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ACQUISITION OF SIZE-SPECIFIC DOSE ESTIMATES FOR ABDOMINAL COMPUTED TOMOGRAPHY EXAMINATION IN NIGERIA: A PRELIMINARY STUDY USING A WATER EQUIVALENT DIAMETER

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ABSTRACT

Background

Size-specific dose estimates is an important metric for personalizing dose measurements during abdominal computed tomography (CT) examination. This study aimed to establish patient size-specific dose data as a guide for dose monitoring of abdominal computed tomography examinations among Nigerians.

Methods

Abdominal CT images of adult subjects obtained from two CT scanners - a light speed VCT –ZTe; (GE Healthcare) 16 – Slice and a Brivo CT 385 series; (GC Healthcare) 16-slice scanners were used in the study. The estimated computed tomography dose index volume ($CTDI_{vol}$) and dose length product (DLP) were extracted from the CT dose report on the patients' electronic Image folders. The effective size of the abdomen was obtained by using electronic caliper on the scanner console to measure the anterior-posterior and lateral dimensions at the level of the widest diameter on the image. With Table1A from the AAPM report 220, conversion factors were determined for a total of 264 abdominal CT images. The corresponding conversion factor was multiplied by the $CTDI_{vol}$ to obtain the size specific dose estimates (SSDE). The relationships between effective diameter (ED), $CTDI_{VOL}$ and age on SSDE were analyzed using minitab statistical software version 17.

Results

The mean CTDlvol was 6.94$\pm$ 1.63mGy, while SSDE was 9.76 $\pm$ 2.56mGy. The SSDE decreased significantly with effective diameter, and increased significantly with the CTDI vol. The effective diameter measured between 8.72.90 and 37.70cm.

Conclusion

The study concludes that the CTDvol and patient's abdominal size are determinant factors in the development of a size-specific radiation protection protocol and optimization of patient dose during abdominal CT examinations based on scanner output.

KEYWORDS: size-specific dose estimate; computed tomography; water equivalent diameter; CT dose Index

INTRODUCTION

The advent of CT has broadly transformed clinical practice and precipitated an overwhelming need for CT-based imaging in many clinical scenarios. Its utilization has gradually reduced requests for conventional radiographic imaging (Beyer et al., 2020). A study by Kocher et al.

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(2011) revealed that 3.2% of emergency patients received CT scans in 2007, with the expected utilization rising to 10% annually. Computed tomography has become the gold standard for a variety of medical indications such as the diagnosis for certain cancers, surgical planning and identifying internal injuries in trauma cases. Aside the diagnostic benefits, a study has shown defensive medicine to be one underpinning factor which contributes to the rise in CT usage (Huda and Mettler, 2011).

With increasing CT installations in low-income countries including Nigeria, a corresponding increase in medical radiation dose in these regions is expected. This understanding is expected to precipitate measures towards optimizing CT investigations while maintaining best dose reduction practices.

An approach that individualizes radiation dose during CT investigations based on a person's body size has been described in the American Association of Physicists in Medicine (AAPM) Report 204 (AAPM, 2007). The AAPM Reports recommends the establishment of CT dose estimates for patients based on size in order to optimize patient's dose and CT image quality. This is so because computed tomography dose index (CTDIvol) and dose length product (DLP) obtained during CT examinations only indicate scanner output, and do not reflect patient-specific dose. Size-specific dose estimate is a relatively new measure of radiation dose introduced by the AAPM, which provides an exact estimate of patient radiation dose taking into account both scanner output and patient dimensions to indicate radiation dose received by the patient from CT investigation.

Evidence has shown this approach to be effective in improving size-dependent, and exam-specific dose practice (Khuloud et al., 2024). Computed tomography dose is characterized in terms of the CT dose index (CTDl) and dose length product (DLP) (Huda and Mettler, 2011). However, CTDI indicates the amount of radiation targeted at a subject after CT investigation, and not the amount of radiation received (Yu et al., 2011). The introduction of SSDE as a dose parameter improves precision in terms of optimizing dose in CT practices, hence the need to promote a personalized dose protocol for CT examinations. Computed tomography dose index and dose length product DLP values are frequently used to represent radiation doses from a CT scanner. These descriptors, however are based only on patient geometry and do not take into account the different attenuations of various substances such as bone, tissue, and air. Size-specific dose estimate (SSDE) provides a simple estimate of the mean patient dose from a CT scanner at the center of the scan range (Yu et al., 2011) using the water equivalent phantom diameter. Abdominal conditions constitute a significant number of CT examination, which by implication form a huge contribution to medical radiation exposure from CT. To control exposure to the abdominal region, and adapt dose thinning measures during CT examination, automatic tube current modulation concept, was introduced to significantly reduce dose during abdominal CT examination. This measure did not account for patient specific characteristics, and thus, dose optimization was not specific to patient size. The patient size-specific dose estimate leverages patient size-specific measures to optimize abdominal CT dose.

