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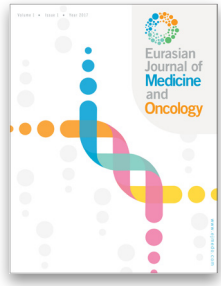

Research Article

Computed Tomography Organ Dose Determination Using ImPACT Simulation Software: Our Findings In South-West Nigeria

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Abstract

Objectives: The aim of this study was to estimate mean organ dose using the imPACT software, and to determine if dose vary significantly for similar organ among the 7 Computed Tomography (CT) units and to compare and correlate our findings with international studies with similar software.
Methods: Seven CT units denoted as A-G was randomly selected. An imPACT Patient Dosimetry Calculator Software was used to determine organ dose to the head, chest, abdomen and pelvic region from 210 patients' CT parameters retrieved from the CT monitor. Data analysis was done using SPSS 16.0 (SPSS Inc, Chicago, IL, USA).
Results: The mean dose to organs in the head (brain and eye lens) was 27.87±9.58 and 55.27±22.34mGy; chest (lungs, breast, thyroid and heart) was 30.63±8.21, 26.41±6.76, 10.21±7.00 and 29.93±9.65mGy; Abdomen (stomach and liver) was 34±12.8 and 33.05±9.93mGy and Pelvis (bladder and uterus) was 32.44±13.8 and 28.97±7.14mGy respectively. Similar organ show statistically significant difference: for brain ($p<0.001$), eye lens ($p=0.001$), lungs ($p<0.001$), breast ($p<0.001$), thyroid ($p=0.008$), heart ($p<0.001$), stomach ($p<0.001$), liver ($p=0.001$), bladder ($p<0.001$) and uterus ($p=0.002$) among the 7 CT units. There was no correlation in organ dose for this study and those of Tanzania, Turkey, Japan and Thailand.
Conclusion: Significant differences exist in similar organ doses among the 7 CT units in Lagos indicating that there was lack of harmonization in CT protocols.
Keywords: Computed tomography, computed tomography dose index, imPACT dosimetric software, Ionization cham-ber, monte carlo code, perspex

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The use of multi-slice Computed Tomography (CT) has increased across South-West Nigeria due to high number of privately owned CT centers. Also, it has become one of the favorites of referring physicians due to its multiple X-ray projection and its ability to see detail. It is acclaimed that the South-West geo political zone have one of the highest number of radiological manpower (radiologist and radiographers) in Nigeria due to the population size with Lagos having over 10 million people. It is considered to have the highest number of modern CT scanners.[1-3] Current stand in Nigeria to harmonize CT protocols and radiation dose in other imaging modalities have not been established due to poor regulatory policies and poor communication between regulators and facility owners.[4]

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Besides the natural background radiation, medical exposure has become the largest source of ionizing radiation exposure to the human population.[5-7] Computed Tomography (CT) is one of the most widely used diagnostic medical imaging modalities in clinical use, and is increasingly used because of the technological advancements and its sophisticated work station.[8-10] According to National Council on Radiation Protection and Measurements (NCRP) report No. 160, CT scans contributed half of the total patient medical exposure.[11] Although, the benefits of computed tomography (CT) in medicine are well known, increased concerns about the radiation dose associated with CT have drawn the attention of imaging experts and professional to discuss how patient dose can be reduced.[12, 13] On the other hand, there are latent dangers (stochastic effect) arising from this radiation to have random effect that may not appear immediately, but may appear in later years or even generations to come.[14] The need to put into consideration organ tolerance in relation to dose optimization by reviewing CT protocols have now become pertinent since organ doses to patients undergoing CT examinations are generally much higher than those associated with conventional, mammographic and fluoroscopic projections.[15, 16]

