How to Appropriately Calculate Effective Dose for CT Using Either Size-Specific Dose Estimates or Dose-Length Product

Samuel L. Brady[1]
Amy E. Mirro[2]
Bria M. Moore[1]
Robert A. Kaufman[1]

OBJECTIVE. The purpose of this study is to show how to calculate effective dose in CT using size-specific dose estimates and to correct the current method using dose-length product (DLP).

MATERIALS AND METHODS. Data were analyzed from 352 chest and 241 abdominopelvic CT images. Size-specific dose estimate was used as a surrogate for organ dose in the chest and abdominopelvic regions. Organ doses were averaged by patient weight–based populations and were used to calculate effective dose by the International Commission on Radiological Protection (ICRP) report 103 method using tissue-weighting factors (E_{ICRP}). In addition, effective dose was calculated using population-averaged CT examination DLP for the chest and abdominopelvic region using published k-coefficients ($E_{DLP = k \times DLP}$).

RESULTS. E_{DLP} differed from E_{ICRP} by an average of 21% (1.4 vs 1.1) in the chest and 42% (2.4 vs 3.4) in the abdominopelvic region. The differences occurred because the published k-coefficients did not account for pitch factor other than unity, were derived using a 32-cm diameter CT dose index (CTDI) phantom for CT examinations of the pediatric body, and used ICRP 60 tissue-weighting factors. Once it was corrected for pitch factor, the appropriate size of CTDI phantom, and ICRP 103 tissue-weighting factors, E_{DLP} improved in agreement with E_{ICRP} to better than 7% (1.4 vs 1.3) and 4% (2.4 vs 2.5) for chest and abdominopelvic regions, respectively.

CONCLUSION. Current use of DLP to calculate effective dose was shown to be deficient because of the outdated means by which the k-coefficients were derived. This study shows a means to calculate E_{ICRP} using patient size–specific dose estimate and how to appropriately correct E_{DLP}.

The need to understand patient population dose for risk analysis is a timely topic. The use of ionizing radiation for clinically diagnostic examinations should always provide unquestionable benefit compared with the risk associated with radiation exposure; however, in the case of clinical research, an institutional review board (IRB) must evaluate risk associated with research participation. An appropriate risk analysis is required for IRB approval for clinical research–oriented CT examinations [1]. In addition, a researcher is faced with the task of how to communicate the risk of participating in a clinical research study using CT. To these ends, the calculation of patient population effective dose has become a popular tool for risk analysis and is further used to help convey associative effective dose values with other known or relatable population effective dose values (e.g., Nuclear Regulatory Commission occupational limits and environmental exposure levels) [2]. However, it should be remembered that effective dose provides a value that takes into account the given exposure conditions, but not the characteristics of a specific individual. The use of effective dose to quantify stochastic risk of carcinogenesis and the induction of genetic effects in a general medical population from imaging modalities using ionizing radiation should be avoided [3, 4].

Effective dose was developed as a somatic dose descriptor that reflects differences in biologic tissue sensitivity to ionizing radiation effects [5–7]. Effective dose (E) is a weighted summation of measured organ dose values ($D_{T,R}$) for the human body ($E = \sum\sum w_T w_R D_{T,R}$). Effective dose weighting factors account for different types of radiation (e.g., w_R = x-ray, gamma-ray, or neutron) and different irradiated tissue types (e.g., w_T = stomach, liver, or brain). The tis-

sue-weighting factor used to calculate effective dose is established by a committee of the International Commission on Radiological Protection (ICRP). In 2007, the ICRP published its latest recommended weighting factors for 30 organs and tissues for the whole body [8]. To calculate effective dose for CT, two approaches are common: the first uses software-based Monte Carlo methods such as CT-Expo (Sascrad) or ImPACT (ImPACT Group), and the second was developed as a simplified method to quickly estimate effective dose using the dose-length product (DLP) and sets of age- and body region–specific k-coefficients ($E = k \times DLP$) [9, 10]. The data used to initially derive k-coefficients were obtained from the United Kingdom's National Radiological Protection Board Monte Carlo organ dosimetry program developed in 1991 [11] and updated in 2002 [12]. These data are based on outmoded technology, do not account for helical CT acquisition with pitch factors other than unity, and do not account for the latest tissue-weighting factor values. There have been several publications updating the k-coefficients to account for changes to tissue-weighting factors (i.e., ICRP Report 103 recommendations) [8, 13, 14]; however, to our knowledge, the use of k-coefficients with DLP values for scans with pitch factors other than unity have not been addressed.