This study aimed to assess patient size-specific dose estimate for the establishment of a dose optimization protocol for abdominal CT examinations.

MATERIAL AND METHODS

A total of 264 abdominal CT images of 264 patients within the age range of 18 to 85 years were drawn from the electronic folders of the two CT scanners for this study. These images were acquired with a light speed VCT –ZTe (GE Healthcare) 16 – Slice and a Brivo CT 385 series; GC Healthcare; May, 2013) 16-slice CT scanners. Imaging protocol used included tube potential of 120 - 140kV, Automatic Exposure Control (AEC) and tube-current- time product of 240 – 245mAs. The use of the AEC system allowed modulation of tube current in the longitudinal and angular directions to adjust scanner output according to the attenuation for each patient at different tube positions. Other technical parameters included 0.5 seconds rotation time, 128 x 0.6 m collimation, and a helical pitch of 0.8, 5mm slice thickness and 5-mm slice interval

Measurements of antero-posterior and lateral dimension were made with electronic calipers as shown in figure 1. For each patient's image, the anteroposterior (AP) and lateral (LAT) dimensions were measured at the level of the widest diameter in the image.

The measurements of the anteroposterior and lateral dimensions were done three times and the average recorded. The effective diameter is the average of the sum of the antero-posterior (AP) and lateral dimensions.

AP represents the anterior-posterior dimension, and LAT the lateral dimension.

$$Effective\ Diameter\ (ED) = \frac{(AP+LAT)}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (1.0)$$

Table 1 in the AAPM report 220 was used to determine the corresponding conversion factor (refer to page 3). Size specific dose estimate was estimated from equation 2

$$SSDE = F_{DW} \times CTDI_{Vol} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.0)$$ (AAPM, 2008).

Where F_{DW} represent SSDE conversion factor of the patient size D_w and $CTDI_{Vol}$ represents the absorbed dose to the scanned volume.

The estimated volume Computed Tomography dose index, ($CTDI_{vol}$), dose length product (DLP) measured in (milligray x centimeters) were obtained from dose report for each CT examination.

Size specific dose estimate (SSDE) values obtained from the CT scanner were analyzed using minitab statistical software version 17. The mean, standard deviation, range and 75th percentile values were computed for patient's age, sex, effective diameter (ED), $CTDI_{Vol}$, and SSDE. Linear regression models were used to estimate relationships between SSDE and Age; SSDE and Effective diameter (ED), as well as SSDE versus $CTDI_{Vol.}$ For each model the slope of fitted line at 95% confidence interval (CI) was estimated.

Table 1: AAPM report 220 for conversion factor based on effective diameter

Lat + AP Dim (cm)	Dw (cm)	Conversion Factor
16	7.7	2.79
18	8.7	2.69
20	9.7	2.59
22	10.7	2.50
24	11.7	2.41
26	12.7	2.32
28	13.7	2.24
30	14.7	2.16
32	5.7	2.08
34	16.7	2.01
36	17.6	1.94
38	18.6	1.87
40	19.6	1.80
42	20.6	1.74
44	21.6	1.67
46	22.6	1.62
48	23.6	1.56
50	24.6	1.50
52	25.6	1.45
54	26.6	1.40
56	27.6	1.35
58	28.6	1.30
60	29.6	1.25
62	30.5	1.21
64	31.5	1.16
66	32.5	1.12
68	33.5	1.08
70	34.5	1.04
72	35.5	1.01
74	36.5	0.97
76	37.5	0.94
78	38.5	0.90
80	39.5	0.87
82	40.5	0.84
84	41.5	0.81
86	42.4	0.78
88	43.4	0.75
90	44.4	0.72