To overcome this problem, different software packages for dose calculation in CT have been developed.[17-22] They include the following: imPACT CT dosimetry calculator (St George's Healthcare, London, UK)[23], CT Dose[24], CT Expo[25] and WinDose[19] with the purpose to determine Computed Tomography Dose Index (CTDI), Dose Length Product (DLP) and Effective Doses using computational method and Monte Carlo simulation. Several methods of estimating organ dose have been proposed, one of such method is the use of a physical anthropomorphic phantom representing adult male and female or pediatric patients using Thermoluminescent Dosimeters (TLDs) as detectors . These phantoms are usually cut into sections, which contain holes for the position of dosimeters.[26-29] More so, recent studies have estimated organ dose through the use of cadavers (postmortem studies).[30, 31]

The aim of this study was to first estimate each organ mean dose in: head (brain and eye lens), chest (lungs, breast, thyroid and heart), abdomen (stomach and liver) and pelvis (bladder and uterus), using the imPACT dose simulation software, to compare similar organ dose among the 7 CT units if they vary significantly, to determine range of percentage mean dose difference for this study and related study and to generally compare mean organ doses with international studies who used similar software and other methods (TLD and postmortem studies).

Methods

A total of seven CT unit within Lagos metropolis (covering Lagos Island and Mainland) was used for this study, out of which three were government owned and four were privately owned hospitals. A total of 210 patients' data were retrieved (77 male and 133 female) from the CT monitor. Particularly, convenience simple random sampling technique was used to carefully select adult male and female who have had CT of the head, chest, abdomen and pelvis. The organs investigated in the head were the brain and eye lens, in the chest were the lungs, breast, thyroid and heart, in the abdomen were the stomach and liver and in the pelvis were the bladder and uterus. This retrospective study lasted for 10 months. The seven CT facilities used were three General Electric, three Toshiba and one Phillips CT machine and were denoted as A-G (Table 1).

The imPACT CT Dosimetry spreadsheet used in this study was donated through the intervention of the International Atomic Energy Agency (IAEA). The focus was to estimate CT organ dose using an adult, hermaphrodite, mathematical phantom (Fig. 1). The imPACT CT Dosimetry spreadsheet is based on Monte Carlo Data Set with pre-calculated Computed Tomography Dose Index measurements in free air ($CTDI_{100}$), center ($CTDI_{100, C}$) and peripheries ($CTDI_{100, P}$) that

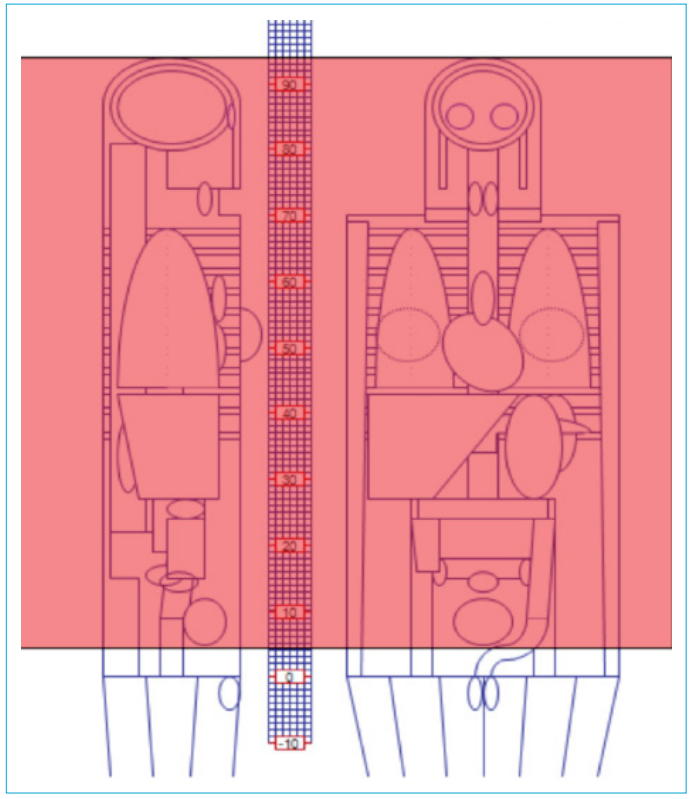

Figure 1. Mathematical phantom used with imPACT software to compute patient doses covering the head, chest and abdonino-pelvic region.

