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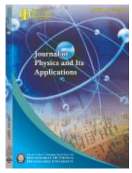

The comparison of size-specific dose estimate in CT examination based on head and body PMMA phantom

Mohd Hanafi Ali[1], Choirul Anam[2], Freddy Haryanto[3], and Geoff Dougherty[4]

[1]*Department of Medical Radiation Sciences, The University of Sydney, Sydney, Australia. Email: hanafi.ali@sydney.edu.au*
[2]*Department of Physics, Faculty of Mathematics and Natural Sciences, Diponegoro University, Tembalang, Semarang, Central Java, Indonesia*
[3]*Department of Physics, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Bandung, West Java, Indonesia*
[4]*Applied Physics and Medical Imaging, California State University Channel Islands, Camarillo, CA, USA*

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ABSTRACT

Nowadays, a dose estimate for individual patients undergoing CT examination is carried out using the metric of size-specific dose estimate (SSDE), which is calculated by multiplying a volume CT dose index ($CTDI_{vol}$) and a correction factor that is a function of patient size. Two $CTDI_{vol}$ values are based on head and body PMMA phantoms. There are also two values of correction factors (k), both for head and body PMMA phantoms. The purpose of this study was to compare the SSDE values calculated using head and body PMMA phantoms with their corresponding correction factors (k). The $CTDI_{vol}$ values were derived from the ImPACT 1.04 software for 12 CT scanners: Sensation 4, Sensation 16, Sensation 64, Light Speed, Light Speed 16, Light Speed VCT, Secura, Brilliance 16, Brilliance 64, Asteion Dual, Aquilion 4, and Aquilion 16. The size of the patients who underwent CT examination was characterized by a water-equivalent diameter (D_w) from 10 cm to 45 cm. The results indicated that the differences in SSDE values based on head and body $CTDI_{vol}$ were within 20%. Thus, the SSDE value can be calculated using the head or body $CTDI_{vol}$ bases with corresponding k value.

1. Introduction

For about three decades, the dose from CT scanners was quantified using the CT dose index (CTDI), which is measured using a standard PMMA phantom with a diameter of either 16 cm or 32 cm [1, 2]. There are several derivatives of CTDI, namely, $CTDIF_{DA}$, $CTDI_{100}$, $CTDI_p$, $CTDI_c$, $CTDI_w$, and $CTDI_{vol}$ [3, 4]. As a dose index, CTDI is very useful for quality control [5], accreditation [6], and comparing the dose level of different CT scanners [7]. However, CTDI is a dose index and is not meant to estimate the dose received by a patient [8, 9]. The discrepancy between CTDI and the dose received by patients can vary by more than 100%, depending on the specific characteristics of the patient [10, 11]. Studies have shown that for fixed setting parameters (kVp, mAs, pitch, etc.), the patient dose is highly associated with patient size [12, 13], weight [14, 15], or body mass index [16, 17]. In 2011, the AAPM issued report No. 204 on pediatric dose estimation in CT, taking into account the patient's size, and introduced the size-specific dose estimate (SSDE) as a new descriptor [18]. The SSDE relies on a volume CTDI ($CTDI_{vol}$) and is corrected by a correction factor based on patient size [19-21].

The SSDE value depends on a number of factors. It is calculated as $CTDI_{vol} \times k(D)$. Thus, the accuracy of SSDE is strongly influenced by three factors, namely, size of the patient (D), correction factor (k), and $CTDI_{vol}$ value. In AAPM reportNo. 204, the size of the patient was characterized by the effectivediameter (D_{eff}) [18], which could be calculated fromthe cross-section of patients. However, for practical considerations, the D_{eff} is estimated using only a lateral diameter, anterior-posterior diameter, or a combination of both [19, 22]. The D_{eff} can also be estimated from the patient's age, but its accuracy will be rather low [23]. However, the D_{eff} only takes into account the size and neglects the composition or attenuation of the patient. In reality, a significant amount of real dose is determined by the composition of the body part being scanned [24, 25]. In order to obtain a more accurate dose estimate, a water-equivalent diameter (D_w) was introduced in lieu of the D_{eff}. The D_w was previously introduced by Wang et al [26] and adopted by AAPM in report No. 220 [27]. The accuracy of SSDE also depends on how the D_{eff} and D_w are calculated [28-30].

