EDITOR'S CHOICE

Dose Is Not Always What It Seems: Where Very Misleading Values Can Result From Volume CT Dose Index and Dose Length Product

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Purpose: The volume CT dose index ($CTDI_{vol}$) and the dose-length product, commonly reported for examinations performed on clinical CT scanners, should not be used as surrogates for patient dose. This is because significant under or overestimates of these actual values can occur when there is a mismatch between the actual body size of the patient and the 16 cm or 32 cm diameter $CTDI_{vol}$ phantoms. This mismatch can be exacerbated in pediatric body examinations because of the fact that some manufacturers use the large diameter phantom while other manufacturers use the small diameter phantom as the $CTDI_{vol}$ reference phantom.

Method: A clinical example is described for a pediatric patient with a 4-fold difference in $CTDI_{vol}$ between a presurgical CT examination and a postsurgical CT examination, even though the actual dose absorbed by the patient was about the same. Using methods published by the American Association of Physicists in Medicine, we calculated the size-specific dose estimate (SSDE), and compared the estimated measurement of dose using the SSDE with the $CTDI_{vol}$.

Results: Using SSDE significantly reduced the discrepancy in radiation dose estimates of $CTDI_{vol}$ in the clinical study, and allowed dose estimate comparisons between scanners to be more meaningful.

Conclusions: Radiation dose estimates are more accurate when using the SSDE metric in lieu of the $CTDI_{vol}$ metric for reporting and comparing patient dose indices.

Key Words: Pediatric CT dose, $CTDI_{vol}$, size-specific dose estimate (SSDE)

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INTRODUCTION

The volume CT dose index, ($CTDI_{vol}$), is a metric reported by manufacturers of CT scanners that provides information regarding the radiation dose to a poly-methyl methacrylate cylindrical phantom. Two phantoms are used, having dimensions of 32 cm diameter for emulating the abdomen and 16 cm diameter for emulating the head of a patient. $CTDI_{vol}$ measurements are made using a 100 mm air ionization chamber placed along the 150 mm phantom length in the center and periphery, for specific CT scanner techniques (kV, mA, rotation time, beam collimation, pitch, field-of-view, and tube filtration) with correction for chamber calibration, partial volume irradiation, and conversion constants [1]. Although useful as a measure of scanner output, $CTDI_{vol}$ should not be used as an indication of patient dose because it does not take into account the size of the patient to which the dose was delivered, and therefore does not reflect patient absorbed dose [2].

Nevertheless, this value (along with dose-length product, [DLP]) is reported in the dose page of each patient CT study. With more patients interested in radiation dose delivered by CT and other medical imaging procedures, requests to get dose information are common, but unfortunately, the dose metrics that are readily available are often misunderstood. As a result, inappropriate and misleading conclusions can occur, as illustrated by a specific encounter at UC Davis Medical Center of a patient who had 2 CT scans, pre- and postsurgery, on different manufacturer's equipment.

