CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The exposure of man to radiation from medical practices arises from diagnostic and therapeutic procedures which is considered the largest component of the radiation dose to the population from artificial sources (Olarinoye, 2010). Over the past two decades, there has been marked growth in the number of diagnostic medical procedures that utilize ionizing radiation. In addition, there has also been an increasing frequency of relatively high-dose procedures from computed tomographic (CT) scanning (Mettler, 2008), a modality considered in medical imaging as the most important contributor to patient exposures (Van da Molen, 2012).

Computed Tomography (CT) has become a very essential diagnostic imaging tool in many clinical settings due its cross-sectional imaging capabilities, high temporal and spatial resolution, and excellent anatomical details (Brenner DJ and Hall EJ, 2007). The introduction of CT into medical practice has resulted in significant benefits to medical management, enabling faster and more accurate diagnosis and the avoidance of interventional surgical techniques (Foley, 2012).

However, patient exposure are more critical in CT because, aside using ionizing radiation, the doses are typically much higher than for radiographic or fluoroscopic procedures (Stephen, 2007). Furthermore, the introduction of multi-section CT scanners resulted in relatively large dose increases compared with doses from single-section scanners (Tsalafoutas & Koukourakis, 2010).

The main concerns about patient dose in CT relate to the stochastic effects which encompasses carcinogenesis and hereditary changes. However, since CT is also used for interventional procedures where the same body region may be exposed many times during a single procedure and a patient may undergo multiple procedures within a limited time scale, deterministic effects are not completely out of the picture (Tsalafoutas, 2007).

Evidence shows that there is a 10-57% increase in the number of CT investigations per year and that CT accounts for 49% of patient dose from medical imaging in the United States (NCRP, 2009), with a 1.7% - 12% increased lifetime attributable risk (LAR) for cancer incidence and 6.8% cancer-related deaths for those undergoing multiple CT examinations (Shah, et. al., 2013). The LAR varies according to patient age and sex, with risk doubling in individuals 20 years or younger and 2.22 times higher in women (Smith-Bindman et. al, 2015).

Most of the evidence on radiation-induced cancer risk comes from 4 groups: Japanese atomic bomb survivors, medically exposed populations, occupationally exposed groups, and environmentally exposed groups. Of these groups, the Japanese atomic bomb survivors provide by far the most robust data (Little, 2009). These data provide clear evidence of radiation-induced cancer risk at doses above 100 mSv, but this is of little relevance to medical imaging, except in cases of multiple high-dose examinations (CT, nuclear cardiology, and complex interventional radiology procedures using fluoroscopy) in a short time period (Pierce and Preston, 2000).

Radiation-induced risk is more controversial at doses between 10 and 100 mSv, the dose range relevant to medical imaging and in particular CT. A single CT of the abdomen may have a dose of around 10 mSv, and patients who undergo multiple CTs or a single multiphasic CT fall into this dose range. Below 10 mSv, which is a dose range relevant to radiography and some nuclear medicine and CT studies, no direct epidemiological data support increased cancer risk. Nevertheless, the risk may still be present at a low radiation dose (Verdun, et. al., 2008)

Notwithstanding the window of hope offered by low dose exposures, radiation dose from medical imaging has come under recent scrutiny in the medical and lay press. This is the result of recent articles on the increased cancer risks associated with computed tomography (CT), as well as recent cases of excess radiation exposure from CT brain perfusion scans (Brenner and Hall, 2007). It is estimated that 29,000 future cancers (approximately 2% of the cancers diagnosed annually in the United States) could be related to CT performed in the United States in 2007. This is comparable to recent estimates of 1.5% to 2.0% by Brenner and Hall (Smith-Bindman).

In Nigeria, aside the multiplication of CT scanners, the number of examinations has shown a steady increase (Ogbole, 2014) and, this rate would obviously increase on the basis of the higher number of examinations performed today (Stephen, 2007). Evidence also demonstrates significantly high doses from CT investigations and dose variations within and between radiology facilities (Smith-Bindman et. al., 2015). These increases in CT investigations has the potential to result to an increased incidence of cancer (Stephen, 2007), hereditary diseases in descendants of the exposed persons, and the possibility of deterministic effects (Olarinoye, 2010). Dose increase have significant health implications for patients and have raised concerns in the literature and media (Shah, et. al., 2013; Hendee & O'Connor, 2012).

Although technological innovations have mitigated dose levels to some extent (Klink, et. al., 2014), wide dose variations between centres still persist (Smith-Bindman, et. al., 2015). Many factors may be responsible for these dose variations and include differences in technology and scanning protocols across centres. The technology of CT has evolved over the years, and recent innovations in detector technology, image reconstruction algorithms and post-processing tools have aided optimization (Ekpo, et. al., 2014). Reconstruction algorithms have been shown to significantly lower dose compared to the filtered back projection (FBP) algorithm in the 4–16 slice GE systems (Hendee and O'Connor, 2012), which appears to be the most popular brand in Nigeria.

Therefore, sensible use of the modality requires strict adherence to the principles of radiation protection (justification, minimization and optimization) to ensure that the risk to patients does not outweigh the benefit gained from the technique (Foley, 2012). Optimization requires that the magnitude of radiation doses be as low as reasonably achievable (ALARA). At the core of optimization is the establishment of diagnostic reference levels (DRLs) which allow the identification of abnormally high dose levels by setting an upper threshold (Foley, 2012).

The Council of the European Union defines DRLs as dose levels that "*are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied.*" A DRL is not a regulatory limit on the dose that can be administered to a patient, but simply an indicative value. If the dose delivered by an imaging facility consistently exceeds the DRL, it is an indication that the facility should further optimize their scanning protocols (EC, 1997).

To address the issue of radiation hazards, several international agencies have all made relevant recommendations aimed at promoting safety in medical exposures. The major objective of the recommendations is to ensure compliance to dose monitoring, a practice required in every hospital, to reassure that exposures are within the reference limits (Wanbani, 2010)**.** However, it was the International Commission on Radiation Protection (ICRP) who proposed the concept of Diagnostic Reference Levels (DRLs) to reduce dose variations and improve optimization (Shrimpton, 2003).

The DRLs also serve as a tool for assessing dose variations across facilities to provide radiation protection benchmark for standard-sized patients. It was proposed to provide a reference to allow facilities with dose outliers trigger optimization strategies. Population characteristics, technology, and examination protocol affect DRLs. Therefore, the ICRP has recommended DRLs to be established taking these factors into consideration, and that local or regional DRLs should equal the national benchmark (ICRP, 2007).

A single facility-based study is not adequate to set DRLs for the general population. However, a centre-specific dose level for optimization purpose known as Facility Reference Level (FRL) can be determined. The FRL is the median dose delivered to a standard patient undergoing a specific routine diagnostic exposure at a given facility. This FRLs define local facility doses for common procedures, compare doses between similar protocols, assess the dose impact of the introduction of new protocols, compare doses between facilities, compare with regional or national DRLs, provide a comparative dose metric for optimization strategies, and indicate compliance with state and territory regulatory requirements (Hart, 2012).

To monitor CT dose, the well-accepted dose descriptors used include the volume (CTDIvol) CT dose index (CTDI), and dose-length product, as per International Electrotechnical Commission requirements (IEC, 2002; Muhogora, 2009). The $CTDI_{vol}$ is a standardised measure of the radiation output of a CT scanner which allow users to compare different scanners and scan protocols (McColough, 2009), because it takes into account protocol-specific information (Foley, 2012). The SI unit is the milligray (IEC, 2002). The DLP combines the $CTDI_{vol}$ and the scan length to quantify the total radiation dose received by the patient during a CT scan, and is given in milligray centimeters (Foley, 2012).

Variations in CTDIvol and DLP are often noted in clinical practice, due to differences in local scan protocols. These protocols have extensive choice of adjustable dose saving features that have been proven to substantially reduce the dose without detriment to the diagnostic quality of the CT images when properly used (Lee, 2008; McColough, 2009). Dose surveys globally, indicate significant variations in $CTDI_{vol}$ and DLP between different radiological departments for the same type of CT examination (Ogbole, 2014; Acquah, 2014). These variations justify dose assessment in order to optimize CT practice (McColough, 2009).

About 72% of European countries as well as the United States have established DRLs for some radiological examinations and subsequent reviews have demonstrated significant dose reductions (16% - 30%) (Brink and Miller, 2015). Dose reductions have also been facilitated by improved quality assurance (QA) and control as well as improvement in imaging technology (Klink, et. al., 2014).

Developing low-resource countries such as Nigeria have poor equipment maintenance policies and radiation protection culture, with most radiology facilities using older and secondhand equipment (Brink and Miller, 2015). These factors, together with the absence of guidelines and regulation on purchase, installation and shelf life of the equipment (Ekpo, et. al., 2014) may increase the dose burden. Patient dose can be controlled through appropriate selection of parameters such as exposure factors, patient positioning, and examination protocol (Brink and Miller, 2015).

However, there are concerns that radiographers' theoretical knowledge of radiation protection is not consistently translated to practice in Nigeria (Ekpo, et. al., 2014). The potential harms of radiation exposure to the population emphasize the need to establish DRLs for common radiologic examinations. Such knowledge is critically important to identify dose outliers, particularly high dose facilities in order to facilitate recommendations for improved radiation protection practices and reduce the dose burden to patients undergoing radiological examinations.

Current works on CT doses in Nigeria focused specifically on the head, which is also adjudged the most common procedure (Garba, et al., 2015; Abdullahi, et al., 2015; Ogbole 2014). These studies, which are few and isolated, showed wide variations (> 30%) in dose output (Garba, et al., 2015; Abdullahi, et al., 2015; Ogbole, 2014). These observed variations, coupled with unavailable national or regional DRLs have presented the need for the establishment of standards through a dose survey (Olarinoye, 2010). This present survey is narrowed down to the Southeast geopolitical zones, and on Anambra State, to serve as precursor to future national DRLs.

Anambra State is one of the oldest of the five states that constitute the Southeast geopolitical zone of Nigeria. Old Anambra State was created in 1976 from part of Eastcentral State, and its capital was Enugu. In 1991, its headquarters was moved to Awka after it became demarcated into Anambra and Enugu States. The population of Anambra State as at the 2006 census is put at four million, one hundred and seventy-seven thousand, eight hundred and twenty-eight persons (4,177,828) (population. gov.ng/wpcontent/themes/expo18).

The first CT scanner in Anambra State was installed at the Nnamdi Azikiwe University Teaching Hospital (NAUTH), Nnewi in 2011. Prior to that time however, the first CT scanner installed in the Southeast geopolitical zone was at the University of Nigeria Teaching Hospital (UNTH), Enugu around 1996-1998, although the first CT scanner in Nigeria was installed on November 19, 1987 at the University College Hospital (UCH) Ibadan, in Southwest Nigeria (Eze, 2012).

An unpublished preliminary survey by the researcher (appendix IV) revealed that there were five models of scanners (GE, Philips, Siemens, Toshiba, Ceretom) distributed in twenty-seven CT centres in Southeast Nigeria as follows: Anambra: 9 (33.3 %); Enugu: 6 (22.2 %); Imo: 6 (22.2 %); Abia: 4 (15 %); and Ebonyi:2 (7.3 %). Thirteen (48.1 %) are privately-owned, five (18.5 %) belong to the Federal Government, four are owned by faith-based organizations (15 %), while ownership of three (11.1 %) is by public-private partnership (PPP) while two (7.3 %) are owned by State governments.

Furthermore, the scanners were manufactured between 1998 and 2015 and installed between 2006 and 2016. As at the time of data collection in 2016, only 63 % (n = 17) of scanners were functional. In Anambra State however, 89 % (n = 8/9) of scanners were functional. Despite the multiplicity of scanners in the state and in the zone, there is no evidence of any uniform dose template to guide CT Radiographers. In requesting CT examination, two guiding principles must be followed. First, the examinations must be appropriately justified. Second, all technical aspects of the examination must be optimized, such that the required levels of image quality can be obtained while keeping the doses low (McColough, 2009).

Recent overdose incidents, and increased attention to carcinogenesis, has however, placed an obligation on the CT community to review the amount of radiation prescribed for CT scans (Tsalafoutas, 2007). The current study was designed to ascertain the radiation dose to the patients from the CT centres in Anambra State with a view to establishing diagnostic reference level for dose optimization.

1.2 Statement of the problem

From personal visits and interaction with the CT Radiographers in Anambra State, it was observed that even when scanners were similar, protocols and practices were dissimilar. This subsequently, led to variable dose outputs which is an indication of arbitrariness in the examination of patients. That scenario presented a justification to investigate CT dose outputs in CT facilities in the state.

Furthermore, the ICRP recommended that all medical exposures were to be subjected to the radiation safety principles of justification, optimization and limitation (ICRP, 1996) in order to reduce dose to patients, the public and personnel. The core principle of optimization is best achieved through compliance to diagnostic reference levels.

To the best of knowledge of the researcher, these are not available for Anambra State specifically, and Nigeria in general. This may have been responsible for the significant variations in the doses to patients in the few local studies undertaken (Abdullahi, et al., 2015; Garba, et al., 2015; Ogbole & Obed, 2014). Diagnostic reference levels that will keep dose within an acceptable limit, is therefore, needful.

In addition, some authors have suggested that the make/model of scanners infuence CT dose output (McCollough, 2011; Yu, 2009; Huda, 2008). In Anambra State, there are three makes of scanners in use for patient investigation. These are: GE, Toshiba and Siemens. The dose output as a function of scanners, has not yet been investigated in the locality.

Research has also shown that CT dose is influenced by gender, age and exposure parameters (Abdullahi, 2015; Aweda, 2007). The correlation between dose-length product and anthropo-technical parameters in the locality needs further investigation to guide in protocol manipulation during CT procedures as these may have influence on the DRLs.

1.3 Aim of the study

The study aims to determine the radiation dose to adult patients from CT of the head in Anambra State of Nigeria, and to produce diagnostic reference levels for the state.

1.3.1. Objectives

(a) To calculate the mean and 75^{th} percentile of the centre-specific computed tomography dose index ($CTDI_{volume}$) and dose-length product (DLP), which are dosimetrics shown on the CT console.

(b) To calculate the mean and 75^{th} percentile of the computed tomography dose index ($CTDI_{volume}$) and dose-length product (DLP) in Anambra State in order to determine the common diagnostic reference levels (DRL) for adult head CT.

(c) To compare protocol parameters, and with the use of ANOVA, assess the influence of scanner model on dose outputs using the protocol parameters applied for head CT.

(d) To determine the relationship between dose-length product and common anthropo-technical parameters using correlation analysis.

1.4. Significance of the study

The diagnostic references levels derived from this work will serve as guide for dose optimization for CT centres in the locality. Also, the relevant radiation regulatory agencies in Nigeria will find the results useful in establishing and implementing guidelines for dose optimization in CT of the Head. Furthermore, researchers may find the work as a useful reference material for future studies.

1.5 Scope of the study

The study involved functional CT facilities in Anambra State. Data collected from them were technical parameters for head protocol, as well as anthropometric and dose data of patients who were aged ≥ 18 years. These centres and their codes were:

- Nnamdi Azikiwe University Teaching Hospital (NAUTH), Nnewi (A);
- Iyi Enu Mission Hospital, Ogidi (B);
- Saint Charles Borromeo Hospital, Onitsha (C); and
- New Hope Medical Centre, Onitsha (D).

1.6 Limitations of the study

No Medical Physicist was found in any of the centres to authenticate the calibration status of the scanners. It was therefore, difficult to have a second opinion on the veracity of the dose outputs. Also, difficulty in getting permission from each CT facility limited the researcher to Anambra State rather than the entire Southeast. A larger sample size of CT scanners that would have enabled comparison of similar scanner outputs was therefore, not realistic.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual review

2.1.1 Computed tomography

Computer tomography is gaining more recognition in Nigeria. It delivers higher radiation doses to patients of up to 20 mSv and radiation induced cancer risks of up to 1 in 1000 per examination (Wall , 2001**),** hence the urgent need for reference doses for routine CT examination is a necessity in Nigeria and all other developing countries in Sub- Sahara Africa (Olowokere, 2012).