With the recent development of several methods to estimate patient organ dose in CT using size-specific dose estimates [15–19], the possibility of calculating effective dose for a patient population using the original means of ICRP report 103 [8] tissue-weighting factors is possible for direct comparison

with the method involving k-coefficients and DLP. The purpose of this study was to show how to calculate effective dose in CT using size-specific dose estimate and to correct the current method using DLP.

Materials and Methods
Patients
Our IRB deemed this quality analysis study to be exempt from the need to obtain informed consent. All data were managed in compliance with the HIPAA. All patient examinations analyzed in this study were performed with a CT scanner (LightSpeed VCT-XTe, GE Healthcare) and were grouped according to each patient's weight, which was obtained immediately before his or her CT examination. The patient weight populations were grouped according to GE Healthcare's Color Coding for Kids weight categories. The number of patients per weight classification is listed in Table 1 for chest examinations and Table 2 for abdominopelvic examinations. A total of 593 patient examinations (352 chest and 241 abdominopelvic) were analyzed for individual organ dose.

Patient Organ Dose Calculation
To determine patient-specific absolute organ dose (D^{organ}), first, each patient's CT was calculated for size-specific dose estimate by measuring the patient's anteroposterior and lateral dimension in the chest and abdominopelvic regions. The anteroposterior and lateral measurements were made at the level of the aortic arch for the chest region and at the level of the right portal vein in the liver for the abdominopelvic region. Measurements were made using any combination of axially reconstructed images or scan projection radiographs [20]; the choice to use either the axial reconstructed image or scan pro-

jection radiograph depended, in large part, on whether there was anatomy clipping on the axial image, as often occurs in the shoulders in pediatric CT. In the case of adolescent patients, typically greater than 40 kg, two effective diameters were measured in the chest differentiating between the sexes. For the male patients, an anteroposterior measurement from the posterior skin to the anterior surface of the sternum was made, and for the female patients, an anteroposterior measurement from the posterior skin to the maximum anterior measurement of the breast was measured. Using the anteroposterior (AP) and lateral (LAT) patient measurements, an effective diameter was calculated for the chest and abdominopelvic regions, as defined in The American Association of Physicists in Medicine Report 204 formulation [21]:

$$\text{effective diameter} = \sqrt{AP \times LAT} \qquad (1).$$

The effective diameter calculated in equation 1 was used to look up a conversion factor ($f_{size\ 16\ or\ 32}$) to scale the volume CT dose index (CTDI$_{vol}$) value associated with each patient's CT examination. The f-s ($f_{size\ 16\ or\ 32}$) coefficient depended on whether the CTDI$_{vol}$ value was derived using either a 16- or 32-cm diameter CTDI phantom [20, 21], as shown in equation 2:

$$SSDE = CTDI_{vol}^{16\ or\ 32} \times f_{size}^{16\ or\ 32} \qquad (2).$$

Second, patient size–specific dose estimate has been shown to have a nearly one-to-one correlation with measured absolute organ dose when the organ was fully enveloped within the scan FOV [15–19] and was used to determine D^{organ}. Absolute organ dose was determined for 23 individual organs, including thyroid, lungs, breast, esopha-