The correction factor (k) in the AAPM report No. 204 was obtained by combining data from four different research groups that used different methods and different types of scanners [18]. All data were then combined to determine the values of the correction factor for various values of patient diameters. The data from the four different studies were highly correlated with a correlation coefficient (R^2) of 0.942. The mean deviation between these four groups was 3.3%, and the maximum difference was +16% for the smallest patient (12.2 cm) [18].These results allowed the creation of a single graph of *k* based on the head PMMA phantom and a singlegraph of k based on the body PMMA phantom. The *k* value may be applied with acceptable accuracy to all types of scanners and all CT centers [18, 31].

The $CTDI_{vol}$ value determines the SSDE. Two values of $CTDI_{vol}$ are measured on the 16 cm (head) and 32 cm (body) PMMA phantoms. Currently, there is no standard for the phantom diameter that should be used for pediatric protocols or when the small or medium acquisition field of view (FOV) is selected [32]. For that purpose, Siemens and Philips use the body PMMA phantom, but GE and Toshiba use the head PMMA phantom [32]. The use of either was expected to produce the comparable SSDE value. Up to now, the comparison of SSDE based on the head and body PMMA phantom has not been accomplished. Therefore, this study sought to evaluate the comparison of SSDE values based on the head and body PMMA phantom for 12 different scanners.

2. Methods

2.1. Water-equivalent diameter

The D_w was originally introduced by Huda et al [15]. However, they did not actually compare the dose of the scanned object and D_w. In 2011, Wang et al provided a mathematical description for the D_w and investigated its relationship with individual patient doses [26]. The current study did not intend to evaluate the feasibility of D_w or the method for calculating it, because this metric has been evaluated and the method for calculating it has already been established [24, 26]. Previous studies have shown that the use of D_w was more appropriate to describe the size of patients, especially for the thoracic region of the body, because the D_w considers not only the size but also the attenuation of the body part. In the current study, we used a D_w range from 10 cm to 45 cm, which covered patient sizes from newborns to very obese adult patients.

2.2. $CTDI_{vol}$

The Imaging Performance Assessment of CT scanners (ImPACT) group developed an Excel (Microsoft) spreadsheet to provide a user friendly interface for determining output CT dose and organ doses by using the National Radiological Protection Board (NRPB) Monte Carlo dose datasets [33]. The software was validated by many investigators of CT dosimetry [34-35]. In this current study, the CTDIvol values were derived from the ImPACT CT patient dosimetry version 1.04 software (released in May 2011) [33] for 12 types of scanners as listed in Table 1. The CTDIvol values were based on two PMMA phantoms, namely the head (16 cm in diameter) and the body (32 cm in diameter). The $CTDI_{vol}$ values were derived at a tube voltage of 120 kVp, tube current of 100 mA, rotation time of 0.6 s, and a spiral pitch of 1. Beam collimation was set to 10 mm or to the value closest to 10 mm if it was not available (see Table 1).

2.3. SSDE calculation

SSDE was calculated as the product of $CTDI_{vol}$ and the correction factor as a function of patient size, $k(D_w)$. When using the head-based $CTDI_{vol}$, a k^h correction factor was used, and when using the body -based $CTDI_{vol}$, a k^b correction factor was used. Therefore, the equations for calculating $SSDE^h$ and $SSDE^k$ can be written as follows:

$$SSDE^h = CTDI^h_{vol} \times k^h \quad (1)$$

$$SSDE^b = CTDI^b_{vol} \times k^b \quad (2)$$

k^b and k^h values were taken from AAPM report No. 204. The graphs of k^h and k^b for various diameters are shown in Fig. 1.

