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Diagnostic Reference Level for Adult Brain Computed Tomography Scans: A Case Study of a Tertiary Health Care Center in Nigeria

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Abstract: *The need to establish Local diagnostic reference level for adult brain computed tomography scan was considered in this study. Brain computed tomography scan is the most common Computed tomography examination performed in the hospital under study. CT scan is recognized as a high dose imaging modality. The quantities estimated in this study were volumetric computed tomography dose index ($CTDI_v$) value, dose-length product (DLP) and the effective dose (DE) received by the patients; the data and results were compared with that of national and international established work. The study was carried out on 40 adult patients undergoing routine brain computed tomography examination. The $CTDI_v$ of 38.08mGy was obtained from the study which is below 60mGy reference value by European Commission. The Dose Length Product obtained in this study was 1477.42mGy.cm and it was found to be comparably higher than the reported values in other countries and 1050mGy.cm by European countries. The effective dose obtained for male and female patients were 3.09mSv and 3.15mSv while 3.10mSv was obtained for both male and female patients. The high dose is attributed to technical parameters, clinical complexity of the patients and untimely quality control program. Comparison of the dose parameters obtained in this study with the national diagnostic reference levels established in other countries indicate that corrective measures are required in elimination unnecessary radiation that does not contribute to overall profile of the patients.*

Keywords: [*Computed Tomography; Head scan, Patient dosimetry, Diagnostic Reference Levels, Radiation Protection.]*

I. Introduction

X-rays is the most frequently used ionizing radiation in medicine despite advances in magnetic resonance imaging and ultrasonography. It has maintained a key role in diagnosis of diseases and therapy. X-ray is the major contributor to the effective dose of both the patient and the personnel. However, because of the radiological risks involved, it is usually recommended that dose to patient from X-ray be kept as low as reasonably achievable with consideration to good image quality [1],[7].

The optimization of patient protection in computed tomography requires the application of examination-specific scan protocols tailored to patient age or size, region of imaging and clinical indication in order to ensure that the dose to each patient is as low as reasonably achievable for the clinical purpose of the CT examination [1]. Diagnostic reference levels (DRLs) are a practical tool to promote the assessment of existing protocols and appropriate development of new and improved protocols at each CT centre by facilitating the comparison of doses from present practice. DRLs were first successfully implemented in relation to conventional X rays in the 1980s and subsequently developed for application to CT in the 1990s (IPEM, 2004). The establishment of reference levels in diagnostic medical imaging requires close cooperation and communication between the physicians who are responsible for the clinical management of the patient and the medical physicist responsible for monitoring equipment and image quality and estimating patient dose [20].

The term diagnostic reference level or reference value sets an investigation level to identify unusually high radiation doses or exposure levels for common diagnostic medical imaging procedures [8]. Diagnostic reference levels are used to manage the radiation dose to the patient. The levels are set at approximately the 75th percentile of the measured data, meaning that the procedures are performed at most institutions with doses at or below the reference level. The medical radiation exposure must be controlled, avoiding unnecessary radiation that does not contribute to the clinical objective of the procedure.

Consequently, reference levels are suggested action levels at which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses [5].

Apart from natural background radiation, medical exposures are at present by far the largest source of exposure to ionizing radiation of the population, and radiation protection measures to prevent unnecessarily high doses from medical exposures should be taken.

The European Commission (EC) introduced the use of diagnostic reference level (DRL) as an efficient standard for optimizing the radiation protection of patients in CT examination and other diagnostic procedures [3]. The dosimetric parameters recommended for monitoring the DRL in CT examination were $CTDI_v$ and DLP [3].

Dose estimates from CT highlight the substantial variations in practice between some CT centers for similar types of examination and similar patient group (adults or children of different sizes). Such observations indicate the need for improvement through implementation of measures to keep all doses within acceptable ranges (optimization) for the clinical purpose of each examination. Examination-specific DRLs for various patient groups can provide the stimulus for monitoring practice to promote improvements in patient protection. Such DRLs can be set not only at a national level (as investigation levels for unusually high typical doses), but also locally by each CT centre (as characterizing its present practice).

