Technical Note

# Size-Specific Dose Estimate and Effective Dose for Pediatric Computed Tomography

**Rukhsar Khan, Mudasir Ashraf Shah, Shagufta Wahab, Rizwan Ahmad Khan[1]**

Departments of Radiodiagnosis and [1]Paediatric Surgery, Faculty of Medicine, J. N Medical College, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

## Abstract

The purpose of this study is to present the multivariate analysis of the size-specific dose estimate (SSDE) and E in pediatric computed tomography (CT) imaging. Pediatric patients scheduled for CT scans of the head, thorax, and abdomen from July 2022 to February 2024 were included in the prospective study. The water-equivalent diameter ($D_w$), SSDE, and E were computed for each examination using the dose report of CT console display computed tomography dose index ($CTD1_{vol}$) and dose length product (DLP). The correlation between SSDE and E on $CTD1_{vol}$, $D_w$, $Area_{ROI}$, body mass index, *Size/(LAT+AP)*, age, $f_{size}$, and $HU_{mean}$ in the region of interest was examined using the multivariate statistical analysis with 95% level of significance ($P < 0.05$). The relationship between $D_w$ and *Size/(LAT+AP), Size/(LAT+AP)*, and $f_{size}$ versus age was investigated using linear regression analysis. The mean values of SSDE for noncontrast head CT and contrast-enhanced CT were found 71.36 *mGy* and 97.38 *mGy*, respectively. While as, the mean SSDE for contrast-enhanced thorax CT was observed to be 5.82 *mGy*, which is less than the mean SSDE of 6.40 *mGy* for noncontrast thorax CT imaging. The range of the SSDE for contrast-enhanced abdomen CT is 2.05 *mGy* to 22.13 *mGy* with a mean SSDE of around 5.71 *mGy* and for noncontrast abdomen imaging, mean value of SSDE was 5.58 *mGy*. The mean value of "E" for noncontrast thorax CT imaging was observed to be 2.7 *mSv* with minimum and maximum 1.17 *mSv* to 10.10 *mSv* respectively, which less than the mean effective dose is of 3.64 *mSv* observed for contrast enhanced thorax CT imaging. The multivariate analysis suggests that SSDE is significantly correlated with $CTD1_{vol}$, $D_w$, and E is found significantly dependent on DLP for both contrast enhanced and noncontrast imaging with $p < 0.05$. A strong positive correlation was found between $D_w$ and *Size/(LAT+AP),* form linear regression analysis. The SSDE is crucial for radiologists evaluating pediatric CT scans and is now an international standard expected to be widely adopted. The strong positive correlation between $D_w$ versus *Size/(LAT+AP),* indicates that *Size/(LAT+AP),*can be used as surrogate in estimate SSDE when $D_w$ calculation is not feasible for pediatric CT imaging.

**Keywords:** Dose length product, effective dose, linear regression analysis, multivariate analysis, size-specific dose estimate, water equivalent diameter

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## Introduction

The use of computed tomography (CT) imaging in children has increased significantly in the last three decades, particularly in India where over 80% of tertiary care hospitals have CT scan facilities.[1-6] CT scans are preferred in children for taking less time and requiring moderate sedation or anesthesia.[7,8] Concerns have been raised about the high doses of ionizing radiation associated with CT imaging, which can be 100–500 times higher than conventional radiography and account for half of the total annual medical radiation exposure.[9-12] Children are more susceptible to the long-term effects of ionizing radiation, with studies showing a higher risk of leukemia and brain tumors from pediatric CT scans.[13-17] Leukemia has a shorter latency period than radiation-associated solid tumors, and the bone marrow in almost all the body regions is exposed to radiation from scan.[18] Moreover, because a majority of pediatric CT scanning is limited to the head, the brain is frequently exposed to radiation as well.[13] Thus, to minimize cancer risk from ionizing radiation, doctors should be cautious with CT scans for young patients who are more vulnerable. Juveniles are

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**Address for correspondence:** Dr. Mudasir Ashraf Shah, Department of Radiodiagnosis, Faculty of Medicine, J. N Medical College, Aligarh Muslim University, Aligarh, Uttar Pradesh, India. E-mail: mudasirashraf8@gmail.com



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more prone to radiation-related disorders due to their longer lifespan and rapid cell growth.[3-6] When CT scans provide the same computed tomography dose index (*CTD1vol*) or dose length product (DLP), the effective dose (E) for children under 1 year of age is approximately three times for the chest or abdomen, five times for the head compared to adults.[18,19] Children may be several times more vulnerable to radiation than adults. As a result, there is serious concern about the necessity and radiation dose optimization for pediatric CT examinations. As the kids grow from infants to obese teenagers, their weight can fluctuate significantly, therefore it is critical to select the right CT scanning parameters and maximize radiation protection.[20-25]

In order to illustrate the radiation doses, the International Electrochemical Commission (IEC) requires all the scan manufacturers to display radiation output with descriptors such as Volume $CTD1_{vol}$ and DLP before and after the examination in the form of a dose sheet or image. One of the primary drawbacks of $CTD1_{vol}$ is its inability to accurately provide radiation risk and due to its disregard for the size and varying attenuation of different patients. The $CTD1_{vol}$ and DLP do not provide the exact radiation dose absorbed by the patient. The American Association of Physicists in Medicine (AAPM) Task Group (TG) report-204, came up with the concept of a size-specific dose estimate (SSDE).[26] The SSDE formalism of TG-204 provides an estimate of the radiation dosage that the patient has received that has been adjusted for patient size. It modifies the reported $CTD1_{vol}$ from the scanner by adjusting the patient dosage; however, this is only based on the patient's geometry and does not take into account the different attenuation of other body tissues. The AAPM TG Report 220 addressed this shortcoming in depth and introduced the term water-equivalent diameter ($D_w$) and its applications in determining the patient's dose.[27,28] The AAPM TG report 293[29] provides the single set of $CTD1_{vol}$-to-SSDE conversion factors head and pediatric body metrics. The present study attempts to evaluate the SSDE and E in pediatric CT and to present the multiple regression analysis of SSDE and E.

## Materials and Methods

### Subject

The Institutional Ethics Committee (ref. no: IECJNMC/908, dated: October 26, 2022) of faculty of Medicine, Aligarh Muslim University, Aligarh, India, approved this prospective study. Since the patients had a planned CT scan and would not be getting another needless scan, the written consent was obtained from the patients guardians. This prospective study included a total of 203 pediatric patients, head 81 (with contrast = 65, without contrast = 16), abdomen 57 (with contrast = 52, without contrast = 05), and thorax 65 (with contrast = 22, without contrast = 43) under the age of 15 years who underwent routine CT head, abdomen, and thorax procedures using a GE Healthcare Revolution EVO CT scanner that was placed in our department in compliance with the standard operating procedure. The exclusion criteria were as follows: Patients >15 years age, poor cooperation during imaging, repeat scans for errors or requests, low-quality images, and presence of metal fixators or foreign objects on the body.