Tube potential and current

Huda et al (**2004**) used 80-140 kVp and an mAs of 340. They noted that an increase in kVp increased dose by a factor of 5. Foley et al (2012) used the following CT parameters in their work: kVp, mA, tube rotation time, number of scan phases, $CTDI_{vol}$ and DLP, beam collimation, scan field of view, scan length, pitch, slice thickness and reconstruction algorithms used.

2.1.2 Computed tomography dosimetrics

a. **Computed tomography dose index volume ($CTDI_{vol}$)**

Based on the recommendation of the International Electro-technical Commission (IEC), current CT scanners provide two dosimetric quantities at the end of each scan namely, computed tomography dose index volume ($CTDI_{vol)}$ and dose-length product (DLP), (Foley, 2012) which are measured in standard homogeneous cylinders of polymethylmethacrylate (PMMA), with diameters of 16 cm for head and 32 cm for body phantoms (Wall, 1995). The $CTDI_{vol}$ is defined as the integral along a line parallel to the axis of rotation (z) of the dose profile for a single rotation and a fixed table position, divided by the nominal thickness of the x-ray beam (Wall, 1995). It is a standardized measure of the radiation output of a CT scanner and allows users to compare different scanners and scan protocols. The SI unit is milligray (Foley, 2012).

Several variants of CTDI exist that describe specific steps in the measurement and calculation processes (McNitt-Gray,2002). These are $CTDI_{100}$, weighted CTDI ($CTDI_w$) and volume CTDI ($CTDI_{vol}$). The $CTDI_{100}$ is measured using a pencil type ionization chamber with an active length of 100 mm, both in free air and within two cylindrical polymethylacrylate phantoms of 16 cm and 32 cm diameter, simulating the head and body of a patient, respectively. The weighted CTDI ($CTDI_w$) is used for approximating the average dose over a single slice while the volume weighted CTDI ($CTDI_{vol}$) accounts for helical scanning (Bauhs, 2008).

b. **Dose length product**

DLP on the other hand combines the $CTDI_{vol}$ and the scan length to quantify the total radiation dose received by the patient during a CT scan, and it is given in milligray/ centimeters (mGy-cm). Because DLP is directly related to patient risk, it may be used to set DRLs values for CT examinations. DLP combines the $CTDI_{vol}$ and the scan length to quantify the total radiation dose received by the patient during a CT scan, and is given in milligray/centimetres. Because DLP is directly related to patient risk, it may be used to set diagnostic reference values for CT examinations (Foley, 2012).

c. **Effective dose**

Effective dose provides a general idea of detriment from ionizing radiation to allow optimization of procedures and to enable a particular examination to be compared to the naturally-occurring background radiation or an alternative imaging examination that provides similar diagnostic information (Osei, 2013). This age and weight-dependent quantity is calculated, and not measured and it is expressed in Sievert (Mettler, 2008). Any estimated value reflects the risk of the examination and not the risk to any specific individual, since the weighting coefficients are averaged over age and gender and several assumptions and simplifications are taken into consideration during effective dose determination (Osei, 2013).

It can best be evaluated by determining the mean doses to all radiosensitive tissues of the individual and combining these with age, sex-, and organ-specific risk coefficients (Mettler, 2008). Therefore, effective dose from various examinations should periodically be undertaken, as an essential part of the medical audit and quality assurance programme in any radiology department (Osei, 2013).

Effective doses to the neonate for a head CT examination are markedly higher than for adults, whereas for body CT, the effective doses are usually within 50% of the adult dose. In part, this is a result of the fact that technique factors (voltage and/or mAs) can be substantially lowered in body CT, but only very modest reductions in technique are made when performing pediatric head CT examinations. (Mettler, 2008).CT examinations tend to have narrow but relatively high effective doses (approximately 2–20 mSv), and doses for interventional procedures usually range from 5 to 70 mSv. This can be compared with an annual effective dose from natural background radiation of about 3 mSv (Mettler, 2008).

Two methods are commonly used in calculating effective dose. The most common is through computer programmes such as OrgDose (version 2) which calculates doses from conventional radiography, fluoroscopy, and computed tomography procedures. The OrgDose program uses the normalised organ dose data from Monte Carlo modeling of conditions of exposure relevant to 27 common models of CT scanners using a mathematically modelled phantom representing an average adult patient. However, these data will contain some uncertainty common to all normalized organ dose data using a phantom of a standard reference size. If applied to a patient whose size differs from the phantom used in the derivation of the normalised organ factors, an uncertainty will be introduced into the calculated organ and effective doses (Osei, 2013).

The other method of deriving effective dose is to calculate it as the sum of the weighted equivalent dose in all the tissues and organs of the body as specified in the ICRP-103 and ICRP-60 reports (Osei, 2013). ICRP-103 and ICRP-60 based DLP to effective dose conversion coefficients for multi-detector brain CT are 0.0019 and 0.0016 $mSv^{-1}.mGy.cm^{-1}$, respectively (Van da Molen, 2012). This calculation method, involving the product of the conversion coefficient and DLP, is employed in this work**.**

2.1.3 Calibration of CT scanners

Computed tomography scanners, in order to give consistent results, undergo both daily and regular calibrations. The daily calibration can easily be undertaken by the Radiographer since it is a system programme that is activated at the click of a computer icon.

Calibration ensures that the dose output remains the same as at the time of commissioning. This dose output are given as prospective and retrospective dose outputs (Foley, 2012). Prospective dose output is activated during protocol manipulation prior to the actual exam and helps the Radiographer to keep an eye on the DRLs. The retrospective dose output is the final dose information and gives an idea of the actual dose applied for the investigation (McCollough, 2007)

2.1.4 Computed tomography protocols

Computed tomography protocols are defined by a set of adjustable parameters. Most of these parameters are discrete, rather than continuous. Consequently, the most appropriate tool for calculating central tendency is mode, rather than the mean. This is because the mean value derived may not be a value on the scanner or in the protocol. Parameters that are limited to a 'yes' or 'no' response are common, rather than discreet variables. The number of scanogram could either be one or two but a centre would normally adopt what suits them. As for gantry tilt, it is either present or not.

2.1.5 Diagnostic reference level in CT

a. **Definition**

Diagnostic reference levels have been defined in European legislation (EC, 1997) as "dose levels in medical radiodiagnostic practices or, in the case of radiopharmaceuticals levels of activity for typical examination for group of standard-sized patients or standard phantoms for broadly defined type of equipment" (Hart et. al, 1994; ICRP, 1996; Olowokere, 2012). The DRLs provide a practical system that allows x-ray departments to compare their radiation doses delivered to patients. In order to do this, the dose must be expressed in terms of dose quantities that are clearly defined and can be easily measured or calculated from readily available exposure parameters (Wall, 2004).

Special attention should be paid to the standardization of radiation dose data during imaging for its ultimate use in benchmarking good practice, and, finally, the identification and perhaps alternative imaging of patients who may have already reached threshold levels of estimated exposure from diagnostic imaging (Stephen, 2007).

b. **Origin of DRLs**

As a result of wide variations in patient dose for the same x-ray examination (up to a factor of 100), the ICRP and International Atomic Energy Agency (IAEA) recommended that all medical exposures should be subjected to the radiation safety principle of justification of practice, and optimization of protection (Faulkner & Corbelt, 1998; Olarinoye & Sharifat, 2012). At the core of optimization is the establishment of DRLs (Foley, 2012). Optimization requires that the magnitude of radiation doses be as low as reasonably achievable, ALARA. The ICRP noted that optimization in medical exposures has been given less attention compared to other applications (Olarinoye & Sharifat 2012). The DRLs are intended to act as thresholds to trigger investigations in ensuring optimized protection of patients and maintaining appropriate levels of good practice. This according to European Commission is to encourage departments to investigate their patient radiation levels (Tung et. al., 2001; Olowokere, 2012).

c. **Significance of DRLs**

Diagnostic reference levels allow the identification of abnormally high dose levels by setting an upper threshold. An awareness of typical dose levels allows CT users to quickly identify and address any protocols which do not meet the ALARA principle (Foley, 2012). DRLs are recommended as guidance doses by the International Atomic Energy Agency (IAEA) (Osei, 2013), and are intended to be a reasonable indication of dose for average-size patients and to provide guidance on what is achievable with current good practice rather than optimum performance (Miller, 2009).

d. **Subject selection for DRL**

Reference levels for diagnostic radiologic procedures are derived from data collected for standardized examinations performed on a standard-size patient or phantom (Miller, 2009). In a work carried out by Huda and Vance (2007), all patients from neonates to adults were examined in the determination of a DRL. Foley et al (2012) however, enlisted only adult patients. In each CT facility a local survey should be carried out using data from a sample of 10 or more routine examinations of each examination type in order to calculate the local mean $CTDI_{vol}$, DLP and *E* values, and these should be compared with the national or international DRL in order to determine whether they are within limits (Tsalafoutas and Koukourakis, 2010).

e. **Weight banding and size correction**

Patients vary in weight, and radiation dose increases exponentially with body-part thickness. It is desirable to correct for this variation. Several methods for normalizing for body habitus exists but weight banding is the simplest method. Weight-banding permits restriction of the analysis to subjects with weights between 60 and 80 kg while size correction allows use of a mathematic transformation to normalize dose data to a standard weight of 70 kg. With a large data set, weight-banding appears to reduce the standard deviation of the data more successfully than does size correction by using equivalent diameters (Miller, 2009). Weight banding that allows for a range of weights, rather than size correction that is narrower, shall be used in this work.

f. **Scope of DRL data**

The ICRP (1996), in addition to recommending that DRLs be set for "common diagnostic procedures" also recommends that DRLs be based on relevant local, regional or national data (Foley, 2012). Since examination protocols varies greatly among various institutions, a local study could provide more relevant information (Osei, 2013). For DRLs to be effective and facilitate optimization strategies, they have to relate to current practices (Foley, 2012**)** and should be set for different types of examination on the basis of wide-scale survey data to help identify potentially-inadequate performance (Wall, 1995).

The DRLs is not universal but specific to a country, region, equipment and procedure. The document of European Commission EC (1999), guidance on diagnostic reference levels for medical exposure indicates that DRLs should be set by member states taking in to account individual national or regional circumstances such as the availability of equipment and training. They should be adequately adapted to new techniques or methods. Additionally, if the measured doses on a sample of standard-sized patients or on a standard phantom for a standard procedure consistently exceed the relevant DRL, a local review of procedure and equipment is required (Olowokere, 2012).

g. **Cut-off level for DRL**

Despite the increasing popularity of DRL, the IAEA has recommended an "action level" instead. This "action level" is the 10^{th} percentile of dose distribution at which to initiate an evaluation of image quality. This is premised on the fact that radiation doses that are substantially lower than expected may be associated with poor image quality or inadequate diagnostic information. Radiation doses well below the 10th percentile for the same procedure in the population used to define reference levels calls for an evaluation of image quality (Miller, 2009). It has been suggested however, that the third quartile of each examination included in the survey is the acceptable yardstick for DRL (Olarinoye & Sharifat, 2009; Wall & Shrimpton , 1995).

h. **Recommended dose levels**

Reference CTDI and DLP limits for adult routine head CT using 16 cm phantom is 60 mGy and 1050 mGy.cm^1 respectively. Recommended for paediatrics are 40 mGy and 300 mGy.cm^1 respectively for < 1 year; 60 mGy and 600 mGy.cm^1 respectively for 5 years; and 70 mGy and 750 mGy.cm^1 respectively for 10 years (Wall, 1995). Huda and Vance (2007) established 30 mGy and 40 mGy for the CTDI of neonates and adults respectively. They also established an effective dose of 3.6 mSv and 0.9 mSv for neonates and adults respectively.

2.2 Theoretical review

2.2.1 Radiation

All living organisms are daily exposed to radiation from both natural and artificial sources (Weisbrot et al, 2003) with the contribution from the naturally-occurring radionuclide being more dominant. Diagnostic and therapeutic procedures form one of the most important exposure of man to artificial radiation **(**Omar, 2015).

2.2.2 Classification

Radiation is classified into ionizing and non-ionizing on the basis of their ability to free an electron from an atom. It is also classified as natural or artificial on the basis of how they are produced. Ionization occurs when sufficient energy is transferred to an atom to liberate an orbital electron generating an electrically charge ion pair (cations and anions). Each ionization releases approximately 33 electron volts (eV) of energy which is more than enough energy to disrupt the chemical bond between two carbon atoms (NSSPI, 2015).

2.2.3 Ionizing radiation

Ionizing radiation has enough energy to remove tightly-bound electrons from atoms, thus creating ions in materials or free radicals in living tissue. These ion pairs can chemically react in other pathways within living cells and, if sufficient in number, will disrupt cellular function, including damage to DNA (EPA, 2015). Ionizing radiation is energetic and penetrating. It exists in either particulate or electromagnetic forms (Figure 2.1). The particulate radiation interacts with the biological tissue either by ionization or excitation. The ionizations and excitations that it produced tend to be localized, along the tracks of individually-charged particles (Hall & Giaccia, 2011).

The environment is permeated with a background of ionizing radiation of both natural and artificial origins. Natural sources of radiation account for about 80% of the total radiation exposure received by the world's population. The exposure of human beings to ionizing radiation from natural sources is a continuing feature of life on earth and inescapable (Okoyede et. al., 2013). Natural sources of ionising radiation include radon gas (which accounts for approximately 55% of the UK average background radiation) and cosmic rays (8%). This background radiation contributes an approximately 2.6-mSv dose per person per year in the UK. The use of ionising radiation in medicine accounts for 15% of the total radiation burden (Mazrani et al, 2007).

Ionizing radiation which has a higher frequency and shorter wavelength than nonionizing radiation, has many uses but can be a health hazard; exposure to it can cause burns, radiation sickness, cancer and genetic damage. Using ionizing radiation requires elaborate radiological protection measures which in general are not required with non-ionizing radiation (EPA, 2015).

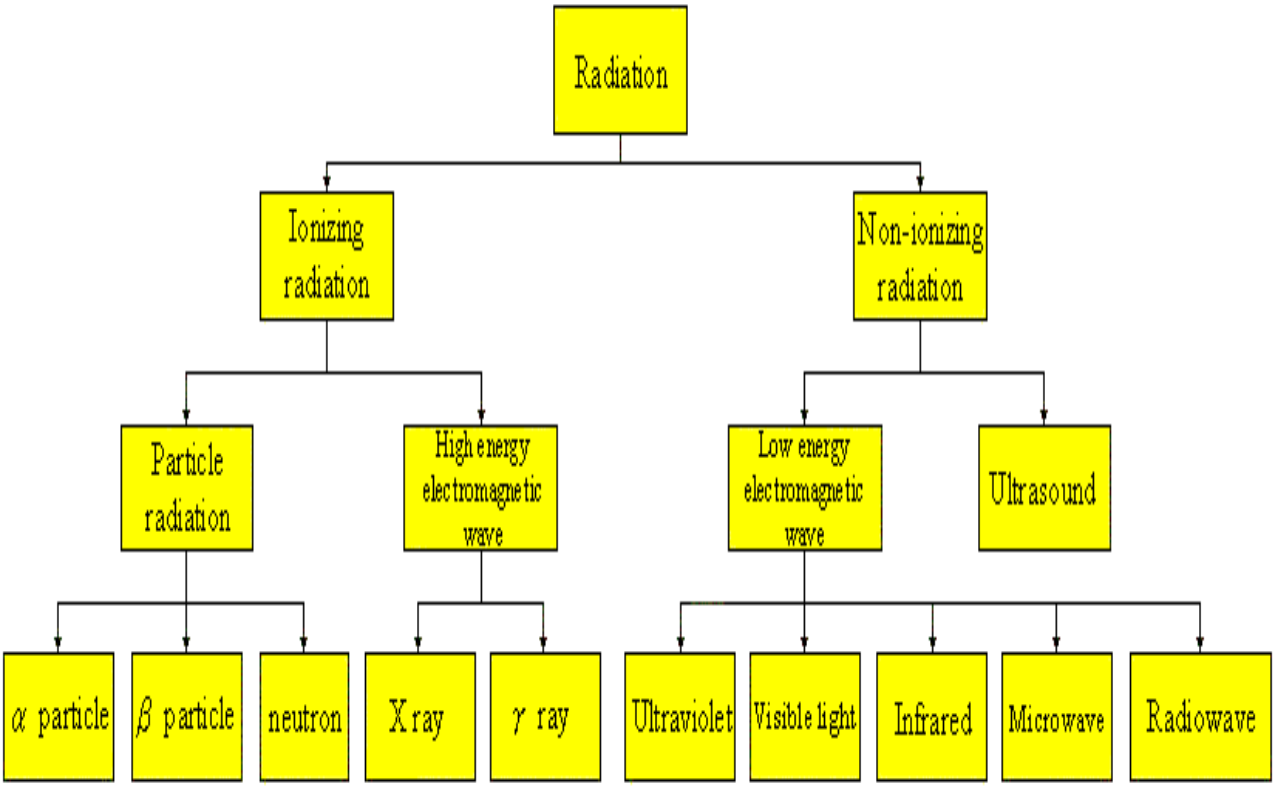


Figure 2.1: Classification of radiation (WHO, 2016)

2.2.4 Electromagnetic spectrum

Electromagnetic radiation is composed of massless waves of oscillating electric and magnetic fields. In a vacuum, these waves move at a constant speed, the speed of light ($3x10^8$ m/s). All electromagnetic waves propagate with characteristic wavelength and frequency, with the wave's energy being directly proportional to frequency and inversely proportional to wavelength. Within the electromagnetic spectrum, only x-rays and gamma rays have enough energy to produce ion pairs. The remaining waves within the spectrum, such as microwaves and radiowaves, are nonionizing (NSSPI, 2015)

It is conventionally divided into regions of radio waves, microwaves, infrared radiation, visible light, ultraviolet rays, X- Rays and gamma rays. Although cosmic rays are high-energy charged particles with energies similar to, or higher than, observed gamma electromagnetic radiation energies, they are not a part of the electromagnetic spectrum**.** A nanometer (10^{-9} m) is the most common unit used for characterizing the wavelength of visible light (EPA, 2015).

