MedCrave
Step into the World of Research
International Journal of Radiology & Radiation Therapy

Research Article
Open Access
CrossMark

Investigation of size specific doses in CT scanning for pediatric patients

Abstract

Context: American Association of Physicists in Medicine (AAPM) report 204 has proposed a new method, "Size specific dose estimate" (SSDE) to represent more accurate estimations of patient doses. SSDE takes into account patient size in order to enable users to optimize $CTDI_{vol}$ based on patient's physical dimensions.

Aims: The purpose of this prospective study was to compare the methodologies suggested by AAPM report 204 and ICRU to calculate the Size specific dose estimate (SSDE) and determine the relationships among patient size, scanner radiation output, and SSDE for pediatric patients who underwent CT at our institution.

Settings and Design: Prospective study is performed to estimate SSDE.

Methods and Material: 14 pediatric patients (mean age: 11.4±6.2 y, weight: 33.14±19.8kg) were enrolled that underwent CT scanning. SSDE was estimated from patient's AP, LAT, SUM dimension and effective diameter measured on localizer radiograph and 3D reconstructed data. For age based SSDE calculation, the age of the patient was correlated to effective diameter of the patient. The relationship between estimated SSDE and weight of the patient was also investigated.

Statistical analysis used: Results were compared with mean and percentage variation**.**

Results: The mean SSDE ($SSDE_{mean}$) estimated with dimension based on localizer radiographs was underestimated by 0.78 %, 7.37 %, 3.56 %, 4.37 % respectively for LAT, AP, SUM, EFF method; when compared against 3D reconstructed data.

The $SSDE_{mean}$ was 86±30.84% higher than the $CTDI_{vol}$ estimated by CT scanner. The variation with age was found to be significant and maximum variation of 124 % was observed for 1 year old patient. The variation in $CTDI_{vol}$ was found to be decreasing with increasing patient age.

The SSDE estimated with ICRU 74 data was significantly underestimated by 13.86±6.49 %.

We observed that SSDE is linear with weight of the patient which suggests that the weight of the patient can be used for SSDE estimation in absence of any dimension measurements.

Conclusions: We conclude that the patient dimension and subsequently SSDE; can be estimated from given methods based on either localizer radiographs or 3D reconstructed data.

Keywords: SSDE, AAPM Report 204, CTDI

Key Messages: Size specific dose estimate (SSDE) represents more accurate estimations of patient doses. SSDE takes into account patient size in order to enable users to optimize $CTDI_{vol}$ based on patient's physical dimensions. Hence the patient doses should be reported in terms of SSDE.

Volume 11 Issue 2 - 2024

Suresh Chaudhari,[1] Shatabdi Chakrabarty[2]
[1]American Oncology Institute, Hyderabad, Telangana, India
[2]RP&AD, Bhabha Atomic Research Centre, Mumbai, Maharashtra, India

Correspondence: Suresh Chaudhari, American Oncology Institute, Hyderabad, Telangana, India,
Email chaudhari_sures@yahoo.com

Received: March 27, 2024 | **Published:** April 25, 2024

Introduction

The rapid evolution of Computed Tomography (CT) technology and the resultant radiation exposure in clinical applications have created a compelling need to understand detailed information regarding CT dose. Diagnostic radiology is the largest contributor to man-made ionizing radiation to which the public is exposed. During the past years the frequency of diagnostic radiologic examinations has increased which also results in increased per capita effective dose. The dose levels imparted in CT exceed those from conventional radiography and fluoroscopy and the use of CT continues to grow.

In the United States, the frequency of diagnostic radiologic examinations has increased almost 10-fold and per-capita annual effective dose from medical procedures has increased about six fold.[1] Occupation exposure is monitored and exposure limits are enforced,[2] however patients exposed to radiation from diagnostic imaging are not subject to similar monitoring or exposure limits. There are no standards established for acceptable radiation dose for different types of scans. For individuals, and especially pediatric patients, the benefits of CT imaging must be balanced against the potential harm from its associated radiation dose. Quantification of radiation dose associated CT studies in clinical practice may enable potential cancer risk associated with these examinations.