1.1 Aim and Objectives

The aim of this work is to assess the level dose delivered during Brain Computed Tomography examination in Asokoro district hospital, Abuja.

The aim of this study was achieved through the following objectives;

1. To estimate the volume computed tomography dose index ($CTDI_v$) that patients received while undergoing CT brain scan
2. To develop local diagnostic reference levels (LDRLs) for dose optimization in CT brain scanS
3. To estimate the effective dose (DE) received by the patients, and to compare data and results with that of National and International work.

The scope of this work is limited to investigation of LDRLs of the dose delivered to adult patients undergoing CT examination of the brain at Asokoro District Hospital Abuja with exception of children (pediatric), geriatric and critically ill patients.

II. Materials And Methods

Elimination of unnecessary or unproductive radiation exposure in brain computed tomography (CT) examination is necessary. To achieve this, practitioners must adhere to the principle of the justification of practice, and optimization of radiation protection. Therefore, the development of Diagnostic Reference Levels for the local context is advised. These reference doses are a guide to the expected exposure dose from a procedure, and are useful as an investigation tool to identify incidences where patient doses are unusually high.

Materials

The following are material needed in carrying out the research work;

- The patients (adult participants)
- CT machines

2.1 Methods.

2.1.1 Patient's Selection

European Commission, 1999, stipulated that data could be obtained either from standard-size patients or a phantom. At the study sites, there are dosimetry phantoms, but no ionization chamber or TLD chips to carry out the direct measurement. Therefore, the use of standard-size patients was employed. Purposive sampling technique [13] was considered as the most appropriate, as standard-sized patients are essential criteria to the design.

2.1.2 Sample Size

A sample size of 40 participants was used in the study. These were obtained through the selection of 40 participants (male and female) that comes for CT examinations of the head in the participating centres using a purposive method of sampling [13]. Purposive sampling technique was considered as the most appropriate, as standard-sized patients are essential to the design. Fourty participants were selected based on the recommendation made by the European Commission which says a minimum of 10 participants shall be recruited for each body part under examination [3]. Only patients (consented adult participants) that met the inclusion criteria for this research, and must be within the weight limits of standard size patient which is 70 ±3 kg for the European population [2] shall be included. The European weight limit will be adopted to make comparison with published values easier because a standard-size patient for Nigerian population could not be found in the literature.

2.1.3 Inclusion Criteria

i. Only adult patients weighing in the range of 67 to 73 kg were included in the study [3].
ii. Patients presenting for routine CT examination of the head (patients that did not require special technique like CT angiography, CT perfusion or helical CT scan).
iii. Data was only acquired on a CT scanner that was calibrated by the Nigerian Nuclear Regulatory Authority (NNRA).

2.1.4 Exclusion Criteria

i. Patients with weight above or below the specified limits of 70 ± 3kg.
ii. Patients who were too sick, and or their weight could not be measured
iii. Patients for non-routine scan of the head (Post neurosurgical cases and psychiatric patients, and patients undergoing special CT examination of the head such as CT perfusion, CT angiography that involves the use of special techniques such as dynamic study or acquisition of thinner sections).

2.1.5 Data Collection

The data were collected by the researcher assisted by the CT radiographers. The data that were collected was recorded on a plane sheets with the following sections: participant demographic information, scan parameters and dose parameters.

i. Patient demographic information

The demographic information that was included in the study are: (i) age, to make sure only adult patients will be included in the study; (ii) gender of the patients; (iii) and (iv) body region which indicates only patients coming for brain CT will be included in the study.

ii. Scan parameters

The exposure parameters are: tube current time product (mAs) and kV.
Other information recorded are: slice thickness, pitch, scan length, number of slices, scan mode, and field of view (FOV).

iii. Dose parameters

After each brain CT scan, the $CTDI_v$ and DLP values obtained from the visual display unit of the CT scanners will be recorded on a plane sheet. These are the parameters found in all of the CT scanners in the study.
The scans are to be done using the existing protocols. This will give a reasonable reflection of what is happening at the study site.