2.2.5 X-Ray

X-ray is an electromagnetic, ionizing and uncharged radiation. When electrons are accelerated to energies in excess of 5 keV and are directed on to a target surface, x-rays are emitted (Gail, 2012). Most X-rays have a wavelength ranging from 0.01 to 10 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz) and energies in the range 100 eV to 100 keV. X-ray wavelengths are shorter than those of UV rays and similar as those of gamma rays. In many languages, X-radiation is referred to with terms meaning Röntgen radiation, after Wilhelm Röntgen (IAEA, 2005).

(a) **Discovery**

Wilhelm Conrad Roentgen, a German Physicist discovered X-rays on 8 November, 1895. His experiments involved the passing of electric current through gases at extremely low pressure. While experimenting in a dark room with a well covered discharge tube, he observed that certain rays were emitted during the passing of the current through discharge tube which illuminated a barium platinocyanide-covered screen placed two meters away. He named the radiation X-rays to underline the fact that their nature was unknown (Tubiana, 1996).

When Röntgen held a piece of lead in front of the electron-discharge tube, it blocked the rays, but he was shocked to see his own flesh glowing around his bones on the fluorescent screen behind his hand. He then placed a photographic film between his hand and the screen and captured the world's first x-ray image. Six weeks later, at the close of 1895, he published his observations and mailed his colleagues a photograph of the bones of his wife's hand, showing her wedding ring on her fourth finger (Waters, 2011).

X-rays and radioactivity were at the origin of the scientific revolution at the end of the 19th and the beginning of the 20th centuries (Tubiana, 1996). In 1901, Roentgen received the first ever Nobel Prize in Physics. This was a true acknowledgement of his remarkable discovery which was going to be highly beneficial for mankind in the coming years. Wilhelm Roentgen died on February 10, 1923 in Munich at the age of 77 (Tubiana, 1996). Many people who were x-rayed or who worked with the original x-ray producing machines suffered from radiation burns and loss of hair. There was also a marked difference in the exposure time required:it took 90 minutes to image the hand using the 19th century machine, compared to 20 milliseconds using modern x-ray machines (Waters, 2011).

(b) **Production of x-ray**

X-rays are produced due to sudden deceleration of fast moving electrons when they collide and interact with the target anode. In this process of deceleration more than 99% of the electron energy is converted into heat and less than 1% of energy is converted into X-ray production (Gail, 2012). The cathode, which is the negative terminal, contains a tungsten filament which emits electron when heated by the process called thermionic emission. The anode is the positive terminal and it is made of tungsten disk in diagnostic radiography and molybdenum in mammography. A high voltage applied between the cathode and anode introduces an electromotive force which propels the electrons to move towards the anode at half the velocity of light. Fast-moving electrons interact with anode in following ways:

- interaction with K-shell electron: production of characteristic radiation.
- interaction with nucleus: production of bremsstrahlung radiation.
- interaction with outer shell electrons: line spectrum (Goel & Mudgal, 2015).

(c) **Uses of x-ray**

X-Ray is the most frequently used ionizing radiation for diagnostic imaging and it is said to be the major contributor to the collective effective dose of the general public (personnel and patient). The need for radiation dose assessment of the patient during diagnostic X-ray examinations has been highlighted by increasing knowledge of hazard of ionizing radiation (Johnston and Brennan, 2000).

Table 2.1: The characteristics of the electromagnetic spectrum

Region	*Frequency (Hz)*	*Wavelength (m)*	*Energy (eV)*
Radio waves	$< 10^9$	> 0.3	$< 7x\ 10^{-7}$
Microwaves	10^9 - $3x10^{11}$	0.001 - 0.3	$7x10^{-7}$ - $2x10^{-4}$
Infrared	$3x10^{11}$ - $3.9x10^{14}$	$7.6x10^{-7}$ - 0.001	$2x10^{-4}$ - 0.3
Visible	$3.9x10^{14}$ - $7.9x10^{14}$	$3.8x10^{-7}$ - $7.6x10^{-7}$	0.3 - 0.5
Ultraviolet	$7.9x10^{14}$ - $3.4x10^{16}$	$8x10^{-9}$ - $3.8x10^{-7}$	0.5 - 20
X-rays	$3.4x10^{16}$ - $5x10^{19}$	$6x10^{-12}$ - $8x10^{-9}$	$20 – 3\ x10^{4}$
Gamma Rays	$3.4x10^{16}$ - $5x10^{19}$	$6x10^{-12}$ - $8x10^{-9}$	$> 3x10^4$

http://science.jrank.org/pages/2368/ElectromagneticSpectrum.html#ixzz3WRqJjeYS

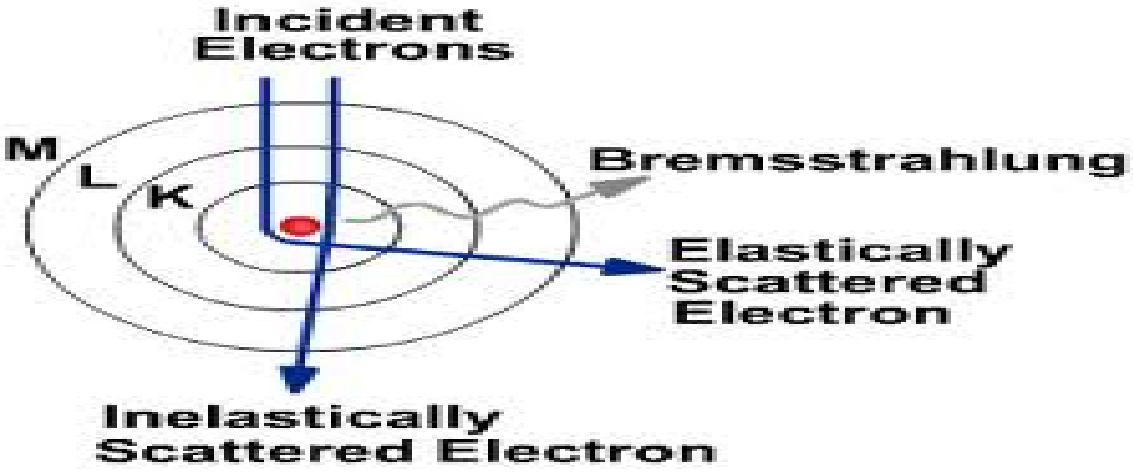


Figure 2.2: Production of Bremsstrahlung x-ray

© www.nde-ed.org/EducationResources/CommunityCollege/Radiography/Physics/

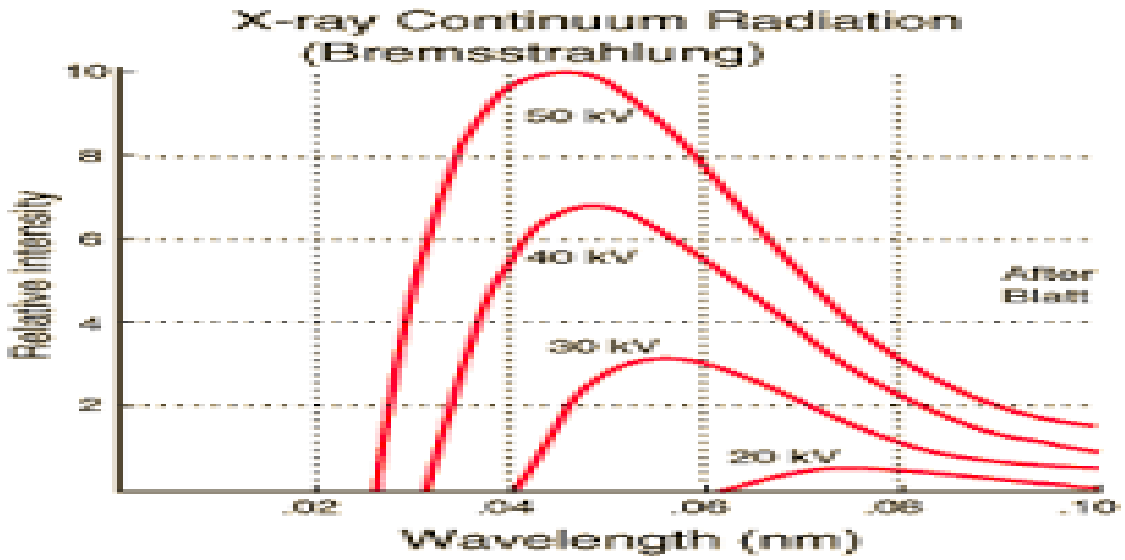


Figure 2.3: Schematic diagram of bremsstrahlung x-ray production

© www.nde-ed.org/EducationResources/CommunityCollege/Radiography/Physics/

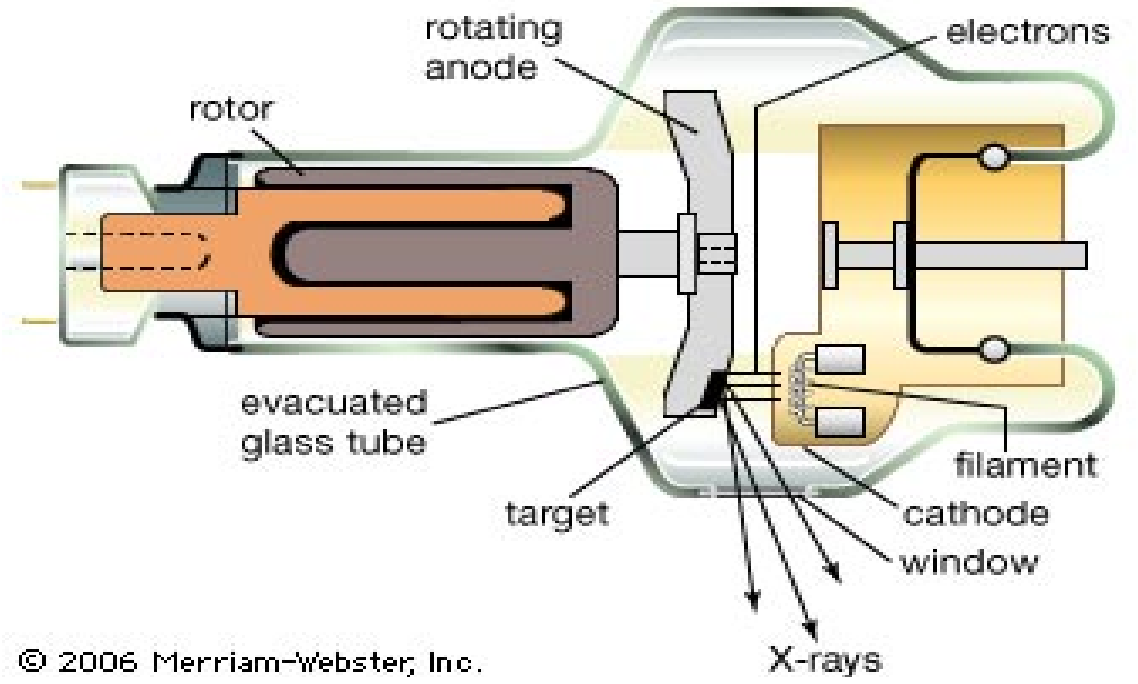


Figure 2.4 An x-ray tube insert

The objective of an x-ray examination is to produce images of sufficient quality of the patient's organ in order to produce adequate diagnostic information for a clinician (Ujah, et. al., 2012). X-rays are used in x-ray machines, mammography machines, fluoroscopy machines and CT scanners (Gail, 2012).

2.2.6 Interaction of radiation with matter

Ionizing radiation and matter

The principal biological effect of ionizing radiation results from damage to DNA. Regardless of the form of ionizing radiation, the common pathway of injury is that the radiation deposits a relatively large amount of energy into the electron orbitals of atoms in the biologic medium. This energy transfer raises the energy level (excites) of the electron and, if sufficient, ejects the electron from the atom, resulting in a now positively charged atom (ionization). These charged particles are chemically active, resulting in breakage of the chemical bonds within the DNA molecule. In addition to this direct injury, ionization radiation interacts with cellular water, forming free radicals, which can also damage the chemical bonds in the DNA strands. Regardless of the form of ionizing radiation (alpha, beta, gamma, x-ray, neutrons) or whether the damage is direct or indirect via free radical formation, the final pathologic injury is disruption of chemical bonds in the DNA strands (WHO, 2016).

DNA damage is dose dependant, with the most common damage being single-strand breaks. As long as the number of breaks is not overwhelming and the complementary DNA template remains intact, these injuries are repaired with little biological consequence. In contrast, if the injury results in a double-strand break, the repair template is lost and can result in cell death, mutations, or carcinogenesis (Hall & Gaccia, 2011).

Since DNA damage is the principal cause of the biologic effects of radiation, tissues with a high turnover rate are more sensitive to the toxic effects of radiation than cells that are more differentiated. Cells and tissues can repair a certain amount of this damage with no apparent clinical consequence; however, at higher doses, normal homeostatic mechanisms are overwhelmed.

Physiologically, damage on the chemical level progresses to cellular dysfunction, which leads to tissue dysfunction, then organ failure and, ultimately, to death (WHO, 2016). Photon can penetrate matter without interacting. However, it can be completely absorbed by depositing its energy, or it can be scattered (deflected) from its original trajectory and will deposit part of its energy in three main ways:

(i) Photoelectric interaction: a photon transfers all its energy to an electron located in one of the atomic shells, usually the outer shell. The electron is ejected from the atom and begins to pass through surrounding matter.

(ii) Compton scattering: only a portion of the photon energy is absorbed and a photon is scattered with reduced energy. The photon that is produced leaves in a different direction than that of the original photon with different energy.

(iii) Pair production: the photon interacts with the nucleus in such a way that its energy is converted to matter producing a pair of particles, an electron and a positively-charged positron. This only occurs with photons with energies in excess of 1.02 MeV (Hall & Giaccia, 2011).

2.2.7 Radiation injuries

Within months of their discovery it was apparent that X-rays had the potential to cause somatic damage to tissue (Mazrani et al., 2007). Ionizing radiation injures tissues variably, depending on factors such as radiation dose, rate of exposure, type of radiation, and part of the body exposed. Symptoms may be local (eg, burns) or systemic (eg, acute radiation sickness) (Bushberg, 2013).