### Image acquisition

A standard protocol was followed to perform a CT scan of the abdomen, head and thorax on all patients, with the following restrictions: Head toward CT gantry spine position. The scanning range was from the diaphragm to the pubic symphysis in abdomen imaging, vertex to $C_2$ vertebra in head scanning, and from 7th cervical vertebra to diaphragm in thorax scanning. A CT unit that is installed in our department was used to perform the CT exams and the following were the preset imaging limits: Tube voltage ($kV$:80 − 120), quality reference ($mAs$:100) detector collimation 128 mm × 0.6 mm, acquisition matrix (512 × 512), field-of-view (314 mm × 314 mm), slice acquisition thickness 5 mm, inter-slice spacing 1 mm and the CT unit used the filtered back projection algorithm for image reconstruction. The periodic quality assurance tests were performed on the said CT unit to verify the quality and appropriateness of the patient care. All the results were within the tolerance range recommended by the Atomic Energy Regulatory Board, Govt. of India and manufacturer.

### Size – Specific dose estimate

The $CTD1_{vol}$ and DLP do not measure the patient-absorbed dose, but these indexes quantify the radiation dose to which a patient is exposed and thus dictate the dose delivered to the patient.[30] Precise patient dimensions are crucial for determining patient dose in CT, as dose depends on both patient size and scanner output.[31,32] Antero-posterior, lateral, and antero-posterior or effective diameter measurements of the patient were used in combination with $CTD1_{vol}$ in AAPM TG report-204 to compute SSDE from CT scan data.[33] The TG-204 SSDE method accounts for patient size but ignores key physical parameters affecting radiation dosage. TG-220 suggests using $D_w$ to account for tissue attenuation in addition to patient geometric measurements when estimating SSDE. According to the TG report-220, the SSDE is $CTD1_{vol}$ with multiplicative conversion factors ($f_{size}$) that rest on $D_w$. Axial CT scans were used to calculate the $D_w$. In all CT imaging studies, the $CTD1_{vol}$ and DLP are displayed on the dosage page of the GE Advance Workstation software, which is based on a 16 and 32 cm Phantom. In addition, the SSDE and $D_w$ were calculated using the TG report-220 and TG report-293 formalism and the subsequent equations:[27,29]

$$D_w = 2\sqrt{\left(\frac{ROI_{mean}}{1000}+1\right)} \times \sqrt{\frac{A_{ROI}}{\pi}} \quad (1)$$

$$f_{size}^{16} = a \times e^{-b \times D_w} \quad (2)$$

where

$$a = 1.9852\left[absorbed\ dose\ to\ tissue\left(mGy\right) / CTDI_{vol,16}\left(mGy\right)\right]$$

and $b$ = 0.0486 cm$^{-1}$ are the 16 cm polymethyl methacrylate phantom (PMMA) $CTD1_{vol}$ normalized dose coefficients as a function of $D_w$.

$$SSDE_B = f_{size}^{B16} \times CTDI_{vol}^{16} \quad (3)$$

$$SSDE_H = f_{size}^{H16} \times CTDI_{vol}^{16} \quad (4)$$

where ROI is the region of interest that encompasses the entire body outline, $A_{ROI}$ is the ROI's area cm², $HU_{mean}$ is the mean Hounsfield (HU) number in the ROI, and $f_{size}^{B16}$ are the conversion factors for the pediatric body matrices that are presented in the TG report-220. These values are automatically provided by team play (Syngo.via Software Version B40) based on the axial CT images. $SSDE_B$, and $SSDE_H$ stands for SSDE for body and head, respectively, in accordance with AAPM TG-293.[28] The $D_w$ is calculated from the $HU_{mean}$ in the ROI and area of the ROI ($Area_{ROI}$) (cm²), automatically generated by team play according the axial CT images.

The $D_w$ has been computed from the mid slice in the CT scan, rather than the individual slices and then calculating the mean $D_{w,mean}$ and $f_{size}^{B16}$ because the calculation of SSDE from on the mid slice $D_w$ provides reasonable results, and avoid the practical issues related associated with finding $D_w$ for each slice.[30]

## Effective dose

The $CTD1_{vol}$, DLP, and E are the excellent measures of radiation dose from CT and could be used immediately to improve the safety of CT by identifying when doses may be higher than necessary and standardizing how to conduct CT examinations. The According to ICRP report-60,[31] the weighted average of organ dose values ($H_T$) for a number of designated organs is the E:

$$E = \sum_i w_i H_{t,i} \quad (5)$$

"E" is measured in millisievert (*mSv*). The tissue weighting factor ($W_i$) assigned to each organ indicates its relative sensitivity to radiation-induced effects, which determines how much that organ contributes to E and $H_t$ is the equivalent dose. It is not possible to measure the E *in vivo*. As a result, E is obtained by multiplying the age and site corrected conversion factor (K) by the DLP. Consequently, E:

$$E = K \times DLP \quad (6)$$

where K is conversion factor: Normalized effective dose per DLP values for different body parts and (standard) patient age groups.[32-34] Following every CT study, the DLP is shown as a dosage sheet, from which the value E is calculated.

## Body mass index

Prior to imaging, each patient had their height and weight measured, and their body mass index (BMI) was computed using a specific, calibrated tool (Indosurgicals: Weight and height measuring instrument). The patients were grouped according to the subcategories of the BMI data: Underweight was defined as BMI < 18.5 kgm$^{-2}$, normal weight as 18.5 ≤ BMI ≤ 24.9 kgm$^{-2}$, overweight as 25 ≤ BMI ≤ 29.9 kgm$^{-2}$, and obese as BMI ≥ 30 kgm$^{-2}$.[35,36]

# Results

A total of 203 participants with a mean age 8.33 years and range of 2 months to 15 years were prospectively studied for SSDE and E estimation. Approximately 15.27% patients only were having normal body weight and height and 85.73% were underweight. The statistical analysis of SSDE, $CTD1_{vol}$, $D_w$, *f*-factor/$f_{size}$, and patient size(*LAT+AP*) for head, thorax, and abdomen with and without contrast studies is presented in Tables 1-3, respectively. In addition, the whole data and mathematical calculations can be seen from the Supplementary File 1 (page 1–6 - Interested readers may contact the corresponding author through email requesting for a copy of the Supplementary File). The SSDE for head without contrast imaging ranges from 34.88 *mGy* to 141.198 *mGy* with a mean value of 71.36 *mGy* and contrast enhanced head CT the average value of SSDE was observed 97.38 *mGy* with a minimum of 57.57 *mGy* and maximum of 139.38 *mGy* respectively as presented in the Table 1. The $D_w$ ranges from 10.00 cm to 21.00 cm with a mean value of 15.2 cm for plain head CT and for contrast enhanced CT imaging the average value of $D_w$ was found to be 14.94 cm. The E ranges from 1.16 *mSv* to 8.97 *mSv* with a mean value of 4.50 *mSv* for noncontrast head imaging and for contrast head CT the mean value of effective dose was observed to be 6.81 *mSv*.