2.1.5 GE Protocol for routine adult brain CT at the study site

The protocol for routine adult brain CT is designed to be in sequential (Axial) mode. The slice group is usually in two batches, namely, batch A for the posterior fossa, and batch B for the cerebrum. The kilovoltage used is normally in the range of 120 kV with 378 mA for the GE (optima 660) 64-slice. The time used for GE 64-slice scanner is 0.6 sec per slice. In most cases automatic mA is prescribed due to its dose saving effect. The slice thickness in both scanners is 1.25 mm for the posterior fossa, and 5 mm for the cerebrum. A single value for the DLP is obtained by simple adding up the two DLP values displayed on the CT console for the two sections; however this does not apply to $CTDI_v$. The $CTDI_v$ was obtained using the formula adopted from [21]:

$$CTDI_{vol}(average) = \frac{[CTDI_v(1) \times length(1)] + [CTDI_v(2) \times length(2)]}{length(1) + length(2)} \quad \text{.................(3.1)}$$

$CTDI_v(1)$ = the displayed $CTDI_v$ for the posterior fossa.
$CTDI_v(2)$ = the displayed $CTDI_v$ for the cerebrum.
Length (1) = the scan length for the posterior fossa.
Length (2) = the scan length for the cerebrum.

Estimation of Effective Dose

Effective Dose (DE) is a measure to express and compare the radiation dose given to patients of various CT – scanner machines introduces by the ICRP in 1977 [10] and is defined as the sum of weighted factor and the dose equivalent to the tissue known to be sensitive to radiation, given as;

$$DE = \sum W_T \cdot H_T \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

where W_T is the specific tissue or organ weighting coefficient (T), H_T is the equivalent dose to tissue T.

In the publication number 102, ICRP in 1977 provides an estimate for the effective dose using the relationship [4];

$$DE = k \cdot DLP \ (mSv) \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

where k ($mSv.mGy^{-1}.cm^{-1}$) is an empirical weighting factor, which is depended on the type of machine and specific to a particular area of the body.

k = Normalized Effective Dose per DLP and for adult head scan is given as k = 0.0021 $mSv.mGy^{-1}.cm^{-1}$ [16].

Data Analysis

The data obtained were saved on an excel spread sheet. The data contain the followings: the demographic information (age, gender, & weight), the scan parameters (kV, mA, slice thickness & FOV)) and dose parameters ($CTDI_v$ & DLP). The data was analyzed using SPSS statistical software version 17.

Statistical method that was employed for the data analysis is the descriptive analysis.

The descriptive analysis was employed to summarize the data for this study. It is used to give a description of the data by determining the measures of location (mean, median, mode and third-Quartile).

III. Results

Routine head CT scans are common examinations performed in this hospital. The data used in this study were obtained from adult patients having head CT procedures from September, 2013 up to January, 2014 in the participating hospital. Dosimetry data were obtained from image headers of the image series. The information extracted included: manufacturer and model name of CT machine, study description, patient age and sex, tube voltage (kVp), protocol name, series information, slice thickness (mm), tube current (mA), exposure time (s), field of view (FOV) in (cm), CTDIvol (mGy), and DLP (mGy.cm).

Table 1: Specific Data of the CT Machine used in the hospital.

S/N	Information	Details of the CT machine
1.	Manufacturer	GE Medical Healthcare
2.	CT Model Type	Optima 660 Bright speed
3.	Year of Manufacture	2011
4.	Year of Installation	2012
5.	Gantry Rotation	360^0
6.	Capacity (slice number)	64-slice
7.	Processor Type	Automatic
8.	Interval at which Quality Control (QC) is Performed	Weekly

Table 2: Scan parameters for the CT machine in the hospital.