It is mandatory for manufacturers of CT scanners to display volumetric CT dose index ($CTDI_{vol}$) and dose-length product (DLP) values associated with particular examination.[3] However $CTDI_{vol}$ and

DLP depend on scan parameters such as tube voltage, tube current, pitch and are estimated for a reference phantom of diameter of 16 cm or 32 cm.

The dose received by a patient from a CT scan is dependent both on patient size and scanner radiation output. But, as $CTDI_{vol}$ is determined for reference phantom of fixed diameter, $CTDI_{vol}$ and DLP are sensitive to changes in scan parameters only, but don't address patient size and hence doesn't estimate patient dose.[4] This is a concern, because for pediatric patients, interpreting the displayed CTDI as patient dose without recognizing the distinction between the two could lead to underestimating patient dose levels by a factor of 2-3 if the 32 cm PMMA phantom is used for reference.

Organ doses could be estimated from $CTDI_{vol}$ by multiplying $CTDI_{vol}$ by a size dependent, scanner-independent factor.[5] American Association of Physicists in Medicine (AAPM) report 204 in collaboration with the International Commission on Radiation Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging has proposed a new method, "Size specific dose estimate" (SSDE) to represent more accurate estimations of patient doses.[6] SSDE takes into account patient size in order to enable users to optimize $CTDI_{vol}$ based on patient's physical dimensions.

Using physical measurements from anthropomorphic phantoms, cylindrical phantoms and Monte Carlo measurements, the task group developed conversion factors between $CTDI_{vol}$ and SSDE. The conversion factors are based on one of five metrics: the patient AP dimension, the lateral dimension, the sum of the AP and lateral dimensions, the calculated effective diameter which can be measured from either localizer radiograph or transverse CT images, or an age-based effective diameter taken from ICRU Report 74.[7]

The purpose of this prospective study was to compare the five methodologies used to calculate the SSDE and determine the relationships among patient size, scanner radiation output, and SSDE for pediatric patients who underwent CT at our institution.

Subjects and methods

Patient selection

14 pediatric patients (male: 10, Female:4) were enrolled for this prospective study that underwent CT scanning during January to March 2015. The mean age of patients was 11.4±6.2 yr (Range: 1 month -18 yr). The mean weight of patients was 33.14±19.8 kg (Range: 10-67 kg). Of these, 7 patients underwent scanning in thorax region and 7 undergone scanning in abdominal region. The weight of the patients was measured immediate prior to CT scanning. The patient data is recorded in Table 1.

Table 1 Patient details

Patient	Age (yr)	Weight (kg)	Site	kV	mA	PITCH	$CTDI_{vol}$ (mGy)
1	13	26.5	Chest	120	210	1.375	11.19
2	18	67	Chest	120	85	1.375	4.53
3	2	11	Chest	120	120	1.375	6.39
4	13	21	Chest	120	85	1.375	4.53
5	11	20	Chest	120	85	1.375	4.53
6	18	55	Chest	120	90	1.375	4.8
7	17	39	Chest	120	85	1.375	4.53
8	14	56	Pelvis	120	130	1.375	6.93
9	9	23	Pelvis	120	120	1.375	6.39
10	6	16.5	Pelvis	120	120	1.375	6.39
11	18	55	Pelvis	120	85	1.375	4.53
12	3	14	Pelvis	120	85	1.375	4.53
13	17	50	Pelvis	120	120	1.375	6.39
14	1	10	Pelvis	120	210	1.375	11.19

CT scanner and scan parameters

All the patients were scanned on GE LightSpeed CT scanner (GE Healthcare, USA) with bore diameter of 80 cm. Patients were immobilized with custom thermoplastic mask in supine position with arms over head. Manufacturer specified protocol with scan field of view (FOV) of large body was used for scanning. Prior to CT scan, frontal and lateral localizer radiographs were acquired. The scan length of the particular patient was determined from the localizer radiograph. Tube voltage for all the patients was 120 kVp, tube current was 116.43±43 mA (Range: 85-210 mA), pitch was 1.375. The scan parameters (tube current, tube voltage, pitch, slice thickness, table speed and scan length) for each patient was documented for analysis. $CTDI_{vol}$, DLP and phantom size was also recorded from the scanner dose report page. Patient specific scan parameters are listed in Table 1.

