mSv)		
NC	Dy	CTP	NC	Dy	CTP	NC	Dy	CTP
4.19	4.75	268.94	132.39	508.31	640.7	2.51	9.66	12.17
4.54	264.75	269.29	153.12	508.31	661.43	2.91	9.66	12.93
4.12	264.75	268.53	160.22	508.31	668.53	3.04	9.66	12.70
5.46	264.75	270.21	223.45	508.31	731.76	3.12	9.66	12.78
7.77	264.75	272.52	247.72	508.31	756.03	4.71	9.66	14.37
6.06	264.75	270.81	184.1	508.31	692.41	2.57	9.66	12.23
7.17	264.75	271.92	234	508.31	742.31	3.27	9.66	12.93
2.54	264.75	267.29	89.27	508.31	597.58	1.17	9.66	10.90
4.76	264.75	269.51	152.48	508.31	660.79	2.9	9.66	12.56
5.77	264.75	270.43	179.63	508.31	687.94	3.41	9.66	13.07
4.16	264.75	268.91	114.56	508.31	622.87	2.18	9.66	11.84
6.66	264.75	271.41	187.83	508.31	696.14	3.57	9.66	13.23
4.82	264.75	269.57	171.46	508.31	679.77	2.4	9.66	12.06
7.01	264.75	271.76	139.37	508.31	647.68	2.65	9.66	12.31
6.85	264.75	270.94	218	508.31	726.31	2.62	9.66	12.28
4.41	264.75	269.16	131.79	508.31	640.1	2.5	9.66	12.16
6.5	264.75	271.25	207	508.31	715.31	2.9	9.66	12.56
3.27	264.75	268.02	116.42	508.31	624.73	1.62	9.66	11.28
5.81	264.75	270.56	211.97	508.31	720.28	4.03	9.66	13.69
3.14	264.75	267.89	109	508.31	617.31	1.52	9.66	11.18
9.9	264.75	274.65	315.38	508.31	823.69	4.41	9.66	14.07
6.15	264.75	270.9	162.4	508.31	670.71	3.08	9.66	12.74
6.25	264.75	271	145.3	508.31	653.61	2.76	9.66	12.42
3.97	264.75	268.72	161.94	508.31	670.25	2.26	9.66	11.92
4.7	264.75	269.45	127.24	508.31	635.55	1.78	9.66	11.44
4	264.75	268.75	153.5	508.31	661.81	2.15	9.66	11.81
7.39	264.75	272.14	285.6	508.31	793.91	5.43	9.66	15.09
6.31	264.75	271.06	222.4	508.31	730.71	2.43	9.66	12.09
4.1	264.75	270.75	128	508.31	636.31	2.43	9.66	12.09
3.87	264.75	268.62	128.5	508.31	636.81	2.46	9.66	12.12

NC: Noncontrast CT; Dy: Dynamic CT; CTP: CT perfusion study; CTP: NC+Dy. The table depicts the effective dose for NCCT, dynamic, and CTP studies

a significant negative correlation with the BMI ($r = -0.889$; $P = 0.000$) and weight ($r = -0.910$, $P = 0.000$) of patients in CTP study.

The scan length did not show any significant correlation to SSDE ($r = -0.012$, $P = 0.951$) and SSDE remained constant even with an increase in the net scan length [Figure 3].

Discussion

The main idea of this study was to provide an insight into the radiation dose delivered by the perfusion CT of lung, a recent CT protocol being increasingly utilized in oncology for diagnostic, therapeutic, and follow-up evaluation of lung cancer. As the study is expected to deliver a high radiation dose, it is essential to notify the radiation dose delivered to the patient. Conventionally, $CTDI_{vol}$ is used to express the radiation delivered by a particular CT protocol, but

Table 3: SSDE for CTP in 30 patients with lung cancer

Diameter (cm) AP, LAT		Effective diameter (cm)	$CTDI_{vol}$	Conversion factor (*f*32D size)	SSDE (in mGy) CTP
23.6	27	25	268.94	1.48	398.0312
14	25	19	269.29	1.84	495.4936
18.8	30	24	268.53	1.53	410.8509
25	32	28	270.21	1.32	356.6772
23.5	35	29	272.52	1.28	348.8256
21.7	36	30	270.81	1.23	333.0963
21	34	27	271.92	1.37	372.5304
14	22	18	267.29	1.91	510.5239
18	25.6	21	269.51	1.71	460.8621
19.7	32	25	270.43	1.48	400.2364
25	32	28	268.91	1.32	354.961
23	34	30	271.41	1.23	333.8343
18	33	24	269.57	1.53	412.4421
21	29	25	271.76	1.48	402.2048
20	32	25	270.94	1.48	400.9912
19.5	30	24	269.16	1.53	411.8148
21	32	26	271.25	1.43	387.8875
25	25	25	268.02	1.48	396.6696
17	33	24	270.56	1.53	413.9568
17	23	20	267.89	1.78	476.8442
21	37	28	274.65	1.32	362.538
16	33	23	270.9	1.59	430.731
15	35	23	271	1.59	430.89
15	27	20	268.72	1.78	478.3216
21	28	24	269.45	1.53	412.2585
24	32	28	268.75	1.32	354.75
23	31	27	272.14	1.37	372.8318
26	35	30	271.06	1.23	333.4038
22	31	26	270.75	1.43	387.1725
22	31	26	268.62	1.43	384.1266