For noncontrast thorax CT imaging, the mean value of effective dose was observed to be 2.7 *mSv* with minimum and maximum values of 1.17 *mSv* to 10.10 *mSv*, respectively, which less than the mean effective dose is of 3.64 *mSv* observed for contrast-enhanced thorax CT imaging, as presented in Table 2. The mean value of SSDE for noncontrast thorax was observed to 6.40 *mGy* which is

**Table 1: Statistical results of head with and without contrast computed tomography studies**

| Parameter | Mean±SD | Minimum | Maximum | Range |
|---|---|---|---|---|
| **Head without contrast CT studies (*n*=65)** | | | | |
| SSDE (*mGy*) | 71.36±20.31 | 34.88 | 141.198 | 106.32 |
| BMI (kg m$^{-2}$) | 14.67±2.18 | 10.00 | 19.00 | 9.0 |
| $CTDI_{vol}$ (*mGy*) | 68.85±21.42 | 32.0 | 139.8 | 107.8 |
| *f* – factor | 1.05±0.073 | 0.83 | 1.27 | 0.44 |
| Age (year) | 6.92±4.73 | 0.17 | 15.00 | 14.83 |
| E (*mGy*) | 4.50±1.69 | 1.16 | 8.97 | 7.81 |
| $D_w$ (cm) | 15.12±1.81 | 10.00 | 21.00 | 11.00 |
| Size (cm) (LAT + AP) | 28.85±2.96 | 19.80 | 41.40 | 21.60 |
| **Head with contrast CT studies (*n*=16)** | | | | |
| SSDE (*mGy*) | 97.38±21.65 | 57.57 | 139.38 | 81.81 |
| BMI (kg m$^{-2}$) | 15.71±2.04 | 11.20 | 18.00 | 6.80 |
| $CTDI_{vol}$ (*mGy*) | 92.98±22.38 | 56.90 | 138.00 | 81.10 |
| *f* – factor | 1.54±0.070 | 0.97 | 1.22 | 0.25 |
| Age (years) | 6.58±5.62 | 6.00 | 15.00 | 14.92 |
| E (*mSv*) | 6.81±3.62 | 2.65 | 14.85 | 12.20 |
| $D_w$ (cm) | 14.94±1.69 | 11.00 | 17.00 | 6.00 |
| Size (cm) (LAT + AP) | 28.74±2.65 | 22.40 | 31.70 | 9.60 |

CT: Computed tomography, SD: Standard deviation, CTDI: CT dose index, BMI: Body mass index, SSDE: Size-specific dose estimate, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

**Table 2: Statistical results of thorax with and without contrast computed tomography studies**

| Parameter | Mean±SD | Minimum | Maximum | Range |
|---|---|---|---|---|
| **Thorax without contrast CT studies ($n$=43)** | | | | |
| SSDE (*mGy*) | 6.40±1.01 | 3.57 | 7.72 | 4.15 |
| BMI (kg m$^{-2}$) | 16.82±2.33 | 10.00 | 20.40 | 10.40 |
| $CTDI_{vol}$ (*mGy*) | 6.62±0.91 | 4.30 | 7.08 | 2.78 |
| *f* – factor | 0.97±0.12 | 0.77 | 1.22 | 0.45 |
| Age (years) | 9.36±5.24 | 0.17 | 15.00 | 14.83 |
| E (*mSv*) | 2.76±1.62 | 1.17 | 10.10 | 8.92 |
| $D_w$ (cm) | 17.18±3.09 | 11.00 | 23.00 | 12.00 |
| Size (cm) (LAT + AP) | 36.96±7.59 | 22.85 | 50.35 | 27.50 |
| **Thorax with contrast CT studies ($n$=22)** | | | | |
| SSDE (*mGy*) | 5.82±1.18 | 2.87 | 7.72 | 4.85 |
| BMI (kg m$^{-2}$) | 17.15±2.22 | 11.10 | 20.00 | 8.90 |
| $CTDI_{vol}$ (*mGy*) | 6.39±1.40 | 2.26 | 7.08 | 4.82 |
| *f* – factor | 0.93±0.12 | 0.77 | 1.27 | 0.50 |
| Age (years) | 12.23±4.63 | 0.17 | 16.00 | 15.83 |
| E (*mSv*) | 3.64±0.96 | 2.56 | 6.79 | 4.23 |
| $D_w$ (cm) | 18.41±3.20 | 10.00 | 23.00 | 13.00 |
| Size (cm) (LAT + AP) | 40.60±7.30 | 22.00 | 52.50 | 30.50 |

CT: Computed tomography, SD: Standard deviation, CTDI: CT dose index, BMI: Body mass index, SSDE: Size-specific dose estimate, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

**Table 3: Statistical results of abdomen with and without contrast computed tomography studies**

| Parameter | Mean±SD | Minimum | Maximum | Range |
|---|---|---|---|---|
| **Abdomen without contrast CT studies ($n$=5)** | | | | |
| SSDE (*mGy*) | 5.58±1.51 | 3.03 | 6.74 | 3.71 |
| BMI (kg m$^{-2}$) | 17.92±1.96 | 16.00 | 21.00 | 5.00 |
| $CTDI_{vol}$ (*mGy*) | 5.991.65 | 3.37 | 7.08 | 3.71 |
| DLP (*mGy.cm*) | 283.46±112.99 | 138.00 | 447.30 | 309.30 |
| $HU_{mean}$ | 43.40±71.89 | -37.00 | 160.00 | 197.00 |
| $Area_{ROI}$ (cm$^2$) | 259.56±118.67 | 82.00 | 400.00 | 318.00 |
| *f* – factor | 0.95±0.19 | 0.77 | 1.27 | 0.50 |
| Age (years) | 10.88±5.96 | 0.42 | 15.00 | 14.58 |
| E (*mSv*) | 5.84±3.52 | 2.07 | 11.42 | 9.35 |
| $D_w$ (cm) | 18.00±4.85 | 10.00 | 23.00 | 13.00 |
| Size (cm) (LAT + AP) | 36.72±9.86 | 21.08 | 47.70 | 26.62 |
| **Abdomen with contrast CT studies ($n$=52)** | | | | |
| SSDE (*mGy*) | 5.71±3.14 | 2.05 | 22.13 | 20.09 |
| BMI (kg m$^{-2}$) | 16.75±2.13 | 10.40 | 22.00 | 11.60 |
| $CTDI_{vol}$ (*mGy*) | 6.29±3.37 | 2.20 | 23.80 | 21.60 |
| *f* – factor | 0.91±0.08 | 0.74 | 1.09 | 0.35 |
| Age (years) | 11.15±4.70 | 1.00 | 15.00 | 14.00 |
| E (*mSv*) | 4.49±2.10 | 1.81 | 13.02 | 11.20 |
| $D_w$ (cm) | 18.85±2.34 | 14.00 | 24.00 | 10.00 |
| Size (cm) (LAT + AP) | 36.72±5.00 | 26.77 | 48.80 | 22.03 |

CT: Computed tomography, SD: Standard deviation, CTDI: CT dose index, BMI: Body mass index, SSDE: Size-specific dose estimate, DLP: Dose length product, HU: Hounsfield, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

greater than the mean SSDE of 5.82 *mGy* for contrast-enhanced thorax imaging. The SSDE for noncontrast abdomen imaging rages from 3.03 *mGy* to 6.74 *mGy* with a mean value of 5.58 *mGy* and for contrast-enhanced abdomen CT SSDE ranges from 2.05 *mGy* to 22.13 *mGy* with mean SSDE of about 5.71 *mGy*, respectively. The average value of $D_w$ for noncontrast abdomen imaging was found to be 18.85 cm which is slightly greater than the mean $D_w$ of 18.00 cm for noncontrast CT. The E ranges from 1.81 *mSv* to 13.02 *mSv* with an average value of 4.49 *mSv* for contrast-enhanced abdomen imaging which is less the mean E of 5.84 *mSv* for noncontrast abdomen, as presented in Table 3. We compared the results of our study with the literature published in the international studies [Table 4] and it was observed that the mean SSDE and $CTD1_{vol}$ values for head of our study are higher than the Chinese study.[39]