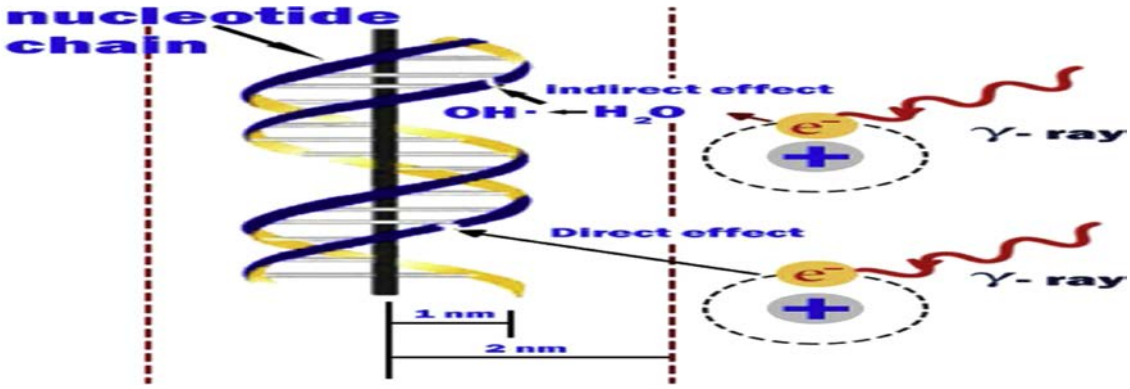


Figure 2.5: Interraction of ionizing radiation with tissue (Hall & Giaccia,2011).

Table 2.2: The time course and severity of clinical signs and symptoms of interaction of dose with tissue

Absorbed dose level	Prodromal phase	Latent phase	Manifest illness	Final phase
0.5–1.5 Gy	Absence of symptoms or nausea and vomiting for 1 day	1 day–several weeks	No symptoms or weakness, nausea and vomiting, temporary hair loss	Recovery
1.5–4 Gy	Nausea, vomiting, fatigue, weakness, diarrhea for up to two days	1–3 weeks	Hematopoietic syndrome (HS): leucopenia and trombocitopenia, hair loss	Recovery possible with supportive care
4–6 Gy	Nausea, vomiting, weakness, diarrhea for up to two days	<1–3 weeks	HS: bleeding, immunosuppression and sepsis, permanent hair loss	Death without supportive care
6–15 Gy	Severe nausea and vomiting, diarrhea in shorter period of time	Several days	HS + gastrointestinal syndrome: diarrhea, bleeding, fluid loss and electrolyte imbalance	Variable with supportive care
>15 Gy	Immediate severe nausea and vomiting	Non-existent	Neurovascular syndrome	Death within 48 h
Williams et al., 2010				

Table 2.3: Risks from radiation Exposure

Phase	Symptom	Whole-body absorbed dose (Gy)				
		1–2 Gy	**2–6 Gy**	**6–8 Gy**	**8–30 Gy**	**> 30 Gy**
Immediate	Nausea & vomiting	5–50%	50–100%	75–100%	90–100%	100%
	Time of onset	2–6 hours	1–2 hours	10–60 min	< 10 min	Minutes
	Duration	< 24 h	24–48 h	< 48 h	< 48 h	Death < 48 h
	Diarrhoea	None	None - mild (< 10%)	Heavy (> 10%)	Heavy (> 95%)	Heavy (100%)
	Time of onset	—	3–8 h	1–3 h	< 1 h	< 1 h
	Headache	Slight	Mild to moderate (50%)	Moderate (80%)	Severe (80–90%)	Severe (100%)
	Time of onset	—	4–24 h	3–4 h	1–2 h	< 1 h
	Fever	None	Moderate increase (10-100%)	Moderate to severe (100%)	Severe (100%)	Severe (100%)
	Onset	—	1–3 h	< 1 h	< 1 h	< 1 h
	Central Nervous System function	No impairment	Cognitive impairment 6–20 h	Cognitive impairment > 24 h	Rapid incapacitation	Seizures, Tremor, Ataxia, Lethargy
Latent period		28–31 days	7–28 days	< 7 days	none	none
Illness		Mild to moderate Leukopenia Fatigue Weakness	Leukopenia Purpura Hemorrhage Infections Epilation after 3 Gy	Leukopenia, fever, diarrhea vomiting,dizziness and disorientation Hypotension Electrolyte disturbance	Nausea Vomiting Severe diarrhea High fever Electrolyte disturbance Shock	N/A (patients die in < 48h)
Mortality	Without care	0–5%	5–95%	95–100%	100%	100%
	With care	0–5%	5–50%	50–100%	100%	100%
	Death	6–8 weeks	4–6 weeks	2–4 weeks	2 days–2 weeks	1–2 days

Source: **Bushberg, 2013**

2.2.8 Adverse effect of radiation interaction with matter

The adverse effects of radiation are grouped deterministic and stochastic effects. Deterministic effects are based on cell killing and characterized by a threshold dose. Below the threshold dose there is no biological effect. Stochastic effects are associated with long-term, low-level (chronic) exposure to radiation. With exposures above the threshold dose the severity of the injury increases with dose. Late toxicities, such as cataract formation and cancer, may appear months or years following an exposure. Other delayed effects are seen in organs with slowly dividing or quiescent, terminally differentiated cells such as the central nervous system, kidneys, and liver. Many of these late radiation effects are attributable to a combination of parenchymal cell death and microvascular disease (Omar, 2015).

The most well-known delayed complication of radiation exposure is malignancy. Exposures to the Chernobyl accident and atomic bomb testing in the Marshall Islands led to high incidences of thyroid malignancies. Atomic bomb survivors have been shown to have an increased risk of leukemia, and young women with Hodgkin disease treated with radiation therapy have been shown to have an increased risk for breast cancer. The explosions at the Fukushima Daiichi Japanese nuclear power plant after the March 2011 massive earthquake increased fear of contamination from radiation and possible health risks (Saha, 2013).

2.2.9 Linear no-threshold principle

The probabilities of experiencing detrimental effects from exposure to low-dose radiation are estimated by extrapolation using a linear model without a threshold (the LNT model). Using this model, possible risks from exposure to low dose ionizing radiation (below 100 mSv) are estimated by extrapolating from data obtained after exposure to higher doses of radiation (Omar, 2015).

2.2.10 Radiation protection

(a). **Definition of radiation protection**

Radiation protection is a science-based discipline in which concepts, methods, and procedures are developed to be used for the protection of humans and the environment from the harmful effects of ionizing radiation. More specifically, radiation protection has the objective of reducing the likelihood of radiation-induced stochastic effects, in particular cancer, and preventing deterministic effects, also called 'tissue reactions (Ujah, et al., 2012).

(b). **Principles of radiation protection**

The international commission on radiological protection (ICRP) has been involved in radiation protection for more than 80 years and in 1990, as well as in subsequent years, recommended that all medical exposures be subjected to radiation safety principles of justification, optimization and limitation of protection (Okoye & Awviri, 2013;Omar, 2012;Ujah et. al., 2012;Olarinoye & Sharifat 2010).

The last 20 years have however, seen a major paradigm shift in radiation biology. Several discoveries challenge the DNA-centric view which holds that DNA damage is the critical effect of radiation irrespective of dose. This theory leads to the assumption that dose and effect are simply linked - the more energy deposition, the more DNA damage, the greater the biological effect. This is embodied in radiation protection (RP) regulations as the linear-non-threshold (LNT) model (Mothersill & Seymour, 2014).

The probabilities of experiencing detrimental effects from exposure to low-dose radiation are estimated by extrapolating from data obtained after exposure to high-dose radiation, using a linear model without a threshold (the LNT model). The LNT model has been widely used to establish international rules and standards of radiation protection (ICRP). It follows the notion that increases in the physical energy deposition of IR linearly increases the carcinogenic risk with increasing dose (Omar, 2015).

However, the science underlying the LNT model is being challenged particularly in relation to the environment because it is now clear that at low doses of concern in RP, cells, tissues and organisms respond to radiation by inducing responses which are not readily predictable by dose. These include adaptive responses, bystander effects, genomic instability and low dose hypersensitivity, and are commonly described as stress responses, while recognizing that "stress" can be good as well as bad. The phenomena contribute to observed radiation responses and appear to be influenced by genetic, epigenetic and environmental factors, meaning that dose and response are not simply related (Mothersill and Seymour (2014). Generally, radiation protection principles are:

(i). Time - Minimize time spent near radioactive source;
(ii). Distance - Maximize distance from source and
(iii). Shielding - Place physical shields around source (WHO, 2016).

2.3. Empirical review

2.3.1 DRL in Nigeria

In Nigeria, no national survey aimed at producing exposure guide for medical examination has been carried out, and both local and national lDRLs/nDRLs are not available; the diagnostic reference levels available for comparison are of European origin and have not been determined in line with equipment, training and patient found in Nigeria (Olowokere, 2012; Olarinoye & Sharifat 2012). This will lead to an important reduction in patient doses in hospitals with high doses and where less than optimum procedures have been identified (Olarinoye & Sharifat, 2012). The dose reduction potential of introducing a DRL is made obvious by the National Radiological Protection Board (NRPB) publication of 1993 which showed reduction in patient doses up to 40% after the establishment of a DRL in 1992. In 2002 a further reduction of 20% was obvious (Hart, 2002).

It has been suggested that when attempting to establish DRLs in Nigeria, it is important to sample as many hospitals as possible and they have to be evenly distributed across the geopolitical zone. These should comprise all government-owned centres and major private practitioners since they record the highest number of patients. All data obtained should then be recorded and analyzed (Olarinoye & Sharifat, 2009). Since Anambra State is the area of study these recommendations shall be adhered to.

2.3.1a Southeast Nigeria

The only documented attempt to establish a DRL in Southeastern Nigeria was carried out by Adejoh et al (2015) in Onitsha, to determine the effective dose from head CT. They undertook the study in a private, faith-based hospital having a 16-slice scanner. Thirty paediatric and adult patients of mixed gender were involved. A maximum of 140kVp and 150mAs were used for the exposure. Their aim was to determine the effective dose from adult head CT scan. This was manually calculated by a multiplication of the DLP with an ICRP-recommended brain weighting factor of 0.0023 $mSv.mGy^{-1}.cm^{-1}$. This yielded an effective dose of 3.32 mSv with a mean and 75^{th} percentile of 2.56 ± 0.51 mSv and 3.11 mSv, respectively.

Like some previous researchers, and in line with standard recommendations, the 75^{th} percentile was adopted in their work. After comparing their findings with others locally and internationally, Adejoh et al (2015) concluded that their dose optimization at the centre of research was an imperative.

An earlier work on typical CT doses was done by Chiegwu et al (2014) in a CT centre in Enugu using seventeen paediatric and adult patients. The authors sought to investigate the radiation doses received by the brain and the lenses of the eyes during diagnostic computed tomography (CT) examination of the head. The absorbed dose was determined using Lithium Fluoride thermoluminescent dosimeters. These were read and using a tissue-specific conversion factor. An effective dose of 0.147 ± 0.056 mSv was derived. The researchers concluded that the radiation doses to the brain and the lenses of the eyes were quite low but advised nonetheless, that unjustifiable unnecessary scans be avoided and dose optimized.

2.3.1b Southwest Nigeria

The necessity for diagnostic reference levels arising from exposure to ionizing radiation in medical practice in Nigeria has been stressed but poorly implemented. In a bold and pioneering effort however, Ogbole & Obed (2014) carried out a work at the University College Hospital, Ibadan on Radiation Doses in Computed Tomography and established centre-specific values which have become a guide to subsequent researchers. A multi-slice scanner with manually selected exposure parameters was used. A maximum kVp of 120, and mAs of 188 were applied. The $CTDI_{vol}$ and DLP values were obtained from the console while effective dose was (E) was calculated using ImPACTscan software. Fifty patients were involved in the study. The CTDI ranged from 69.3 - 77.7 mGy.

The mean values established for DLP and effective dose were 1898 mGy.cm and 2.8mSv, respectively. They drew a conclusion that CT doses in their centre were higher than European Commission recommended guidelines and suggested the need for further optimization of CT practice.

While this work is a step in the right direction, it suffers from a pitfall of not establishing the 75th percentile of their doses. This may be because they were not interested in establishing a DRL.

2.3.1c Northcentral Nigeria

Mundi (2015) also established diagnostic reference level in CT for Abuja using adult subjects. Their work was carried out at the Asokoro District Hospital, Abuja using a 64-slice GE scanner. Forty adult patients presenting for head CT investigations were involved. The tube current (mA) and tube potential (kVp) were manually selected with maximum values 120 kVp and 227 mAs, respectively.

Just like Ogbole (2014) in Ibadan, dose outputs were given using CTDI, DLP and effective dose. However, unlike Ogbole (2014) effective dose was calculated manually using a 1977 ICRP-recommended brain weighting factor of 0.0021 mSv.mGy^{-}1.cm^{-1}. In line with standard recommendations, the 75th percentile was adopted in their work. A $CTDI_{volume}$, DLP and effective dose of 38.08 mGy, 1477 mGy.cm and 3.10 mSv respectively, were obtained. While their absorbed dose and effective dose was higher than those found in the literature for European Commission, their CTDI was much lower. The researchers were therefore, were of the opinion that further optimization of head CT examinations was needful at the centre.

2.3.1d Northeast Nigeria

An attempt has also been made to establish a DRL for northern Nigeria by Garba (2015). In a work titled, "Computer tomography dose index for head CT in northern Nigeria" he sought to investigate the typical values of $CTDI_{weight}$ and DLP in use in three foremost, northern tertiary hospitals using fifty-four adult patients. The centres had GE and Philips scanners having between 4 and 16-slices respectively. A maximum kVp of 131 and mAs of 450 was used at the centres. Just like Mundi (2015) Garba used both purposive sampling technique to recruit weight-relevant subjects as well as the recommended 75th percentile. A combined result for the three centres gave a $CTDI_{weight}$ and DLP of 77 mGy and 985 mGy.cm, respectively.

While their $CTDI_{weight}$ was higher than those found in the literature their DLP was well below similar values from some European countries. The researcher attributed the high $CTDI_{weight}$ to a high mAs.

2.3.2 Diagnostic reference levels in Africa

(a). **Ghana**

In a bold survey by Gedel & Gablah (2014) carried out in Ghana between 2008-2009, in paediatric patients, questionnaire was used as the instrument for data collection. The $CTDI_{weight}$, $CTDI_{volume}$, DLP and effective dose derived were 67.96 mGy, 51.8 mGy, 651.34 mGy.cm and 7.2 mSv respectively. The researchers also found that dose to paediatric patients was higher than that to adults although results for adults were not displayed in their work. They subsequently recommended that policies on CT operation and training be formulated in the hospital. Computed tomography operators were equally advised to select protocols tailored to individual patient size to aid in achieving desirable diagnostic image quality at low doses.

(b). **South Africa**

In a survey undertaken by Sikwila et al (2014) in South African to determine the radiation dose in paediatric patients subjected to MDCT imaging following neurosurgery, one hundred and sixty-nine children aged 0-12 years were used. Data were collected retrospectively from the hospital information system. Range of tube current used was 89-360 mAs. Effective dose was derived from a multiplication of absorbed dose and age-adjusted conversion coefficients. Dose-length product and effective dose were 1183 mGy.cm and 3.6 mSv, respectively. The authors concluded that radical changes to the existing paediatric protocols were not necessary given that the average DLP and effective dose were within acceptable limits compared to current literature.

(c). **Tanzania**

Some work on CT radiation dose have been carried out in different parts of Africa. Ngaile & Msaki (2006) estimated patient doses from CT examinations in Tanzania using CTDI dosimetric in eight CT centres. The mean CTDI value derived was 63.9 mGy. The authors noted a large variation of mean organ doses among hospitals carrying out similar CT examinations.

This they attributed to diverse scanning protocols employed in different hospitals as well as scanner type. They concluded that patient organ doses could substantially be minimized through careful selection of scanning parameters based on clinical indications of study, patient size, and body region being examined.

(d). **Kenya**

In a dose survey carried out by Wambani et al (2010) in Kenya, they sought to assess the level of patient dose in computed tomography examination, compare the dose with the international diagnostic reference levels and then establish their preliminary national diagnostic reference levels. They used questionnaires to ascertain typical exposure parameters from 21 CT centres. Armed with this phantoms were exposed and the dose recorded. Mean tube voltage and current used were 130kVp and 249 mAs, respectively. Mean $CTDI_{weight}$, DLP and effective dose derived were 51mGy,1364mSy.cm and 2.5mSv, respectively.

2.3.3 Diagnostic reference level in Europe

Several works on CT radiation doses have been carried out and DRLs have been established in many European countries. There are even legislation to ensure strict compliance with the tenets of radiation protection.