S/N	Exposure Parameters	Values
1.	KVp	120
2.	Ma	378
3.	Body Region	Head 16cm
4.	Time (s)	0.6
5.	MAs	226.8
6.	Pitch	1
7.	Slice thickness at the posterior fossa	1.25mm
8.	Slice thickness at the cerebrum	5.00mm

Table 3: Demographic Information of the patients; mean (range) of age, mean (range) of the weight and the sex distribution.

S/N	Demographic Information	Values
1.	Age (Year)	40 (19 – 55)
2.	Weight (kg)	70.5 (67 – 73)
3.	Sex	20 Males, 20 Females
4.	Field Of View (FOV)(cm)	25.25(22.20 – 29.50)

Table 4: Volumetric Computed Tomography Dose Index ($CTDI_{vol}$) and the Dose Length Product (DLP) obtained at the hospital.

Dose Parameters	No of Patient(s)	Min Value	1st Quartile	Mean	Median	Max Value	3rd Quartile
$CTDI_{vol}$(mGy) male	20	35.27	35.94	36.76	36.57	38.76	37.81
$CTDI_{vol}$(mGy) Female	20	35.08	36.13	37.29	37.15	40.24	38.16
DLP ,male (mGy.cm)	20	1305.86	1371.58	1421.43	1427.36	1582.16	1470.72
DLP, female (mGy.cm)	20	1291.16	1355.76	1443.72	1445.95	1806.96	1501.63
$CTDI_{vol}$(mGy) Male & Female	40	35.08	36.07	37.04	36.87	40.24	38.08
DLP(mGy.cm) Male & Female	40	1291.16	1374.27	1432.80	1432.53	1806.96	1477.42

Table 5: Comparison of CT scan parameters used in study with other published work in literature for four other countries in the world.

CT Scan Parameters	Switzerland Treier et al., (2010)	Portugal Santos et al., (2013)	Kenya Wambani et al., (2010)	India Saravanakumar et al., (2014)	This Study
kVp	120	125.11	130	120	120
mAs	320	289.95	249	100	226.8

Table 6: Comparison of 3rd Quartile Values of Dose Parameters ($CTDI_{vol}$ & DLP) of this work with other established values in Literature.

Dose Parameter	Switzer-land Treier et al., (2010)	Portugal Santos et al., (2013)	Kenya Wamb-ani et al., (2010)	India Saravanaku-mar et al., (2014)	Europ-ean Comm-ission EC.(1999)	This Study
CTDIvol (mGy)	65	75	51	32	60	38.08
DLP (mGy.cm)	1000	1010	1364	925	1050	1477.42

IV. Estimation of the Effective Dose (mSv) in this work

In the publication number 102, ICRP in 1977 provides an estimate for the effective dose using the relationship [4];

DE = k · DLP (mSv) ……………………………… (4.1)

with k ($mSv.mGy^{-1}.cm^{-1}$) is an empirical weighting factor, which is depended on

the type of machine and specific to a particular area of the body.

k = Normalized Effective Dose per DLP and for adult head scan is given as k = 0.0021 $mSv.mGy^{-1}.cm^{-1}$ [16].

From Table 4, the 3rd Quartile values of the DLP were obtained as follows;
DLP = 1470.72(mGy.cm) for male
DLP = 1501.63 (mGy.cm) for female
DLP = 1477.42(mGy.cm) for male & female

From equation 4.1
Effective dose (DE) for male patient(s) is;
DE = 0.0021 x 1470.72 (mSv)
DE = 3.09mSv
Effective dose (DE) for female patient(s) is;
DE = 0.0021 x 1501.63 (mSv)
DE = 3.15mSv

Effective dose (DE) for male &female patient(s) is;
DE = 0.0021 x 1477.42 (mSv)

DE = 3.10mSv

The Effective Dose value for female patients (3.15mSv) was found to be comparably higher than the Effective Dose value for male patients (3.09mSv).

The Effective Dose for both male and female was found to be; DE = 3.10mSv.