had been measured in a standard Perspex head and body dosimetry phantom, using the same ionization chamber, and a consistent technique that have proven to be good for most of the CT scanners used. These measurements in turn are useful for calculation of CTDI weighted ($CTDI_w$), CTDI volume ($CTDI_{vol}$), DLP and other dose parameters. One other factor that was considered were scanners that are not included in the data set; to address this, scanner matching data that enables newer scanners to be used with the NRPB-SR250 dose distribution data obtained from Monte Carlo calculations for older scanner models was added to the spreadsheet, creating flexibility to calculate organ dose with more recent scanners. It was based on this established fact that the spreadsheet was used for this study (Fig. 2).

Based on scan region (that is for organs in the head, chest abdomen and pelvis) the following was determined from each CT used: manufacturer or brand name, scanner model, tube voltage, tube current, scan range, rotation time, spiral pitch and collimation. Parameters that were inputted manually into the CT Dosimetry spreadsheet was the tube current, rotation time and spiral pitch which vary in protocol and from vendor to vendor. GE Bright Speed Edge and GE Bright Speed Elite were matched with GE Light Speed Ultra scanner from the spreadsheet since they have similar configuration and dose distribution. Similarly, GE Optima™ 660 was matched with GE Light Speed VCT; Toshiba Aquilion 16, 64 and 128 was matched with Toshiba Aquilion 16 and Philips Brilliance 16 was found on the data set (Table 1). Scanner-matching data used for this study had an uncertainty of not more than 15% of organ dose measurement since original scanner model where not available in the data set. [32-34]

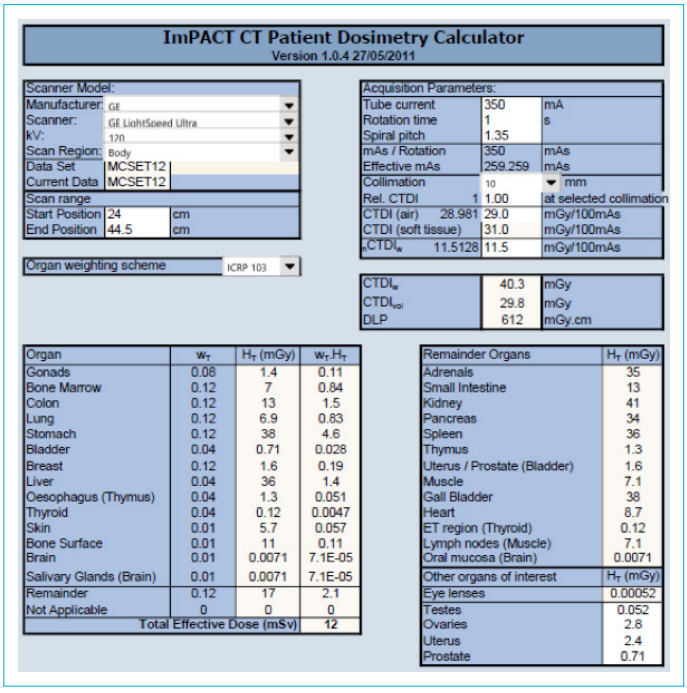

Figure 2. An overview of the imPACT CT dosimetry spreadsheet.