(a). **Germany**

In one popular nationwide survey carried out by Brix et al (2003) in Germany to investigate the dose profiles of a multi-slice and single-slice spiral CT, 113 CT centres were surveyed using questionnaire to elicit response on dose parameters from the Radiographers. The researchers noted that the scan range for brain CT was 12cm which covered vertex to base of the skull. At 122 kVp and 317 mAs, maximum exposure factors used. Three dosimetrics were used to establish DRL.

While $CTDI_{weight}$ and DLP were recorded from the console, the effective dose was calculated using ICRP-103 recommendation. The $CTDI_{weight}$, DLP and effective dose for multi-slice scanners were 61mGy, 1016mGy.cm and 2.8mSv, respectively. These values are not much different from the figures in preliminary studies from Nigeria.

(b). **Ireland**

Towing a closely similar line Foley (2012) in a work carried out in Ireland using scanners from four centres with multi-slice capability ranging from 2-128, calculated the 75th percentile of the $CTDI_{volume}$ and DLP in ten patients. A $CTDI_{volume}$ of 66/58 mGy and DLP of 940mGy.cm were established. The researchers also noted that a wide variation in mean doses was noted across sites. And that the main CT parameters that affected dose were peak tube potential, tube current, ATCM use, collimation, scan length and the use of either spiral or sequential scanning.

(c). **Netherlands**

A national survey form Netherlands carried out by Molen in 2010 from 14 hospitals, 19 scanners and 186 patients who weighed 74kg, were 1.74m tall and had a BMI of 25.4 kg/m2 ± 15%. Questionaires were used to elicit responses from CT Radiographers. In this survey effective dose was calculated using ICRP-103 conversion factor of 0.0019 $mSv.my^{-1}cm^{-1}$. The cut off was 75th percentile. A DLP of 814mGy and effective dose of 1.5mSv were derived. The researchers concluded that CT doses in the Netherlands was associated with relatively low radiation doses in standard patients.

(d). **Switzerland**

In Switzerland, Aroua et al (2004) established the 75th percentile of CTDI and DLP as 60mGy and 800mGy.cm respectively.

2.3.4 Diagnostic Reference Level in America

In a work carried out by Huda and Vance (2007), to determine typical organ doses, and the corresponding effective doses, to adult and pediatric patients undergoing a single CT examination, Monte Carlo dosimetry data were used to obtain average doses in the directly irradiated region. Dosimetry data were used to compute the total energy imparted, which was converted into the corresponding effective dose, using patient-size-dependent effective-dose-per-unit-energy-imparted coefficients. Representative patient doses were obtained for scanning protocols that took into account the size of the patient being scanned by typical MDCT scanners.

Absorbed doses in head CT increase from 30 mGy in newborns to approximately 40 mGy in adults. Adult head CT ED were approximately 0.9 mSv while that for neonates was 3.6 mSv. The authors concluded that organ absorbed doses in CT were substantially lower than threshold doses for the induction of deterministic effects, and effective doses were comparable to annual doses from natural background radiation.

In another work, Osei & Darko (2013) reported that effective dose from patients subjected to X-Ray and CT examinations were investigated. Data from ninety-four CT scan patients were used. Effective dose was estimated using a computer software, OrgDose (version 2). The mean effective dose for head CT examinations in adults and paediatrics were 1.8 mSv and 1.1 mSv, respectively. They observed that a reduction in effective dose from CT examinations could be achieved by reducing mAs as well as the extent of the scan length as much as possible, without missing any vital anatomical regions of interest.

2.3.5 Diagnostic reference levels in Asia

(a). **Indonesia**

Noor & Normahayu (2012) undertook a dose survey of three CT centres to establish effective dose used in practice. The sample comprised one hundred patients. Effective dose was derived using a computer software, CTDosimetry version 1.0.4 dose calculator. Their results revealed that the effective doses received by patients ranged from 1.25 –2.51 mSv for male patients and 1.14 – 2.39 mSv for female patients.

(b). **Iran**

In a related work carried out by Firouzi et al (2014) in Iran, two hospitals with single-slice CT scanners were surveyed within four weeks in 2011 to ascertain typical CT doses to different anatomical parts of the body. Questionnaires were used to elicit data on scanner parameters and machine specifications from CT operators. The information was subsequently used to expose phantoms and doses recorded. Head scans were divided into base of the skull and sinus. The mean $CTDI_{weight}$ for base of the skull and sinus were 12.2 mGy and 13.13mGy, respectively while DLP gave 99.64mGy.cm and 96mGy cm, respectively.

2.3.6 Current status of DRLs in Nigeria

Computed tomography is becoming increasingly available in Nigeria due to the better diagnostic information obtainable yet, there are very little data available to address the dose concern of CT examinations. (Ogbole, 2014; Scholtz, 2015). Some isolated studies using CT have shown variations of 2.8 mSv to 3.1 mSv in effective dose of the head (Adejoh, 2015; Mundi, 2015; Garba, 2015; Ogbole & Obed, 2014). These observed variations in Nigeria in the local surveys have presented the need for the establishment of standards.

There are also no national or zonal dose reference levels to guide CT users on threshold doses. Although, in the interim, the European Commission recommendations are available for peer review of practice, this is deemed inappropriate because of the differences in population, training of radiographers and scanner programming (Klink, et. al., 2014).

The current study aims to explore dose levels for adult head CT examinations in Anambra State, and to propose local dose reference levels for optimization of CT examinations. This may serve as preliminary DRLs for the the state, zone, or the entire country.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Research design

The design of the study was mixed, with both a prospective cross-sectional and a retrospective component. Anthropometric parameters like age, gender, height, and weight were ascertained and recorded in the prospective phase. Protocol parameters used for each examination were also retrieved real time from the console. The patients were also followed up from the point of entry into the department till the end of the investigation. The stored dose data as well as biometric parameters like bi-parietal and occipito-frontal diameter were calculated and retrieved in the retrospective phase.

3.2 Area of study

A pilot study involving total enumeration of CT centres in Anambra State was carried out by the researcher prior to the main survey. It was discovered that there were nine (9) CT centres in the State. The distribution were: Onitsha (4); Nnewi (2); Awka (2) and Ogidi (1). One in Awka was not commissioned and so, was not in use. It was therefore, excluded. The second one in Awka was installed around July 2017, and had not got enough database of patients as at the time of the survey which commenced in October, 2015. A new centre in Onitsha shared a similar fate. Also in Onitsha, one of the centres did not have installed dosimetrics and so, was also excluded. That fate was equally shared by another centre in Nnewi. The study was eventually carried out at four of those centres which met the inclusion criteria of having installed dosimetrics and having been in operation for six months or more. Incidentally, these centres had the highest patient throughputs in Anambra State as revealed by the pilot survey. The four centres, with location and ownership were:

(a). Nnamdi Azikiwe University Teaching Hospital, Nnewi. The facility is owned by the federal government.

(b). Saint Charles' Borromeo Hospital, Onitsha. It is owned by the Catholic Church.

(c). Onitsha Medical Diagnostic Centre. The centre is privately owned.

(d). Iyi-Enu Mission Hospital Ogidi. This is owned by the Anglican Church.

For the sake of confidentiality, codes A, B, C and D (not following the order above) were used to represent the centres during presentation of results.

There were however, five other CT centres in the state which were excluded. One was in Nnewi and had no installed dose metrics. Another one in Onitsha also did not have installed dosimetrics. A CT facility in Awka was installed for many years but was neither commissioned nor put into use. Two new facilities sited in Awka and Onitsha were on test-run as at the time of data collection. The distribution of CT centres in Anambra State and Southeast Nigeria are as shown in Appendix II.

Although technical information on CT scanners were got from Radiographers who were in different states of the South-East, dose data could not be retrieved because of the cumbersome process of obtaining permission in many centres. So, an initially contemplated South-East survey was shelved in preference for one domiciled in Anambra State. However, the information gleaned from the pilot study was relevant to the present work (appendix II).

3.3 Ethical Considerations

Ethical approval was obtained from the Human Research Ethics Committee of both the Nnamdi Azikiwe University Teaching Hospital (NAUTH), Nnewi, and Faculty of Health Sciences, Nnamdi Azikiwe University, Nnewi Campus. Permission to undertake the study was equally obtained from each of the other three CT centres (appendix I). Informed, written consent on a prepared form was also received from subjects prior to their enlistment in the study. For confidentiality of information, image anonymity features were activated during retrospective data collection from the digital archive of the CT console in centres A and D and workstations of centres B and C (appendix III).

3.4 Population

The population sampled comprised all adult head CT investigations undertaken in the selected centres in Anambra State within the period of the study. This was a total of one thousand, one hundred and four (1,104) digitally stored CT image folders with 53.1 % (n = 586) being male and 46.9 % (n = 518) representing females.

3.5 Sample size determination

A formula proposed by Taro Yamani (1967) and quoted by Uzoagulu (2011) for known population was used to derive the sample size. The CT population (N) was retrieved from the records at the CT facilities:

$$n = \frac{N}{1 + N(e)^2}$$

Where n = sample size

N = population (known)

e = error limit/alpha value (5%; 0.05)

$$\text{This gave } \frac{1104}{1 + 1104\,(0.0025)} = \frac{1104}{3.76} = 294$$

The sample size was eventually rounded off to 300 in order to have an even number when shared across the four centres.

3.6 Sampling

Although over a thousand subjects qualified for the study, only the first three hundred who met the inclusion criteria were included through convenience sampling. The subjects were enlisted as they came for the investigation. Those who could not stand for assessment of height and weight were however, excluded. The rationale was that all adult head CT requests qualified for the sampling frame. This sampling and data retrieval continued prospectively from October 2015 and extended till May 2017.

3.7 Inclusion Criteria

i. Scanners with installed CT dose metrics (CTDIvol and DLP)

ii. Facilities that had been in operation for atleast six months.

iii. Examinations with no repeats

iv. Non-contrast examinations

v. Subjects aged $\geq$ 18 years (Pickard, 2015; Blaivas, 2007)

vi. A weight of 70 $\pm$ 10 kg (Miller, 2009; Molen, 2010)

3.8 Materials

Computed tomography scanners

A General Electric (GE) Brightspeed, 4-slice scanner manufactured in 2007 and installed in 2011 was available at centre A. Both centres B and C had a similar Toshiba Alexion, 16-slice scanners manufactured in 2013 and installed in 2014. The private diagnostic centre had a 16-slice Siemens Somaton-Perspective scanner manufactured and installed in 2015. The scanners in centres A and D were installed and programmed by different engineers, while a similar engineer installed and programmed the ones in centres B and C. All the scanners had helical and axial scan modes. The variations in protocols were minimal and it was not gender biased. Arrangement of the knobs however, varied substantially with the make of the scanner. The scanners were also self-calibrating and these softwares were activated daily. All centres had licensed Radiographers and reporting Radiologists. The newest centre had worked for at least six months before the commencement of the survey (appendix II).

Table 3.1 Selected scanner information

Centre	Ownership	Location	Model	Slice	Manufact-ured	Installed	No of radiographers
A	Federal Government	Nnewi	GE	4	2007	2011	≥ 40
B	Anglican Communion	Ogidi	Toshiba	16	2013	2014	4
C	Catholic Church	Onitsha	Toshiba	16	2015	2014	2
D	Private	Onitsha	Siemens	16	2013	2015	1

3.9 Methods of data collection

Data collection was multi-phased. A prepared form was available where all the relevant information were recorded (appendix VI).

3.9.1. Phase I: Measurement of anthropometric parameters

Commencing from October 2015 till the end of data collection in May 2017, the researcher was dressed in clinical gown like the radiographers and participated in the CT procedures. As part of departmental routine in two of the centres, patients vital signs as well as height and weight were measured and recorded on the request cards. In the other two centres, vital signs were recorded as departmental protocol but not height and weight. The researcher therefore, provided portable weight and height rule for them.

To measure weight, the subject was made to empty pockets of mobile phones, bunches of keys and other objects that could add a gram or more to the weight. The weight was taken bare-foot. The subject stood erect on the beam balance without resting hands or body on the table or wall. The weight, in kg was read to the nearest 0.5kg.

While still standing erect and as motionless as reasonably achievable, with heels, gluteal muscles and occiput touching the upright bar of the height scale, the short, horizontal bar of the scale was adjusted to make firm contact with the vertex of the head. The height was then read off to the nearest 0.1centimetre. The body mass index was calculated as weight (in kg) over height^2 (in metre). With the aid of a calculator, the body mass index was subsequently calculated from the weight and height using the formula: weight/height^2 (kg/m^2). These data were recorded at the back of the subjects request cards and archived.

3.9.2 Phase II: Measurement and recording of biometric parameters

The bi-parietal and occipito-frontal diameters were measured in this phase of data collection. These data were needed to calculate the cephalic indices needed for correlation analysis later in the work. The measurements were done on digital skull images on the monitor (appendices Vf and Vg).

For the measurement of cephalic index, on-screen linear measurement cursor was activated. On the postero-anterior (PA) scanogram, the most elongated lateral bony prominences which represent the biparietal (BPD) diameters were identified. A horizontal line was then drawn from one parietal bone to the other, at an azimuth of 90 degrees. This line has a distance of about 4 - 5.5cm superior to the supraorbital margin. An azimuthal variation from 90 degrees is evidence of rotation of PA scanogram and the image qualified for exclusion.

On the lateral scanogram, occipito-frontal diameter (OFD) was measured using a straight line which bisected the hypodense frontal sinus (glabella) at an azimuth of 77-90 degrees. The cursor was then extended to the most protuberant part of the occipital bone (inion) posteriorly (Appendices I and II).

The percentage of the BPD to the OFD was then calculated and represented the cephalic index (CI) for that subject. The digital measurements were recorded in the prepared data collection form. The on-screen calculations were not saved in order to allow the images revert to their original state for clinical reasons (Hayward et. al., 1977).

3.9.3. Retrieval of technical data from the CT console

From October 2015 till the end of the survey in May 2017, the subjects' requests cards were retrieved from the archives and used to identify their digital folders on the console. All the scan series on the console were then scrutinized to retrieve technical information used for the investigation.

During data collection, retrieval of cards was halted when a sample size of 75 was reached for each centre. Confidentiality of the subjects was maintained by the activation of partial data anonymity features of the scanner. A dose survey sheet was used for data collection. The sheet was designed to extract patient anthropometric characteristics such as age, height weight, and gender. It also allows for collection of information related to imaging parameters such as scan mode, tube potential (kVp), tube current and time (mAs), gantry rotation time, pitch, and slice thickness.

3.9.4. Retrieval of dose data

The dosimetry technique was based on the methods proposed by the European Commission (1999), which recommended that before dose measurements are carried out, quality control (QC) should be performed for each machine and the results compared with the CT dose indices displayed on the control console to ensure that the output of the machines were fairly constant since acceptance testing (Saravanakumar, 2014). Computed tomography engineers carried out quarterly quality control known as preventive maintenance, in the centres. The calibrations were undertaken by the radiographers daily as part of quality control practices (appendix V).

The last series in each subject's investigation is specifically the dose report which gave the $CTDI_{vol}$ and DLP outputs. To enable head CT dose comparison between centres, only the DLP and CTDIvol of non-contrast scans in centres that performed contrast-enhanced brain CT scans were used. The $CTDI_{vol}$ (mGy) appeared as a single horizontal row of data when a single slice thickness is used, and more than one row when multiple slices are used (appendix V). The dose data were obtained from these rows.

For single rows, the data were copied directly while the mean of the data was adopted for multiple rows. The DLP always appeared as a cumulative value for each subject. This value was used. Care was taken to ensure that 'head' (16 cm) phantom rather than 'body' (32 cm) phantom appeared boldly by the dose data. All the information were subsequently collated and prepared for data analyses.

3.10 Data Analysis

The data were categorized into anthropometric (measurements on subjects), biometric (measurements on images), technical, and dose. The anthropometric data included age, gender, weight, height, and body mass index. Data categorized as biometric included occipito-frontal diameter, biparietal diameter and cephalic index. The technical data involved all exposure parameters from the scanner, while dose data were CTDIvol, DLP and effective dose. These data were analyzed with the aid of Statistical Package for the Social Sciences (SPSS) version 20.0 (SPSS Incorporated, Chicago, Illinois, USA). Mean, mode and range were used to summarize all anthropo-technical data. Results were given as mean ± standard deviations.