The AP, LAT, and effective diameter, $CTDI_{vol}$, *f*32D size are also depicted in the table

this is a metrics of radiation output and not of the patient dose. To some extent this limitation is overcome by the use of DLP, which includes the parameter of scan length in its calculation. As it does not include any patient factor, it is not a true representation of the radiation dose expression in the patient. Therefore, a new dose metrics, SSDE which also depends on the patient size and thus provides a better estimate of the adsorbed dose is being addressed and discussed in the context of a high radiating examination of CTP, which was conducted in 30 patients of lung cancer.

The weight of our patients ranged from 46 to 73 kg, and it has already been suggested that for patients with weight between 36 and 100 kg $CTDI_{vol}$ underestimates the patient dose.[17] Therefore, the estimation of SSDE is more important in the Indian context where the patients have a smaller size and lesser weight.

The effective diameter varied from 18 to 30 cm and accordingly the conversion factor varied from a maximum

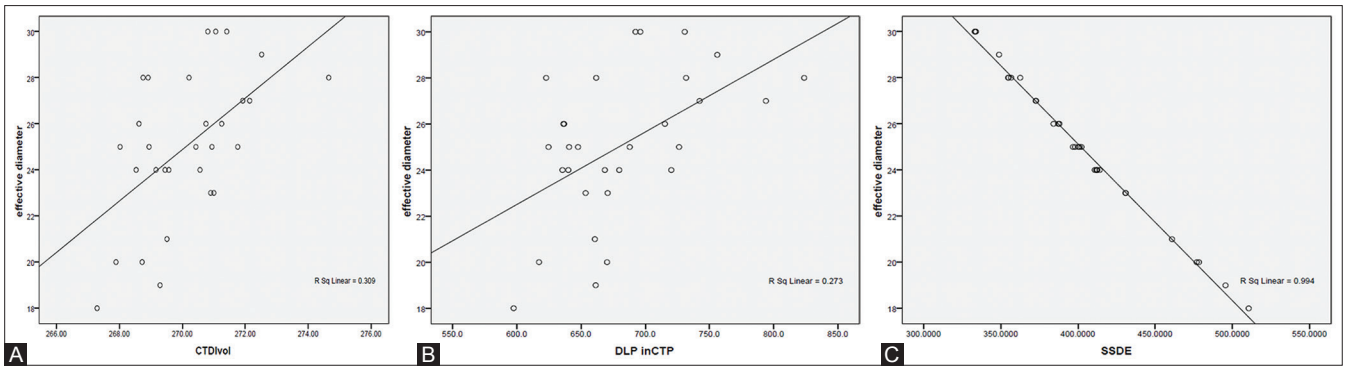

Figure 2 (A-C): (A) Relation between the $CTDI_{vol}$ and effective diameter. (B) Relation between the DLP and effective diameter. (C) Relation between the SSDE and effective diameter

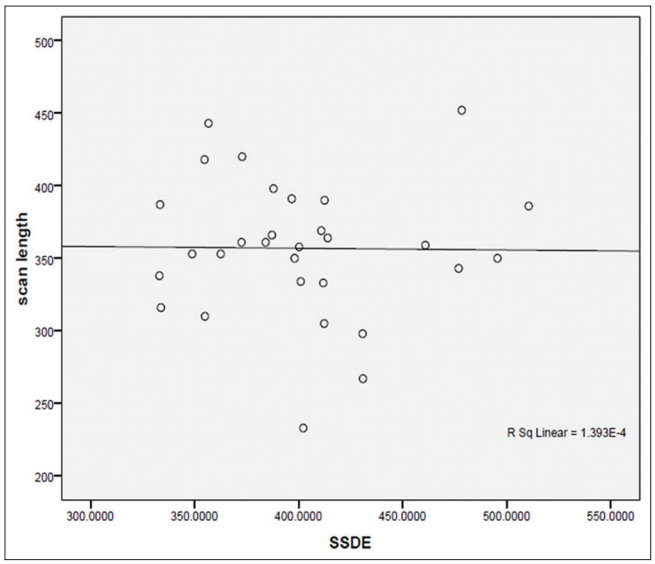

Figure 3: Relation between the SSDE and scan length

of 1.91 to a minimum of 1.23, respectively, as opposed to the maximum being 1.65 (for the smallest sized patient) in a Western study involving same number of patients undergoing a CT for a renal colic. This suggests more relevance of SSDE in the Indian context. The conversion factor for the small-sized patient was higher in comparison to the larger patients, thus expecting a higher SSDE value for the smaller patients with the same protocol.