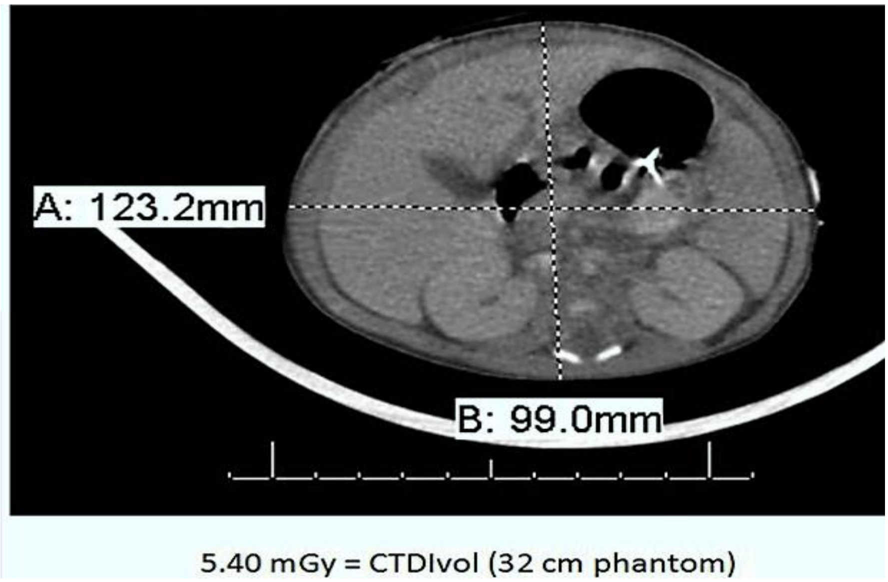

Figure 1: Axial CT image of the Abdomen at the level of the umbilicus. It shows how AP and LAT Dimensions were measured from Abdominal CT images.

RESULTS

The mean age was 48.50 $\pm$ 17.0years with effective diameter (ED) of 27.00 $\pm$ 3.8cm for abdomen CT images. The mean scanner output as indicated by the CTDlvol was 6.94$\pm$ 1.6mGy. The mean SSDE was 9.76 $\pm$ 2.6 mGy. The SSDE 75th percentile value was10.39mGy. Mean ED, CTDI and SSDE were 26.90±3.6 cm, 6.78±1.4 mGy and 9.56±2.4mGy for women and 27.09±4.1 cm, 7.11±1.8 and 9.92±2.7mGy for men respectively. From the scatter plot (Figure 2), SSDE decreased significantly with effective diameter (ED), with the effective diameter accounting for 17% of variance in SSDE. The SSDE also increased significantly with CTDIvol, with the CTDIvol, accounting for 46% % of variance in SSDE. (Figure 3)

Table 2: Effective Diameter, CTDI vol and SSDE with the age of patients

Statistic	Age in (yr)	Effective Diameter (cm)	$CTDI_{vol}$(mGy)	SSDE(mGy)
Mean	48.02	27.00	6.94	9.76
Standard Deviation	16.28	3.84	1.63	2.56
Minimum	19.00	8.71	5.05	6.05
Maximum	85.00	37.70	12.20	23.82
75th Percentile	61.00	29.60	6.81	10.39

TABLE 3: SSDE, CTDIvol, ED with sex of the patients

Statistic	Age(y) Women	ED(cm)	$CTDI_{VOL}$ (mGy)	SSDE (mGy)	Age(y) Men	ED (cm)	$CTDI_{VOL}$ (mGy)	SSDE (mGy)
Mean	46.13	26.90	6.78	9.56	49.97	Th	7.11	9.92
Standard Deviation	14.73	3.60	1.42	2.37	17.58	4.08	1.81	2.74
Minimum	19.00	13.17	5.05	6.05	20.00	8.72	5.05	6.27
Maximum	85.00	37.70	10.27	23.82	85.00	36.85	12.22	23.79
75^{th} Percentile	60.00	29.17	6.48	10.00	66.00	29.95	8.95	10.94