Table 1: Type of scanners and the collimation values used in this study

Scanner	Beam collimation (mm)
Siemens	
Sensation 4	10
Sensation 16	10
Sensation 64	10
GE	
Light Speed	10
Light Speed 16	10
Light Speed VCT	10
Philips	
Secura	12
Brilliance 16	10
Brilliance 64	10
Toshiba	
Asteion Dual	10
Aquilion 4	12
Aquilion 16	12

3. Results

3.1. $CTDI_{vol}$ from various types of scanners

The $CTDI_{vol}$ values for the body and head PMMA phantoms from the 12 scanners listed in the ImPACT software are shown in Fig. 2. The body $CTDI_{vol}$ values were approximately half the head $CTDI_{vol}$ values. The average body $CTDI_{vol}$ value was 5.9 ± 1.7 mGy and the average head $CTDI_{vol}$ value was 11.9 ± 3.2 mGy. The maximum differences in $CTDI_{vol}$ values among the 12 scanners were 157% for the body and 143% for the head.

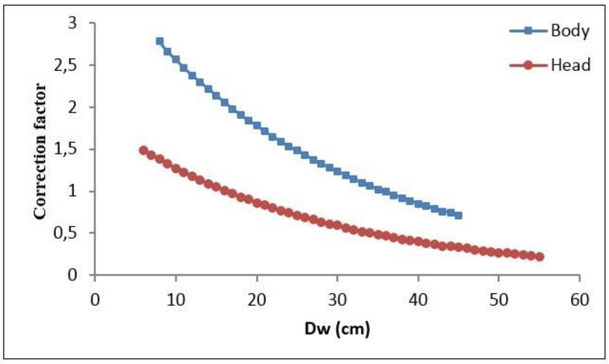

Fig. 1: The graphs plotting the correction factors k^b and k^h against the diameters of the patient [18]

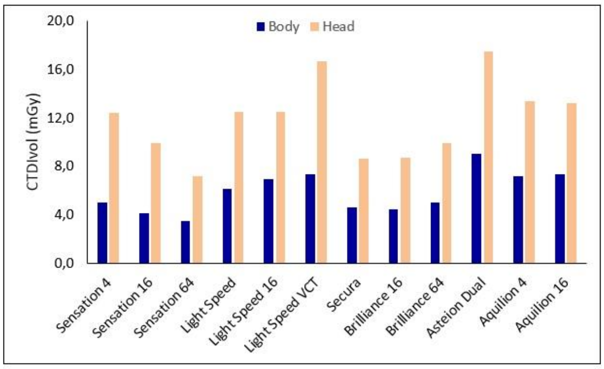

Fig. 2: The CTDI$_{vol}$ values for the body and head PMMA phantoms from the 12 scanners listed in the ImPACT software

3.2. SSDE from various types of scanners

The SSDE values for the 12 scanners are shown in Fig. 3. The SSDE values decreased exponentially with increasing D$_w$ because the values of *k* used to calculate the SSDE also decreased exponentially with increasing D$_w$. The SSDE values among the 12 scanners used appeared to have a maximum difference of up to 157% when calculated using the body CTDI$_{vol}$ and 143% when calculated using the head CTDI$_{vol}$. These differences reflect the differences in CTDI$_{vol}$ values as shown in Fig. 2.

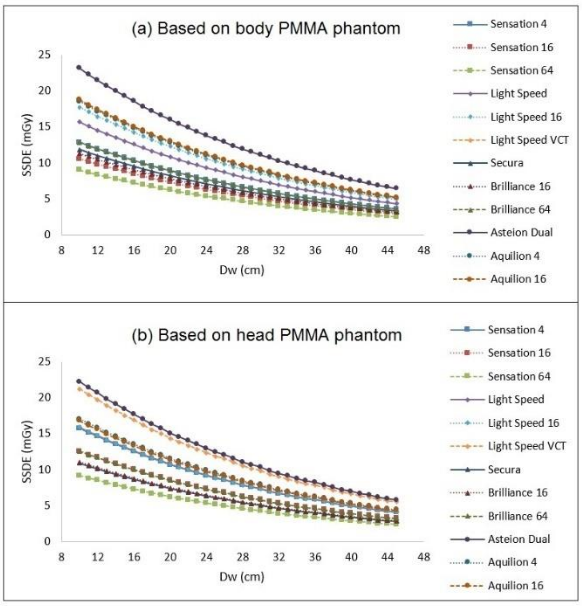

Fig. 3:SSDE versus D$_w$ for 12 scanners, (a) based on the body CTDI$_{vol}$, and (b) based on the head CTDI$_{vol}$

