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Optimization of head computed tomography scan in a tertiary institution in Edo State, South-South Nigeria

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ABSTRACT

Objective: The study is aimed at optimizing the existing CT protocol for head scans in a Specialist Teaching Hospital in Edo State with a 16-slice Siemens Somatom Emotion scanner. Also, the study determined the volume computed tomography dose index ($CTDI_{vol}$) and Dose Length Product (DLP) from the patient's dose profiles. The results from this study were compared with relevant studies.

Materials and Methods: The scanner was used to acquire head CT of 160 patients retrospectively. Also, a locally designed head phantom was used to simulate individual patients using a similar protocol by changing the tube current (mA) and total scan width (TSW) only from the existing protocol.

Results: Percentage dose reduction (PDR) for the $CTDI_{vol}$ and DLP ranged 42.00-46.80% and 37.13-43.54% respectively. The optimized $CTDI_{vol}$ and DLP were lowest compared to studies in the United Kingdom (UK), Italy, India, Ireland, Sudan, Nigeria, European Commission (EC), United States of America (USA) and Japan. Only the DLP for India was lower than our optimized value.

Conclusion: The need to understudy CT configuration is necessary, this will allow end-users to optimize certain parameters in the CT scanner, which will reduce the patient dose without compromising image quality.

Keywords: Optimization, Computed Tomography (CT), Dose Length Product (DLP), Computed Tomography Dose Index ($CTDI_{vol}$), Peak kilovoltage (kVp), Milliampere-seconds (mAs)

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INTRODUCTION

Computerized tomography (CT), has in recent years experienced tremendous technological advances, developing from the first generation in the early 1970s through the seventh generation to multi detector computed tomography (MDCT) (1, 2) computed tomography (CT) examinations typically deliver relatively higher radiation dose than other diagnostic imaging machines.

In Europe, diagnostic radiology represents the largest man-made contribution to population dose (3, 4), this observation may not be different in developing countries like Nigeria where there is high proliferation of CTs. The radiation dose from CT is relatively higher according to the International Commission on Radiological Protection (ICRP) documents and from research articles (5, 6) and CT have the tendencies to increase patient cancer risk (7, 8).

Training of personnel on the use of CT scanners may help to improve the quality of care at lower doses and subsequently reduce cancer risk to patients. The risk associated with radiation exposure can be considered as deterministic or stochastic effects. Deterministic risk results from cell death and is quantified in terms of radiation dose to a particular region that has a threshold level beyond which these effects generally occur.

They are rarely seen with diagnostic X-ray based examination but are common in radiotherapy. Radiation risks from stochastic (long term) effects may result to cancer and genetic effects and may occur in the offspring of the irradiated subject. There is no given threshold for this, as any dose received may have the potential to cause lethal damages to the cells (**9, 10**).

Although, several research based work had been done globally and locally in Nigeria to estimate $CTDI_{vol}$ and DLP in a bid to establish reference dose levels (RDL) in CT for different body regions (**11, 12**), there is no evidence that the dose reduction/optimization has been carried out, based on parameter adjustment (kVp, mA, Scan time, pitch) and there are no standardized procedures for CT imaging across the diagnostic hospital in Edo State and in Nigeria at large. This is because each hospital has its own specific protocol, which is largely dependent on the expertise of the radiographer.

Studies have demonstrated that a dose reduction of up to 50% is achievable when mAs and kVp are reduced by half (**13, 14**). Also, the Iterative reconstruction (IT) techniques have demonstrated the potential for improving image quality and reducing radiation dose in CT relative to the filtered back projection (FBP) techniques for conventional CTs (**15-18**).

This work focuses on the adult head CT examination with emphases on reducing milliampere (mA) by 39% and total scan width (TCW) by 75% and keeping kVp, pitch, scan length and other parameters constant. This study is also aimed at comparing the optimized $CTDI_{vol}$ and DLP values with national and international studies.