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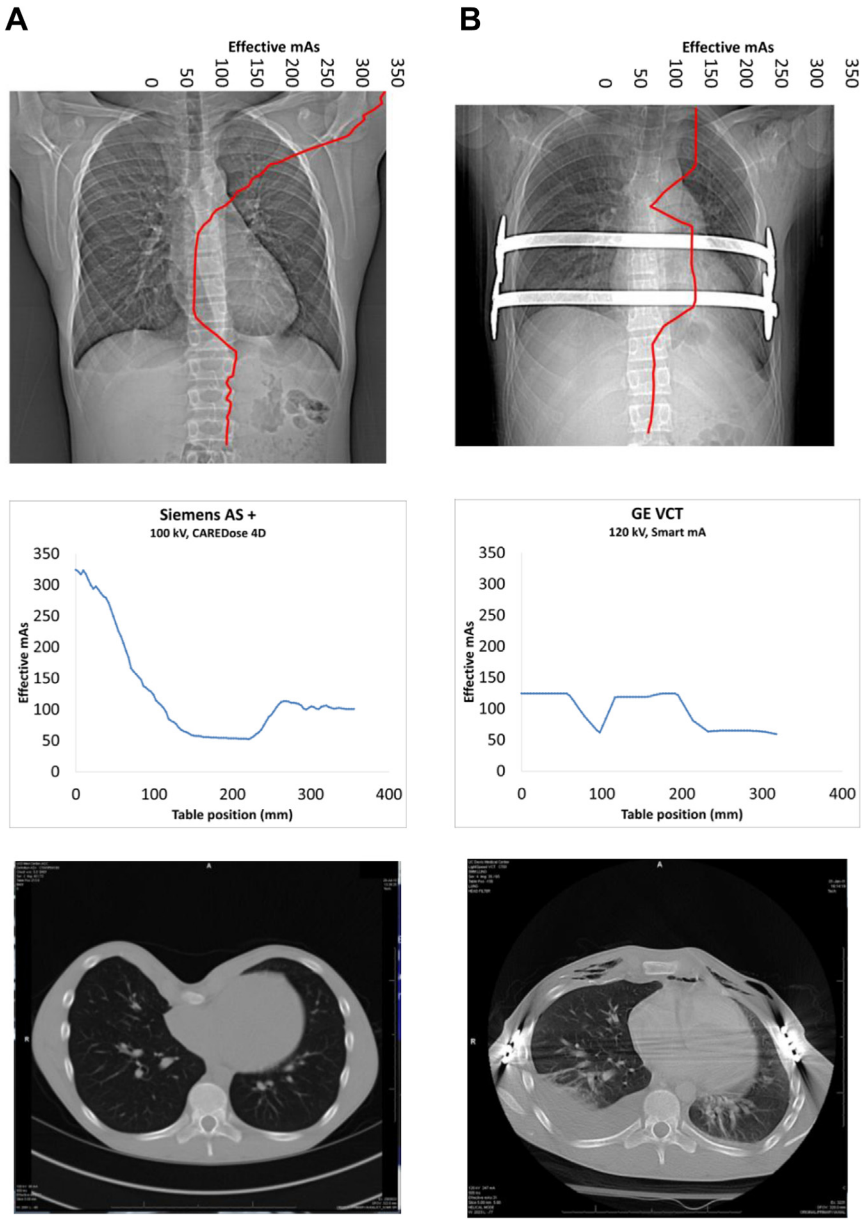

Fig 1. **(A)** Presurgery scan, Siemens Definition AS+, 100kV, CareDose4D. Top: CT localizer radiograph with mA modulation and effective mAs scale superimposed. Middle: tube current modulation with table position “0” at top of localizer. Bottom: Reconstructed axial scan. **(B)** Postsurgery scan, GE VCT, 120 kV, Smart mA. Top: CT localizer radiograph with mA modulation and effective mAs scale superimposed. Middle: tube current modulation with table position “0” at top of localizer. Effective mAs is calculated by dividing mAs/slice by pitch. Bottom: Reconstructed axial scan. kV = kilovolt; mA = milliampere.

BACKGROUND

A CT scan was performed on a 14-year-old patient of 1.78 m height and 60.6 kg weight, using a Siemens Definition 128 AS+ scanner (Siemens AG, Forchheim, Germany) at the UC Davis Medical Center outpatient clinic. The purpose of the scan was for surgical planning for repair of an involuted chest (pectus excavatum) deformity. The protocol used the Siemens tube current modulation technique, Care-Dose 4D at 100 kV, with a 0.5 s rotation time. The CT localizer radiograph, tube current effective mAs as a function of table position, and axial scan of the pulmonary region are shown in Figure 1A. During surgery, metal Nuss Bars were placed across the patient’s chest to correct his pectus excavatum deformity. After surgery, a second CT scan was performed for the clinical suspicion of pneumonia on the inpatient General Electric VCT scanner (GE Healthcare, Waukesha, Wisconsin), using the GE tube current modulation protocol, Smart mA, at 120 kV and 0.5 s rotation time. The CT localizer radiograph, tube current effective mAs as a function