The patients were centered in the scanner while acquisition of radiograph to reduce radiographic magnification and magnification effect. When patient is positioned at the isocenter of the gantry, no magnification needs to be applied. Gantry isocenter was the midpoint of the field of view while patient's center was determined as midpoint AP diameter. The distance between these two points was recorded as the off-centering estimation. Vertical off centering will result in magnification or minification of the lateral dimension measured from localizer radiograph. The correct dimension was measured using the formula:

$$Actual\ dimension = \left(\frac{606\,mm \pm shift}{606\,mm}\right).\ Observed\ dimension \quad (1)$$

Where, 606mm is the focal spot to isocentre distance.

Patient dimension measurements

Estimation of SSDE requires the information of patient size and $CTDI_{vol}$. The patient size was determined as per the method adopted by AAPM Report 204.

Lateral (LAT) dimension: The lateral dimension is width (left to right dimension) of the body part being scanned. The lateral dimensions of the patient were measured from frontal localizer radiograph as shown in Figure 1. The lateral dimensions were also measured on coronal plane of 3D reconstructed data where maximum dimension occurs to compare its efficacy against localizer radiograph.

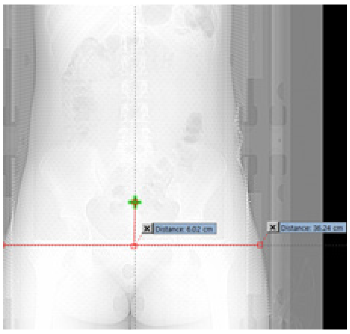

Figure 1 Measurement of LAT dimension.

Anteroposterior (AP) Dimension: The AP dimension is thickness (anterior to posterior dimension) of the body part being scanned. The AP dimensions of the patient were measured from lateral localizer radiograph as shown in Figure 2. The AP dimensions were also measured on sagittal plane of 3D reconstructed data where maximum dimension occurs to compare its efficacy against localizer radiograph.

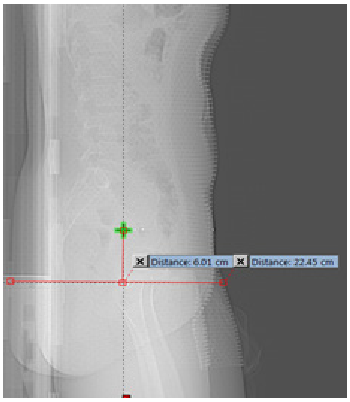

Figure 2 Measurement of AP dimension.

SUM Dimension: This does not require any direct measurement but is the sum of lateral and AP dimension (AP+LAT). Dimensions were derived from both localizer radiograph and 3D reconstructed data (Figure 3).

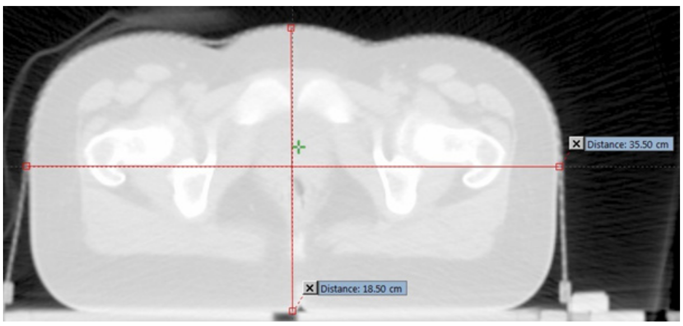

Figure 3 Measurement of AP and LAT dimension from 3D reconstructed data.