MATERIAL and METHODS

This study was carried out in the department of radiology in a Specialist Teaching Hospital (STH) in Edo State from the period of June – November, 2020. A 16 slices Somatom Emotion scanner (Siemens) was used (Table 1). A convenient sampling technique was used. This was done retrospectively by accessing the CT workstation to select patients that had head CT. A Digital Imaging and Communications in Medicine (DICOM) MicroDicom software was used to analyze the images obtained. A total of one hundred and sixty real patients (160) between the ages of 18 to 87 years were evaluated retrospectively. A locally designed 16cm head phantom was used with the protocols of the 160 patients to estimate new $CTDI_{vol}$ and DLP values, by reducing the mA by 39% and total collimator width (TCW) by 75% after the radiologist was satisfied with the images. The new protocol was implemented (Table 2). The initial protocol with patients was retrospective while the new protocol with the phantom was prospective. CT parameters that remained constant for both protocols were scan length (SL), kVp, exposure time, and pitch. Parameters that were manipulated in the new protocol were mA, and Collimator width. In general, parameters used included: scan length (SL), collimator width (CW), kVp, mA, exposure time and pitch. Corresponding $CTDI_{vol}$ and DLP were retrieved from the system archiving unit and were recorded. Images were then transferred from the CT monitor to a windows 8 system having a pre-installed microDicom viewer for dose profile evaluation.

Percentage dose reduction for $CTDI_{vol}$ and DLP were expressed mathematically as:

$$\%\ dose\ reduction = \frac{Unoptimized\ CTDI_{vol} - Optimized\ CTDI_{vol}}{Unoptimized\ CTDI_{vol}} \qquad (1)$$

$$\%\ dose\ reduction = \frac{Unoptimized\ DLP - Optimized\ DLP}{Unoptimized\ DLP} \qquad (2)$$

Statistical analysis: Data analysis was done using SPSS Inc. Released 2018. IBM SPSS Statistics for Windows, Version 22.0. (Chicago, USA). Descriptive statistics was used to determine the mean $CTDI_{vol}$ and DLP. A One-Way ANOVA was used to compare the machine parameters. An independent sample t test was used to compare the mean of the $CTDI_{vol}$ and DLP for unoptimized and optimized. P-value < 0.05 was considered statistically significant.

RESULTS

The average machine parameters according to age of the patients for head CT scans were the scan length (SL), total collimator width (TCW), kVp, mA, pitch and exposure time. Machine parameter that remained constant throughout all scan was the total collimator width (TCW), kVp, mA, and pitch (Table 2).

The same machine parameter was used with a locally designed head phantom to mimic a real patient. The parameters used were the scan length (SL), total collimator width (TCW), kVp, mA, pitch and exposure time. The mA and TCW was reduced by 39 and 75% respectively to achieve our dose optimization process (Table 3)

There was a statistically significant difference between the unoptimized and optimized $CTDI_{vol}$ and DLP respectively ($P < 0.001$). The percentage dose reduction (PDR) for the $CTDI_{vol}$ ranged from 42.00-46.80% and while the percentage dose reduction (PDR) for the DLP ranged from 37.13-43.54% (Table 4).

Comparison of this study with national and international $CTDI_{vol}$ was made. Out of a total of nine comparison made with the unoptimized protocol, four were above while five were below our results. Comparison with the optimized protocol showed that only one country had $CTDI_{vol}$ higher than our study. Relative difference (RF) in $CTDI_{vol}$ between optimized values and the referenced article was in the range of 9-83%. There was no statistically significant difference between unoptimized and optimized $CTDI_{vol}$ ($P = 0.666$) (Table 5).