The correlation between SSDE and E among BMI, $CTD1_{vol}$, age, DLP, $HU_{mean}$, $Area_{ROI}$, $D_W$, size(*LAT+AP)* and size-based correction factor $f_{size}$ for noncontrast head and contrast-enhanced head imaging, thorax noncontrast and contrast-enhanced CT, and contrast-enhanced abdomen imaging studies was analyzed using the multivariate statistical analysis at a 95% level of confidence significance ($p < 0.05$). As observed from the multivariate analysis Tables 5-9, the SSDE is significantly correlated with $CTD1_{vol}$, $D_w$ and E is found significantly dependent on DLP for both contrast-enhanced and noncontrast imaging with $P < 0.05$. Table 9 presents the multivariate analysis of contrast enhanced CT imaging for the abdomen. As presented in the table, the SSDE and E are found significantly dependent on *CTD1vol* and DLP, respectively.

The *f*-factor/$f_{size}$ is the SSDE conversion factor which is different for head and body scans, but for pediatric body scanning, the conversion factor, the $f_{size}$ based on the use of 16 cm diameter PPMA phantom for $CTD1_{vol}$ is recommended.[28] $f_{size}$ is also based on scanning parameters such as the tube potential setting. The calculation of $f_{size}$ is based on the patient size and the differential attenuated of the patient body, which represented by $D_w$. The linear regression analysis between *f*−factor/$f_{size}$ and age, and $D_w$ and size(*LAT+AP)* [Figures 1-10]. The linear regression analysis was performed between $f_{size}$ and age to verify the dependence of $f_{size}$ on age. The *f*−factor/$f_{size}$ shows strong negative correlation with age for head, thorax and abdomen for both noncontrast and contrast-enhanced CT imaging, as presented in Figures 1, 3, 5, 7 and 9. The negative correlation between $f_{size}$ and age is due to the increase in the patient dimensions and organ size with age. In order to delve the dependence of $D_w$ on patient size the linear regression analysis was performed between $D_w$ and size(*LAT+AP)* as presented in the Figures 2, 4, 6, 8 and 10. A positive and ideal correlation is found between $D_w$ and size(*LAT+AP)* with $r < 0.92$ for abdomen and head CT imaging. A strong positive dependence $D_w$ was also found for thorax CT imaging on size(*LAT+AP)* for both noncontrast and contrast-enhanced CT imaging with $r < 0.88$ and $r < 0.74$, respectively [Figures 6 and 8]. The patient's geometry and variable attenuation resulting from a range of tissue densities in the scanned volume are taken into account in the $D_w$ calculation. The rise in patient dimensions and the differential tissue densities lead to increase of the $D_w$ with size(*LAT+AP)*.

**Table 4: Comparison of mean size-specific dose estimate and computed tomography dose index$_{vol}$ values for paediatric computed tomography imaging reported in the published literature**

| Age (years) | Anatomic site | CTDI$_{vol}$ (mGy) | SSDE (mGy) | Reference |
|---|---|---|---|---|
| 0–16 | Thorax (noncontrast) | 8.07 (median) | 14.9 (median) | Özsoykal *et al*., 2018[37] |
| | Abdomen (noncontrast) | 8.07 (median) | 14.6 (median) | |
| 0–1 | Head (noncontrast) | 45.8 (median) | 56.8 (median) | Duminda *et al*., 2022[38] |
| 1–5 | | 50.4 (median) | 60.7 (median) | |
| 5–10 | | 57.2 (median) | 67.3 (median) | |
| 10–15 | | 57.2 (median) | 66.1 (median) | |
| 0–1 | Chest (noncontrast) | 2.9 (median) | 7.3 (median) | |
| 1–5 | | 4.5 (median) | 10.0 (median) | |
| 5–10 | | 5.4 (median) | 11.4 (median) | |
| 10–15 | | 10.0 (median) | 16.6 (median) | |
| 0–1 | Abdomen (noncontrast) | 3.8 (median) | 8.4 (median) | |
| 1–5 | | 5.6 (median) | 8.4 (median) | |
| 5–10 | | 8.8 (median) | 12.8 (median) | |
| 10–15 | | 10.0(median) | 17.6 (median) | |
| ≤0.5 | Head (noncontrast) | 6.63±0.66 (mean) | 6.98±0.39 (mean) | Jian Zhang and Xiaojun Zhang, 2024[39] |
| 0.5<1 | Head (noncontrast) | 7.56±0.45 (mean) | 7.34±0.24 (mean) | |
| 1≤5 | Head (noncontrast) | 8.67±0.62 (mean) | 7.84±0.34 (mean) | |
| 5≤10 | Head (noncontrast) | 9.92±0.60 (mean) | 8.52±0.36 (mean) | |
| 10≤15 | Head (noncontrast) | 10.78±0.64 (mean) | 8.90±0.34 (mean) | |
| <0.5 | Chest (noncontrast) | 1.62±0.25 (mean) | 3.75±0.56 (mean) | |
| 0.5<1 | Chest (noncontrast) | 1.68±0.24 (mean) | 3.85±0.51 (mean) | |
| 1≤5 | Chest (noncontrast) | 1.98±0.37 (mean) | 4.26±0.71 (mean) | |
| 5≤10 | Chest (noncontrast) | 2.75±0.48 (mean) | 5.40±0.70 (mean) | |
| 10≤15 | Chest (noncontrast) | 3.74±0.55 (mean) | 6.37±0.53 (mean) | |
| <0.5 | Abdominopelvic (noncontrast) | 1.77±0.6 (mean) | 4.14±0.77 (mean) | |
| 0.5<1 | Abdominopelvic (noncontrast) | 1.79±0.30 (mean) | 4.21±0.68 (mean) | |
| 1≤5 | Abdominopelvic (noncontrast) | 1.99±0.35 (mean) | 4.40±01 (mean) | |
| 5≤10 | Abdominopelvic (noncontrast) | 2.70±0.62 (mean) | 5.36±0.87 (mean) | |
| 10≤15 | Abdominopelvic (noncontrast) | 4.86±1.44 (mean) | 8.28±2.03 (mean) | |
| ≤0.5 | Head (noncontrast) | 14.1 (median) | 15.4 (median) | Poosiri *et al*., 2024[40] |
| 0.5≤3.0 | Head (noncontrast) | 21.1 (median) | 20.1 (median) | |
| 3.0≤6.0 | Head (noncontrast) | 27.4 (median) | 25.3 (median) | |
| 6.0≤12 | Head (noncontrast) | 31.4 (median) | 28.1 (median) | |
| 12≤15 | Head (noncontrast) | 40.1 (median) | 35.1 (median) | |
| 0–15 | Head (noncontrast) | 68.85 (mean) | 71.36 (mean) | Present study |
| | Head (with contrast) | 92.98 (mean) | 97.38 (mean) | |
| 0–15 | Thorax (noncontrast) | 6.62 (mean) | 6.40 (mean) | |
| | Thorax (with contrast) | 6.39 (mean) | 5.82 (mean) | |
| 0–15 | Abdomen (noncontrast) | 5.99 (mean) | 5.58 (mean) | |
| | Abdomen (with contrast) | 6.29 (mean) | 5.71 (mean) | |