TABLE 1: Chest Absolute Organ Doses by Patient Weight Category

Organ	5.0–7.4 kg (Pink)	7.5–9.4 kg (Red)	9.5–11.4 kg (Purple)	11.5–14.4 kg (Yellow)	14.5–18.4 kg (White)	18.5–22.4 kg (Blue)	22.5–31.4 kg (Orange)	31.5–40.4 kg (Green)	40.5–55 kg (Black)
No. of patients	10	10	12	37	57	58	68	35	65
Average (± SD) dose-length product (mGy × cm)	30 ± 3	36 ± 13	22 ± 10	19 ± 5	25 ± 4	30 ± 6	37 ± 7	57 ± 15	89 ± 28
Bone surface	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.6	0.5
Breast	2.9	3.1	3.2	2.5	3.3	3.9	3.5	4.7	4.1
Heart wall	4.0	4.2	4.1	3.0	3.0	3.1	3.6	5.4	3.8
Lungs	3.9	4.5	4.4	3.1	3.5	3.5	4.1	5.7	4.5
Esophagus	3.5	3.7	3.8	2.9	2.9	3.1	3.0	4.7	4.4
Red bone marrow	0.7	0.8	0.8	0.5	0.5	0.6	0.9	1.2	1.4
Skin	1.1	0.8	0.9	0.7	0.5	0.6	1.2	1.2	0.5
Thymus	4.0	4.5	4.4	3.1	3.3	3.6	3.8	5.4	4.8
Thyroid	2.3	3.2	3.2	2.6	2.5	2.6	4.2	5.6	5.7

Note—Except where noted otherwise, data are organ dose in milligrays. Colors in column headings refer to GE Healthcare's Color Coding for Kids weight categories.

TABLE 2: Abdominopelvic Absolute Organ Doses, by Patient Weight Category

Organ	6–7.4 kg (Pink)	7.5–9.4 kg (Red)	9.5–11.4 kg (Purple)	11.5–14.4 kg (Yellow)	14.5–18.4 kg (White)	18.5–22.4 kg (Blue)	22.5–31.4 kg (Orange)	31.5–40.4 kg (Green)	40.5–55 kg (Black)
No. of patient	8	8	12	25	36	46	53	23	30
Average (± SD) dose-length product (mGy × cm)	81 ± 17	88 ± 26	66 ± 4	59 ± 4	73 ± 5	92 ± 4	116 ± 11	150 ± 20	222 ± 45
Adrenal gland	3.6	4.3	4.6	3.7	4.1	3.9	4.8	7.0	3.3
Bladder	4.6	5.7	5.2	3.4	4.0	3.9	4.2	5.4	5.4
Bone surface	1.0	1.2	1.2	1.1	1.7	1.5	1.1	1.7	1.3
Colon	4.6	5.4	5.2	3.5	4.1	4.4	5.3	5.8	5.6
Gallbladder	5.7	6.7	6.2	4.2	5.3	5.4	5.8	6.7	4.4
Intestines	4.6	5.4	5.2	3.5	4.1	4.4	5.3	5.8	5.6
Kidneys	5.0	6.0	5.7	3.9	4.4	4.9	5.3	6.4	4.4
Liver	5.1	6.4	6.0	3.7	4.7	4.9	5.8	7.4	4.0
Ovaries	5.1	5.6	5.2	3.4	4.2	4.4	4.2	4.8	4.2
Pancreas	4.5	5.5	5.2	3.5	5.2	4.9	6.4	6.9	4.7
Prostate	4.7	6.0	5.2	3.8	4.3	4.4	3.7	5.6	5.3
Red bone marrow	1.0	1.2	1.1	0.8	0.9	1.0	1.1	1.7	1.9
Skin	1.5	1.8	1.5	1.1	1.3	1.5	1.1	1.7	1.3
Spleen	4.7	6.2	5.7	3.2	4.1	3.9	4.8	6.0	3.3
Stomach	4.8	5.6	5.1	4.3	5.3	4.9	5.8	6.7	4.4
Testes	4.3	4.2	4.6	3.3	3.7	2.4	3.7	2.6	6.6
Uterus	4.9	5.7	5.2	3.4	4.2	4.4	4.2	5.2	5.2

Note—Except where noted otherwise, data are organ dose in milligrays. Colors in column headings refer to GE Healthcare's Color Coding for Kids weight categories.

