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Original Article

Patient Dose Estimation Using CT-Expo Software at Two Hospitals in North-Central Nigeria

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ABSTRACT

Objective: Simulation software has aided the estimation of organ dose from computed tomography (CT) examinations. The aim of this study was to use the CT-Expo (SASCRAD, Fritz-Reuter-Weg, Buchholz, Germany) software to determine volume CT dose index ($CTDI_{vol}$), dose length product (DLP), organ dose and effective dose.

Methods: A total of 171 patient data were retrieved from a Toshiba Aquillion 16-slice CT scanner (Toshiba Corp., Tokyo, Japan) representing CT unit A and a Philips Brilliance 16-slice CT scanner (Koninklijke Philips N.V., Amsterdam, Netherlands) representing CT unit B and a CT-Expo spreadsheet was used to estimate the dose delivered.

Results: Head CT scans were the most frequently seen (64%) at the 2 facilities studied. The CT parameters of peak kilovoltage (kVp) and pitch between the 2 units were statistically different ($p<0.05$). There was no significant difference in $CTDI_{vol}$ between CT unit A and B ($p=0.199$). A comparison of $CTDI_{vol}$ and DLP of CT units A and B with other studies revealed no statistically significant difference ($p<0.05$). The mean effective dose (E) for the abdomen was greater compared with other studies, but without a statistically significant difference ($p<0.05$). Furthermore, no significant difference in organ dose was seen between CT units A and B ($p=0.677$). A comparison of organ dose with other studies indicated no relevant difference ($p<0.05$).

Conclusion: The CT-Expo software showed good results with the imPACT software (ImPACT scanner evaluation group, London, UK). CT unit A had greater differences in $CTDI_{vol}$ and DLP compared with unit B. This difference could be associated with the significant difference seen in the kVp and pitch of both scanners.

INTRODUCTION

Ionizing radiation is capable of causing cell death or radiation-induced reproductive failure, which can lead to changes in the genes involved in cell growth, loss of normal nuclear structure, degradation of DNA and carcinogenesis.[1–3] Despite its ability to completely alter or change genetic structure, it is indispensable to modern medicine for diagnosis and treatment. Medical practice involving ionizing radiation includes diagnostic examinations, interventional procedures, and radiotherapy treatments typically undertaken in a radiology, nuclear medicine, or radiation oncology department or clinic. Globally, it is estimated that approximately 3.6 billion diagnostic examinations and 6 million therapeutic treatments are performed annually.[4] Primarily, the people exposed to ionizing radiation for medical purposes are the patients themselves. These exposure situations are deliberate and voluntary with some diagnostic or therapeutic health benefits to be gained. Recent figures show that diagnostic medical exposures, including radiology and nuclear medicine, account for about one-fifth of the average annual output dose to the global population from all sources.[5]

The radiation effects associated with ionizing radiation can be classified as either deterministic (effect of radiation has a threshold to cause damage) or stochastic (no radi-

ation threshold is necessary to cause damage). There is irrefutable evidence from epidemiological studies that ionizing radiation exposure at high doses is associated with an increase in cancer incidence and morbidity.[6] To accurately evaluate the associated radiation-induced risks, knowledge of doses to the specific region or organ is recommended in the determination of the probability of inducing any deterministic effects or corresponding stochastic risk of carcinogenesis and genetic effects.[7,8]

Among diagnostic modalities, computed tomography (CT) is the greatest contributor to population dose, although it accounts for a much smaller proportion of the total number of examinations. Optimizing patients' procedures, and maintaining good practice is a priority for all diagnostic radiological examinations, including CT examinations. The risk is greater for children, who are more radiosensitive than adults.[9]

Since its launch into clinical practice as a scanning technology more than 40 years ago, CT has developed and advanced, and its use has become more widespread. However, concerns over patient radiation dose risk from CT scans have grown, and the introduction of multi-slice scanners has focused further attention on this issue.[10,11] In 2007, the International Commission on Radiological Protection (ICRP) provided the Diagnostic Reference Levels (DRL) to be used in medical diagnosis for the management and evaluation of CT dose quantities and for identification of unusually high doses. The DRL is not a limitation of diagnostic radiation dose or a reference for organ doses, but provides quantities to compare protocols, promote optimization, and avoid unnecessary doses.