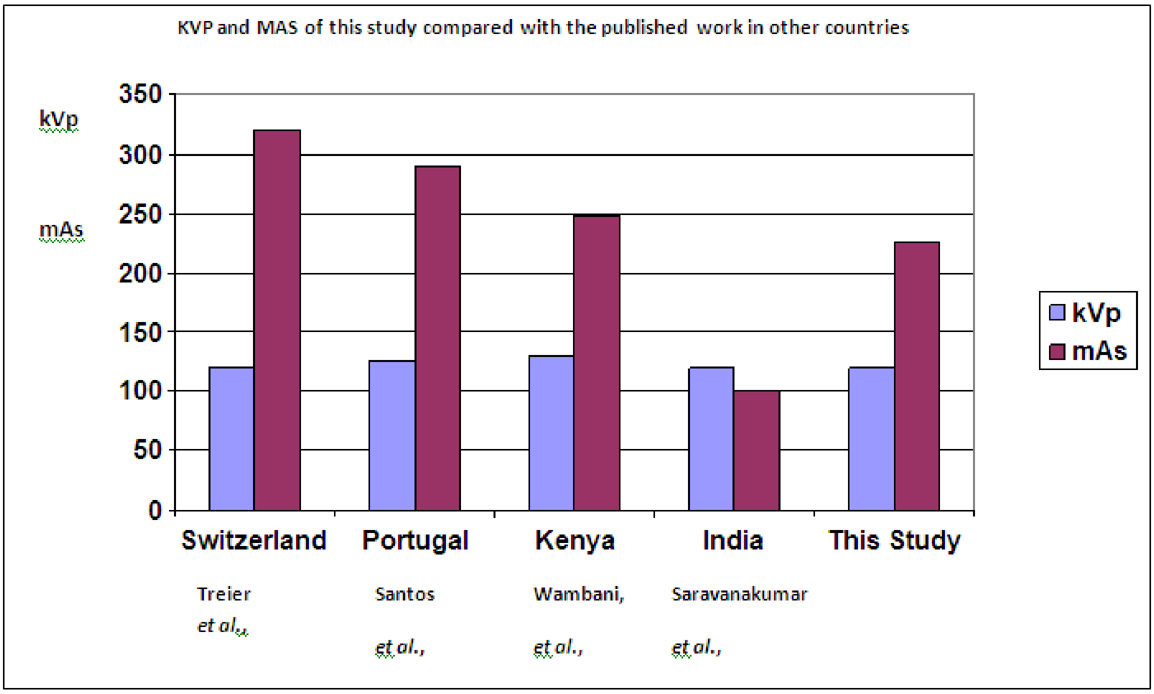

Figure 1: Comparison of the kVp and mAs for the established work in other countries and that obtained in this study.