Effective Diameter (EFF): Since the patients were selected in Thorax and Pelvic region, the patient exhibit approximate circular section which can be represented by effective diameter (EFF). Hence the effective diameter represents the circle whose area is same as that of patient cross section.

$$Effective\,diameter = \sqrt{AP.LAT} \quad (2)$$

Age based effective diameter (EFF_{age}): Patient size was also determined using the association of the patient's age with their effective diameter as per ICRU Report 74. The ICRU 74 data correlates patient age with patient's effective diameter.

Patient dimensions were measured using digital calipers in Advantage SIM v4.4 (GE Healthcare, USA). For consistency, each patient was measured at the same anatomic landmark. Taking carina as chest landmark and upper border of pubic symphysis as landmark of abdomen and pelvis, AP dimension was measured at every 5 cm interval (along cranio-caudal direction) from the start to the end of the scan length. Lateral dimension was also measured at every 5 cm interval. All of these dimensions were also measured on the 3D reconstructed data. The average dimension using each procedure was used for SSDE calculation.

Conversion factor and SSDE determination

Patient-specific, scanner-independent conversion factors can be derived by estimated $CTDI_{vol}$ for patients of different sizes.[5] The $CTDI_{vol}$ is estimated by most of the CT scanner software before exam and it correlates to doses measured for phantom size of 16 cm or 32 cm depending on the protocol and selected scan FOV.

SSDE was calculated by following formula defined in AAPM Report 204 depending on the phantom size used for CT scanner estimated $CTDI_{vol}$:

$$SSDE = f_{size}^{16X} \cdot CTDI_{vol}^{16} \quad (3)$$

$$SSDE = f_{size}^{32X} \cdot CTDI_{vol}^{32} \quad (4)$$

Where,

$f_{size}^{16/32}$, is the conversion factors defined in AAPM Report 204 for phantom of diameter 16cm or 32cm.

X, is the dimension measured with specific method (AP, LAT, SUM, EFF or EFF_{age}).

SSDE was estimated from AP dimension ($SSDE_{AP}$), LAT dimension ($SSDE_{LAT}$), SUM dimension ($SSDE_{SUM}$) and effective diameter ($SSDE_{EFF}$). The estimated SSDE from each method was compared against $CTDI_{vol}$ estimated by CT scanner. For age based SSDE calculation ($SSDE_{age}$), the age of the patient was correlated to effective diameter of the patient from the look up table provided in ICRU 74 report. The relationship between estimated SSDE and weight of the patient was also investigated.

Results

Accuracy of length measurement

Patient dimensions measured on localizer radiographs were found to be within 0.38±0.34 mm when off-centering correction factors derived from eq.1 were applied. This demonstrates that if the patients are positioned at scanner centre, no magnification or minification correction factor is required.

Patient dimension

Lateral (LAT) dimension*:* The mean patient dimension measured on localizer radiograph and 3D reconstructed data was 24.74±4.05

Citation: Chaudhari S, Chakrabarty S. Investigation of size specific doses in CT scanning for pediatric patients. *Int J Radiol Radiat Ther.* 2024;11(2):33‒37. DOI: 10.15406/ijrrt.2024.11.00382

cm and 24.36±4.07 cm respectively. The mean variation in patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 1.91 % with maximum of 4 %.

Anteroposterior (AP) Dimension: The mean patient dimension measured on localizer radiograph and 3D reconstructed data was 16.01±5.96 cm and 16.32±6.02 cm respectively. The mean variation in patient dimension measured with localizer radiograph and 3D reconstructed data was found to be -1.3 % with maximum of -3.88%.

SUM: The mean patient dimension measured on localizer radiograph and 3D reconstructed data was 40.67±10.04 cm and 40.65±10.02 cm respectively. The mean variation in patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 0.19 % with maximum of 4.59 %.