In Nigeria, large radiation doses to patients were observed in ordinary X-ray exposures, and large variations in the radiation dose were also observed both within and between hospitals. It is therefore likely that similar situations exist with CT. Records of radiation doses from CT exams in Nigeria and the harmonization of CT protocols and dose reference levels have not been established due to poor implementation of regulatory policies and monitoring, but there is evidence of a proliferation of CT facilities in the country.[11,12] The need to add consideration of organ dose tolerance in relation to dose optimization by reviewing CT protocols has now become even more pertinent, since organ doses to patients undergoing CT examinations are generally much higher than those associated with conventional, mammography and fluoroscopy examinations.

This study was intended to determine the radiation dose delivered to adult patients during CT examination at 2 hospitals (radiology department) in North-Central Nigeria using CT-Expo software, which is a representation of a hermaphrodite mathematical model. The CT dose parameters to be determined were the volume CT dose index ($CTDI_{vol}$), dose length product (DLP), effective dose (E), and specific organ dose, and the aim was to compare the results with other relevant studies.

MATERIAL AND METHODS

A 6-month retrospective study of CT scans of adult patients at the diagnostic radiology departments of 2 tertiary hospitals in North-Central Nigeria were recorded during the period from October 2016 to March 2017. A total of 171 adult cases were selected and the details were recorded. Demographic information (age and sex) of the patients were noted to ensure that only adult patients were included in the study. The examinations under review were routine, non-contrast CT scans of the head, chest, and abdomen.

The hospitals in the study passed a quality control test. The type and specification of the device in use at each unit was Toshiba Aquillion 16-slice scanner (Toshiba, Corp., Tokyo, Japan) (Hospital A) and Philips Brilliance 16-slice (Koninklijke Philips N.V., Amsterdam, Netherlands) (Hospital B). To calculate the organ dose and E, the scan parameters of the Digital Imaging and Communications in Medicine (DICOM) headers were used: tube current, tube voltage, scan length, pitch, beam collimation, table feed, rotation time, and slice thickness for each patient selected. These parameters were recorded on a separate data sheet.

Patient organ dose evaluation was performed using CT-Expo software (version 2.3; SASCRAD, Fritz-Reuter-Weg, Buchholz, Germany) an MS-Excel application written in Visual Basic for the calculation of patient dose in CT examinations. It is based on computational methods used to evaluate the data collected in German surveys on CT exposure practice in both 1999 and 2002. The software allows for the calculation of the following dose quantities:

- Weighted CTDI
- Volume CTDI
- Dose length product
- Organ doses
- Effective dose (according to ICRP 60 and 103)

In contrast to similar programs for CT dose calculations, CT-Expo offers the user a number of unique features, such as:[13]

a) Dose calculations for all age groups (adults, children, neonates)
b) Dose calculations for each gender
c) Dose calculations for all existing scanner models
d) Correction of scanner-specific influences
e) Correction of over-beaming effects
f) Correction of over-ranging effects in spiral mode

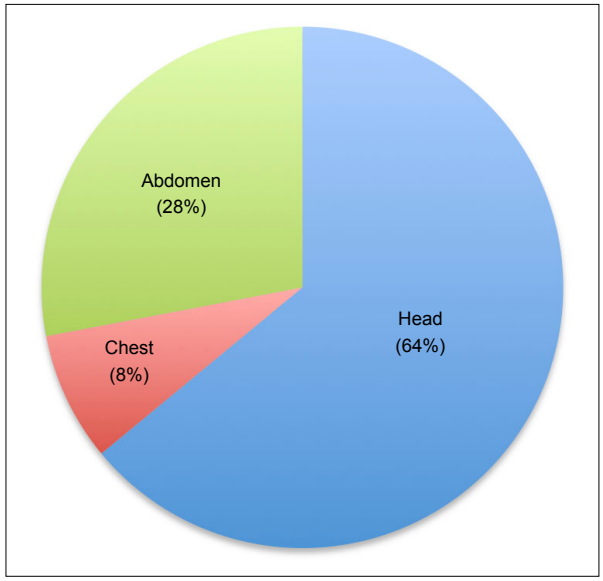

Figure 1. Distribution of patients for each type of examination.