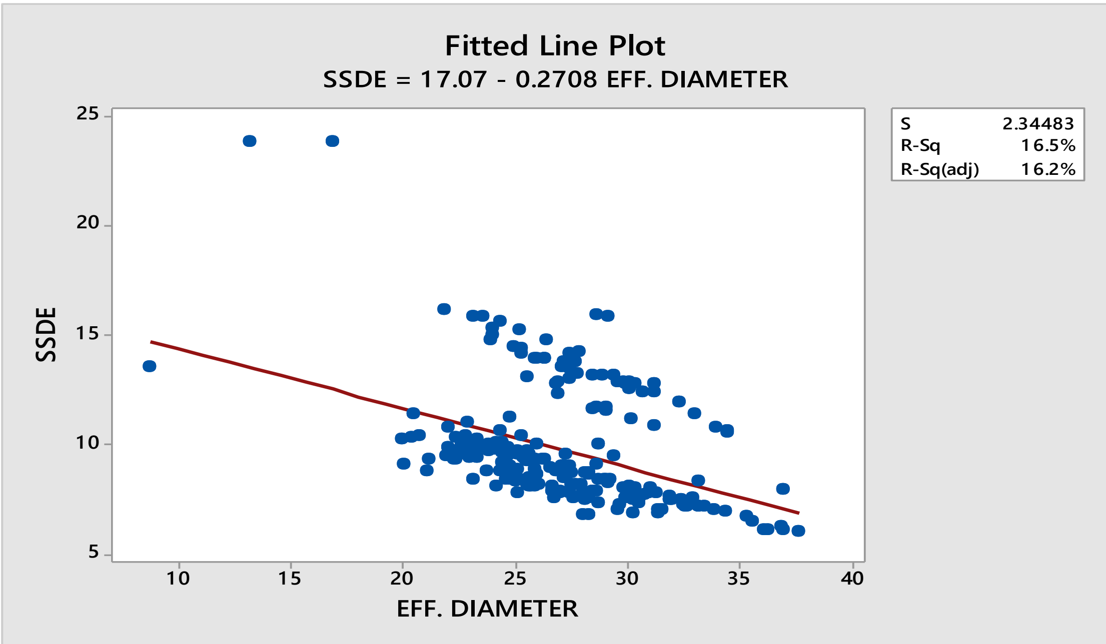

Figure 2: SSDE vs Effective Diameter in CT Abdomen SSDE decreased significantly with effective diameter, with the eff. Diameter accounting for 17% of variance in SSDE.

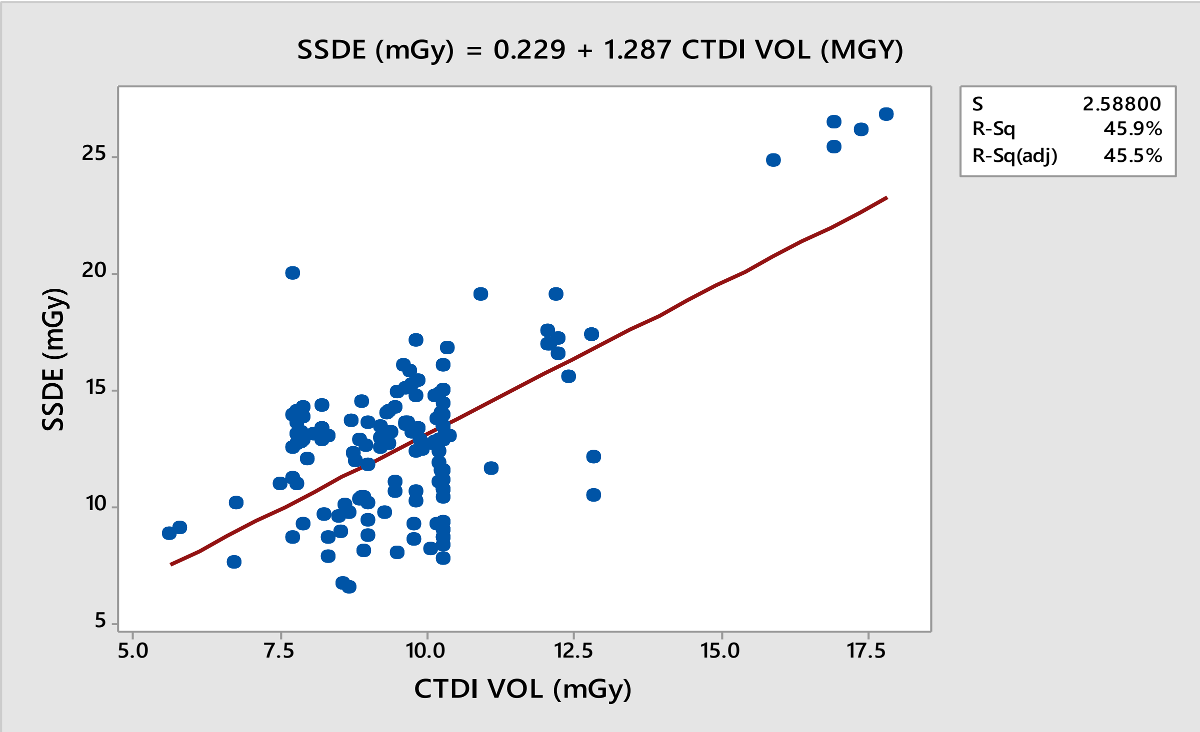

Figure 3: SSDE vs $CTDI_{vol}$ in CT Abdomen SSDE increased significantly with CTDIvol, with the CTDIvol accounting for about 46% of variance in SSDE