Mathematical expression guiding the formula for CTDI weighted ($CTDI_w$) in relation to CTDI at the center and CTDI and at the peripheries was:

$$CTDI_W = \frac{1}{3}CTDI_{100,C} + \frac{2}{3}CTDI_{100,P}$$

Where c=center and p=periphery

The imPACT version used was 1.0.4× (27/05/2011), which was able to model various conditions of exposure for the range of common makes of CT scanner as discussed in NRPB-R250. Parameters of the spreadsheet were also used to determine relative CTDI (Rel. CTDI), normalized $CTDI_{air}$ and normalized weighted CTDI ($_nCTDI_w$).Normalized measurement in free air ($CTDI_{air}$) was converted to tissue (CTDI soft tissue) automatically when $CTDI_{air}$ value was inputted into the imPACT spreadsheet. This was done by using the International Commission on Radiation Units and Measurement (ICRU) factor for muscle which is given by:

$$CTDI_{tissue} = CTDI_{air} \times 1.07$$

The relative CTDI (Rel.CTDI) was calculated using each centre collimation, relative to the CTDI at 10mm collimation. Normalized weighted CTDI ($_nCTDI_w$) was obtained by divid-

Table 1. Brief description of the CT machines used

Scanner model	Manufacturer (Brand name)	Scanner slice	Max. power (KVA)	Max. voltage (KV)	Max. current (mAs)	Max FOV (cm)
GE Bright speed edge	General electric	8	53.2	140	440	50
GE Optima™ 660	General electric	64	72.0	140	560	50
Toshiba aquilion	Toshiba	128	100	135	600	50
Philips brilliance CT 16	Philips	16	60	140	500	50
GE Bright speed elite	General electric	16	53.2	140	440	50
Toshiba aquilion	Toshiba	16	60	135	500	50
Toshiba aquilion	Toshiba	64	100	135	600	50

Max: Maximum; FOV: Field of View.

ing the weighted CTDI ($CTDI_w$) value by the mAs (miliampere seconds), which can be written mathematically as:

$$_{n}CTDI_{w} = \frac{CTDI_w}{mAs}$$

It was necessary to note that the $_{n}CTDI_{w}$ is characteristic quantity for scanner (dose rate coefficient), it represent the capacity of a scanner in terms of output. It is independent of the patient dose. Also, % mean dose differences were determined and their ranged were compared using the relation:

$$\%\ diff = \frac{2|\Delta d|}{\sum d} \times 100$$

Where $|\Delta d|$ = difference in dose, $\sum d$ = summation of dose.

Statistical Tool Used

Data analysis was done using Microsoft Excel and SPSS Version 16.0. Descriptive statistics was used to determine mean organ dose and % difference, Independent Sample t test and Pearson correlation was used to analyze our data. For $p<0.05$ was termed to be statistically significantly.

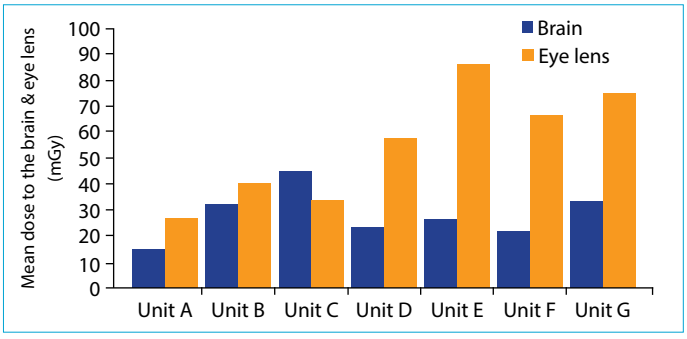

Figure 3. Mean dose to the brain and eye lens in CT unit A-G in the head region.

Table 2. Mean organ dose for Head region in 7 CT facility using the ImPACT Software calculator

CT Facility	Selected organ Head region	Mean dose (mGy)
CT Unit A	Brain	15.0±1.5
	Eye lens	27.6±2.0
CT Unit B	Brain	31.8±10.9
	Eye lens	39.5±12.8
CT Unit C	Brain	44.7±9.3
	Eye lens	33.4±13.3
CT Unit D	Brain	22.6±7.4
	Eye lens	57.3±10.3
CT Unit E	Brain	27.4±13.6
	Eye lens	86.2±11.1
CT Unit F	Brain	21.5±5.6
	Eye lens	68.4±17.1
CT Unit G	Brain	32.1±13.6
	Eye lens	74.5±12.8

Results

Doses to organs in the head region were as follows: CT Unit A-G, which comprise of the brain and eye lens was 15.0 and 27.6 mGy, 31.8 and 39.5 mGy, 44.7 and 33.4 Gy, 22.6 and 57.3 mGy, 27.4 and 86.2 mGy, 21.5 and 68.4 mGy and 32.1 and 74.5mGy respectively (Table 2).