SSDE: Size-specific dose estimate, CTDI: Computed tomography dose index

## Discussion

Compared to conventional radiography, CT scans have different radiation dose distribution due to three unique characteristics: Smaller tissue exposure, uniform radiation from multiple angles, and higher radiation dose for better contrast resolution.[41,42] Further, scattered radiation outside primary beam during CT slice acquisition contributes significant dosage to surrounding tissues.[43] The radiation dose for a single CT scan of the organ under examination ranges from 15 *mSv* in adults to 30 *mSv* in neonates, depending on the machine settings.[44] Typically, two to three CT scans are performed per study, with a higher risk of radiation-induced cancer for young children due to their increased radiosensitivity and longer time for cancer to develop. The National Research Council Committee on the Biological Effects of Ionizing Radiation has reported that children under ten are several times more susceptible to radiation than adults.[19,45] Consequently, to ensure radiation safety, patient dose management for pediatric CT imaging is crucial, along with establishing local diagnostic reference levels.[46] Recent research by Bosch de Basea Gomez *et al*.[47] suggests an increased cancer risk from low CT radiation doses in children, teens, and young adults, emphasizing the importance of justifying pediatric CT scans and optimizing

**Table 5: Multivariate analysis of the head without contrast computed tomography studies**

| Dependable variable | Independent variable | Regression coefficient | SE | p |
|---|---|---|---|---|
| SSDE (*mGy*) | BMI (kg $m^{-2}$) | 0.077 | 0.59 | >0.05 (NS) |
| | $CTDI_{vol}$ (*mGy*) | 1.04 | 0.013 | <0.05 (significant) |
| | DLP (*mGy.cm*) | −0.00332 | 0.00864 | >0.05 (NS) |
| | $HU_{mean}$ | 0.0447 | 0.066 | <0.05 (significant) |
| | $Area_{ROI}$ ($cm^2$) | 0.18 | 0.066 | >0.05 (NS) |
| | *f* – factor | 558.36 | 424.56 | <0.05 (significant) |
| | Age (years) | −0.42 | 0.47 | >0.05 (NS) |
| | $D_w$ (cm) | 20.37 | 19.13 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | 2.03 | 1.57 | <0.05 (significant) |
| E (*mSv*) | BMI (kg $m^{-2}$) | 0.035 | 0.09 | >0.05 (NS) |
| | $CTDI_{vol}$ (mGy) | −0.024 | 0.02 | >0.05 (NS) |
| | DLP (*mGy.cm*) | 0.0044 | 0.0013 | <0.05 (significant) |
| | $HU_{mean}$ | −0.009 | 0.024 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 5.33105 | 13.41 | >0.05 (NS) |
| | Age (years) | −0.18 | 0.070 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | 0.15 | 0.19 | >0.05 (NS) |

SE: Standard error, NS: Not significant, SSDE: Size-specific dose estimate, CTDI: Computed tomography dose index, BMI: Body mass index, DLP: Dose length product, HU: Hounsfield, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

**Table 6: Multivariate analysis of the head with contrast computed tomography studies**

| Dependable variable | Independent variable | Regression co-efficient | SE | p |
|---|---|---|---|---|
| SSDE (*mGy*) | BMI (kg $m^{-2}$) | −0.16 | 0.22 | >0.05 (NS) |
| | $CTDI_{vol}$ (*mGy*) | 0.96 | 0.08 | <0.05 (significant) |
| | DLP (*mGy.cm*) | 0.005 | 0.007 | >0.05 (NS) |
| | $HU_{mean}$ | 0.008 | 0.05 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 0.07 | 0.06 | >0.05 (NS) |
| | *f* – factor | −79.23 | 215.08 | >0.05 (NS) |
| | Age (years) | −0.09 | 0.16 | >0.05 (NS) |
| | $D_w$ (cm) | −8.924 | 9.37 | >0.05 (NS) |
| | Size (cm) (LAT + AP) | 0.076 | 0.59 | >0.05 (NS) |
| E (*mSv*) | BMI (kg $m^{-2}$) | −0.045 | 0.36 | >0.05 (NS) |
| | $CTDI_{vol}$ (*mGy*) | 0.03 | 0.05 | >0.05 (NS) |
| | DLP (*mGy.cm*) | 0.02 | 0.11 | <0.05 (significant) |
| | $HU_{mean}$ | 0.107 | 0.073 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 0.056 | 0.06 | >0.05 (NS) |
| | Age (years) | 0.025 | 0.26 | >0.05 (NS) |
| | Size (cm) (LAT + AP) | −0.66 | 0.82 | >0.05 (NS) |

SSDE: Size-specific dose estimate, CTDI: Computed tomography dose index, SE: Standard error, NS: Not significant, BMI: Body mass index, DLP: Dose length product, HU: Hounsfield, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

doses. This report from a central university medical college, which is tertiary care referral center working as the apex center in Western Uttar Pradesh, India, with the patients of all strata coming from a radius of 100 to 150 km, on the evaluation of SSDE for paediatric CT imaging. The importance SSDE evaluation is essential in quantifying radiation doses during CT scans to achieve precision and reliability in CT imaging. This methods involves the normalization of the CT scanner's output represented by $CTD1_{vol}$, as through a designated size conversion factor ($f_{size}$).[48] The SSDE is essential for radiologists evaluating CT scans in particular for pediatric patients. It is now part of the international standard for CT scanners by the International Electrotechnical Commission and expected to be widely adopted in future. Radiologists, medical physicists, and technologists can use SSDE data to adjust scanning protocols and minimize radiation exposure, especially for pediatric patients, optimizing the balance between image quality and radiation dose. The results of the present study may significantly enhance the patient dose estimates and radiation safety in pediatric CT imaging.

The purpose of our study was to calculate the SSDE and E for pediatric CT imaging. The $D_w$ depends on the patient's cross-sectional area as well as the attenuation of the tissues it contains. It is the diameter of a water cylinder with the same total X-ray attenuation as that found in the patient's axial cross-section. The focus of the multivariate statistical analysis was to determine how SSDE and E related to all other factors that

**Table 7: Multivariate analysis of the thorax without contrast computed tomography studies**

| Dependable variable | Independent variable | Regression co-efficient | SE | *p* |
|---|---|---|---|---|
| SSDE (*mGy*) | BMI (kg $m^{-2}$) | 0.0076 | 0.0099 | >0.05 (NS) |
| | $CTDI_{vol}$ (*mGy*) | 0.96 | 0.02 | <0.05 (significant) |
| | DLP (*mGy.cm*) | 4.03097E-5 | 3.31981E-4 | >0.05 (NS) |
| | $HU_{mean}$ | 9.39253E-5 | 5.33389E-4 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 2.48277E-4 | 0.00135 | >0.05 (NS) |
| | *f* – factor | −1.50 | 2.44 | >0.05 (NS) |
| | Age (years) | 1.08133E−4 | 0.008 | >0.05 (NS) |
| | $D_w$ (cm) | −0.29 | 0.01 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | −0.006 | 0.006 | >0.05 (NS) |
| E (*mSv*) | BMI (kg $m^{-2}$) | 0.077 | 0.078 | >0.05 (NS) |
| | $CTDI_{vol}$ (*mGy*) | −0.030 | 0.017 | >0.05 (NS) |
| | DLP (*mGy.cm*) | 0.02 | 0.003 | <0.05 (significant) |
| | $HU_{mean}$ | −0.0024 | 0.0019 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 0.002 | 0.003 | >0.05 (NS) |
| | Age (years) | −0.23 | 0.054 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | −0.03 | 0.05 | >0.05 (NS) |