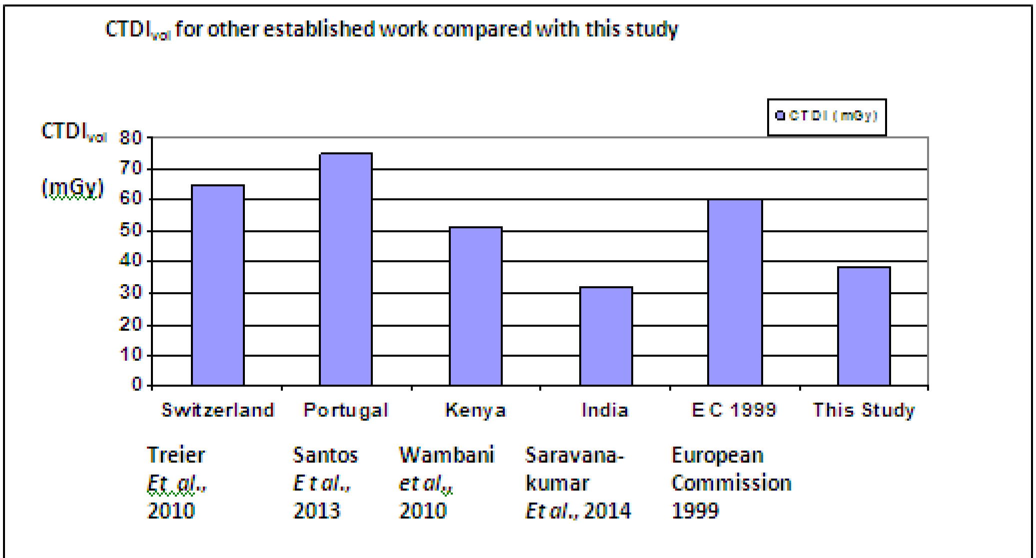

Figure 2: Comparison of 3rd Quartile value of $CTDI_{vol}$ for the established work with the value obtained in this study.

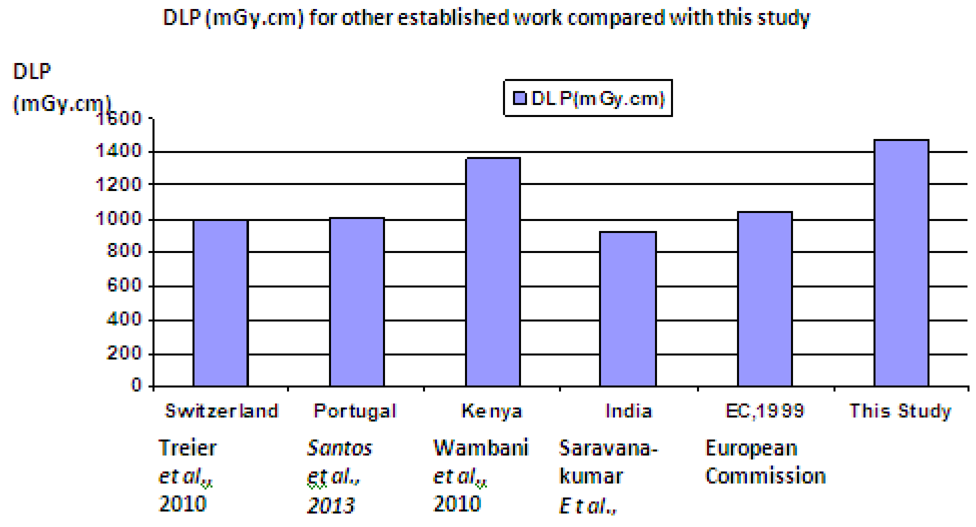

Figure 3: Comparison of the DLP (mGy.cm) for other established work in literature with this study.

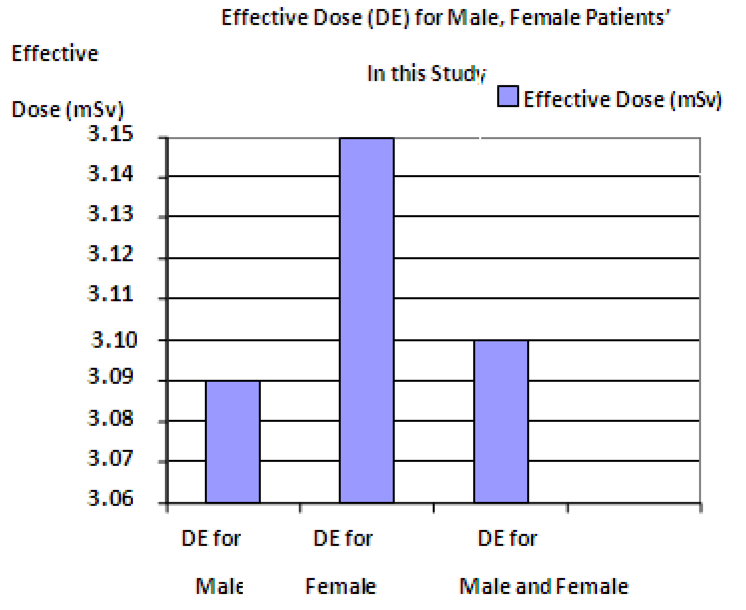

Figure 4: Comparison of the Effective Dose (mSv) for Male, Female and for both male and female patients in this study.