Comparison of this study with national and international DLP was made. Out of a total of nine comparison made two results (Nigeria and Japan) from other study were above our unoptimized DLP protocol. On the other hand, optimized DLP protocol showed the least when compared to other studies (724mGy.cm) and the relative difference (RF) in DLP between optimized and other studies was 19-60%. There was no statistically significant difference between unoptimized and optimized DLP ($P = 0.606$) (Table 6). Head CT for unoptimized protocol at 180mA and 130kV, had better image contrast compared to the optimized protocol at 110mA and 130kV, with relative image noise (Figure 1 and 2)

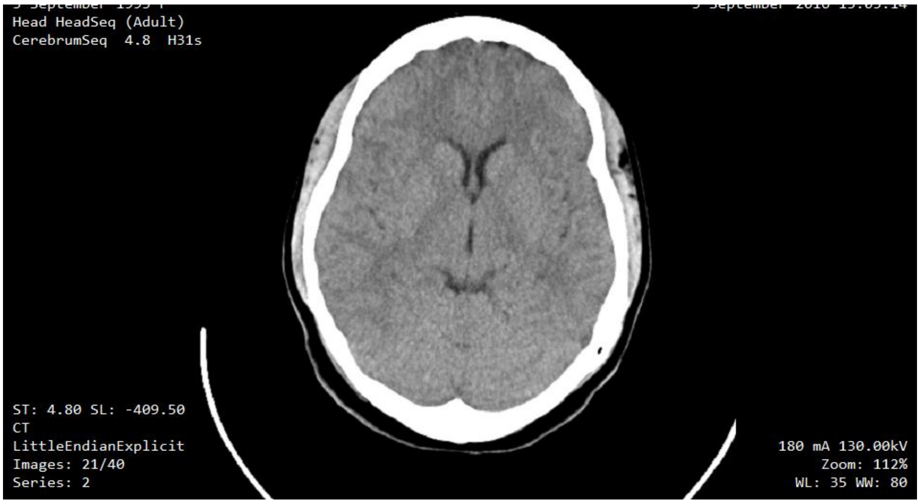

Figure 1. A slice of the unoptimized CT image at 180mA and 130kV

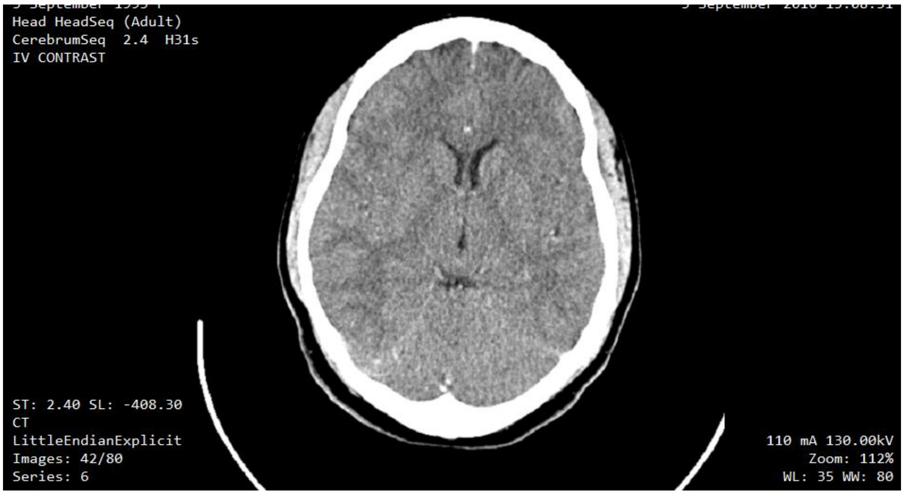

Figure 2. A slice of the optimized CT image at 110mA, 130Kv (with relative image noise)

Table 1. Siemens Somatom Emotion 16-Slice CT machine specification

Generator Maximum output:	50kw
mA range:	20mA-345mA
KV switch:	80KV, 110KV, 130KV
Al equivalent	5.5mmAl
Detector arrangement:	24 rows
Pitch factor:	0.4 to 1.5 (with cone beam correction) 0.4 to 2.0 (without cone beam correction)
Reconstructed slice widths	0.6, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 8.0, 10.0 mm
HU scale	–1,024 to +3,071
Extended HU scale	–10,240 to +30,710
Scan times full scan (360°)	0.6, 1.0, 1.5 s
Slice thickness	0.6–19.2 mm
Scan range:	153cm
Scan speed:	100mm/sec.
FOV variable:	50 cm (70 cm reconstructed FOV available*)
Gantry aperture:	70cm
Gantry tilt:	+/-30°
Spiral acquisition modes	4 x 0.6 mm, 16 x 0.6 mm, 16 x 1.2 mm
Sequence acquisition	modes 4 x 0.6 mm, 12 x 0.6 mm, 16 x 0.6 mm, 2 x 5 mm, 12 x 1.2 mm, 2 x 8 mm, 16 x 1.2 mm