SE: Standard error, NS: Not significant, HU: Hounsfield, SSDE: Size-specific dose estimate, CTDI: Computed tomography dose index, BMI: Body mass index, DLP: Dose length product, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

**Table 8: Multivariate analysis of thorax with contrast computed tomography studies**

| Dependable variable | Independent variable | Regression coefficient | SE | *p* |
|---|---|---|---|---|
| SSDE (*mGy*) | BMI (kg $m^{-2}$) | −0.04233 | 0.02661 | >0.05 (NS) |
| | CTDIvol (*mGy*) | 0.9424 | 0.03865 | <0.05 (significant) |
| | DLP (*mGy.cm*) | 2.62164E-4 | 7.89267E-4 | >0.05 (NS) |
| | $HU_{mean}$ | 0.00245 | 0.00128 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 0.003 | 0.003 | >0.05 (NS) |
| | *f* – factor | −12.49 | 6.33455 | <0.05 (significant) |
| | Age (years) | −0.01696 | 0.02382 | >0.05 (NS) |
| | $D_w$ (cm) | −0.076096 | 0.26647 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | 0.019 | 0.0138 | >0.05 (NS) |
| E (*mSv*) | BMI (kg $m^{-2}$) | 0.158 | 0.082 | >0.05 (NS) |
| | $CTDI_{vol}$ (*mGy*) | 0.011767 | 0.107 | >0.05 (NS) |
| | DLP (*mGy.cm*) | 0.013 | 0.002 | <0.05 (significant) |
| | $HU_{mean}$ | −0.0014 | 0.00224 | >0.05 (NS) |
| | $Area_{ROI}$ ($cm^2$) | 0.00161 | 0.00224 | >0.05 (NS) |
| | Age (years) | −0.18916 | 0.05811 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | −0.026 | 0.045 | >0.05 (NS) |

SE: Standard error, NS: Not significant, HU: Hounsfield, SSDE: Size-specific dose estimate, CTDI: Computed tomography dose index, BMI: Body mass index, DLP: Dose length product, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

affect the radiation dosage the patient receives during a CT scan. It is a strong statistical method for assessing more than two variables and any relationships between them is termed as multivariate analysis.[49] In compliance to the AAPM TG-220 and TG-293 recommendations, the SSDE was calculated using the $D_w$ and the currently displayed *CTD1vol*.[27,29] According to the references in the ICRP report-60, the E was calculated using the DLP and the multiplication of the age and site compensated conversion factor (K).[31-33] From the multivariate analysis tables [Tables 4-8], the SSDE is discovered substantially dependent on $D_w$, $CTD1_{vol}$, size(LAT+AP) and $f_{size}$ (AAPM conversion factor supplied by TG-220) with $p < 0.05$ for head, and thorax CT imaging for noncontrast imaging with the exception that SSDE is significantly correlated with $CTD1_{vol}$ only for contrast enhanced CT imaging. The $D_w$, takes into consideration the differential attenuation due to various tissue densities in the body in addition to the patient geometric size and $f_{size}$ presented in the Table 2D of the TG-220 provides the conversion factors based on the use of 16 cm diameter of PMMA for $CTD1_{vol}$ takes into account the geometric size and the differential attenuation of the different tissue in the scan area. Thus, the dependence of SSDE on $D_w$, size/(LAT+AP), and $f_{size}$ is obvious due to the geometric dimensions and differential attenuation because of various tissue densities in the body. When the CT table is incremented during an acquisition, the $CTD1_{vol}$, which is an indicator for measuring, comparing, and communicating radiation output of a CT unit, offers an estimate of the average dosage from

**Table 9: Multivariate analysis of the abdomen with contrast computed tomography studies**

| Dependable variable | Independent variable | Regression coefficient | SE | *p* |
|---|---|---|---|---|
| SSDE (*mGy*) | BMI (kg m$^{-2}$) | 0.002 | 0.057 | >0.05 (NS) |
| | CTDI$_{vol}$ (*mGy*) | 0.90 | 0.04 | <0.05 (significant) |
| | DLP (*mGy.cm*) | 3.10238E-4 | 0.0011 | >0.05 (NS) |
| | HU$_{mean}$ | −0.005 | 0.006 | >0.05 (NS) |
| | Area$_{ROI}$ (cm$^2$) | −0.004 | 0.010 | >0.05 (NS) |
| | *f* – factor | 6.33 | 5.39 | >0.05 (NS) |
| | Age (years) | −0.07 | 0.04 | >0.05 (NS) |
| | D$_w$ (cm) | −0.03 | 0.07 | >0.05 (NS) |
| | Size (cm) (LAT + AP) | 0.22 | 0.04 | >0.05 (NS) |
| E (*mSv*) | BMI (kg m$^{-2}$) | −0.02 | 0.06 | >0.05 (NS) |
| | CTDI$_{vol}$ (*mGy*) | 0.03 | 0.04 | >0.05 (NS) |
| | DLP (*mGy.cm*) | 0.017 | 0.0013 | <0.05 (significant) |
| | HU$_{mean}$ | −0.004 | 0.006 | >0.05 (NS) |
| | Area$_{ROI}$ (cm$^2$) | −9.095E−4 | 0.0044 | >0.05 (NS) |
| | Age (years) | −0.31 | 0.042 | <0.05 (significant) |
| | Size (cm) (LAT + AP) | 0.06 | 0.81 | >0.05 (NS) |

SE: Standard error, NS: Not significant, HU: Hounsfield, SSDE: Size-specific dose estimate, CTDI: Computed tomography dose index, BMI: Body mass index, DLP: Dose length product, LAT+ AP: (Lateral Dimensions+ Anterior- Posterior Dimensions)

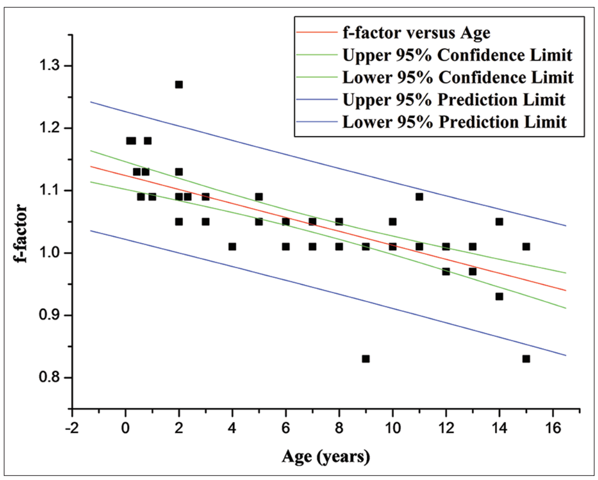


**Figure 1:** Linear regression analysis of *f*-factor with age (years) for head noncontrast computed tomography imaging ($r = -0.73$)