Effective Diameter (EFF): The mean patient dimension measured on localizer radiograph and 3D reconstructed data was 19.86±4.92 cm and 19.88±4.97 cm respectively. The mean variation in patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 0.5 % with maximum of 4.49 %.

Age based effective diameter (EFF_{age}): The mean age based effective diameter was found to be 21.82±4.79 cm

The effective diameter calculated (EFF) with the AAPM Report 204 methodologies showed poor correlation (r = 0.28) with respective age based effective diameters (EFF_{age}) of ICRU 74 data (Figure 4).

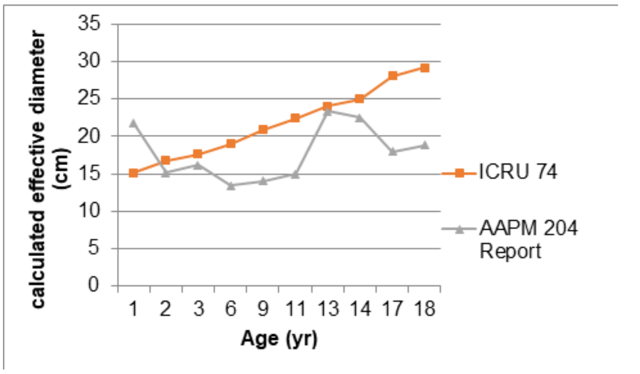

Figure 4 Comparison between the calculated effective diameter of patients based on ICRU 74 report and that based upon AAPM 204 report.

Estimated SSDE:

$SSDE_{LAT}$: The mean estimated SSDE based on patient dimension measured on localizer radiograph and 3D reconstructed data was 10.78±4.78 mGy and 10.85±4.67 mGy respectively. The mean variation in estimated SSDE based on patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 0.78±1.84 % with maximum of 3.51 %.

$SSDE_{AP}$: The mean estimated SSDE based on patient dimension measured on localizer radiograph and 3D reconstructed data was 11.06±4.88 mGy and 11.88±5.02 mGy respectively. The mean variation in estimated SSDE based on patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 7.37±4.15 % with maximum of 15.76 %.

$SSDE_{SUM}$: The mean estimated SSDE based on patient dimension measured on localizer radiograph and 3D reconstructed data was 10.90±4.84 mGy and 11.25±4.80 mGy respectively. The mean variation in estimated SSDE based on patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 3.56±2.17 % with maximum of 7.03 %.

$SSDE_{EFF}$: The mean estimated SSDE based on patient dimension measured on localizer radiograph and 3D reconstructed data was 10.93±4.84 mGy and 11.36±4.84 mGy respectively. The mean variation in estimated SSDE based on patient dimension measured with localizer radiograph and 3D reconstructed data was found to be 4.37±2.56 % with maximum of 8.94 %.

$SSDE_{age}$: The mean estimated $SSDE_{age}$ was 9.69±4.74 mGy. The mean $SSDE_{age}$ calculated with ICRU 74 was underestimated by 13.86±6.49 % compared with combined mean ($SSDE_{mean}$) of $SSDE_{LAT}$, $SSDE_{AP}$, $SSDE_{SUM}$, $SSDE_{EFF}$. Figure 8 shows the comparison of $SSDE_{mean}$ and $SSDE_{age}$

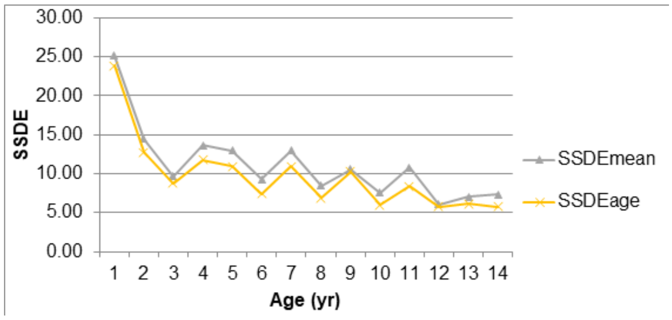

Figure 5 Variation between SDE_{age} estimated using ICRU74 data and $SSDE_{mean}$ calculated with AAPM Report 204 conversion factors.