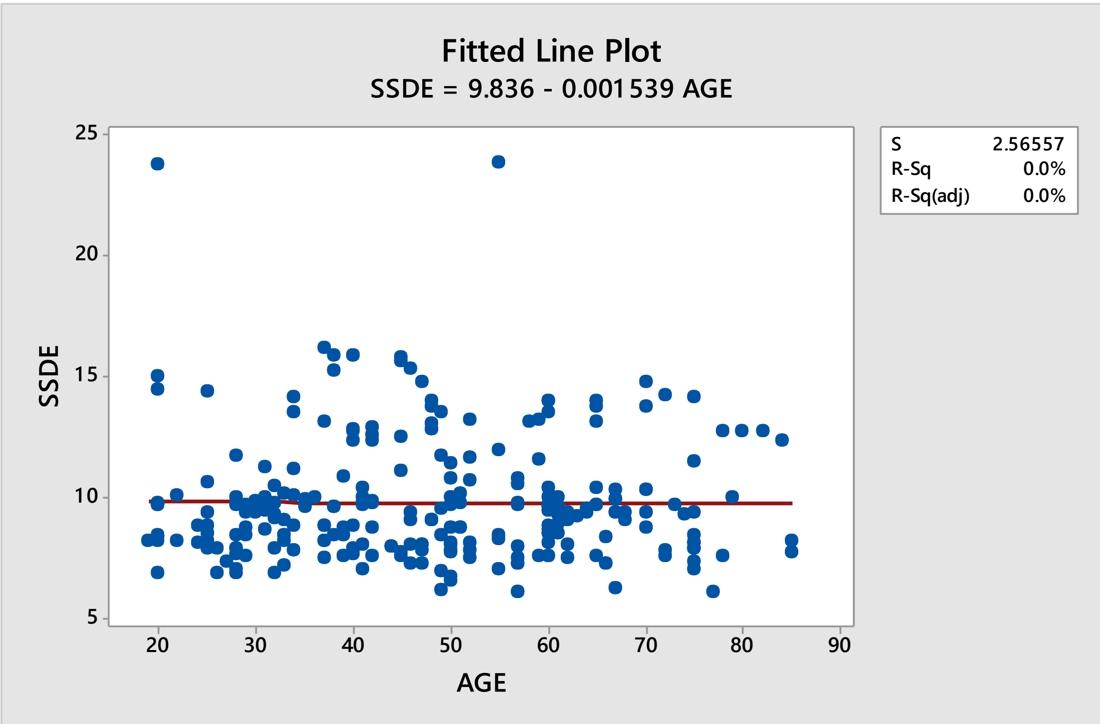

Figure 4: Scatter plot demonstrating the relationship between SSDE and Age

DISCUSSION

This study is the first attempt to apply SSDE in adult abdominal CT examination in Nigeria. The size-specific dose estimate was similar to the result of Moore et al., (2014), with 75th percentile and mean SSD values at 10.39mGy and 9.76mGy, respectively. Values were also comparable for male and female (Table 3). The SSDE was seen to decrease significantly with increasing effective diameter (ED), which accounted for 17% of the variance in SSDE (Figure 2). This relationship implies that the impact per unit area of exposure (ionization) is more with a smaller exposed area, and therefore more ionization. This means that, for comparable scanner outputs (CTDIvol), the SSDE per patient could be a function of the patient's size, and result indicates higher SSDE values for subject with bigger linear dimensions (Figures 3). A similar result was obtained in a study by Brady and Kaufman (2012), which reported that size-specific dose estimate was dependent on body size in a group of children of varied ages and body masses. A positive relationship was seen between the SSDE and CTDI (Figure 3), with CTDIvol accounting for about 46% of the variability in SSDE, in consonance with previous published evidence (Israel et al., 2010). The CTDI is an important metric for estimating SSDE: for the CT scan of the abdomen, if the scan range were extended either ways, superiorly or inferiorly, such that the lungs or pelvic bone could be included in the scan, the $CTDI_{vol}$ value of the scan changes, as the reported $CTDI_{vol}$ value is averaged throughout the entire scan length. Including lung tissues would tend to reduce the reported $CTDI_{vol}$, while an increase in $CTDI_{vol}$ is seen where a greater part of the pelvic region is included. Patient-to-patient variations are also expected because of differences in body habitus, for example, variations in the proportion of muscles to adipose tissue and the spatial distribution of body fat (Shah et al., 2023). $CTDI_{vol}$ is expected to differ, even for patients of the same AP + LAT dimension, with the estimate of patient dose influenced by patient's size (Israel et al. 2011). The strength of adjustment of scanner output for a change in patient size should be established by the user for a specific diagnostic task. The size of a patient changes along the z-axis of a CT scan of the abdomen owing to variations in the body shape, size and attenuation at different areas, with significant variation of D_w in each of the scan range. The size variation is expected to produce varying SSDE values for different body size and shape, the size-dependent conversion factor and $CTDI_{vol}$, which vary because of the use of automatic exposure control in most CT scans of the body.