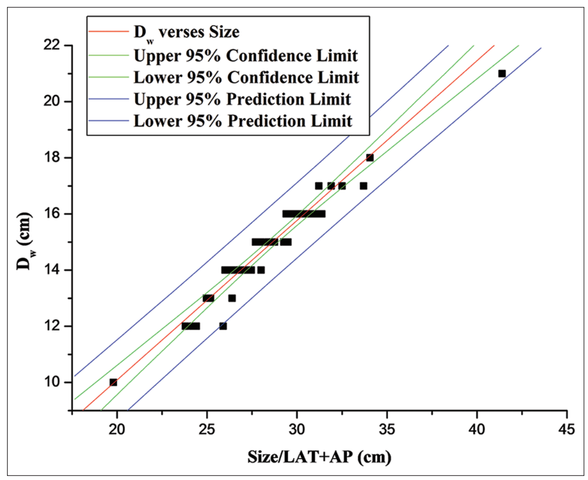


**Figure 2:** Linear regression analysis of $D_W$ (cm) with age *size/LAT+AP* (cm) for head noncontrast computed tomography imaging ($r = 0.93$)

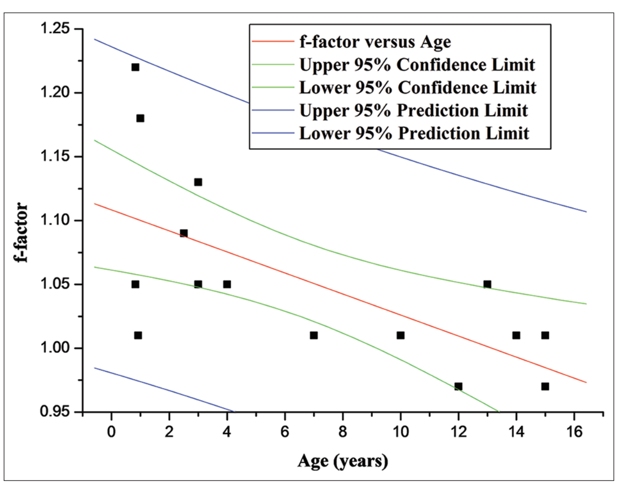


**Figure 3:** Linear regression analysis of *f*-factor with age (years) for head contrast enhanced computed tomography imaging. ($r = -0.65$)

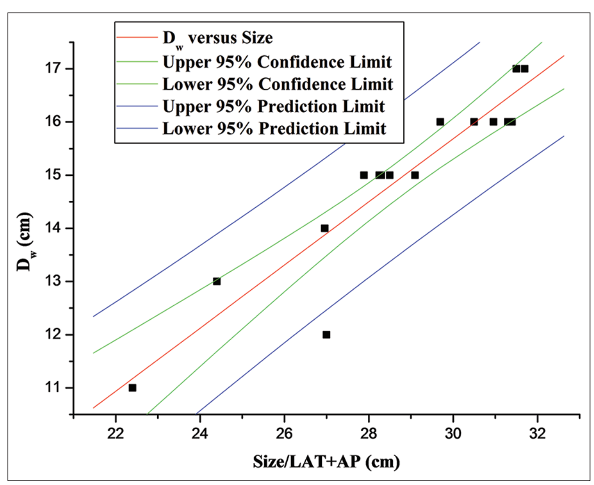


**Figure 4:** Linear regression analysis of $D_W$ (cm) with age *size/LAT+AP* (cm) for head contrast enhanced computed tomography imaging ($r = 0.93$)

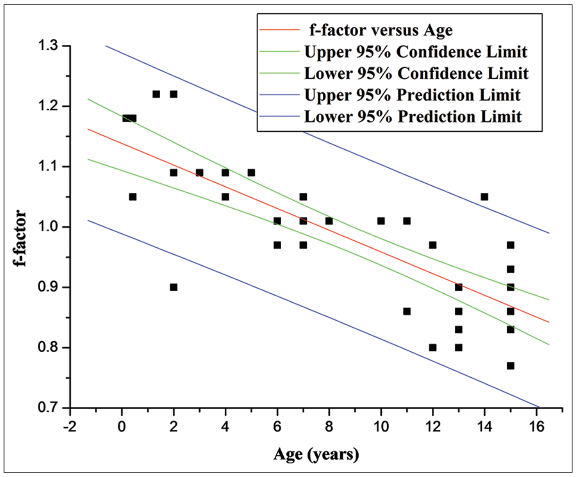


**Figure 5:** Linear regression analysis of *f*-factor with age (years) for thorax noncontrast computed tomography imaging ($r = -0.80$)

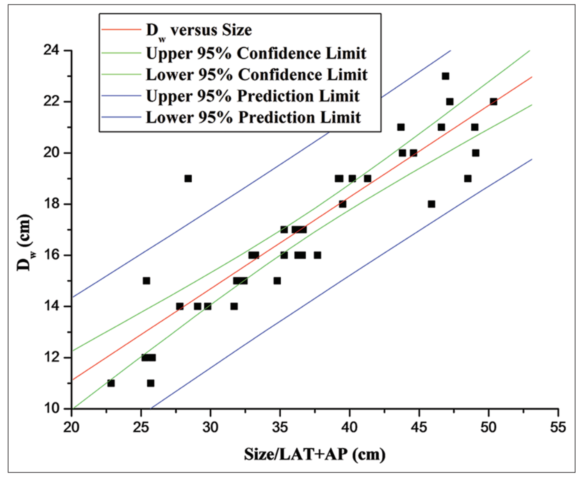


**Figure 6:** Linear regression analysis of $D_W$ (cm) with for *size*/*LAT*+*AP* (cm) thorax noncontrast computed tomography imaging ($r = 0.88$)

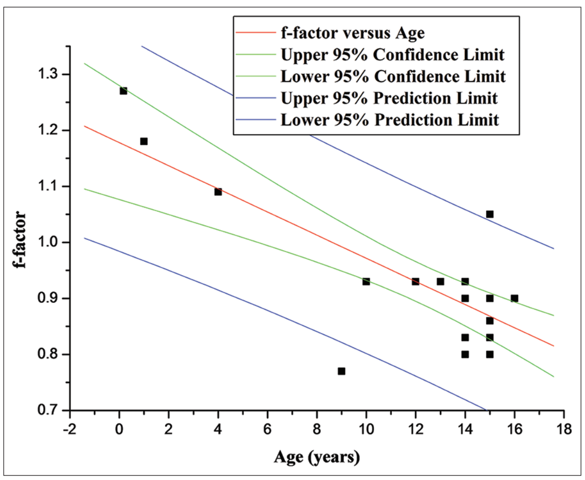


**Figure 7:** Linear regression analysis of *f*-factor with age (years) for thorax contrast enhanced computed tomography imaging ($r = -0.78$)