V. Discussion

The information relating to the CT machine used in this study reveal that the machine is relatively new. The result obtained in this Research provides a base for Local Diagnostic Reference Levels (LDRLs) for adult head scan in the hospital.

The comparison of patients doses with other published work reveal that a CT study should use as little radiation dose as possible, while still meeting the image quality needs of the examination and this should be done according to radiation safety principles.

A total of 40 adult patients participant were included in this study. The information relating to the CT machine was given in table1. The scan or exposures parameters (tube potential, tube current time product, pitch and slice thickness) used for the study were shown in table 2.

Table 3 shows the demographic information of the patients; mean (range) of age, mean (range) of the weight and the sex distribution. The information related to the patient shows that all the patients that were included in study are adult who come routine head scan in the hospital. Although, children, critically ill and old age patients were exempted from the study. The ages of the patients were between 19 to55 years with the mean average age of 40 years. Patients' weights considered for this study were between 67kg to 73kg [3] with average mean of 70.5kg. The sex distribution of the patients was 20 males and 20 females.

Table 4 presents the volumetric computed tomography dose index ($CTDI_{vol}$) and the dose length product (DLP) obtained at the hospital which is the dose parameters for routine axial head (brain) scan at the study site.

The table shows 1st and 3rd quartile values of (35.94mGy & 37.81mGy) for $CTDI_{vol}$ of male patients, (36.13mGy & 38.16mGy) for $CTDI_{vol}$ of female Patients, (1371.58mGy.cm & 1470.72mGy.cm) for DLP of male patients, (1355.76mGy.cm & 1501.63mGy.cm) for DLP of female patients respectively.

The table also shows the 1st and 3rd quartile values of all the patients (male and female) in the study as (36.07mGy & 38.08mGy) for $CTDI_{vol}$ and (1374.27mGy.cm & 1477.42mGy.cm) for DLP respectively.

The local diagnostic reference levels (LDRLs) for this study has been established as the 3rd quartile value of $CTDI_{vol}$ (38.08mGy) and 3rd quartile value DLP (1477.42mGy.cm) for all the patients.

Table 5 shows the comparison of CT scan parameters used in study with those obtained in similar surveys in four other countries such as Switzerland, Portugal, Kenya and India[14,15,17,19]. It has been observed from the table that the kVp for countries like Portugal (125.11kVp) and Kenya (130kVp) with established data were higher than the kVp for this work (120kVp). It has also been found that the kVp for Switzerland (120kVp), India (120kVp) and this work (120kVp) maintained an exact value. The mAs of Switzerland (320mAs) maintain the highest value followed by Portugal (289.95mAs) and Kenya (249mAs). Meanwhile, this study has a value of 226.8mAs and is higher than that of India (100mAs) [14,15,17,19] .

Table 6 gives the comparison of 3rd quartile values of dose parameters ($CTDI_{vol}$ & DLP) of this work with other established values in literature[3,14,15,17,19] . The table shows the 3rd quartile values of $CTDI_{vol}$ and DLP for four established data in other countries compared with the European Commission recommended dose levels and the values obtained in this work. The $CTDI_{vol}$ and DLP for Switzerland (65mGy 1000) [17], Portugal (75mGy and 1010) [14], Kenya (51mGy and 1364mG.cm) [19] and the European Commission committee on radiation protection recommended dose levels (60mGy and 1050mGy.cm) were higher compared to the value obtained in this work (38.08mGy)[,2,3,4]. The DLP obtained in this work (1477.42mGy.cm) is found to be comparatively higher than the EC recommended dose value (1050mGy.cm) and that of the other countries with published values. India with CTDIvol of 32mGy and DLP of 925mGy.[15] has the lowest published value below the EC, 1999 recommended values[2,3,4].