Table 2. Average technical parameters for existing patient protocol

Age range	SL (mm)	TCW (mm)	kVp	mA	Pitch	Exposure time (s)
18-27	187	9.6	130	180	1	33
28-37	189	9.6	130	180	1	27
38-47	196	9.6	130	180	1	30
48-57	214	9.6	130	180	1	33
58-67	187	9.6	130	180	1	32
68-77	190	9.6	130	180	1	30
78-87	192	9.6	130	180	1	28

Table 3. Average technical parameters for the new protocol (phantom)

Age range	SL (mm)	TCW (mm)	kVp	mA	Pitch	Exposure time (s)
18-27	187	2.4	130	110	1	33
28-37	189	2.4	130	100	1	27
38-47	196	2.4	130	110	1	30
48-57	214	2.4	130	100	1	33
58-67	187	2.4	130	110	1	32
68-77	190	2.4	130	110	1	30
78-87	192	2.4	130	110	1	28

* Patients parameters were used with the phantom

Table 4. Percentage dose reduction for optimized $CTDI_{vol}$ and DLP

Age group (yr)	Avg. unoptimized ($CTDI_{vol}$)	Avg. optimized ($CTDI_{vol}$)	PDR	Avg. unoptimized (DLP)	Avg. optimized (DLP)	PDR
18-27	63.50	36.83	42.00	1261	712	43.54
28-37	63.22	34.22	45.87	1196	706	40.64
38-47	62.90	34.70	44.83	1193	723	37.13
48-57	63.54	35.54	44.07	1219	753	38.88
58-67	63.11	34.67	45.06	1231	785	37.45
68-77	63.25	34.63	45.25	1280	732	38.83
78-87	62.50	33.25	46.80	1148	680	39.90

PDR = Percentage dose reduction Avg = Average

Table 5. Comparison of this study's CTDIvol with other studies

Country	$CTDI_{vol}$ (mGy) ǂ	$CTDI_{vol}$ (mGy) ђ
This study	63	35
UK (24)	58	58
Italy (25)	64	64
India (26)	32	32
Ireland (27)	64	64
Sudan (28)	65.4	65.4
Nigeria (29)	61	61
EC (30)	60	60
USA (31)	57	57
Japan (32)	85	85

ǂ = unoptimized $CTDI_{vol}$, ђ = optimized $CTDI_{vol}$

Table 6. Comparison of this study DLP with other studies

Country	DLP (mGy.cm) ǂ	DLP (mGy.cm) ђ
This study	1211	724
UK (24)	890	890
Italy (25)	1086	1086
India (26)	925	925
Ireland (27)	857	857
Sudan (28)	758	758
Nigeria (29)	1310	1310
EC (30)	1000	1000
USA (31)	1011	1011
Japan (32)	1350	1350

ǂ = unoptimized $CTDI_{vol}$, ђ = optimized $CTDI_{vol}$

DISCUSSION

Parameters like mA have been seen to contribute to patient dose during CT examinations. The product of the tube current and exposure time parameters was statistically significantly different between the unoptimized and optimized values (P < 0.001) with percentage dose reduction of 39% on the mA. This have been seen to translate into 45 and 40% dose reduction in $CTDI_{vol}$ and DLP respectively. The study showed that kVp had a significant impact on exposure time, scan length and the optimized mA (P < 0.001).

In a study by Frush et al, the principal selectable parameters that contribute to radiation dose are tube current (mA), peak kilovoltage (kVp), pitch, and gantry cycle time (in seconds). The relationship between the tube current and radiation dose was linear. Decreasing tube current by 50% essentially decreased radiation dose by 50% but at increased image noise (**19**). Our study was below the 50% dose reduction achieved in Frush's study because our mA was reduced by 39%. Although, 45% dose reduction was achieved, which was 5% lower than Frush's study.