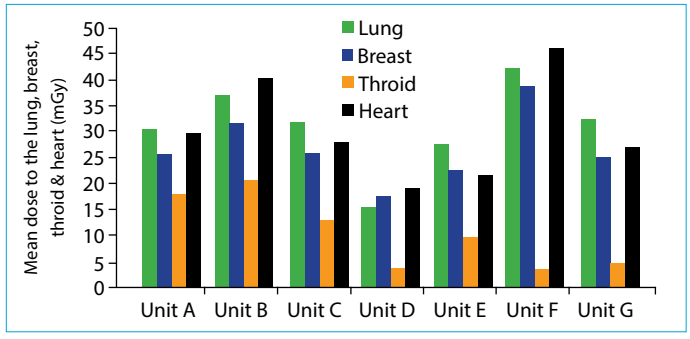

Figure 4. Mean dose to the lungs, breast, thyroid and heart in CT unit A-G for chest region.

Table 3. Mean organ dose for Chest region in 7 CT facility using the imPACT Software calculator

CT Facility	Selected Organ Chest region	Mean dose (mGy)
CT Unit A	Lung	30.1±10.1
	Breast	25.3±8.3
	Thyroid	17.8±14.6
	Heart	29.3±10.1
CT Unit B	Lung	36.4±10.2
	Breast	31.3±8.7
	Thyroid	20.4±10.8
	Heart	39.9±9.7
CT Unit C	Lung	31.4±3.3
	Breast	25.6±3.9
	Thyroid	12.7±4.1
	Heart	27.6±4.3
CT Unit D	Lung	15.3±9.6
	Breast	17.3±10.9
	Thyroid	3.4±9.8
	Heart	18.9±11.2
CT Unit E	Lung	27.4±3.2
	Breast	22.2±4.5
	Thyroid	9.3±5.2
	Heart	21.4±6.3
CT Unit F	Lung	41.7±7.6
	Breast	38.4±7.1
	Thyroid	3.3±8.3
	Heart	45.7±9.7
CT Unit G	Lung	32.1±11.7
	Breast	24.8±12.5
	Thyroid	4.6±10.4
	Heart	26.7±9.4

Table 4. Mean organ dose for Abdomen & Pelvic region in 7 CT facility using the imPACT Software calculator

CT Facility	Selected Organ Abdomen & Pelvic region	Mean dose (mGy)
CT Unit A	Stomach	27.8±6.6
	Liver	26.1±6.2
	Bladder	29.8±7.1
	Uterus	24.6±6.1
CT Unit B	Stomach	18.5±8.2
	Liver	17.3±7.3
	Bladder	19.6±8.2
	Rectum	21.7±6.7
CT Unit C	Stomach	41.3±5.5
	Liver	45.1±8.1
	Bladder	38.8±7.3
	Uterus	30.3±4.7
CT Unit D	Stomach	33.7±7.6
	Liver	37.0±7.2
	Bladder	31.2±7.9
	Uterus	32.6±6.9
CT Unit E	Stomach	56.2±6.4
	Liver	43.3±7.2
	Bladder	60.2±5.7
	Uterus	31.3±6.6
CT Unit F	Stomach	38.3±4.6
	Liver	34.7±3.3
	Bladder	21.8±4.1
	Uterus	41.1±3.0
CT Unit G	Stomach	22.2±3.7
	Liver	27.9±3.5
	Bladder	25.7±4.3
	Uterus	20.9±3.6