g) Free and standardized dose assessment from scan parameters as well as from dose data provided by the scanner

h) Assessment of dose contribution resulting from scan projection radiographs

Table 1. Mean scan parameters of examinations

Examination	CT unit	mAs	kVp	Scan length (cm)	Pitch
Head	A	200	118	16.8	0.6
	B	124	120	21.4	0.3
Chest	A	74	116	32.6	1.2
	B	141	120	63.8	0.2
Abdomen	A	112	116	40.1	0.8
	B	196	120	47.3	0.2

CT: Computed tomography; kVp: peak kilovoltage; mAs: milliampere seconds.

i) Comparison with results from the German CT survey

j) A comprehensive benchmark functions including guidance on dose optimisation.

The scans of body parts examined were matched to phantoms, with the start and end of scans defined as from the top of the head through to the base of the skull for a head scan, from the clavicles through the base of the lungs for a chest scan, and from the top of the liver to the top of the pubic symphysis for an abdomen scan. Exam-technique parameters were used to estimate organ doses. The results of organ dose and E using tissue weighting factors from ICRP publication no. 103 were recorded.[14]

Statistical analysis

The data analysis was performed using SPSS for Windows, Version 16.0 (SSPSS Inc., Chicago, IL, USA). Descriptive statistics, the one-sample t-test, and the independent sample t-test were used at a 95% level of significance. $P<0.05$ was considered statistically significant.

RESULTS

The distribution of head (64%), chest (8%), and abdomen (28) examinations performed for the 171 patients who underwent CT procedures in the 2 teaching hospital radiology CT units located in North-Central Nigeria in the study is demonstrated in a pie chart in Figure 1.

Assessment of the scan parameters of the 2 CT units revealed no statistically significant difference in mAs (milliampere seconds) ($p=0.594$) or scan length ($p=0.368$); however, differences were seen in peak kilovoltage (kVp) $p=0.007$) and pitch ($p=0.024$) in the 3 body regions (Table 1).

The $CTDI_{vol}$ at the 75th percentile for CT unit A for the head, chest, and abdomen were 140, 19, and 112.63 mGy, respectively. Similarly, for unit B, for the head, chest, and abdomen, the finding were 60.9, 10.6, and 15.5 mGy, respectively. An independent sample t-test indicated no significant difference in the $CTDI_{vol}$ at the 75th per-

Table 2. Comparison of volume CT dose index in this study and other studies at the 75th percentile

Region	CT unit	This study	EC	USA	Ireland	Switzerland	Germany	Kenya	Nigeria
Head	A	140	60	57	58	65	65	61	61
	B	60.9							
Chest	A	19	30	15	11	10	12	19	17
	B	10.6							
Abdomen	A	112.63	35	20	12	15	20	20	20
	B	15.5							

All measurements in mGy. CT: Computed tomography; EC: European Commission states.

centile (p=0.199). The results of a comparison of this study's $CTDI_{vol}$ at the 75th percentile for CT unit A with the European Commission states (EC) (p=0.266),[15] the USA (p=0.199),[16] Ireland (p=0.185),[17] Switzerland (p=0.210),[18] Germany (p=0.221),[19] Kenya (p=0.218),[20] and Nigeria (p=0.215)[21] was not significant. The comparison of the $CTDI_{vol}$ at the 75th percentile for CT unit B with the EC group (p=0.531), the USA (p=0.940), Ireland (p=0.933), Switzerland (p=0.968), Germany (p=0.892), Kenya (p=0.848), and Nigeria (p=0.872) also yielded no statistically significant difference (Table 2).