gus, thymus, heart wall, bone marrow, bone surface, skin, liver, kidneys, gallbladder, pancreas, adrenal gland, spleen, stomach, colon, bladder, prostate, intestines, testes, ovaries, and uterus. For organ and tissue types not fully covered within the scan FOV (i.e., bone marrow, bone surface, and skin), a correction factor ($CF_{SSDE,organ}$) was used and multiplied by the patient size–specific dose estimate ($SSDE_{patient}$), as described in Moore et al. [17] and shown in equation 3:

$$D^{organ} = CF_{SSDE}^{organ} \times SSDE_{patient} \qquad (3).$$

Each organ dose was averaged for all patients within each weight category.

Effective Dose

Two approaches to calculate effective dose were compared in this study. The first was calculated as previously described [6], using the original method of multiplying each organ dose with weighting factors established by the most recent recommendation in ICRP report 103 [8], as shown in equation 4:

$$E_{ICRP} = \sum_{T}\sum_{r} (w_T \times w_R \times D^{organ}) \qquad (4),$$

where w_T refers to tissue-weighting factors provided in ICRP report 103 (see Table 3 in chapter 4 of ICRP report 103), w_R is equal to unity as de-

fined for photon radiation (see Table 2 in chapter 4 of ICRP report 103), and D^{organ} is the averaged patient population–specific absolute organ dose as calculated in equation 3. In accordance with the recommendations of ICRP report 103, all patient-specific organ equivalent doses (i.e., $H_{male\ or\ female,\ organ} = w_R \times D^{organ}$) were averaged before being multiplied by the sex- and age-averaged w_T. For an example, see equation 5:

$$E_{organ\ dose} = \sum_{T} w_T \left(\frac{H_{male}^{organ} + H_{female}^{organ}}{2} \right) \qquad (5).$$

The second approach was unique to calculating effective dose for CT because, until recently, patient organ dose values in CT were unavailable. To calculate effective dose from a CT examination, each patient's examination DLP was recorded as displayed on the patient dose report in the patient's record [22, 23]. Separate DLPs were recorded for chest and abdominopelvic scan regions. The scanning length for the chest was landmarked from the top of the lung apices to approximately 10 mm below the lung base. The abdominopelvic scans were landmarked from the diaphragm to the bottom of the ischium. Chest and abdominopelvic studies were performed separately.

To calculate effective dose, the CT examination DLP was multiplied by a k-coefficient de-

rived from a table published by Deak et al. [13], as shown in equation 6:

$$E_{DLP} = k \times DLP \qquad (6).$$

A program was written using MATLAB (version R2012a, MathWorks) to take the k-coefficients for the chest, abdomen, and pelvis provided at five discrete age points (i.e., newborn, 1 year, 5 years, 10 years, and adult) from the Deak et al. publication and to interpolate the k-coefficients for all ages [24]. The abdomen and pelvis k-coefficients were averaged together to produce a k-coefficient for the abdominopelvic scanning region. The k-coefficients from Deak et al. were published to account for the updated w_T from ICRP report 103 [8]. However, those k-coefficients were derived with a pitch factor of unity using constant x-ray tube output, were normalized using CTDI values measured with a 32-cm diameter phantom (for both pediatric and adult chest and abdominopelvic regions), and with irradiated body region lengths that were approximately 50% shorter than prescribed clinically at our institute [13, 22]. For comparison, a second E_{DLP}, $E_{DLP\ corrected}$, was calculated by correcting for the following: patient weight categories (< 9.5 kg) with CTDI values derived from a 16-cm diameter CTDI phantom; for patient weight categories (≥ 9.5 kg) imaged with a pitch of 1.375; for patient weight

categories (≥ 31.5 kg) that use beam current modulation where the k-coefficients in the chest and abdominopelvic regions were reduced by 9% and 7%, respectively [14]; and for irradiated body region lengths averaged from actual patient data that were longer than those published by Deak et al.