3.3. SSDE comparison based on the body and head CTDI$_{vol}$

The SSDE values based on either the body or head CTDI$_{vol}$ should be identical. However, the two may differ significantly. The comparisons of SSDE values based on the body and head CTDI$_{vol}$ for the 12 scanners are shown in Fig. 4 and Table 2. The differences between them were within 20%. The highest absolute difference was for the Sensation 4 scanner (18.8 ±2.6%), and the lowest absolute difference was for the Sensation 64 scanner (1.5 ± 2.1%).

Table 2: The difference in SSDE values based on the body and head CTDI$_{vol}$ for 12 scanners

Scanner	The difference of SSDE based on body and head CTDIvol (%)
Siemens	
Sensation 4	-18.8 ± 2.6
Sensation 16	-15.6 ± 2.5
Sensation 64	1.5 ± 2.1
GE	
Light Speed	1.9 ± 2.1
Light Speed 16	13.2 ± 1.9
Light Speed VCT	-9.6 ± 2.4
Philips	
Secura	10.5 ± 1.9
Brilliance 16	5.3 ± 2.0
Brilliance 64	5.2 ± 2.0
Toshiba	
Asteion Dual	6.9 ± 2.0
Aquilion 4	10.9 ± 1.9
Aquilion 16	13.4 ± 1.9

4. Discussion

SSDE is a descriptor used to estimate the dose for an individual patient undergoing a CT examination. SSDE is designed to be as simple as possible; therefore, it can be calculated easily in the clinical setting. However, three main reasons cause the SSDE estimate to differ from the real dose, i.e., inaccuracies in the value of the correction factor (*k*), in characterizing the individual patient (depending on the metrics and techniques used), and in the CTDI$_{vol}$ value. SSDE is calculated on the basis of a single CTDI$_{vol}$ value (either the head or body) [36] taken from the screen console, the DICOM header, or the dose report. In addition, CTDI$_{vol}$ may be measured using the pencil ionization chamber or CT dose profiler [2]. At every imaging center, the CTDI$_{vol}$ should be measured periodically as part of a quality control program [5]. The measurement is usually carried out using two types of PMMA phantoms, namely, the head and body phantoms.

SSDE for head examinations would be using the head CTDI$_{vol}$value, and for thoracic, abdominal, and pelvic examinations, it would be using the body CTDI$_{vol}$value. However, for pediatric protocols or when the small FOV is selected, there is no standard for the phantom diameter that should be used. For example, The body CTDI$_{vol}$ value was used by Siemens and Philips, and on other hand GE and Toshiba use the head CTDI$_{vol}$ value [32]. In this current study, the SSDE calculation based on both two CTDI$_{vol}$ values was compared.