Table 5. Overall average dose of each organ

Regions	Organ	Mean dose (mGy)
Head	Brain	27.87±9.58
	Eye lens	55.27±22.34
Chest	Lung	30.63±8.21
	Breast	26.41±6.74
	Thyroid	10.21±7.00
	Heart	29.93±9.65
Abdomen & Pelvic region	Stomach	34.00±12.80
	Liver	33.06±9.93
	Bladder	32.44±13.80
	Uterus	34.68±17.74

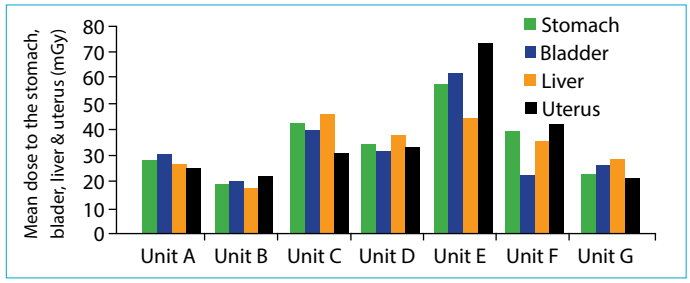

Figure 5. Mean dose to the stomach, liver, bladder and uterus in CT unit A-G in the Abdomino-pelvic region.

Doses to organs in the chest region were as follows: CT Unit A-G, which comprise of the lung, breast, thyroid and heart were 30.1, 25.3, 17.8 and 29.3 mGy, 36.4, 31.3, 20.4 and 39.9 mGy, 31.4, 25.6, 12.7 and 27.6 mGy, 15.3, 17.3, 3.4 and 18.9 mGy, 27.4, 22.2, 9.3 and 21.4 mGy, 41.7, 38.4, 3.3 and 45.7 mGy and 32.1, 24.8, 4.6 and 26.7 mGy respectively (Table 3).

Doses to organs in the abdomen and pelvic region were as follows: CT Unit A-G, which comprise of the stomach, liver, bladder and uterus were 27.8, 26.1, 29.8 and 24.6 mGy, 18.5, 17.3, 19.6 and 21.7 mGy, 41.3, 45.1, 38.8 and 30.3 mGy, 33.7, 37.0, 31.2 and 32.6 mGy, 56.2, 43.3, 60.2 and 31.3 mGy, 38.3, 34.7, 21.8 and 41.1 mGy and 22.2, 27.9, 25.7 and 20.9 mGy respectively (Table 4).

Furthermore, the mean overall dose to eye lens, brain, lung, breast, thyroid, heart, stomach, liver, bladder and uterus was 55.27, 27.87, 30.63, 26.41, 10.21, 29.93, 34, 33.05, 32.44 and 28.97mGy respectively (Table 5).

Our findings show that there were significant differences for similar organ among the 7 CT units: for brain ($p<0.001$), eye lens ($p=0.001$), lungs ($p<0.001$), breast ($p<0.001$), thyroid ($p=0.008$), heart ($p<0.001$), stomach ($p<0.001$), liver ($p=0.001$), bladder ($p<0.001$) and uterus ($p=0.002$) among the 7 CT units (Fig. 3-5). There were no significant differences when comparing mean dose for similar organs in this study and related studies except for the brain and thyroid whose difference were significant. There were no correlation between this study and those of Tanzania ($p=0.642$), Turkey ($p=0.826$), Japan ($p=0.406$) and Thailand ($p=0.592$). Percentage (%) mean differences in organ dose between our study and related studies for different organs were between the ranges of 1-133 (Table 6).