The $CTDI_{vol}$ and DLP showed a positive correlation ($r = 0.556$, $P = 0.000$ and $r = 0.522$, $P = 0.003$, respectively) to the effective diameter; and increased as the effective diameter of the patient increased. This can be attributed to the ATCM function of the system, which is automatically switched on in thoracic CT.

On the contrary, SSDE showed a strong negative correlation ($r = -0.997$, $P = 0.000$) with the effective diameter for the CTP study. As the dynamic CT contributes to the larger component of the dose in CTP (constituting NCCT and dynamic scans), the CTP is not dependent on the scan length

Table 4: Minimum, maximum, median, mean, and standard deviation of $CTDI_{vol}$, DLP, ED, and SSDE in CTP study in 30 patients of lung cancer

Dose descriptor	CTP lung					
	Min	Max	Range	Median	Mean	SD
$CTDI_{vol}$ (mGy)	268.62	274.65	269.89	6.03	270.138	1.627
DLP (mGy.cm)	597.58	823.69	226.11	669.39	681.445	53.496
ED (mSv)	10.90	15.09	4.19	12.295	12.501	0.923
SSDE (mGy)	333.10	510.52	177.42	398.032	388.90	81.27

but on the effective diameter (representing the patient size). Thus, SSDE will prove to be a better dose metric to determine the effective dose in the patient as suggested by other researchers, who found better correlation between the organ dose and SSDE than $CTDI_{vol}$.[18]

The relationship between $CTDI_{vol}$, DLP, and SSDE with the effective diameter for CTP study is shown in Figure 2A–C. Comparison of SSDE in CTP with respect to the weight and BMI of the patients had a significant negative correlation of ($r = -0.910$, $P = 0.000$) and ($r = -0.889$; $P = 0.000$), respectively, with the correlation being better for weight. In a previous study, the correlation of SSDE was better with patient weight for thoracic CT examination, whereas it was better for BMI for abdominal examinations.[19]

The SSDE values pertaining to the effective diameters taken from the transverse/axial images showed a significant ($r^2 = 0.6$, $P < 0.01$) correlation with the patients' weight.[14]

Though no such relation was determined, SSDE showed a significant negative correlation with all the patient size parameters (effective diameter, weight, and BMI) used in our study. BMI has not been studied previously in any CTP study, nor its relation to SSDE has been determined.

This suggests that the weight or the BMI of the patients can be used as a guide to calculate the radiation received, in a CTP examination. This will prove to be a less tedious way to estimate the dose and can also give some idea to the clinicians regarding the radiation dose that would be delivered in comparison to a normal-sized adult.

The small-sized patients (lesser effective diameter) had larger values for SSDE suggesting a larger radiation dose. This also indicated the need to tailor the radiation dose according to the patient size especially in children, to avoid unnecessary radiation during CTP and leave scope for follow-up examination when required.

In fact, in a study it was concluded that SSDE is a useful dose measure for CT examinations involving different scanner platforms, different techniques and variable-sized patients. It can also be used to monitor the dose reduction strategies in children undergoing CT angiography.[20]

Even though perfusion CT techniques have been in clinical use for a few years now, there is a paucity of literature with respect to the radiation burden associated with it. The mean radiation dose in CTP study were $CTDI_{vol}$ = 270.138 ± 16.27 mGy and DLP = 681 ± 53.496 mGy.cm. The SSDE was 388.90 ± 81.27 mGy, which was 1.21 to 1.63 times more than the $CTDI_{vol}$. The mean ED in CTP for lung cancer in this study was 12.50 ± 0.923, while the previous published study found it to be 13.7 mSv in perfusion CT of thorax.[21] This difference of 1.2 mSv can be accounted for by inclusion of the radiation doses received from the topogram in their study, whereas our study only included NCCT and dynamic acquisition. Other differences are (1) *z*-axis coverage ranging from 11.4 to 15.7 cm in their study and fixed at 19.2 mm in ours; (2) mean DLP value was 719.9 mGy.cm in comparison to 508.310 mGy.cm in our study; (3) mean $CTDI_{vol}$ was 96.2 mGy (32.3–169.4 mGy), while it was 270.138 ± 16.27 mGy in the present study. Despite the *z*-axis coverage, the dose in the previous study exceeded ours as their acquisition parameters were different and the 64-slice MDCT used in our study had tube current modulation facility. Moreover, the method used to calculate the ED in both the studies was different. To the best of authors' knowledge, we did not find any study on CTP having a *z*-axis coverage of 19.2 mm. In the absence of any published values of SSDE in CTP, we could not compare our results.

In conclusion, the radiation dose can be represented as a scanner radiation output ($CTDI_{vol}$ and DLP) or as SSDE, which is more specific estimate of radiation dose and by incorporating the patient size to estimate the absorbed dose. The smaller-sized patients had greater radiation exposure in CTP study. This study will prove to be a useful guide for undertaking future studies on SSDE in CTP of thorax.

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Conflicts of interest
There are no conflicts of interest.

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