The diagnostic reference levels (DRLs) for the examinations was then calculated based on mean and 75^{th} percentiles. A *percentile* (or a centile) is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations fall (Robert, 2007). The 75th percentile which is often used for setting DRLs identifies the 25% of centres that generate higher doses. Where dose variation is tight, a 95^{th} percentile is preferable. The 75^{th} percentile also represents the recommended dose values that should not be exceeded, while the mean provide dose levels facilities should strive towards (O'Leary and Rainford, 2013).

The effective dose was calculated from the product of the dose-length product (DLP) and, 0.0023mSv.mGy^{-1}cm^{-1}, a brain CT conversion coefficient recommended by ICRP, (1996).

An analysis of variance (ANOVA) was carried out to test for significant differences in the mean dose output among the four centres in Anambra State. A Turkey's post-hoc analysis was subsequently done to establish the specific centres responsible for the differences found. Percentages were used to express variations in the 75th percentile between the present study and that of the European Commission. The percentiles were derived from the mean dose of all centres combined. It determines a value at which 75% of the distribution falls or do not exceed.

The relationship between the anthropo-technical parameters (Age, weight, height, BMI, OFD, BPD, CI, kVp, mA, gantry tilt, scan range, duration of gantry rotation) and the DLP was determined using a univariate Pearson correlation tests. The grading of coefficient of correlation was ≤ 0 (no correlation), ≤ 0.2 (poor), 0.3 – 0.4 (mild), 0.5 – 0.6 (moderate), 0.7 – 0.8 (good), 0.9 (excellent), and 1 (perfect). All tests were carried out at an alpha (α) level of 5% (0.05), two-tailed, for statistical significance. The results are categorized into descriptive statistics displayed in tables.

CHAPTER FOUR

RESULTS

4.1 Computed tomography scanner information

Given in Table 4.1 is the distribution of CT scanners in Anambra State as at December 2016. There were nine specific centres spread across the three senatorial districts of Onitsha (5), Nnewi (2), and Awka (2). Ownership cuts across private (4), faith-based organizations (2), federal government (1), state government (1) and public private partnership (1). Only three models of scanners were available; GE (6), Toshiba (2) and Siemens (1). The slices range from one to sixteen. The scanners were manufactured between 1998 – 2015 and installed within a 5-year period of 2010 – 2015.

4.2 Populations of head CT examinations

Shown in Table 4.2 is the population of head CT examinations (N) that met the inclusion criteria and the sample size (n). The population that met the inclusion criteria was one thousand, one hundred and four (1,104). Out of this, a sample size of 300 comprising 75 subjects from each centre was drawn. Male subjects constituted 54 % (n = 162) of the sample while females had 46 % (n = 46 %).

4.3 Distribution of subjects according to clinical indications

Shown in Table 4.3 is the frequency distribution of the subjects according to the clinical indications. Head CT had three basic clinical indications; cranium (n = 164) made up 55 % of the cases while sinuses (n = 78; 26.0 %) and facial bones (n = 58; 19 %) were the other two regions involved.

4.4 Anthropometric characteristics of subjects

The 300 subjects had an age range of 18 – 93 years and a mean of 70.0 ± 19.1 years. Weight, height, and BMI had a range of 60 – 80 kg, 144 – 186 cm, and 19.0 – 43.2 kg/m^2, respectively. The BPD, OFD and cephalic index also had ranges of 120 -154 cm, 174 – 203 cm and 65 – 85 % , respectively. The modal value, mean, and standard error of mean are also shown (Table 4.4).

Table 4.1 Distribution of CT centres in Anambra State as at December, 2016

S/ No	Name of centre	Location	Ownership	Model	Slice	Manufac-tured	Installed	Included	Reason for inclusion/ exclusion
1.	NAUTH	Nnewi	Federal Government	GE	4	2007	2011	Yes	Large database & inherent dosimetrics
2.	Iyi-Enu Missions Hospital	Ogidi	Anglican	Toshiba	16	2013	2014	Yes	Large database & inherent dosimetrics
3.	Saint Charles' Borromeo Hospital	Onitsha	Catholic	Toshiba	16	2013	2014	Yes	Large database & inherent dosimetrics
4.	New Hope Diagnostic Centre	Onitsha	Private	Siemens	16	2015	2015	Yes	Large database & inherent dosimetrics
5.	Conquest Imaging	Nnewi	Private	GE	1	1998	2012	No	No dosimetrics
6.	General Hospital	Onitsha	Public Private Partnership	GE	4	2007	2013	No	No dosimetrics
7.	Eldorado Diagnostic centre	Awka	Private	GE	16		2016	No	Scanty database
8.	GRA Diagnostic centre	Onitsha	Private	GE	16		2016	No	Scanty database
9.	COOUTH, Amaku	Awka	State Government	GE	8	?	?2010	No	Not in use

Key:

NAUTH = Nnamdi Azikiwe University Teaching Hospital, Nnewi

COOUTH = Chukwuemeka Odimegwu-Ojukwu University Teaching Hospital, Amaku, Awka

GE = General Electrics

Table 4.2 Distribution of subjects according to centre and gender

Variable	N			n		
	Gender					
Centre	M	F	**M+F**	M	F	**M + F**
A	206	132	**338**	41	34	**75**
B	202	143	**345**	42	33	**75**
C	126	111	**237**	40	35	**75**
D	105	79	**184**	39	36	**75**
Total	639	465	**1104**	162 (54.0 %)	138 (46.0 %)	**300 (100 %)**

Key: N = population
n = sample size
M = Male
F = Female
M + F = Male + Female

Table 4.3 Distribution of subjects according to clinical indications

Parameter	**Anatomy**			**Total**
Centre	Cranium	Sinus	Facial bones	
A	38	22	15	75
B	40	21	14	75
C	41	18	16	75
D	45	17	13	75
Total	164 (55.0%)	78 (26.0%)	58 (19.0%)	300 (100%)

Table 4.4 Anthropometric characteristics of subjects

Variable	n = 300		Mean (± standard deviation)			SE Mean
	Range	Mode	Male (n = 162)	Female (n = 138)	Male + Female (n = 300)	
Age (year)	18 – 93	78	71.0 ± 18.6	70.1 ± 18.8	70.0 ± 19.1	1.1
Weight (kg)	60 – 80	80	73.7 ± 11.2	75.7 ± 15.6	74.1 ± 6.4	0.7
Height (cm)	144 – 186	168	170.0 ± 7.8	160 ± 10.4	166.0 ± 10.3	1.2
BMI (kg/m^2)	19.0 – 43.2	25	25.2 ± 3.1	30.1 ± 6.0	27.1 ± 5.2	0.6
BPD (cm)	120 – 154	133	137.7 ± 5.8	137.0 ± 8.5	137.2 ± 6.7	0.8
OFD (cm)	174 – 203	182	187.0 ± 7.6	185.0 ± 4.3	186.3 ± 6.8	0.8
CI (%)	65 – 85	71	73.5 ± 4.0	75.0 ± 5.1	73.8 ± 4.1	0.5

Key: SE = standard error
BMI = body mass index
BPD = biparietal diameter
OFD = occipito-frontal diameter
CI = cephalic index

4.5 Protocol and dose data

Table 4.4 gives an overview of CT protocol parameters. Computed tomography protocols are defined by a set of adjustable parameters. Most of these parameters are discrete, rather than continuous. The modal values of the parameters are: 120 kVp (tube potential), 250 mA (tube current), 1s (duration of gantry rotation), 0.75/1.5 (pitch), 2.5 mm (slice thickness), and 14 cm (range). The most popular scan mode was helical, while choice of scanogram was 2. Gantry tilt and gap was not popular (zero).

4.6 Computed tomography dose data in Anambra State

The combined $CTDI_{vol}$ dose output in Anambra State is given in Table 4.7. A significant degree of variability in the dose output was noticed between the centres. While centres A (57/60 mGy) and B (57/59 mGy) had comparable mean/75^{th} percentile, C (74 mGy/87 mGy.cm) had a much higher value. When the four centres were taken as a single population, the dose had a range of 24 – 94 mGy. Both male and female populations had a comparable mean/75^{th} percentile of 57 mGy/67 mGy.cm and 58 mGy/68 mGy.cm, respectively. This was similar to the common mean/75^{th} percentile (58 mGy/67 mGy.cm). The $CTDI_{vol}$ dose output in Anambra State is manifestly 67 mGy. The standard error of the mean, which represents the measure of the variability of several samples of the population from the mean, showed little variation (0.8).

Following a similar pattern as in the $CTDI_{vol}$, the mean/75^{th} percentile of the DLP was different in centre A (1095/1390 mGy.cm), B (1173/1302 mGy.cm), C (1618/1785 mGy.cm) and D (733/792 mGy.cm). The DLP in the State, as shown in the table is therefore, 1500 mGy.cm. The standard error of the mean, showed little variation (24.0).

Table 4.5: Values of protocol parameters used for investigation

Parameter	Range	Centre				
		A	B	C	D	Modal
Tube potential (kVp)	80 - 140	120	120	140	120	120
Tube current (mA)	10 - 400	230	250	250	250	250
mA modulation (yes/no)	10 - 400	No	Yes	Yes	Yes	Yes
Duration of gantry rotation (sec)	0.4 - 4	1	1	2	0.5	1
Pitch (≤ 1.5)	0.75–1.5	1.5	0.75	0.75	1.5	0.75/1.5
Slice thickness (mm)	0.5 - 10	2.5/5	0.75	2.5	2.5	2.5
Gap (mm)	1 - 10	0	0	0	0	0
Slice row (numeric)	1- 4	2	1	1	1	1
Scan range (cm)	10 - 26	16	14	14	14	14.0
Gantry tilt (degree)	0 - 30	17.5	0	0	0	0
Scout azimuth (degree)	0 - 360	90/180	0/90	0/90	0/90	0/90
Aperture diameter (cm)	70 - 75	70	75	75	80	75
Number of Scanogram	1 - 4	2	2	2	2	2
Scan mode	A/he/cine	Axial	Helical	Helical	Helical	Helical

NB: The protocol parameters have a fixed value and range. The fixed values do not allow for intermediate ones or the extension of range. So, the radiographer is limited to definite choices. As a result, the most frequently used values (modal) were adopted. Using mean will create values that did not exist.

Legends: mA modulation = tube current that changes value depending on the density of the anatomy of interest. The manual mA is fixed, irrespective of density. **Pitch** = Gives an idea of tissues that was spared during scan. Sparing of tissue is strong evidence of radiation protection. A pitch value of (1) indicates contiguous scans without tissue sparing. Less than or greater than (1) gives evidence of overlap (multiple scan over same area) or gap, respectively. **Scan range** = indicates the extent of tissue covered by the radiation**. Gantry tilt** = higher tilt increases the distance traversed by radiation and hence, higher dose**. Azimuth** = Lens of the eye and thyroid gland which are radiosensitive should be spared by making the beam emanate from the side of the head (90^{o}) or posteriorly (180^{o}). **Scanograms** = initial x-rays taken before the real axial cuts. They are two even though the maximum possible is four.

Table 4.6: Mean and 75th percentile of dose output in Anambra State

Parameter Centres	Range	Mean				75th percentile		
		CTDIvol (mGy)						
		Male	Female	M + F	SE Mean	Male	Female	M + F
A	40 - 94	56	57	57	1.1	59	60	60
B	44 - 59	57	57	57	0.5	60	59	59
C	65 - 87	73	75	74	1.0	87	87	87
D	24 - 74	43	44	44	0.8	45	46	46
Combined	24 - 94	57	58	58	0.8	67	68	67
		DLP (mGy.cm)						
A	337 - 1982	1096	1094	1095	46.0	1388	1394	1390
B	664 - 1951	1168	1175	1173	26.0	1304	1300	1302
C	921 - 1973	1619	1617	1618	26.4	1784	1785	1785
D	350 - 1177	735	731	733	14.0	792	790	792
Combined	337 - 1982	1154	1156	1155	24.0	1501	1500	1500

Key: M + F = Male + Female
SE = standard error

4.7 Dose output as a function of scanner model

The model of scanner, because of peculiar software and algorithms, is assumed to play a significant role in dose output. To that effect, specific and similar protocol parameters were noted for each centre as well as the appropriate parameter recommended in the literature. For inappropriate parameters, the tally against each centre were: (A): mA modulation, slice row, scan range, gantry tilt (60 mGy/1390 mGy.cm); (B): mA, pitch, azimuth (59 mGy/1302 mGy.cm); (C): kVp, mA, DGR, pitch, azimuth (87 mGy/1785 mGy.cm); (D): mA, azimuth (46 mGy/792 mGy.cm). All the centres defaulted on the issue of allowing some gap in the tissue. Two centres (B and C) with similar Toshiba machine, which were manufactured, bought, installed and programmed jointly presented the scenario for a fitting comparison. The protocol parameters had more dissimilarities than similarities, so were the dose output (B = 59 mGy/1302 mGy.cm; and C = 87 mGy/1785 mGy.cm). For the other two scanners, appropriate programming appeared to be responsible for dose output rather than the model of scanners.

4.8 Effective dose data

Shown in Table 4.8 is the effective dose value from the dose output in Anambra State. Effective dose is calculated from equivalent dose and brain tissue weighting factor as recommended by ICRP (1999). In CT the equivalent dose is contained in the DLP. For the four centres, the effective dose ranged from 2.50 to 4.11 mSv with a mean of 3.56 mSv.

4.9 Correlation analysis between DLP and anthropo-technical parameters

The DLP has a strong positive, and significant correlation with the $CTDI_{vol}$ ($r = 0.737$, $p = 0.001$). A weak positive and non-significant correlation was observed between the DLP and OFD ($r = 0.241$; $p = 0.096$), age ($r = 0.202$; $p = 0.050$), gantry tilt ($r = 0.195$; $p = 0.180$), and ($r = 0.169$; $p = 0.246$). A weak negative and non-significant correlation was equally observed between the DLP and kVp ($r = -0.219$; $p = 0.131$), BPD ($r = -0.193$; $p = 0.183$), weight ($r = -0.177$; $p = 0.224$), mA ($r = -0.170$; $p = 0.243$) and cephalic index ($r = -0.143$; $p = 0.326$). There was no correlation between DLP and duration of gantry rotation, height and BMI. These are summarized in Table 4.10.

Table 4.7: Dose output as a function of scanner type/model

Parameter	Range	Centre				
		GE (A)	Toshiba (B)	Toshiba (C)	Siemens (D)	Recom-mended
Tube potential (kVp)	80 – 140	120	120	140	120	120
Tube current (mA)	10 – 400	230	250	250	250	230
Ma modulation (yes/no)	10 – 400	No	Yes	Yes	Yes	Yes
Duration of gantry rotation (sec)	0.4 – 4	1	1	2	0.5	≤ 1
Pitch (≤ 1.5)	0.75–1.5	1.5	0.75	0.75	1.5	>1
Slice thickness (mm)	0.5 – 10	2.5/5	0.75	2.5	2.5	≤ 5
Gap (mm)	1 – 10	0	0	0	0	≥5%
Slice row (numeric)	1- 4	2	1	1	1	1
Scan range (cm)	10 – 26	16	14	14	14	14
Gantry tilt (degree)	0 – 30	17.5	0	0	0	≤15
Scout azimuth (degree)	0 – 360	90/180	0/90	0/90	0/90	90/180
Aperture diameter (cm)	70 – 75	70	75	75	80	Nil
Number of Scanogram	1 – 4	2	2	2	2	2
Scan mode	A/he/cine	Axial	Helical	Helical	Helical	Debatable
CTDIvol (75th percentile)	46 – 87	60	59	87	46	60 (EC)
DLP (75th percentile)	792 – 1785	1390	1302	1785	792	1050 (EC)
ED (mSv)	2.50 – 4.11	3.19	3.25	4.11	2.50	3 mSv
ANOVA between groups (CTDIvol)		F = 90.42; p = 0.001; significant				
ANOVA between groups (DLP)		F = 88.92; p = 0.001; significant				

Table 4.8: Effective dose values (mSv) from DLP and ICRP brain weighting factor (0.0023 mSv.mGy.cm^{-1})

Parameter	Male	Female	M + F
A (mSv)	3.19	3.18	3.19
B (mSv)	3.26	3.25	3.25
C (mSv)	4.11	4.11	4.11
D (mSv)	2.5	2.51	2.50
Combined	3.56	3.56	3.56

Table 4.9 Correlation of DLP with anthropo-technical parameters using Pearson's correlation analysis

Variable	Mean (± SD)	p	r	Inference
$CTDI_{vol}$	58.0 ± 11.8	0.001	0.770	Significant
OFD (cm)	186.3 ± 6.8	0.096	0.241	Not significant
kVp	118.0 ± 7.4	0.131	-0.219	Not significant
Age (year)	70.0 ± 19.1	0.050	0.202	Not significant
Gantry tilt (^{o})	17.1 ± 4.4	0.180	0.195	Not significant
BPD (cm)	137.2 ± 6.7	0.183	-0.193	Not significant
Weight (kg)	74.7 ± 1.4	0.224	-0.177	Not significant
mA	202.4 ± 51.4	0.243	-0.170	Not significant
Scan range (cm)	16.7 ± 3.2	0.246	0.169	Not significant
CI	73.8 ± 4.1	0.326	- 0.143	Not significant
DGR (sec)	1.1 ± 0.3	0.537	-0.090	Not significant
Height (cm)	166.0 ± 10.3	0.763	-0.044	Not significant
BMI (kg/m^2)	27.1 ± 5.2	0.787	0.040	Not significant

Key: DGR = duration of gantry rotation

CI = cephalic index

mA = tube current

kVp = tube potential

OFD = occipito-frontal diameter

4.10 Comparison of multiple dose works

A comparison of the dose output from the present work made in relation to similar local and foreign works is shown in Table 4.11. The 75th percentile of the $CTDI_{vol}$ (67 mGy) and the DLP (1500 mGy.cm) from this work had a deviation of between 13 – 43 % ($CTDI_{vol}$) and 2 – 34 % (DLP) with other local works. For foreign works however, the deviation of the $CTDI_{vol}$ (2 – 24 %) is milder, while that of the DLP (9 – 47 %) was much more than that in local works.