The DLP at the 75th percentile for CT unit A for the head, chest, and abdomen were 2687.2, 734.8, and 2152.35 mGy.cm, respectively. Similarly, CT unit B results for the head, chest, and abdomen were 1141.73, 458.3, and 685.73 mGy.cm, respectively. An independent sample t-test revealed no significant difference in the DLP at the 75th percentile (p=0.150). Comparison of this study's DLP at 75th percentile for CT unit A with the EC group (p=0.138), the USA (p=0.171), Ireland (p=0.083), Switzerland (p=0.125), Germany (p=0.143), Kenya (p=0.563), and Nigeria (p=0.337) was not significant. In addition, a comparison

Table 3. Comparison of dose length product in this study and other studies at the 75th percentile

Region	CT unit	This study	EC	USA	Ireland	Switzerland	Germany	Kenya	Nigeria
Head	A	2687.2	1000	1011	540	1000	950	1612	1310
	B	1141.73							
Chest	A	734.8	400	545	390	400	400	895	735
	B	458.3							
Abdomen	A	2152.35	800	1004	600	650	900	1842	1486
	B	685.73							

All measurements in mGy. CT: Computed tomography; EC: European Commission states.

Table 4. Comparison of CT-Expo software results for this study with other related studies using imPACT software

Organ	This study (CT unit A)	This study (CT unit B)	Nigeria	Turkey	Tanzania	UK	Japan
Brain	53.2	97.6	27.87	37	63.9	–	–
Eye lens	87.4	126.9	55	45	31.5	–	22.4
RBM	11.5	11.3	–	–	3.5	2.7	1.5
Skin	9.9	6.2	–	–	–	–	–
Breast	31.4	17.3	26.41	–	26.1	21.4	15.9
Lung	19.1	18.7	30.63	33	7	22.4	19.6
Thyroid	13.1	15.6	10.21	51	12.3	2.3	0.6
Skin	4.9	5.4	–	–	–	–	–
Liver	83.8	24.1	33.06	13	34.1	20.4	27.8
Stomach	84.9	24.6	34	–	35.6	22.2	26.9
Ovary	18.6	10.5	–	–	24	22.7	15.1
Skin	21.9	7.6	–	–	–	–	–

CT: Computed tomography. CT-Expo; SASCRAD, Fritz-Reuter-Weg, Buchholz, Germany; ImPACT; ImPACT scanner evaluation group, London, UK.

Table 5. Comparison of effective dose with similar studies

Body region	This study	Osei & Darko	Clarke et al.	Tsai et al.	Origgi et al.	Aldrich et al.	EC	UK
Head	6.6	1.8	1.3	1.6	1.8	2.8	2.0	1.5
Chest	8.2	7.9	5.6	8.4	7.9	9.3	8.8	5.8
Abdomen	24.9	–	5.8	7.4	7.9	10.1	9.0	5.3

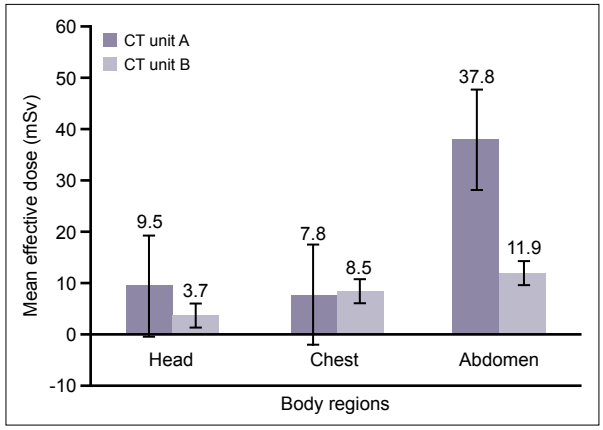

Figure 2. Mean effective computed tomography dose.

of this study's DLP at the 75th percentile for CT unit B with EC members (p=0.920), the USA (p=0.736), Ireland (p=0.297), Switzerland (p=0.782), Germany (p=0.967), Kenya (p=0.120), and Nigeria (p=0.243) revealed no statistically significant difference (Table 3).