In a study by Cohnen et al, who investigated CT of the head using reduced current and kilovoltage and the relationship between image quality and dose reduction. It was observed that, in the conventional mode, the highest surface dose was 83.2 mGy (scanner 1: helical mode, 55.6 mGy), and 66.0 mGy (scanner 2: helical mode, 55.9 mGy). By changing kVp and mAs, a dose reduction of up to 75% (scanner 1), and 60% (scanner 2) was achieved. There were no observable differences in image quality between scans obtained with doses from 100% to 60% of standard settings (**20**). This study showed a maximum dose reduction when only the tube current and collimator width were changed. The maximum dose reduction was 47%. Differences obtained may be due to both reductions in mAs and kVp from the above study.

Also, a study by Sodickson et al, who studied strategies for reducing radiation exposure from multidetector computed tomography in the acute care setting.

An average effective mAs of 276 were obtained for the first patient and 272 for the second patient. However, the decrease from 120kVp to 100 kVp resulted in a 42% reduction in $CTDI_{vol}$ from 18.6 mGy to 10.7 mGy. Comparison with our study reveals that a decrease in average effective mAs from 270 to 165 had a maximum dose reduction of 46.8% (63 to 35mGy for the brain) (**21**). The % variation in dose reduction could be associated with a reduction in other machine parameters like scan length, kVp, mAs and pitch.

In addition, other methods for dose reduction have been alighted; one of such methods was in a study by Sulagaesuan et al, who reviewed how to reduce emergency CT radiation doses with simple techniques, using the quality initiative project. The study used automatic tube current modulation (ATCM) method against conventional means. The $CTDI_{vol}$ and DLP for head CT were reduced by 53 and 57% respectively. Although the approach was different from ours where conventional means was used for dose reduction. Our study showed a dose reduction across all age groups, with mean value of 45 and 40% for $CTDI_{vol}$ and DLP respectively. Dose reduction with ATCM method was better compared to our study (**22**). In another related study by Baskan et al, who investigated the effect of radiation dose reduction on image quality in adult head CT with a noise-suppressing reconstruction system with a 256 slice multi detector computed tomography (MDCT). The study revealed that when the standard dose and low dose groups were compared qualitatively, no significant differences were found in overall quality. By selecting the appropriate level of Iterative reconstruction, 34% dose reduction was achieved without compromising image quality. Dose reduction from our study was better compared to Baskan's study, based on the adjusted parameters. A maximum dose reduction of 47% was obtained from our study (**23**).

Comparison of the optimized value for this study showed that this study $CTDI_{vol}$ was higher than a study that was conducted in India (-9.38%). Similarly, there were difference in $CTDI_{vol}$ and DLP values when optimized values from this study was compared to other studies (P < 0.001).

The optimized $CTDI_{vol}$ and DLP were lower compared to studies in the United Kingdom (**24**), Italy (**25**), India (**26**), Ireland (**27**), Sudan (**28**), Nigeria (**29**), European Commission (EC) (**30**), United States of America (USA) (**31**) and Japan (**32**). Only the DLP for a study in India was lower than our optimized value, although the DLP result used a 100 mm long pencil ionization chamber (IC) and polymethylmethacrylate (PMMA) phantom. Studies have shown no statistically significant differences in CTDI and DLP values with either manufacturer's data or phantom measurements with IC or thermoluminescent dosimeters (**33, 34**).

CONCLUSIONS

A study to optimize head CT from a specialist hospital in Edo State Nigeria has been carried out. The dose indicators ($CTDI_{vol}$ and DLP) were reduced by 45 and 40% respectively, with relative noise on the images. The optimized $CTDI_{vol}$ and DLP were lower compared to most studies. The study proved useful and can be implemented for clinical practice. This will help to reduce the patient's exposed dose without compromising image quality.

Author contributions: CUC, ADO, CCN; Literature search and study design, statistical analyzes, Article write up and revision **CCN;** Critical Review

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Ethical issues: All authors declare originality of research.

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