Statistical Techniques

Data analysis was calculated using PRISM (version 6.02, GraphPad Software). Statistical significance was determined using the Holm-Sidak method, with α = 5%. Computations assume data normality. All error bars in this study represent the square root of the sum of the squares of each single SD from the weight category data mean.

Results

Absolute Patient Dose

Patients weighing 5–55 kg were analyzed in this study. The mean (± SD) patient weight was 22 ± 15 kg, and the mean patient age was 6 ± 5 years (range, 4 months to 23 years). Although most CT examinations analyzed in this study were performed for patients in the pediatric age range, some young adults who were being monitored for pediatric tumors, whose weight was 55 kg or less, also were evaluated. Patient population absolute organ dose values were sorted into nine weight categories commensurate to the Color Coding for Kids weight categories, and average patient population organ dose values are listed in Table 1 and Table 2 for chest and abdominopelvic regions, respectively.

Effective Dose

Effective dose was calculated from the weight-based organ dosimetry (E_{ICRP}) population data derived from Tables 1 and 2, and from each weight-based population's average DLP (E_{DLP}) for the chest and abdominopelvic scanning regions (Figs. 1A and 1C).

For the chest region, E_{DLP} overestimates E_{ICRP} for patients weighing less than 7.5 kg, and underestimates E_{ICRP} for patients weighing 7.5 kg or more (Fig. 1A). E_{DLP} was determined to be statistically significantly different (all $p < 0.001$) from E_{ICRP} for all patient populations except those weighing 7.5–9.4 kg and 40.5 kg or more. For chest CT, the aggregate percentage difference between E_{DLP} and E_{ICRP} was 21% (1.4 vs 1.1), with a maximum difference of 83% (2.2 vs 1.2) for the patient population weighing less than 7.5 kg. $E_{DLP\ corrected}$ was calculated, correcting for CTDI measurements made in a 16-cm diameter phantom for patients weighing 0–9.4 kg and for patients weighing 11.5 kg or more imaged

with a pitch factor of 1.375 (Fig. 1B). The new aggregate percentage difference between E_{ICRP} and $E_{DLP\ corrected}$ is 7% (1.4 vs 1.3).

The calculated E_{ICRP} values for chest CT patient populations showed a general linear trend of increasing up to an asymptotic limit (patients weighing ≥ 40.5 kg or approximately 15 years old), which matched known trends in thoracic dimensional growth [25, 26]. The stepwise discontinuity in effective dose values for patient populations around the 11.5 kg mark is due to differences in CT acquisition parameters. Patients weighing less than 11.5 kg were imaged with increased tube current because of smaller (3.75 mm) reconstructed image thickness compared with the 5.0-mm-thick images for patients weighing 11.5 kg or more. Therefore, increases in E_{ICRP} and, by extension, stochastic risk linearly increase with increasing patient population weight and are attributed to increases in exposure parameters.

For the abdominopelvic region, E_{DLP} overestimates E_{ICRP} for all patient population weight classifications (Fig. 1C). E_{DLP} was determined to be statistically significantly different (all $p < 0.001$) from E_{ICRP} for all patient populations except those weighing 7.5–11.4 kg. The aggregate percentage difference between E_{DLP} and E_{ICRP} was 42% (2.4 vs 3.4), with a maximum difference of 159% (5.7 vs 2.2) for the patient population weighing 5.0–7.4 kg. $E_{DLP\ corrected}$ was similarly calculated as described for the chest (Fig. 1D). The new aggregate percentage difference between $E_{DLP\ corrected}$ and E_{ICRP} is 4% (2.4 vs 2.5).