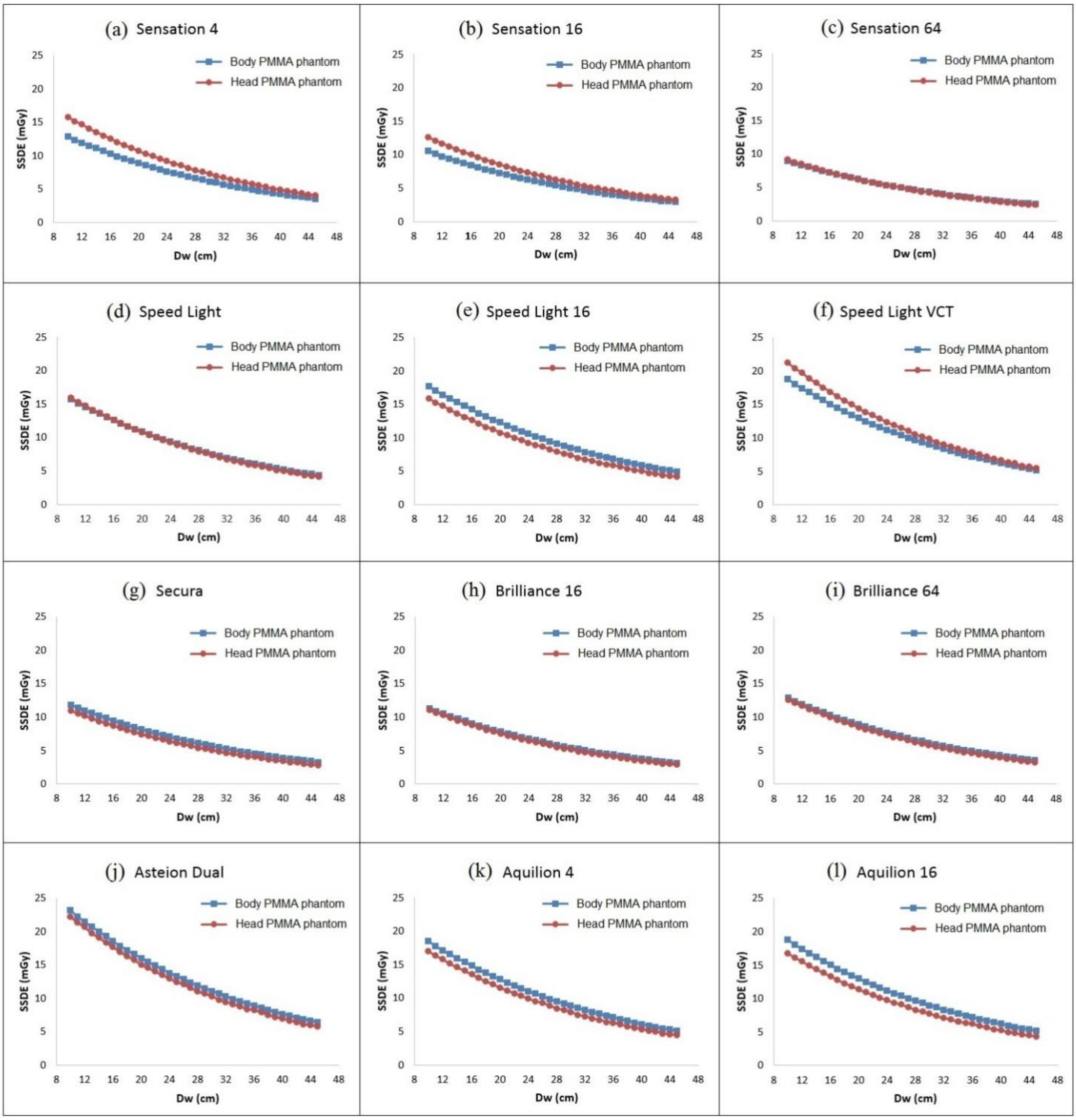

Fig. 4: The graph of SSDE based on the head and body $CTDI_{vol}$versus $D_w$for individual scanner

The finding of the current study was that the differences in SSDE values based on the head and body $CTDI_{vol}$ were within 20%. From the 12 scanners that were examined, six (~50%) produced a difference of more than 10%. Hence, the current study showed the SSDE calculation could use eitherbody or head $CTDI_{vol}$ value with the corresponding *k* value.

We found that the SSDE value for one type of scanner could not be estimated from another type of scanner, even when the scanners are from the same manufacturer or have the same number of detector arrays. The difference in SSDE values among scanners can vary more than 100% because of their different specifications. Consequently, the estimates of organ dose and effective dose must also bedetermined using the same type of scanner. The conversion factor to estimate organ doses is more flexible if it is normalized by $CTDI_{vol}$, as reported by Turner et al [37]. The current study was only carried out on 12 different scanners. A more extensive study should be conducted to include modern MDCT scanners with detector arrays above 64.

5. Conclusions

The differences in SSDE values based on the head and body $CTDI_{vol}$derived from the ImPACT software for the 12 scanners were within 20%. Hence, the SSDE value could be calculated using the head or body $CTDI_{vol}$ bases with the corresponding *k* value.

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