Table 6. Comparison of organ dose and % mean differences (mGy) for this study with other international studies

Organ	This study (Nigeria)[a]	Cakmak et al. (Turkey)[a]	% mean Diff.	Ngaile et al. (Tanzania)[a]	% mean Diff.	Kawaguchi et al. (Japan)[a]	% mean Diff.	Puekpuang et al. (Thailand)[a]	% mean Diff.
Brain	27.87	37.00	28	-	-	-	-	-	-
Eye lens	55.00	45.00	20	63.9	15	-	-	-	-
Lung	30.63	33.00	7	31.5	3	34.00	10	19.5	44
Breast	26.41	-	-	26.1	1	29.00	9	14.9	56
Thyroid	10.21	51.00	133	12.3	19	50.00	132	-	-
Heart	29.93	33.00	10	-	-	-	-	19.2	44
Stomach	34.00	-	-	35.6	5	38.00	11	8.5	120
Liver	33.06	13.00	87	34.1	3	36.00	9	10.4	104
Bladder	32.44	32.00	1	28.8	12	38.00	16	-	-
Uterus	34.68	25.00	32	26.5	27	-	-	-	-

[a]: comparison was done with imPACT Software only. % mean diff: Percentage mean difference.

Discussion

Organ doses to the brain and eye lens in this study among the 7 CT units showed high differences with p<0.001 and p=0.001 respectively, indicating that the technical parameters used in each CT unit among the hospitals were different. The highest dose to the brain and eye lens was noticed in CT unit C and E (44.7mGy and 86.2mGy) respectively and the lowest dose was noticed in CT unit A (15.0mGy and 27.6mGy) respectively, with an overall mean dose of 27.87mGy and 55.27mGy respectively. The results were slightly comparable to a study carried out in Turkey by Cakmak et al. whose estimated dose to the brain and eye lens using imPACT Software was 37mGy and 45mGy. The modulus % difference between our study and Cakmak dose to the brain and eye lens using the imPACT Software was 28 and 20 respectively.[35] In the same vein, our result was consistent with a study conducted in Tanzania by Ngaile et al. who also used the imPACT Software to determine organ doses. Ngaile's dose range to the brain was 32.5-84.4mGy which was higher than those obtained in our study which was 15-44.7mGy.[36]

Also, Organ dose to the lungs, breast, thyroid and heart in this study among the 7 CT units also showed similar differences in dose value with lungs (p<0.001), breast (p<0.001), thyroid (p=0.008), heart (p<0.001), further proving statistically significant differences in protocol used by each CT unit among the hospitals. The dose range to the lung in this study was 15.3-41.7mGy, with an average dose of 30.63mGy. This was comparable to a study conducted in Tanzania by Ngaile et al. whose range for the lungs was 20.1-44.0mGy, with an average dose of 32mGy. Further insight show that there was no significant difference between this study mean dose and a study carried out in Turkey by Cakmak et al., whose mean dose using the imPACT Software was 33mGy. In another related study conducted in Thailand by Puekpuang et al.[37] using imPACT Software, the dose range was 15-20mGy, with an average dose of 19.5mGy. Our (15-41.7mGy) minimum dose was consistent but was quite higher at maximum dose when compared to Puekpuang et al.[37] A comparison of this study dose range (15-41.7mGy) with a postmortem study conducted in USA by Sinclair et al. with dose range (14-21.9mGy) was consistent at the minimum dose point but showed disparity at the maximum dose point.[30]

Furthermore, the dose range and mean dose to the breast for this study was 17-31.3mGy and 26.41mGy, these values were in line with Ngaile et al. whose dose range and mean dose was 14.8-36mGy and 26.1mGy respectively. Similarly, Sinclair et al. who used postmortem subject had a dose range of 10.3-25.2mGy, which was quite lower than this study. Also in another study in Japan carried out by Kawaguchi et al.,[38] mean dose for Aquilion 64 was 29mGy which was comparable with this study but there was slight difference with Aquilion RXL whose mean dose value was lower than this study. Dose range to the breast from Puekpuang et al. study was 14-15mGy and its mean dose was 14.9mGy. These values were lower than this study in terms of the range and mean dose.