Table 1. Data and acquisition parameter values for presurgery and postsurgery CT scans for the clinical example presented

	Presurgery CT Scan	PostSurgery CT Scan
Manufacturer/model	Siemens/Definition AS+	General Electric/VCT
Study	CT Chest	CT Chest with contrast
Dose modulation	CareDose 4D	Smart mA
kV	100	120
mA	Variable	Variable (max = 249 mA)
Rotation time	0.5 s	0.5 s
Acquisition geometry	Helical	Helical
Collimator beam width	38.4 mm	20 mm
Pitch	0.80	0.97
Acquisition field-of-view	50 cm	32 cm
$CTDI_{vol}$ phantom diameter	32 cm	16 cm
Indicated $CTDI_{vol}$: chest	4.78 mGy	17.7 mGy
Indicated $CTDI_{vol}$: abdomen	4.78 mGy	11.1 mGy
DLP (chest + abdomen)	181 mGy-cm	601 mGy-cm

$CTDI_{vol}$ = volume CT dose index; DLP = dose length product; kV = kilovolt; mA = milliampere; mGy = milligray

of table position (tube current modulation was converted to effective mAs by dividing by the pitch, with a maximum set limit of 249 mA), and axial scan of the pulmonary region are shown in Figure 1B.

At the request of the parent who was concerned about radiation dose to her child, the $CTDI_{vol}$ and DLP values for both CT procedures were released without modification. The $CTDI_{vol}$ (and DLP) values were about 4 times *higher* for the postsurgery scan. The “overdose” on the postsurgery scan was alarming to the parent, and the CT technologist who shared these data was unable to explain why the dose had increased. This issue was referred to medical physicists for review of the examination procedures/protocols and of the radiation dose metrics.

METHODS

Patient image data for these 2 CT examinations were retrieved from the UC Davis Medical Center PACS at the request of the Radiology Quality and Safety committee. Data pertinent to defining the radiation dose to the patient included the kV, mAs (slice by slice extracted from the DICOM metadata), rotation time, beam collimation width, and pitch, as listed in Table 1. Most of these values are similar across the 2 scans.

For each of the 2 scans, we calculated the size-specific dose estimates (SSDE) using the methodology outlined in *Size Specific Dose Estimates (SSDE) in Pediatric and Adult CT Examinations* [3]. The purpose of this publication was to generate a measurement of absorbed dose that would account for the discrepancy between the $CTDI_{vol}$ calibration phantom diameter and patient body size. The publication provides conversion factors as a function of effective patient diameter for the 32 cm diameter and 16 cm diameter calibration phantoms, to adjust the indicated $CTDI_{vol}$ (in mGy) to a corresponding SSDE (in mGy), based upon patient size effective diameter (Table 2). In essence, this serves as a normalization factor.

Effective patient diameter was determined from an axial image at the center of the scanned volume using anterior-posterior and lateral distance measurements [3] (Fig. 2). We estimated an effective diameter of 25 cm on both the pre- and postsurgery scans, with $CTDI_{vol}$ to SSDE conversion factors of 1.48 for the Siemens CT scanner using the 32 cm diameter phantom, and 0.71 for the GE scanner using the 16 cm diameter phantom.