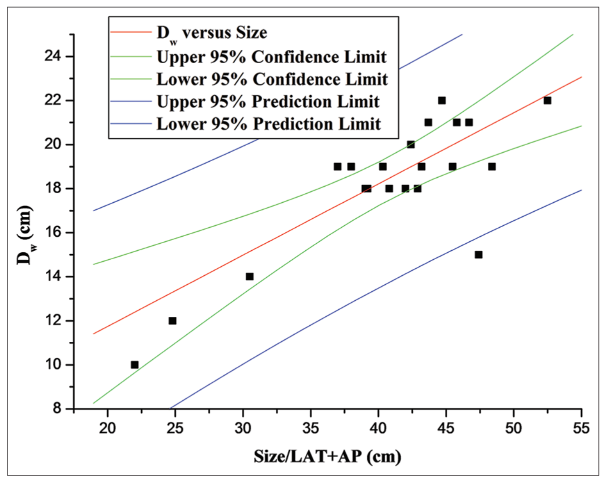


**Figure 8:** Linear regression analysis of $D_W$ (cm) with age *size*/*LAT*+*AP* (cm for thorax contrast enhanced computed tomography imaging ($r = 0.74$)

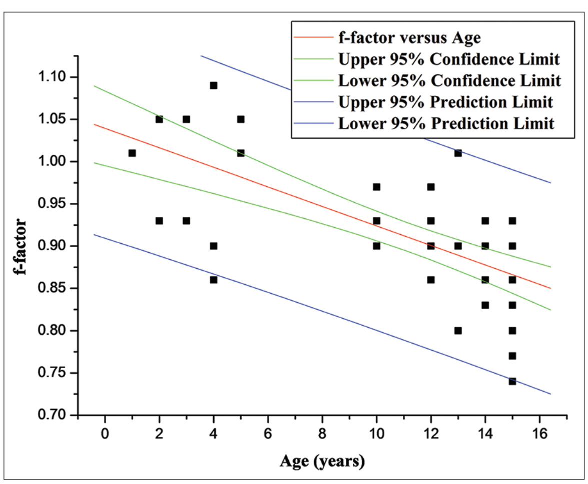


**Figure 9:** Linear regression analysis of *f*-factor with age (years) for abdomen noncontrast computed tomography imaging ($r = -0.67$)

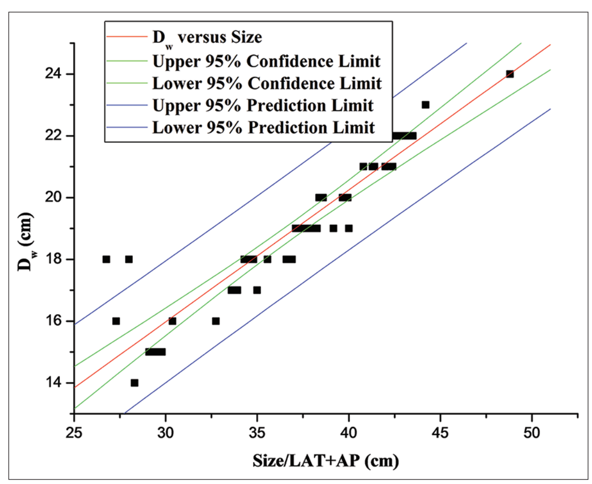


**Figure 10:** Linear regression analysis of $D_W$ (cm) with age *size*/*LAT*+*AP* (cm) for abdomen noncontrast computed tomography imaging ($r = 0.91$)

several acquisitions. Since the radiation dose a patient receives during imaging is directly tied to both patient variables and the output of the CT scanner, precisely measuring the patient's size is essential to predict the patient absorbed dose. A 16 or 32 cm diameter cannot, in terms of geometric dimensions, accurately represent an actual patient, regardless of inhomogeneous X-ray attenuation. Therefore, in comparison to the real exposure, the radiation doses reported via $CTD1_{vol}$ were under estimated.[46] The $CTD1_{vol}$ displayed on the CT unit's console underestimates the dose to majority of the patients by 20% to 50% with the values for smaller patients being up to 50%.[47] The reason for the disparities is that nearly every patient we treat in our department is significantly smaller than the conventional Dosimetry phantom, which was created for the European-North American population. In our institution, patients from various socioeconomic backgrounds come to us from a 100 to 150 km radius. In addition, many international students as well as staff patients and students from various regions of India come for imaging. The E is found to be significantly correlated with DLP and age for patient undergoing CT with $p < 0.05$, which suggests that the E is influenced by site which is scanned and the dimensions of the patient. All other parameters were found weakly correlated with the E and SSDE with $p < 0.05$. The higher values of SSDE for contrast-enhanced CT imaging for the head and abdomen are due to an increase in the CT number (HU) by iodinated contrast media is mainly caused by the photoelectric effect, which also leads to an increase in radiation dose[50,51] and hence higher SSDE values. On the other hand, the slightly lower SSDE values for contrast-enhanced CT imaging of the thorax than noncontrast CT may be due to the large lung volume involved in the scanning range. The negative correlation between $f_{size}$ and age is due to the increase in the patient dimensions and organ size with age. This is consistent with Fujii *et al*.[52] and Poosiri *et al*.[40] study findings. Their study reported that the relationship between the SSDE and age and weight in pediatric brain CT scans, using the Automatic Exposure Control (AEC) system, were best fit by applying a power function, resulting in mean estimation errors close to 0, with $R^2 = 0.71$ and 0.86, respectively.[40,52] Further, Poosiri *et al*.,[40] used data from pediatric patients scanned with a single helical CT brain scan protocol without AEC.

The regression analysis shows the strong positive correlation between $D_w$, and age, $D_w$ versus size/$(LAT+AP)$ proves that the age and size/$(LAT+AP)$ can be used as surrogate in estimating SSDE when the $D_w$ calculation is not possible or if the data is not available for the paediatric CT imaging. Further, negative correlation is observed between $f$−factor and age, suggested that SSDE decreases with patient age. The negative correlation between $f_{size}$ and age is due to the increase in the patient dimensions and organ size with age. In addition, the increased patient size and different tissue densities contribute to $D_w$ growth with size/$(LAT+AP)$. On comparing our results with the literature published several research groups across the globe; we found that the mean SSDE and $CTD1_{vol}$ values of our study for head scans are higher than the mean SSDE and $CTD1_{vol}$ values for head scan from the Chinese study by Zhang and Zhang.[39] However, the mean SSDE and $CTD1_{vol}$ values for the chest and abdomen were more or less comparable with literature. The discrepancy in the results may be due the scanning conditions and ethnicity of the patients.

The study has several shortcomings: It focused on single-scanner pediatric patients, included mostly underweight individuals reflecting local demographics, had a limited number of noncontrast abdomen CT cases, and may have personal bias due to measurements taken by only one observer.

## Conclusion

The SSDE is essential for radiologists assessing CT scans, especially in the pediatric cases. It is now an international standard for CT scanners set by the International Electrotechnical Commission and is expected to see widespread use among radiologists. In addition, it may be improved to balance radiation doses and diagnostic quality by automatically providing SSDE information. The SSDE for head without contrast ranges from 34.88 $mGy$ to 141.198 $mGy$, with a mean of 71.36 $mGy$. For contrast-enhanced head CT, average SSDE was 97.38 $mGy$. Our study found higher mean SSDE, and $CTD1_{vol}$ values for head scans compared to a Chinese study. The negative correlation between $f_{size}$ and age is due to the increase in the patient dimensions and organ size with age. These findings are consistent with Fujii *et al*.[52] and Poosiri *et al*.[40] Further, the increased patient size and different tissue densities contribute to $D_w$ growth with size/$(LAT+AP)$. Thus, size/$(LAT+AP)$ can serve as a surrogate for estimating SSDE in pediatric CT imaging when $D_w$ calculation is unavailable or data is lacking.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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