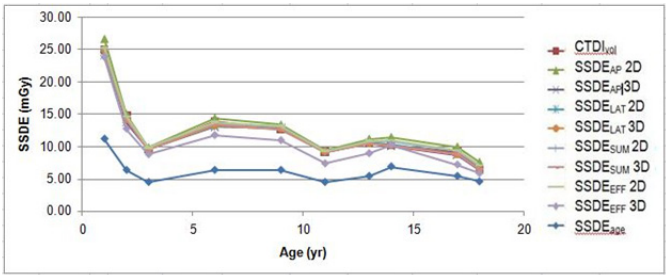

Figure 6 Comparison of CTDIvol & SSDE estimated with different methods.

Variation between $CTDI_{vol}$ and SSDE

The calculated $SSDE_{mean}$ was 86±30.84 % higher than the $CTDI_{vol}$ estimated by CT scanner. The variation with age was found to be significant and maximum variation of 124 % was observed for 1 yearr old patient. The variation in $CTDI_{vol}$ was found to be decreasing with increasing patient age.

The weight of the patient was found to be effective parameter to correlate $CTDI_{vol}$ and $SSDE_{mean}$, as the variation is linearly decreasing as shown in Figure 7 & 8.

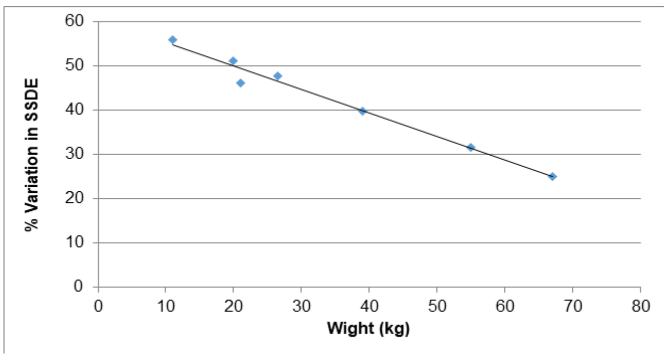

Figure 7 Percentage variation of $CTDI_{vol}$ with combined SSDE against patient weight (Chest).

Citation: Chaudhari S, Chakrabarty S. Investigation of size specific doses in CT scanning for pediatric patients. *Int J Radiol Radiat Ther.* 2024;11(2):33‒37. DOI: 10.15406/ijrrt.2024.11.00382

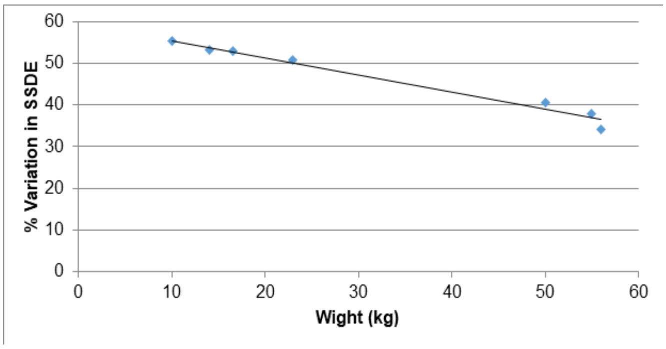

Figure 8 Percentage variation of $CTDI_{vol}$ with combined SSDE against patient weight (Pelvis).

Discussion

Patient dimension measured on localizer radiographs and 3D reconstructed data for LAT, AP, SUM, EFF, EFF_{age} was found to be within 5 %. The results suggest that the patient dimension can be estimated with reasonable accuracy on localizer radiograph.

The effective diameter calculated with direct measurement of patient dimensions from the localizer radiograph exhibit a linear trend and can be direct adopted for SSDE estimation. The results are consistent with AAPM report 204.