Furthermore, comparison of the organ dose to the head (brain, eye lens, red bone marrow, and skin), chest (breast, lung, thyroid, and skin), and abdomen (liver, stomach, ovaries, and skin) between the 2 CT units were not statistically different (p=0.677). There were no difference in mean dose for CT unit A and studies conducted in Nigeria (p=0.120),[22] Turkey (p=0.385),[23] Tanzania (p=0.163),[24] the UK (p=0.125),[25] and Japan (p=0.051).[26] Similarly no significant differences were seen for CT unit B and studies conducted in Turkey (p=0.414), Tanzania (p=0.447), Nigeria (p=0.610), the UK (p=0.788), and Japan (p=0.172) (Table 4).

The mean E value from both scanners is presented in a graph (Fig. 2). The mean E delivered by CT unit A to the head, chest, and abdomen was 9.5, 7.8, and 37.8 mSv, respectively, and for CT unit B, the results were 3.7, 8.5, and 11.9 mSv, respectively. There was no statistically significant result in either case (p=0.360) (Table 5).

DISCUSSION

The $CTDI_{vol}$ at the 75th percentile for CT unit A showed the greatest difference in scans of the head, when compared with other studies. It was 80% higher than that reported for the EC, 84.3% higher than seen in the USA, 82% higher than Ireland, 73.2% higher than Switzerland and Germany, and 78% higher than that reported in Kenya and Nigeria. This difference could largely be as a result of the kVp and pitch used, as well as the type of scanner used. The difference in $CTDI_{vol}$ at the 75th percentile between CT unit B for the head and other studies was below 7%.

The $CTDI_{vol}$ at the 75th percentile for CT unit A for the chest was higher compared with studies conducted in the USA (23.5%), Ireland (53.3%) Switzerland (62.1%), Germany (45.2%), and Nigeria (11.1%), but was the same as that reported in Kenya. The $CTDI_{vol}$ at the 75th percentile for CT unit B for the chest was lower than that seen in the EU (95.6%), the USA (34.4%), Ireland (3.7%), Germany (12.4%), Kenya (56.8%), and Nigeria (46.4%), but was higher than the results from Switzerland (5.8%), with the least difference seen in a comparison with Ireland.

The $CTDI_{vol}$ at the 75th percentile for CT unit A for the abdomen was highest when contrasting with the EC (105.2%), the USA (139.7%), Ireland (161.5%), Switzerland (153%), Germany (139.7%), Kenya (139.7%), and Nigeria (139.7%). The abdomen had the highest percentage of difference in $CTDI_{vol}$. The percentage of difference for CTDIvol at the 75th percentile for CT unit B for the abdomen was lower compared to the EC, the USA, Germany, Kenya, and Nigeria, but was higher than that seen in Ireland (25.5%) and Switzerland (3.3%).

The DLP at the 75th percentile for CT unit A for the head was quite a bit higher than that of the EC, the USA, Ireland, Switzerland, Germany, Kenya, or Nigeria. The DLP at the 75th percentile for CT unit B for the head was lower in this study than previously reported values in Kenya and Nigeria. The percentage of difference between CT unit A and B was 80.7%. The chest DLP in CT unit A was similar in value to the results of another study conducted in Nigeria, but was higher than other studies conducting similar research. The DLP for the chest in CT unit B had the greatest difference when compared with research conducted in Kenya (64.5%). The DLP for the abdomen for CT unit A was greater than the other studies used, but the CT unit B abdomen DLP value was significantly lower compared with that of the EC group, the USA, Germany, Kenya, and Nigeria.

The CT-Expo results showed no difference in organ dose between CT units A and B. The CT-Expo software results for this study were also compared with the imPACT dosimetric calculator (ImPACT scanner evaluation group, London, UK), and the results obtained revealed no difference between our study and research conducted in Nigeria (Akpochafor et al.), Turkey (Cakmak et al.), Tanzania (Ngaile et al.), UK (Shrimpton et al.) and Japan (Nishizawa et al.).

The mean difference in E to the head for both CT units was highest compared to Osei and Darko (114.3%),[27] Clarke et al. (134.2%),[28] Tsai (122%),[29] Origgi et al. (114.3%),[30] Aldrich et al. (80.9%),[31] an EC group (107%)[32] and the UK (126%).[33] The E to the chest in this study was less than that reported by Tsai et al., Aldrich et al., and the EC group. However, the mean E to the abdomen was higher than other values studied.