The calculated E_{ICRP} values were fairly consistent in the abdominopelvic region, which was expected because of the generally similar abdominopelvic habitus found in pediatric patients. The subtle variation among mean E_{ICRP} can be attributed to variations in exposure parameters, such as tube current and tube potential.
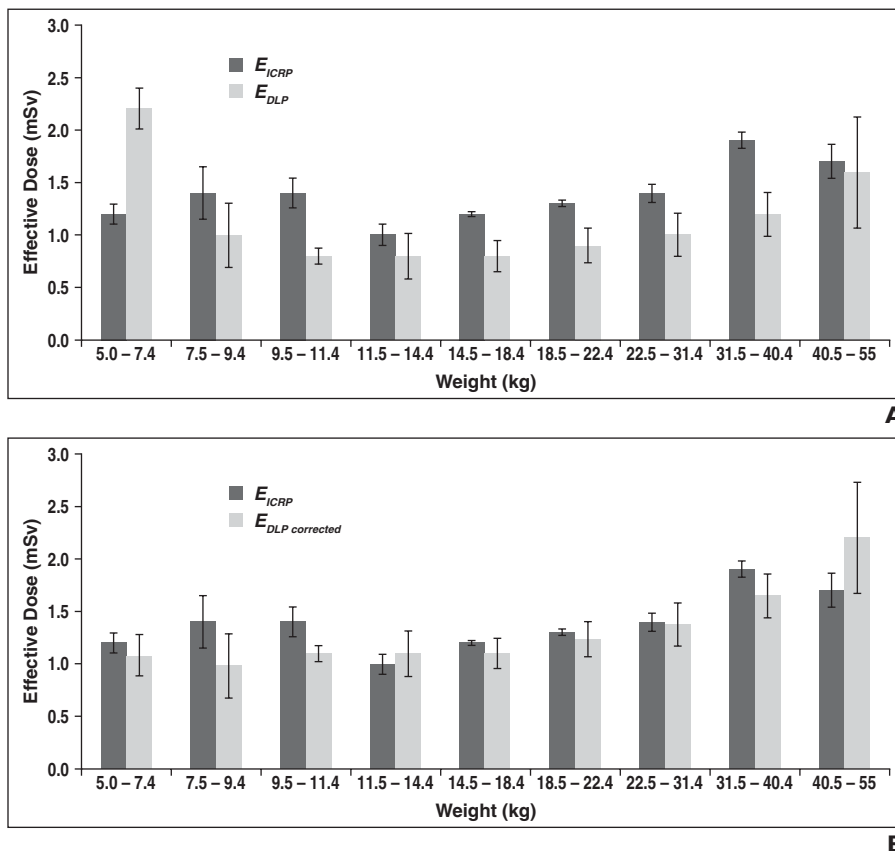