4.11 Kolmogorov-Smirnov test for normality of biometric parameters

As shown in Table 4.5 an exploratory data analysis using Kolmogorov-Smirnov test was conducted to determine if the biometric variables were normally distributed. Results for the test for normality indicated that both the BMI group ($D = 0.140$, $p = 0.017$) and OFD group ($D = 0.134$, $p = 0.027$) deviated significantly from normality despite having few extreme outliers. The remaining biometric parameters were normally distributed ($p > 0.05$).

4.12 Kolmogorov-Smirnov test for normality of $CTDI_{vol}$ and DLP data

Table 4.6 indicated that both the combined $CTDI_{vol}$ ($D = 0.115$, $p = 0.001$) and DLP ($D = 0.091$, $p = 0.001$) deviated significantly from normality despite having few extreme outliers. Amongst the centres, $CTDI_{vol}$ showed significant deviation from normality in A, B and C ($p < 0.05$) whereas DLP deviated significantly from normality ($p < 0.05$) only B and D.

4.13 ANOVA for dose output

Shown in Table 4.9 is the result of a statistical exploration using one-way ANOVA. There was a statistically significant difference between groups as determined by one-way ANOVA for $CTDI_{vol}$ ($F = 90.42$, $p = 0.001$) and for DLP ($F = 88.92$, $p = 0.001$). A Tukey post hoc test revealed that the the $CTDI_{vol}$ and DLP of centre A did not have any statistically significant difference ($p = 0.001$) from that of all other centres. However, while centres A and B shared some similarity in their data, C and D varied from all other centres.

Table 4.10 Comparison between Dose output in Anambra and other works

Author	Location	Year	CTDIvol (mGy)			DLP (mGy.cm)		
			Mean	75th percentile	% variation	Mean	75th percentile	% variation
Current	Anambra	2017	58	67	0	1155	1500	0
Garba	Northeast	2015		77	13		985	34
Mundi	Abuja	2015		38	43		1477	2
Wanbani	Kenya	2010		51	24		1364	9
Tsai	Taiwan	2007		72	7		850	43
Santos	Portugal	2013		75	11		1010	33
Brix	Germany	2003		61	9		1016	32
Foley	Ireland	2012		66	2		940	37
Treier	Switzerland	2010		65	3		1000	33
Aroua	Switzerland	2004		60	11		800	47
EC	Europe	1999		60	11		1050	30

Table 4.11 Test for normality of biometric parameters

Parameter	Kolmogorov-Smirnov test			
	Number of Extreme outliers	Deviation, D	p-value, p	Inference
BMI (kg/m^2)	1	0.140	0.017	Non-normal
OFD (cm)	2	0.134	0.027	Non-normal
Age (years)	1	0.118	0.087	Normal
Weight (kg)	1	0.108	0.200	Normal
Height (cm)	2	0.109	0.200	Normal
BPD (cm)	0	0.075	0.200	Normal
CI (kg/m^2)	2	0.125	0.053	Normal

Key: BMI = body mass index
OFD = occipito-frontal diameter
BPD = biparietal diameter
CI = cephalic index

Table 4.12 Test for normality of dose data

Centre	Dose parameter	Kolmogorov-Smirnov test			
		Number of Extreme outliers	Deviation, D	p-value, p	Remark
A	$CTDI_{vol}$ (mGy)	1	0.173	0.001	Non-normal
	DLP (mGy.cm)	0	0.080	0.200	Normal
B	$CTDI_{vol}$ (mGy)	2	0.473	0.001	Non-normal
	DLP (mGy.cm)	0	0.156	0.005	Non-normal
C	$CTDI_{vol}$ (mGy)	1	0.459	0.001	Non-normal
	DLP (mGy.cm)	0	0.123	0.063	Normal
D	$CTDI_{vol}$ (mGy)	1	0.125	0.06	Normal
	DLP (mGy.cm)	0	0.154	0.004	Non-normal
Combined	$CTDI_{vol}$ (mGy)	2	0.115	0.001	Non-normal
	DLP (mGy.cm)	0	0.091	0.001	Non-normal

Key: $CTDI_{vol}$ (mGy) = volume Computed Tomography Dose Index (average dose in a single slice)

DLP (mGy.cm) = Cummulative dose after the whole exam

Table 4.13 Analysis of variance for $CTDI_{vol}$ and DLP output for CT in Anambra State

Dose type	Centre	Mean ± SD n = 300	ANOVA				
			Within group Turkey's Post Hoc		Between groups		Inference
			p	inference	F	p	
$CTDI_{vol}$ (mGy)	A	57 ± 11.0	0.001	C, D	90.42	0.001	Significant
	B	57 ± 4.0	0.001	C, D			
	C	74 ± 10.0	0.001	All centres			
	D	44 ± 4.0	0.001	All centres			
DLP (mGy.cm)	A	1095 ± 386	0.001	C, D	88.92	0.001	Significant
	B	1173 ± 233	0.001	C, D			
	C	1618 ± 237	0.001	All centres			
	D	733 ± 122	0.001	All centres			

CHAPTER FIVE

DISCUSSION, SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

In order to reduce dose to patients the International Commission on Radiological Protection (ICRP) recommended the establishment of diagnostic reference levels (ICRP, 1996), the absence of which has produced significant variations in local brain CT dose in Nigeria (Mundi et al., 2015; Garba et al., 2015; Ogbole, 2014; Table 4.11). This work was an attempt to bridge the gap by establishing standard reference levels that will guide CT users.

This work revealed a significantly variable centre-specific $CTDI_{vol}$ and DLP values of 24 – 94 mGy and 337 – 1982 mGy-cm, respectively. This variability is often the justification for the establishment of a common DRL (Wall & Shrimpton, 1998). The combined 75^{th} percentile of the $CTDI_{vol}$ and DLP were 67 mGy and 1500 mGy-cm, respectively. These are therefore, recommended as the diagnostic reference levels for Anambra State. This recommendation was made keeping in view the 60 mGy and 1050 mGy.cm, established by the European Commission (Wall, 1995).

5.2 Centre-Specific Dose Outputs

One of the objectives of this study was to generate centre-specific dose outputs in the first instance. Dose output for CT scanners other than for the purpose of DRL are specified in means or median values (Huda, 2008), while DRLs are specified in 75^{th} percentile (Foley, 2012). The mean $CTDI_{vol}$ dose output in Anambra State was pegged at 58 mGy. Each centre demonstrated some degree of variability from this common mean. While centres A (57 mGy) and B (57 mGy) had comparable but lower values, C (74 mGy) had a much higher value. Although D (44 mGy) had the least dose output, it contributed to the variability observed. Male (57 mGy) and female (58 mGy) populations had comparable means with each other and with the common mean.

The mean $CTDI_{vol}$ output (58) in Anambra State is comparable to the 75th percentile value (60 mGy) by the European Commission (1999). This is an indication that the dose output in this present study is higher. However, since the variability is narrow (3.3 %), it is an indication of good practice. In the centres surveyed it was observed that the values for $CTDI_{vol}$ had a wide variation (24 – 94 mGy) and had a 75th percentile value of 67 mGy. The 75th percentile for a single centre alone was 74 mGy, which was 10 % higher than the common value. This centre almost appeared to be an extreme statistical outlier. Dose audit convention however, does not encourage the exclusion of any centre which has met the inclusion criteria (Foley et al., 2012; ICRP, 1996). The cut off value of 67 mGy is therefore, the actual $CTDI_{vol}$ for the state.

The almost comparable, although slighter higher, values between this work and that of the EC may be because the CT scanners often come programmed from UK from where they are often purchased from. Domestication of the default protocols by Nigerian radiographers may have led to the similar dose outcomes, as noted above. Three centres (B, C and D) left their scanners in the programmed default protocols that came with the machine. For the purpose of a diagnostic reference level however, the 75th percentile of the population dose, rather than the mean, is the acceptable yardstick (Wall and Shrimpton, 1998; Foley et al.,2012). Consequently, this work adopted that measurement yardstick.

This 67 mGy is also comparable to the 66 mGy generated in 2012 in Ireland by Foley. The design of their survey was almost similar to the present study. Scanners were from four centres with multi-slice capability ranging from 2-128. The calculated 75th percentile of the $CTDI_{volume}$ 66 mGy. Just like in this work, a wide variation in mean doses across sites was observed. Once could infer that there are similar dose characteristics between studies done in the UK and the present study.

This may be as a result of similar training. Local radiographers always have a training programme organized by either the manufacturer of the scanner or supplier. The initial training were speculated to have been carried out by foreigners (Ogbole,2014). With this similarity in dose habit, cancer risks from the UK can appropriately be extrapolated to our population.

The present study however, turned up a value that was 13 % (77 mGy) lower than a local work carried done in Northeast Nigeria a year earlier (Garba, 2015). It is also 11 % (75 mGy) lower a similar work from Portugal carried out four years earlier (Santos, 2013). The lower CTDIvol from this study in comparison to the works mentioned earlier suggests that practices are very variable as much as dose. Also, perhaps radiographers in the locality were proficient in the manipulation of exposure parameters, particularly the kVp and mAs, since these are the core components of the CTDIvol (Foley, 2012). This gives hope that the optimum optimization of patient protection is actually possible in the locality.

The result (38 mGy) of a similar local work carried out in Abuja by Mundi et. al. (2015) however, showed 43 % variation from the 67 mGy threshold of this work. Also, in comparison to similar works in Africa, lower values have been reported (64 mGy) as shown by Ngaile & Msaki (2006). Our value was also higher than some foreign, non-African works by a variation of 2 – 24 (Foley et al., 2012; Treier, 2010; Wanbani, 2010; Tsai, 2007;Aroua, 2004; Brix, 2003; EC, 1999).

This difference may be attributable to diverse scanning protocols employed in different hospitals as well as scanner types. Patient doses could substantially be reduced through careful selection of scanning parameters based on clinical indications of study, patient size, and body region being examined. Such reduction in CTDIvol is achievable in any centre where the radiographers are willing to manipulate protocols tailored to each patient's body habitus and disease conditions, rather than a permanent reliance on default protocols.

A statistical exploration undertaken to ascertain the extent of variation within and between groups as determined by one-way ANOVA, gave statistically significant difference between groups for $CTDI_{vol}$ (F=90.42, p=0.001). A subsequent Turkey's post hoc test revealed that centres with the highest (C) and lowest (D) dose were most responsible for the variation. The necessity for a uniform template is therefore, justified. But a template is considered inadequate without corresponding appropriateness of protocol (Huda, 2004).

5.3 Common Dose Outputs in Anambra State

The DLP from this work gave a combined mean of 1155 mGy.cm. Following a similar pattern as in the $CTDI_{vol}$, the dose output showed remarkable variation in centre D (733 mGy.cm) and in centre C (1618 mGy.cm). Centre A (1095 mGy.cm) had lower values than the common mean and milder degree of variability from centre B (1173 mGy.cm). Male (1154 mGy.cm) and female (1156 mGy.cm) genders also had comparable means with themselves and the common mean. The standard error of the mean was 24.0. This suggests that the variation of the data from the population mean was not excessive. The mean DLP (1155 mGy.cm) showed 9 % variation from the value (1050 mGy.cm) of the European Commission (1999).

The 75^{th} percentile of the DLP which is necessary for setting a DRL was 1500 mGy.cm. Just as was observed with the $CTDI_{vol,}$ the DLP from a single centre alone (921–1973 mGy.cm) was responsible for the positively skewed 75^{th} percentile of 1500 mGy.cm. Compared to other local works, this cut off was higher than the works of Abdullahi (2015) by 2 % (1477 mGy.cm), and Garba (2015) by 34 % (985 mGy.cm). Similarly, it showed a 9–47 % (800–1364 mGy.cm) higher variation than other foreign works (Foley et al., 2012; Treier, 2010; Wanbani, 2010; Tsai, 2007;Aroua, 2004; Brix, 2003; EC, 1999). This difference may be explained by the scan range applied in the examination.

The DLP is a combination of radiation intensity and scan range (Foley et al., 2012; McCollough, 2011). The scanning length for a particular type of CT examination can vary due to the pathology of the patient, the size of the patient, and the experience of the user. For all these reasons, CT protocols need to be reviewed so as to limit irradiation only to the collimated area of the anatomy under investigation (Wildberger et al., 2001). Evidently, the radiographers in Anambra state extended the range beyond what is appropriate. If the CTDIvol is 67 mGy, the DLP can only be high if the scan range is extensive. It is reported in literature that a scan range of 9 – 10 cm can address CT sinus (Huda, 2008) but that was totally unlikely in the centres surveyed as there were similar protocols for any part of the head with a modal range of 140 cm.

Notwithstanding the high DLP (1500 mGy.cm), it was lesser than a similar work carried out in the premier teaching hospital in Nigeria in 2014 where a mean value (not 75th percentile) of 1898 mGy.cm was recorded. This high values and wide variation in dose output point to the arbitrariness in dose administration and the possible absence of regulation. The need for a template that will place an ethical obligation on the radiographers is therefore, imperative.

Another dose-influencing parameter which is relatively unknown is pitch. Pitch is defined as table movement per gantry rotation divided by slice thickness or collimator width of the x-ray beam. A pitch of 1.0 meant that the x-ray beams from adjacent rotations were essentially contiguous. Pitches >1 is an implication of gap between the x-ray beams from adjacent rotations. Pitches < 1 implied x-ray beam overlap (and thus double irradiation of some tissue) and so are not clinically advised (Goldman, 2008). Two centres had an inappropriate pitch of 0.75. This will definitely contribute to the increased radiation dose noticed in some centres.

Helical and axial scan mode needs to be taken into consideration too. When other parameters are constant, helical gives more dose. But this remains.While some authors are of the opinion that helical mode delivers less radiation (McNitt-Gray, 1999; Pitman et al., 1997), others think otherwise (Kalra, 2012). It is advised however, that the need to prescribe multiple contiguous helical scans should be infrequent with modern high speed multi-detector row scanners (Aweda, 2007). Three of the centres in this work programmed their higher slice scanner for helical scan mode, a probably possibility for the high inter-centre DLP output.

Although not a dose-influencing parameter, azimuth is a key player in patient radiation protection. It is advisable to select proper scan azimuth to ensure that radiosensitive organs are spared. An azimuth of ‘0’, ‘90/270’ and ‘180’ degrees represent AP, lateral and PA projections respectively in the scanogram phase. Aside centre (A), all other three centres had azimuths that were wrong. This mis-programming needs to be corrected if the lens of the eyes and the thyroid gland are to be spared during CT of the head. This technique is corroborated by the fact the thyroid often receives the highest amount of dose during scan (Huda, 2008).