CONCLUSION

The CT-Expo software was a good tool for accessing patient doses in the 2 facilities studied (CT units A and B).

The $CTDI_{vol}$ and DLP for CT unit A to the head and abdomen were higher than those of CT unit B, and were also the highest when compared with other studies, although these differences were not statistically significant when compared with other studies. CT unit B results were consistent with other studies, suggesting that the CT unit B protocol might be useful to CT unit A in achieving dose optimization. Nevertheless, it is important to remember that dose discrepancies may have been greatly affected by kVp and pitch, which were statistically significant in this study.

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Informed Consent

Retrospective study.

Peer-review

Internally peer-reviewed.

Authorship Contributions

Concept: R.I.O., M.E.E.; Design: R.I.O., M.E.E.; Data collection &/or processing: R.I.O., M.E.E., A.D.O.; Analysis and/or interpretation: R.I.O., M.E.E., A.D.O.; Literature search: R.I.O., M.E.E., A.D.O.; Writing: R.I.O., M.E.E., A.D.O.; Critical review: R.I.O., A.D.O.

Conflict of Interest

None declared.

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Kuzey ve Orta Nijerya'daki İki Hastanede CT-Expo Yazılımı Kullanılarak Hastaya Verilecek Dozun Hesaplanması

Amaç: Simülasyon yazılımı bilgisayarlı tomografi (BT) incelemelerine dayanarak organa verilecek dozun hesaplanmasına yardımcı olmuştur. Bu çalışmanın amacı volüm BT doz indeksi ($CTDI_{vol}$), doz süresi (DLP), organa verilen dozla etkili dozu saptamak için CT-Expo (Microsoft Corp., Redmond, WA, USA) yazılımını kullanmaktır.

Gereç ve Yöntem: Bir A ünitesinin BT'sinden (Toshiba Aquillion 16-kesitli BT tarayıcı [(Toshiba Corp., Tokyo, Japonya]) ve B ünitesinin BT'sinden (Philips Brilliance 16-kesitli BT tarayıcı (Koninklijke Philips N.V., Amsterdam, Hollanda) toplam 171 hastanın verileri elde edildi ve verilmiş dozu hesaplamak için CT-Expo hesap tablosu kullanıldı.

Bulgular: Çalışılan iki kuruluşta en sık kraniyal BT (%64 oranında) taramaları kullanıldı. İki cihaz arasında BT parametrelerinden maksimum kilovoltaj (kVp) ve miliamper/saniye (mAs) cinsinden elektrik akım şiddeti istatistiksel açıdan anlamlı farklılık gösterdi ($p<0.05$). A ve B olarak adlandırdığımız BT cihazları arasında volüm BT $CTDI_{vol}$ açısından anlamlı bir farklılık yoktu ($p=0.199$). Başka çalışmalara göre A ve B cihazlarının $CTDI_{vol}$ ile doz ile süresi çarpımı arasında istatistiksel açıdan anlamlı farklılık yoktu ($p<0.05$). Diğer çalışmalara göre batın için ortalama etkili doz (E) daha yüksek olmasına rağmen farklılık istatistiksel açıdan anlamlı değildi ($p<0.05$). Ayrıca, BT cihazları A ile B arasında organa verilen dozda anlamlı bir farklılık görülmedi ($p=0.677$). Diğer çalışmalarla karşılaştırıldığında organa verilen doz açısından anlamlı bir farklılık belirlenemedi ($p<0.05$).

Sonuç: CT-Expo yazılımının sonuçlarıyla imPACT yazılımının (ImPACT scanner değerlendirme grubu, Londra, BK) sonuçları iyi bir uyum göstermiştir. B kodlu BT ünitesine göre A kodlu BT ünitesiyle hesaplanan $CTDI_{vol}$ ve DLP arasında büyük farklılıklar vardı. Bu farklılık her iki tarayıcının kVp'si ve çözünürlük derecesinde saptanan anlamlı farklılık ile ilişkili olabilirdi.

Anahtar Sözcükler: Bilgisayarlı tomografi; bilgisayarlı tomografi volüm/doz indeksi; doz-süre çarpımı; etkili doz; organ dozu.