Fig. 1—Effective dose (*E*) calculation for patient weight populations undergoing CT examination.
A–D, *E* was calculated using original method where each organ dose was multiplied by weighting factor provided by International Commission on Radiological Protection report 103 (E_{ICRP}) [8]. For chest (**A**) and abdominopelvic (**C**) regions, E_{ICRP} was compared to *E* calculation method using CT examination dose-length product (DLP) multiplied with *k*-coefficient (E_{DLP}). E_{DLP} is shown to have several limitations. Limitations were corrected ($E_{DLP\ corrected}$) and compared with E_{ICRP} for chest (**B**) and abdominopelvic (**D**) regions. Lines and whiskers denote 95% CIs.
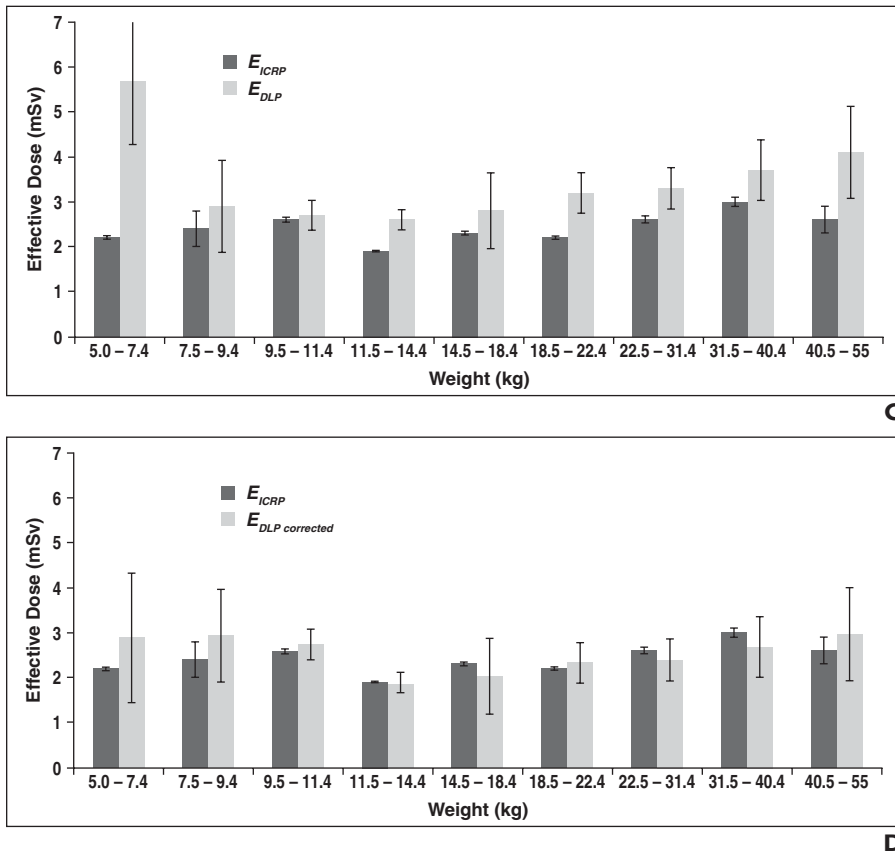
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Fig. 1 (continued)—Effective dose (*E*) calculation for patient weight populations undergoing CT examination. **A–D**, *E* was calculated using original method where each organ dose was multiplied by weighting factor provided by International Commission on Radiological Protection report 103 (E_{ICRP}) [8]. For chest (**A**) and abdominopelvic (**C**) regions, E_{ICRP} was compared to *E* calculation method using CT examination dose-length product (DLP) multiplied with k-coefficient (E_{DLP}). E_{DLP} is shown to have several limitations. Limitations were corrected ($E_{DLP\ corrected}$) and compared with E_{ICRP} for chest (**B**) and abdominopelvic (**D**) regions. Lines and whiskers denote 95% CIs.

Initially, the values for E_{DLP}, for patient chest and abdominopelvic CT, showed a decreasing trend in effective dose with weight, and then increases for patients weighing 11.5 kg or more (Figs. 1A and 1C). This trend is counterintuitive to the accepted linear no-threshold risk model that predicts increasing stochastic risk with increasing exposure to ionizing radiation. The E_{DLP} values were found to be overrepresentative of potential patient risk because the DLP values used to calculate effective dose were derived from 16-cm diameter CTDI phantoms, but the k-coefficients were derived from weighted CTDI ($CTDI_w$) values measured in a 32-cm diameter CTDI phantom [13]. Once corrected, $E_{DLP\ corrected}$ showed an appropriate linear trend in risk in line with the linear no-threshold model.

Discussion

In this study, we compared two methods for calculating effective dose for chest and abdominopelvic CT examinations in patients weighing 5–55 kg. A major benefit of calculating effective dose for patient populations undergoing CT examinations is the ability to directly compare patient relative risk with other imaging modalities involving ionizing radiation, such as radiography, fluoroscopy, or nuclear medicine. However, because CT dose metrics, such as CTDI and DLP, were not similar to other ionizing radiation imaging modality metrics, a direct comparison of calculated CT effective doses was not possible [4]. With the recent development of a method for estimating patient organ dose for CT examinations using patient size–specific dose estimates, effective dose can be calculated using the same method as for other ionizing radiation imaging modalities—namely, the individual organ dose can be combined with ICRP tissue-weighting factors, and, by extension, risk can be compared with other modalities using ionizing radiation.