From table 4, the 3rd quartile values of the DLP were obtained as follows;
DLP = 1470.72(mGy.cm) for male
DLP = 1501.63 (mGy.cm) for female
DLP = 1477.42(mGy.cm) for male & female

The radiation dose received by the patient depends on the magnitude of the x-ray intensity and duration of exposure.
The Effective Dose value for female patients (3.15mSv) was found to be comparably higher than the Effective Dose value for male patients (3.09mSv).
The Effective Dose for both male and female was found to be; DE = 3.10mSv.
Low-dose radiation carries cancer risk to patients receiving it and the possibility of deterministic effects, such as skin injury, temporary bandage-shaped hair loss, as well as leukemia and brain tumors [22].

5.1 Summary of the Study Findings

1. The CT machine in the hospital was relatively new.
2. The minimum and maximum values of $CTDI_{vol}$ were 35.08mGy and 40.24mGy respectively.
3. The minimum and maximum values of DLP were 1291.16mGy.cm and 1806.96mGy.cm respectively.
4. The mean values of $CTDI_{vol}$ and DLP were 37.04mGy and 1432.80mGy.cm respectively.
6. The 3rd quartile values of $CTDI_{vol}$ and DLP were 38.08mGy and 1477.42mGy.cm which shows that the value of $CTDI_{vol}$ was below the European Commission recommended value of 60mGy but the DLP value was found to be above EC, 1999 recommended value of 1050mGy.cm.
7. The 3rd Quartile values of $CTDI_{vol}$ (38.08mGy) and DLP (1477.42mGy.cm) represent the Local Diagnostic Reference Levels (LDRLs) for this study.
8. The effective dose (DE) for male and female patients were 3.09mSv and 3.15mSv respectively.
9. The effective dose (DE) for all the patients in the study was found to be 3.10mSv.

VI. Conclusion

The study has established the Local Diagnostic Reference Levels (LDRLs) for adult brain CT scan in the hospital. The Dose-Length Product (DLP) obtained in this study carried out on 40 adult patients undergoing routine brain examination was 1477.42mGy.cm and it is found to be comparably higher than the reported values in other countries and the recommended value of 1050mgy.cm by E.C, (1999) for such examination. The $CTDI_{vol}$ of 38.08mGy was obtained in this study which is below the reported value of 60mGy by European Commission, (1999)[3,4]. Although this study is not representative of what happens in every hospital but it is an indication that a considerable optimization potential of CT practice through the standardization of imaging protocols is possible in Nigerian hospitals. Effective Dose obtained in this study for male patients was 3.09mSv and for female patients was 3.15mSv which shows female patients received higher dose compared to male patients. Meanwhile, the high DLP and effective dose obtained in this study may be justified by the advanced pathological state of the patients which in turn shows that dose delivered to the patients are not in conformity with ALARA (as low as reasonably achievable) principle in most CT centres in Nigeria. The high dose received by the patients in this study is attributed to variation in technical parameters, clinical procedures, radiographic technique, untimely quality control program and perhaps the condition of the CT machine.

VII. Recommendation

1. This research work indicate that there is still a large optimization potential of diagnostic CT examinations for adults brain scan in Asokoro District Hospital and possibly in other CT centers in Nigeria.
2. The hospital under study should implement a monitory and functional radiation safety committee comprising of radiographer and medical physicists for periodic re-audits at short-time intervals and the consequent justification of CT examinations, which provide unusually high patient doses.
3. A coordinated effort and team-work between the few radiologists, imaging technologists, biomedical engineers and medical physicists must also be enhanced by the hospital management.
4. The regulatory body in Nigeria (such as NNRA) should initiate an optimization process that can be enhanced through a combination of training of imaging personnel, medical physicists and the inclusion of patient dose criteria in the quality assurance standards to be developed.
5. National survey should be carried out in Nigerian hospitals so as to set a National Diagnostic Reference Levels (NDRLs) for adult brain examination in CT centers so that radiation doses can be compare and take remedial action without affecting image quality

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