RESULTS

The $CTDI_{vol}$ and corresponding SSDE estimates are shown in the lung and abdomen areas for the CT scans (Fig. 3). For the lung area, a $CTDI_{vol}$ ratio (after-to-before surgery) of 3.7 was calculated, indicating a significantly higher dose was delivered during the “after surgery” procedure; however, with SSDE methods

Table 2. Selected patient “effective” diameter and conversion factors abstracted from Tables 1D and 2D in AAPM TG-204 publication [3]

TG-204: PATIENT Effective Diameter (cm)	Table 1D* 32 cm diameter Conversion Factor	Table 2D* 16 cm diameter Conversion Factor
9	2.66	1.32
12	2.38	1.18
15	2.14	1.05
16	2.06	1.01
19	1.84	0.90
20	1.78	0.86
23	1.59	0.77
24	1.53	0.74
25	1.48	0.71
26	1.43	0.69
29	1.28	0.61
30	1.23	0.59
33	1.10	0.52
40	0.85	0.40

*Tables 1D and 2D refer to tables in TG-204 document.

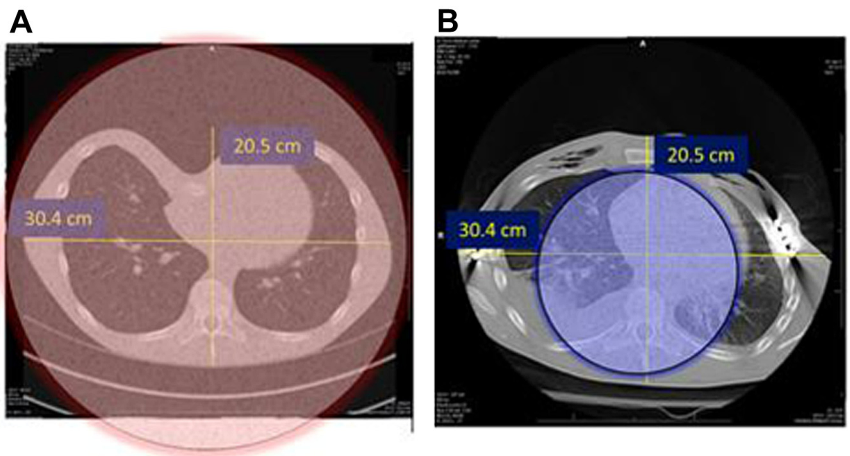

Fig 2. The $CTDI_{vol}$ estimate to the patient is determined from the CT acquisition parameters (kV and effective mAs) and dose to the phantom (*not the patient*). When the $CTDI_{vol}$ phantom diameter does not match the patient diameter, inaccurate dose estimates are recorded. **(A)** Presurgery axial patient image and superimposed/highlighted $CTDI_{vol}$ calibration phantom diameter (32 cm). **(B)** Postsurgery axial patient image and superimposed/highlighted $CTDI_{vol}$ calibration phantom diameter (16 cm). $CTDI_{vol}$ = volume CT dose index.

applied, this ratio was reduced to 1.8. Similarly, for the abdomen area, a $CTDI_{vol}$ ratio (after-to-before surgery) of 2.3 was calculated, indicating a higher dose was delivered during the "after surgery" procedure; however, by applying SSDE methods, the ratio was reduced to 1.1, indicating a similar estimated dose in the abdomen for the 2 scanner procedures.

DISCUSSION

$CTDI_{vol}$ is derived from the technique factors used during CT acquisition, including kV, effective mA for the study, pitch, and the corresponding calibration phantom used by the manufacturer for the acquisition.

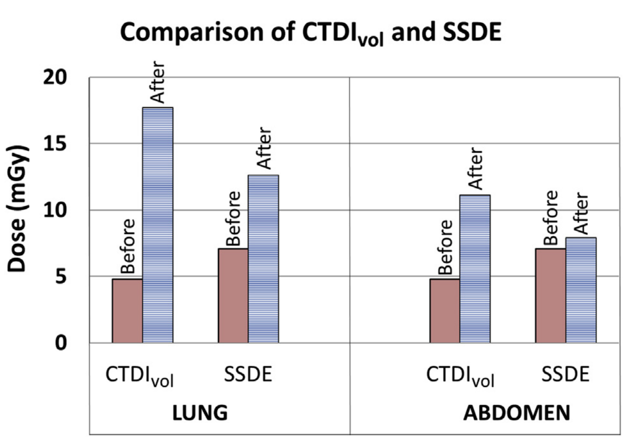

Fig 3. $CTDI_{vol}$ (before surgery/after surgery CT scans) and SSDE (before surgery/after surgery CT scans) are illustrated for the lung (left) and abdomen (right). SSDE provides a first order correction factor applied to the reported $CTDI_{vol}$ that improves the patient dose estimate accuracy and minimizes discrepancies among CT scanners. $CTDI_{vol}$ = volume CT dose index; SSDE = size-specific dose estimate.