Although CTDIvol and DLP reflects the absorbed dose by the patient (Beyer et al., 2020), they do not indicate the exact dose a patient receives from CT examination (Yu et al., 2011). Several authors have also pointed out that effective dose is not a metric of patient dose (AAPM, 2008; Martin, 2007; Brink and Morin, 2012). Using only $CTDI_{vol}$ or effective dose to compare patient radiation dose may result in underestimation by a factor as high as 2.5 (AAPM, 2007). The SSDE is fast gaining acceptance and recognition as a valuable tool in modifying CT protocols, and describing individual dose from CT investigations in some developed countries (Bankier and Kressel, 2012; Turner, Zhang and Khatonabadi, 2011).

In a previous study (Cheng, 2013), proposed a method for automated estimation of patient effective diameter in Abdomen CT. It was found that effective diameter in the middle section of an abdominal CT examination was close to the mean effective diameter, and the difference between the SSDE calculated by using the effective diameter of the middle image in the scan range and the mean of the per-image SSDE was relatively small. In The current study, we used D_w to quantify patient attenuation, which was calculated based on the CT number of each pixel to take into account the attenuation of each voxel. (Although the term "effective diameter" was used in AAPM Report 204, (APPM, 2007). The size-specific conversion factors were based on the effective diameter of water-equivalent materials, which is the same as calculating D_w).

In this study, patient dose estimated with size-specific dose estimate was dependent on patient size and increased with body volume. This result differs from the study by Christner *et al.* (2012), in which the size-specific dose estimate was independent of size. An essential difference was that the study by Christner et al. (2012), was performed on a different manufacturer's scanner (Siemens Healthcare) whereas our study was performed using general electric (GE) Healthcare scanners. One possible reason for this difference may be the diverse mechanism of automatic exposure control systems used by the two manufacturers. Also, the present study showed that the SSDE of a patient is not dependent on age (Figure 4). This may be expected as patient size may not directly depend on age. For a given CT technique, the patient dose increases as patient size increases, this is due to increase attenuation of the incident x-ray beam. The report states that, because patient size is included in the calculation of SSDE, SSDE gives a more meaningful estimate of patient dose, and therefore patient risk than the value of $CTDI_{vol}$ which is currently saved in patient dose reports. The patient cohort in the study represented a wide spectrum of patient size, thus, results may be generalizable to any adult population.

We chose to do this because greater size variation along the z-axis was expected in adult patients compared with pediatric patients. However, further work with pediatric patients is important to obtain effect of pediatric patient size variation on SSDE calculations, particularly because SSDE conversion factor as a function of patient size (Dw) changes more rapidly at low Dw values in children than at large Dw values in adults. The limitation of this study was that it included CT scanners from a single manufacture, and manufacturer's equipment specific differences per patient size variation with scanner output for abdominal CT investigation could have added more value to the present study. Values from this work could be used to provide baseline data for further studies.

CONCLUSION

SSDE values was determined for a population of Nigerian adults undergoing CT examinations. The study concludes that the CTDIvol and patient's abdominal size are determinant factors in the development of a size-specific radiation protection protocol, and optimization of patient dose during abdominal CT examinations based on scanner output. It is therefore recommended that attention be given to small-sized patients who need the biggest correction factor for body size in radiation dose estimation. These SSDE values can be adopted to develop a radiation protection protocol for abdominal CT in Nigeria.

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