Calculating effective dose by either method (E_{DLP} or E_{ICRP}) comes with limitations [27], which are important to understand to better interpret the results. First, the tissue-weighting factor (w_T) values used to scale the equivalent organ doses in the original effective dose calculation method (E_{ICRP}) are determined only for tissues known to be sensitive to radiation damage. This determination is based on committee decision after a statistical analysis of increased risk to cancer induction; mortality; and, in the case of gonadal irradiation, heredity. The values of the various tissue-weighting factors are relatively scaled depending on the calculated risk of aggregated health detriment from the Life Span Study of atomic bomb survivors and other population-based medical, occupational, and environmental radiation exposures [4, 8]. Because the tissue-weighting factors are based on the Life Span Study, they are prone to change with time because of the aging population under analysis and because of better understanding of stochastic radiation risk factors for different tissue types. An example of a change in tissue-weighting factor is for the gonads, which decreased from 0.2 to 0.08 because of the discovery of the lack of hereditary issues surrounding gonadal irradiation [8]. The tissue-weighting factors are averaged over all ages and sexes. An example of how the ICRP committee determines an age- and sex-independent value for a particular tissue-weighting factor is the thyroid: the radiation risk factor associated with thyroid cancer detriment is 0.021 (female) and 0.008 (male), but was assigned a value of 0.04 because of the known high thyroid sensitivity to ionizing radiation detriment in children [8]. In general, the tissue-weighting factors are selected in a conservative manner. The values are intended to equate non-uniform whole-body exposure; hence, the tissue-weighting factors sum to unity.

Second, the k-coefficients used to calculate E_{DLP} were originally derived from a series of dose calculations using Monte Carlo and mathematic phantoms [28] scaled for pediatric interpretation [10, 12, 29]. The mathematically derived effective dose values were normalized to dose-free-in-air on the axis of rotation of the scanner; however, these led to k-coefficients dependent on CT scanner design and model. To remove the scanner dependency, the k-coefficients were later derived from the effective dose values normalized by the $CTDI_w$, and by dividing each scanning region (i.e., head neck, chest,

and abdomen) by the length (*L*) of the scan used to calculate the organ doses [12, 29], as shown in equation 7:

$$K = \frac{E}{CTDI_w^{32\,cm} \times L} \qquad (7).$$

It should be noted that the effective dose values were not normalized by the current definition of DLP because $CTDI_w$ was not normalized by pitch other than unity. These initial *k*-coefficients for pediatric CT effective dose calculations were published by The European Commission [29], and republished by McCollough et al. [23] and have since been updated [13, 14] to account for the new tissue-weighting factor values from ICRP report 103 [8].

This study shows how the method for calculating effective dose in CT using *k*-coefficients combined with DLP generally does not agree with the method using individual organ dose and ICRP tissue-weighting factors. The results of this study are in agreement with those of a publication that found discrepancies on the order of 34–74% when calculating effective dose using the ICRP versus the DLP methods [30]. The major limitation to using *k*-coefficients, as shown in this study, is that they have not been appropriately updated to be applied using modern CT examination techniques. Though it is possible to make corrections to render E_{DLP} more accurate, such as shown by calculating $E_{DLP\ corrected}$, correcting published *k*-coefficients requires an understanding of how the particular coefficient was derived—namely, *k*-coefficient values are heavily dependent on the phantom diameter used as a normalization factor, scanning length, pitch factor, and version of ICRP report used to derive the coefficient value.

In conclusion, clinical researchers have an obligation to provide the most accurate estimate of risk for an experimental medical procedure that involves CT with ionizing radiation. Effective dose provides a general idea of detriment from ionizing radiation to allow comparison of different procedures and provide a simple means for explaining ionizing radiation risk to a potential research participant. A comparison of two methods to calculate effective dose in a CT population has been provided. Limitations in the manner in which E_{DLP} is calculated were discussed, and a means to correct E_{DLP} was shown. With the advent of patient-specific organ dose using size-specific dose estimate for CT, E_{ICRP} can be calculated using tissue-weighting factors to better allow relative risk–based assessment of CT examinations with other radiologic procedures bypassing the limitations of using *k*-coefficients.

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