Currently, there is no enforceable national or international standard for the phantom diameter (16 cm or 32 cm) that should be used for specifying $CTDI_{vol}$ for pediatric body (abdomen) protocols, and the CT manufacturer can choose either the 32 cm or 16 cm diameter phantom. Currently, for pediatric body protocols, Siemens and Philips use the 32 cm diameter phantom, and GE, Toshiba, and Hitachi use the 16 cm diameter phantom when the medium or small acquisition field-of-view is selected. Because of differences that can exist between patient effective diameter and calibration phantom diameter, the $CTDI_{vol}$ referenced to the patient can be significantly under- or over-estimated. Therefore, dose estimates that rely on the $CTDI_{vol}$ values reported by the CT scanner can vary widely, *even when the actual patient dose is comparable.*

Although not perfect, use of SSDE methods can significantly reduce discrepancies between the patient and calibration phantom size, and also for CT manufacturers' choice of $CTDI_{vol}$ phantom diameter used for calibration. In the specific clinical example, comparable CT manufacturer tube current modulation algorithms were used, and in the abdomen area, similar SSDE values were obtained. In the lung area, the presence of highly attenuating Nuss Bars and resulting increase in tube current was the cause of the higher SSDE of the postsurgery scan.

Because the DLP is directly linked to the $CTDI_{vol}$ metric as a product of the body length irradiated, it is also affected by inaccuracy; however, further investigation is necessary to determine how the DLP, often used as the metric to estimate patient effective dose with the use of an anatomy-specific "k" conversion factor [1], can become more accurate with patient size taken into account. At this time, however, SSDE should not be used to determine a "size-specific conversion DLP surrogate" [3].

There are many opportunities for improvement of patient care, and as this example demonstrates, a policy for releasing CT dose information to interested parties should be instituted. Many nuances and details in the reporting of radiation dose can lead to significant overestimates or underestimates, and corresponding misinterpretation can be potentially detrimental to the patient, patient's parents, and even to the institution. At the minimum, a size-specific conversion using SSDE methods should be applied to the $CTDI_{vol}$ reported values before release, if at all possible.

CONCLUSIONS

Determining accurate CT dose is more complex than simply using the $CTDI_{vol}$ values reported by the scanner. $CTDI_{vol}$ is dependent on acquisition parameters, as well as calibration phantom diameter, and can result in a significant overestimate or underestimate of the actual dose delivered to the patient because of discrepancies in body size versus calibration phantom size. Another, even greater discrepancy, resulting in up to a 4-fold difference, can occur for pediatric examinations when comparing dose metrics for studies obtained with different CT scanner manufacturers that use a 32 cm versus a 16 cm PMMA calibration phantom diameter. The application of SSDE conversion factors provides patient dose estimates with improved accuracy and precision by accounting for differences in body habitus and $CTDI_{vol}$ calibration phantom diameter. Mitigating these discrepancies prior to delivering CT radiation dose information to the patient is a prime reason to apply SSDE methods as a first step in a larger, future effort to achieve more accurate radiation dose and risk estimates for the patient.

TAKE-HOME POINTS

- $CTDI_{vol}$ can be up to a factor of 4-fold different for pediatric CT body examinations
- SSDE methods correct for discrepancies in $CTDI_{vol}$ versus patient size
- Comparison of dose estimates between scanners is improved with SSDE implementation

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