In addition, this study range and mean dose to the thyroid was 3.3-17.8mGy and 10.21mGy respectively. This was in line with Ngaile et al. whose dose range and mean dose was 4.6-21.5mGy and 12.3mGy respectively. Large difference was seen in mean dose between this study and Cakmak et al. whose dose with imPACT Software was 51mGy. Similarly this difference in dose was seen in Kawaguchi et al. whose mean dose using Aquilion 64 and RXL was 50 and 21mGy respectively.

The range and mean dose to the heart for this study was 21.4-45.7mGy and 29.93mGy respectively. This was higher than Puekpuang et al. study whose range and mean dose was 12-20.2mGy and 19.2mGy respectively. In the same vein, Cakmak et al. mean dose using the imPACT Software was 33mGy; it was quite higher than this study's mean dose to the heart.

Further evaluation of results show that this study's range/mean dose to the stomach and liver was 18.5-56.2mGy/34mGy and 17.3-45.1/33.06mGy respectively. These dose values were higher than Sinclair et al. whose dose range was 11-28.4 and 12.2-28.7mGy respectively and this study dose values were higher than Puekpuang et al whose dose range was 0.5-19 and 1.2-18mGy respectively. Close similarity of this study's stomach and liver dose was noticed to be in line with Ngaile et al. whose range/mean dose was 22.5-46.4mGy/35.6mGy and 21-42.8mGy/34.1mGy respectively. Cakmak et al. dose to the liver (13mGy) using the imPACT Software was quite lower compared to this study mean dose. Kawaguchi et al. mean dose to the stomach and liver from Aquilion 64 and RXL was 38/36mGy and 17/15mGy. Aquilion 64 was more consistent with this study. Aquilion RXL was lower in dose than that of this study.

The range and mean dose to the bladder was 19.6-60.2mGy and 32.44mGy and to the uterus was 20.9-71.6mGy and 34.68mGy for our study. A study of organ dose to the bladder by Cakmak et al. using imPACT Software was 32mGy and to the uterus was 25mGy. Our study was in line with Cakmak et al. for the bladder using imPACT Software. Organ dose to the uterus for this study was generally higher than Cakmak et al. study using the same imPACT Software. Also, this study dose range (at minimum) was consistent

with Ngaile et al. whose dose range was 19.5-38.6mGy for bladder and 17.5-42.7mGy for uterus, difference was seen in the dose range at maximum. Generally for both organs (bladder and uterus), this study's mean dose was in line with Ngaile et al. whose mean dose were 28.8 and 26.5mGy respectively.

Comparison between this study mean organ dose (for all organ) and Cakmak et al. was p=0.684, for Ngaile et al. was p=0.879, for Kawaguchi et al. was p=0.244 and for Puekpuang et al. was p=0.006 respectively. Difference in mean dose between this study and Puekpuang et al. could largely depend on choice of protocol used which could be influenced by body makeup and type of scanner used.

The % mean difference in organ dose between this study and Cakmak et al. was between factors of 1-133 with the highest noticed for thyroid and the least for bladder. The % mean dose difference for this study when compared to Ngaile et al. was closer with range of 1-27 with highest dose noticed in the uterus and the least to the breast. Comparison of % difference with Kawaguchi et al was between ranges of 9-132, similar to Cakmak et al. for maximum value. While that of Puekpuang et al. was between ranges of 44-120.

Conclusion

Organ dose among seven CT unit in Lagos State, South-West Nigeria have been determined using the imPACT Software Calculator. Significant difference was seen in CT protocol among the 7 unit which influenced organs doses. To a great extent, there was no difference in organ dose between this study and related studies. Nevertheless there exist no correlations in organ dose between our study and other international studies. Some of the differences in dose value might be attributed to data match of newer scanners with the spreadsheet and manually inputting data into the spreadsheet against the spreadsheet data. Fashioning out modalities to harmonize CT protocol has become necessary in this region. More awareness and training on radiation safety to patients with the use of CT should be encouraged.

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Disclosures

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