The SSDE estimated with dimension based on localizer radiographs was underestimated by 7.37 %, 3.56 %, 4.37 % respectively for LAT, AP, SUM, EFF method; when compared against SSDE estimated with dimension based on 3D reconstructed data. The results suggest that the 3D reconstructed data may give better estimate for SSDE based on AP dimension. The results are in agreement with AAPM report 204 methodology. However SSDE estimated by LAT radiographs has a good agreement of 0.78 % with respect to SSDE estimated from 3D reconstructed data.

Brady et al.[8] Concluded that that the combination of AP and lateral measurements, either as a sum or calculated effective diameter, is more useful than either alone. Our results are consistent with this; however in our study SSDE estimated with individual LAT measurements was also found be in good agreement with SSDE estimated based on SUM, EFF method.

The age based effective diameter suggested in ICRU 74 report does correlate with patient age and dimension for our patient population. The SSDE estimated with ICRU 74 data was significantly underestimated by 13.86±6.49 % when compared to SSDE estimated with direct measurement of patient dimensions from the localizer radiograph/3D reconstructed data. The reason for this is attributed to large variation in body dimension due to pediatric age group. We conclude that the ICRU 74 data cannot be generalized for direct use in clinic.

$CTDI_{vol}$ was significantly underestimated by 86% when compared against SSDE. Similar study done by Westra et.al reported 3.5 fold underestimation of $CTDI_{vol}$ when compared with entrance skin dose measurement.

We observed that SSDE is linear with weight of the patient which suggests that the weight of the patient can be used for SSDE estimation in absence of any dimension measurements. Similar results were found by Pourjabbar et al.[9] where they postulated that the patient weight may be used to estimate SSDE.

Conclusion

The AAPM report 204 provides the useful and simple methodology to correct the $CTDI_{vol}$ reported by scanner to SSDE for individual patient irrespective of age and body dimension. The SSDE can be estimated prospectively and reported for pediatric patients. Individual patient dose can be managed with Patient-specific CT imaging and personalization of scan protocols based on SSDE.

Acknowledgments

None.

Conflicts of interest

Authors declare no conflict of interest.

References

1. Mettler FA Jr, Huda W, Yoshizumi TT, et al. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology.* 2008;248(1):254-263.
2. AERB safety code No. AERB/RF-MED/SC-1 (Rev. 1). Radiation therapy sources, equipment and installations, Atomic energy regulatory board. 2011.
3. IEC 60601-2-44. Medical electrical equipment –Part 2-44: Particular requirements for the basic safety and essential performance of X-ray equipment for computed tomography.
4. McCollough CH, Leng S, Yu L, et al. CT Dose index and patient dose: they are not the same thing. Radiology. 2011;259(2):311–316.
5. Turner AC, Zhang D, Khatonabadi M, et al. The feasibility of patient size-corrected, scanner-independent organ dose estimates for abdominal CT exams. *Med Phys.* 2011;38(2):820–829.
6. American association of physicists in medicine. Size-specific dose estimates (SSDE) in pediatric and adult body CT Examinations: report of AAPM Task Group 204. College Park, Md: American Association of Physicists in Medicine, 2011.
7. ICRP, 1996. Conversion Coefficients for use in Radiological Protection against External Radiation. ICRP Publication 74. Ann. ICRP 26 (3-4).
8. Brady SL, Kaufman RA. Investigation of american association of physicists in medicine report 204 size-specific dose estimates for pediatric CT implementation. *Radiology.* 2012;265(3):832-840.
9. Pourjabbar S, Singh S, Padole A, et al. Size-specific dose estimates: Localizer or transverse abdominal computed tomography images? *World J Radiol.* 2014;6(5):210-217.

Citation: Chaudhari S, Chakrabarty S. Investigation of size specific doses in CT scanning for pediatric patients. *Int J Radiol Radiat Ther.* 2024;11(2):33–37.
DOI: 10.15406/ijrrt.2024.11.00382