It has been suggested that CT doses need to take into account patient age, head size, as well as the selected technique factors (Huda, 2004). In line with this, the researchers investigated the relationship between some anthropo-technical parameters and DLP. Our findings are not in agreement with the suggestion as we found little or no relationship. However, CTDIvol and DLP were strongly correlated ($r = 0.770$, $p < 0.05$). This appears *fait accompli* knowing that CTDIvol is a core component of the DLP. For head CT scan in adults, tube current and tube potential rather than age and weight should be put into consideration. The radiologists and radiographers should also have image quality and justifiable patient dose as a dual goal at all times.

The higher cut off value for DRL from this locality gives the justification for optimizing the $CTDI_{vol}$ and DLP to a comparable level with foreign ones. The task involves all members of the CT department/units; requesting Physicians, Radiologists, Medical Physicists and Radiographers. They should by all means desire optimum image quality, but that interest should go *parri passu* with a keen concern for reduction in the radiation dose their patients are subjected to.

Effective dose, which is a risk-weighted measure of radiation to organs in the body associated with radiological examination, is considered a good indicator of radiological risk . While methods to calculate effective dose have been established they depend heavily on the ability to estimate the dose to radiosensitive organs from the radiological procedures. The determination of the radiation dose to these organs is very difficult, and direct measurement is not possible (Osei, 2013).

In the present work, the range of effective dose in the four centres was 2.5 – 4.11 mSv, with a mean of 3.56 mSv. This is comparable to the 3.6 mSv calculated by Huda and Vance (2007) in the UK. The similarity may be an indication of similar practice between Nigeria and UK. It might also have to do with the default protocol on CT scanners imported from the UK. If these protocols are applied in Nigeria without adjustment, they are likely to turn out the same dose output as the country of purchase. However, our effective dose value was higher than the 1.14 – 2.51 mSv established by Noor & Normahayu (2012) in Indonesia, and the 1.4 – 3.0 mSv calculated by Christner et. al. (2010).

The implication is that the DLP from the present study was higher. This calls for further attention to the optimization of patient protection during CT procedure.

Although the value from this work appears high, it has been noted that about 1–14 mSv is the radiation dose associated with a typical CT scan, and this is comparable to the annual dose received from natural sources of radiation, such as radon and cosmic radiation (1–10 mSv), depending on location (ICRP). Mettler et. al. (2008), gave a wider range of 2 20 mSv for CT examinations, which include head CT. That our value is far from the maximum limit gives some relief. Nevertheless, an obligation is still placed on radiographers in Anambra State to review the amount of radiation prescribed for CT scans and to improve the usefulness of the data for daily clinical practice. It is believed that such an ethical obligation will ultimately result in an aggressive effort to minimize CT doses and optimize image quality (McCollough, 2009).

This appears to be the situation from non‐African countries where strict regulation may be the norm. It is also reported in literature that there are strict guidelines regarding radiation protection in the European Commission and their member countries (Brix, 2003). This oversight function may be the missing ingredient between doses generated in Nigeria and other non-African countries.

5.4 Dose Outputs as a function of model of scanners

The model of scanner, because of peculiar software and algorithms, is assumed to play a significant role in dose output (McCollough, 2011; Yu, 2009; Huda, 2008). To that effect, specific and similar protocol parameters were noted for each centre and assessed for deviations from values recommended in the literature. Two centres (B and C) with similar Toshiba machine, which were manufactured, bought, installed and programmed jointly, presented the scenario for a fitting comparison. It was noted that their protocol parameters had more dissimilarities than similarities between them. The corresponding dissimilarity in dose output (B = 59 mGy/1302 mGy.cm; and C = 87 mGy/1785 mGy.cm) may suggest that protocol parameters, rather than make/model of scanner, is responsible for dose behavior. Inappropriate protocol setting could be termed human errors.

Our conclusion finds corroboration with Boone et. al. (2012) who did substantial work among American populations. They were of the opinion that the vast majority of overexposures occur due to human error as a result of inappropriate tube current modulation settings. They also pointed out that human error will remain a factor in CT operation. We are in total agreement with this line of thinking. McCollough et. al. (1999) however, colours the perspective of this work through their assertion that both scanner models and protocols were an influence on dose. While their idea is a logical one, and their conclusion the result of experimentation, ours is an impression from a survey, although not less logical. One is therefore constrained to adopt their report as more factual. Our inability to experiment would however, limit our discussion to protocol, rather than model of scanners. It is hoped that future researchers would look into that aspect with the aid of anthropomorphic phantoms.

For the other two scanners, appropriate/inappropriate programming also appeared to be responsible for dose output rather than the model of scanners. Of the four scanners, none had similar exposure parameters as the other. So, also were the dose dissimilar. Perhaps, an experiment in which all scanners had similar protocols would have given a clearer picture of the influence of scanners on dose, but that was not realistic. Faced with that limitation, the obvious leeway is to scrutinize the specific protocol parameters for their role in dose output.

It is emphasized that a CT scanner should be programmed with protocols tailored to the anatomy of interest. The techniques that significantly influence the radiation dose given to the patient (Jangland, 2008), and the radiation output characteristics of the scanner constitute the clinical protocol which determines the dose to the patient (Ogbole, 2014). It was noted that the variations in dose output often noted in clinical practice, are due to differences in local scan protocols (Foley, 2012). The major duty of the radiographer therefore, is to ensure that the protocols applied to each examination is appropriate.

Computed tomography protocols have extensive choice of adjustable dose saving features that have been proven to substantially reduce the dose without detriment to the diagnostic quality of the CT images when properly used (McCollough, 2006; Lee, 2008). In designing a suitable protocol, different adjustable parameters are manipulated (McCollough, 2006; Lee 2008). A protocol is efficient if it minimizes dose while producing images with high diagnostic quality (Saravanakumar, 2014). If corrections are applied to the CT protocols used (Aweda, 2007), and regular patient dose audits are done, there will be meaningful reduction of unnecessary patient doses (Huda, 2008).

The skill of the Radiographer and their knowledge of radiation dose is relevant in setting up the optimal intensity combination that will reduce radiation dose while still producing images with minimal noise and of high diagnostic quality. The convention of looking up to Europe for guidance and the experience of using similar roving CT engineers in the locality may have been responsible for the similarity in kVp of 120 as well as several technical parameters noted in the centres surveyed. It has been suggested that a kVp of 120 kVp rather than 140, will lead to 20 to 40% reduction in patient dose (Kopp, 2002).

It was with this understanding that the researcher recorded the protocol (technical) parameters in the centres. A high dose output may be an indication of inadequacy of protocols. For tube currents a scanner has a choice between manual and automatic mAs modes. The manual mode uses the same mAs value for each slice, leading to higher radiation dose to that region (McDermmott, 2009). The automatic mAs mode adjusts the radiation intensity in line with changing density. This is the popular mA mode as it allows a range of mA values to be used at different points of the patient (Ranalo, 2013), and substantially reduce dose (Scholtz, 2015). The concept of automatic tube current modulation is based on the premise that pixel noise is attributable to quantum noise in the projections. By adjusting the tube current to follow the changing patient anatomy, quantum noise can be adjusted to maintain the desired noise level (Aweda, 2007).

In selecting automatic mA features however, a minimum and maximum mA value must be selected (Timoty, 2015). If the system desires a higher mA without being able to attain it, then image noise will increase above the level expected and If a lower mA is desired, then patient dose may be unnecessarily increased (Ranalo, 2015). The tube current determines the radiation quality and its variation causes variation in patient dose. Decrease in kVp causes increase in noise. This is particularly so when the patient size is large. The choice of kVp is therefore, crucial. An optimal kVp for abdominal scan for an averagely sized patient may be 120 kVp instead of 140 kVp as this will lead to 20 to 40% reduction in patient dose (Kopp et al., 2002).

The volume CTDI is substantially influenced by the tube current-time (mAs) and tube voltage (kVp), which collectively make up the intensity of radiation (Tipnis et al.,2016; Goo & Suh, 2006), and also by pitch and collimation (Aweda, 2007). Reducing the beam intensity (mAs and kVp) is a the most significant way of reducing patient dose without adverse effect on image quality. A 50% reduction in tube current reduces dose by half. This is because the current-time settings (mAs) are proportional to the photon fluence and beam energy (Kalra, 2012). Although with high exposure parameters (130 kVp, 249 mAs) as used in a survey by Wambani et al (2010), the CTDIvol was low. This may mean that scanner type, aside the radiation intensities, plays a part in the CTDIvol.

When these parameters are kept constant as often happens in automatic tube current modulation, a similar $CTDI_{vol}$ ensues irrespective of patient size or anatomical area scanned. Therefore, automatic tube current modulation is a strategy for fluctuating the mAs in tandem with the thickness of the anatomy and for keeping $CTDI_{vol}$ constant in spite of that. Three of the four centres surveyed in this work operated in that mode.

Manual tube current selection always fluctuates with pitch and has the tendency to increase the radiation dose per slice if pitch is <1. The radiographer, therefore, needs to be vigilant to consistently use tube currents as low as reasonably achievable. This is, however, not realistic in a center with multiple radiographers with different attitudes to radiation optimization.

As revealed by the review of literature, centers outside Africa had an attitude of using automatic tube current modulation (mA) as their preferred mA mode, rather than maual selection. This practice is noted to maintain constant image quality regardless of patient attenuation characteristics, thus allowing radiation dose to patients to be reduced (Brix, 2003; Kalra 2004). That practice helped to keep the doses in centres (B) and (D) to an acceptable level.

From this work, Centre (A) adopted the manual tube current mode. The remaining centres were however, programmed for automatic tube current modulation. For an ideal situation (which is rare in practice) the expected CTDIvol output should be A → B = C = D. In practice the output was C → A → B → D. Only the result of Centre (C) confounded the equation. The output from Centre (C) was as a result of inappropriate programming of technical parameters such as tube potential (140 kVp), tube current (250 mA) and duration of gantry rotation (2s).

Technical parameters should be programmed meticulously to keep dose at its barest minimum. It can be inferred therefore, that this variation in technical parameters (kVp, GRT) was responsible for the spike in dose output from that specific centre. Since the $CTDI_{vol}$ is basically influenced by the aforementioned parameters, and the DLP is influenced by the $CTDI_{vol}$, invariably, the dose output for that centre and the state would be high.

If the CT scanner system is programmed *ab initio* with skillful optimization technique, the tendency for dose drop is high as shown by the output from centre D (24 – 74 mGy). The skill of the radiographer and their knowledge of radiation dose is relevant in setting up the optimal intensity combination that will reduce radiation dose while still producing images with minimal noise and of high diagnostic quality.

The convention of looking up to Europe for guidance and the experience of using similar roving CT engineers in the locality may have been responsible for the similarity in kVp of 120 used as well as the fairly similar tube current (250 mA). It was reported by Kopp et al. (2002) that a tube potential of 120 kVp rather than 140, will lead to 20% reduction in patient dose.

Since the DLP is the product of CTDIvol and scan range. Centres that limit their technique to the area of interest would somehow achieve some level of dose drop much more than centres who are generous in their delimitation. In practice, there is a tendency to extend the area of coverage to include regions beyond the actual area of interest which will further increase patient dose. Nevertheless, it is essential to establish scanning protocols that restrict the examination to what is absolutely essential (Aweda, 2007). To that extent, the 140cm scan range adopted by 3 of the centres is in order. If all four centres adopted a much longer range, the mean and 75th percentile of the dose output that was eventually derived may have been much higher.

Centre (A) had the highest range (16cm). Interestingly, the dose from that centre was lesser than centre (C) with a lower range (14cm). This stalemate was clarified by another work where it was suggested that a reduction in tube potential and tube current are better influences on dose than scan range (Huda, 2004). Reducing scan range, therefore, still remains a useful technique in dose optimization. In addition, scan range becomes a better influence on radiation dose when other technical parameters are kept constant, a fact that was not keenly kept in view at the centre (C) (Kalra, 2004).

A centre adopted a scan range of 15cm. The dose output for that centre was higher than others. The DLP is a product of CTDIvol and range so, a higher range led to higher DLP. The other three centres adopted a range of 14 cm which reduced their dose. However, since there were still variations in their dose output inspite of this comparable scan range, it would be appropriate to look up to other parameters for this variation. The extent of body length covered in scanning does not affect the $CTDI_{vol}$ value but certainly affects DLP. The scanning length for a particular type of CT examination can vary due to the pathology of the patient, the size of the patient, and the experience of the user. For all these reasons, CT protocols need to be reviewed so as to limit irradiation only to the collimated area of the anatomy under investigation (Wildberger, 2005).

Efficient and safe operation of a CT scanner is also dependent on the user interface that the CT scanner employs, and unfortunately there is wide variability between CT manufacturers in both the user interface and the nomenclature used to describe the operation of the scanner. Competition between the CT manufacturers has resulted in incredible innovation and dramatic improvements in CT scanner capacities and image quality, and this should continue to be encouraged. However, a standard interface for the CT operator should be encouraged by professional organizations in radiology. overdose and other CT accidents due to operator error are likely to continue unless major changes occur that create a more uniform CT control panel (Boone et. al., 2012).

5.5 Relationship of DLP with anthropo-technical parameters

It has been suggested that CT doses need to take into account patient age, head size, as well as the selected technique factors (Huda, 2004). In line with this, the researcher investigated the relationship between some anthropo-technical parameters and DLP using Pearson's correlation analysis. The DLP was the dependent variable while the anthropo-technical parameters were the independent variables.

The technical parameters tested were: tube potential (kVp), tube current (mA), duration of gantry rotation (s), gantry tilt (^{o}) and scan range. The anthropometric parameters included age (years), height (cm), weight (kg), body mass index (kg/m^2), biparietal diameter (cm), occipito-frontal diameter (cm), and cephalic index. Only the CTDIvol which is a product of kVp and mA, was the dose information tested against DLP to serve as a sort of control.

The analysis showed the dose‑length product (DLP) in a positive and strong relationship with the CTDIvol. This relationship was both statistically ($p < 0.001$) and clinically ($r = 0.770$) significant. This was expected as the former is the major component of the DLP. That the correlation was not perfect suggests that other variable(s) may be involved. That logic is in order as the scan range (cm) is the additional requirement, which in combination with CTDIvol, generates the DLP. Perhaps the scan range applied in this survey was inconsistent.

Evidence from centres B –D gives a fairly consistent modal value of 14 cm but increased to 16 cm with centre A. Perhaps this discrepancy may have been responsible for the good (r = 0.770), rather than perfect (r = 1.0) correlation found.

Correlations with anthropo-technical parameters was not statistically significant ($p \geq 0.05$). The strongest relationship was with OFD (r = 0.241), which incidentally, was weak. Relationship with kVp was negative and weak (r = 0.219). Age was positive but equally weak (r = 0.202). The relationship was weaker still with gantry tilt, BDP, weight, mA, scan range and cephalic index (r = 0.169 – 0.195). There was no relationship with duration of gantry rotation (r = -0.090), height (r = -0.044) and BMI (r = 0.040).

The implication is that the CT protocol applied was static rather than tailored to take account varying patient age, and other anthropometric parameters. Adjusting protocols in line with patient body habitus is necessary. Chan et. al. (2012) posited that effective dose increased with increasing BMI and increasing amounts of intra-abdominal fat. They also noted that for an increase in BMI by 5 kg/m^2, there is a 1.95 mSv increase in effective dose, which is equal to 97.5 chest radiographs per CT examination (Chan, 2012).

Observation of the CT protocols in Anambra showed two major divisions of adults and paediatrics, respectively. As long as patients are grouped under a broad categorization of adults or paediatrics, irrespective of body habitus, the tendency for some patients to receive higher dose is always there. As noted by Brisse et. al., (2009), radiographers had difficulty in optimizing the age-appropriate tube current manually because the cross-sectional area of the head changes by varying age. Visits to the centres in Anambra State did not reveal any such difficulty. Therefore, dependence on default protocols rather than manipulation of parameters, account for the fixed nature of protocol.

As long as that scenario persists, the relationship of DLP with anthropo-technical parameters will be poor and there would be no need to bother about those parameters during a scan. But in a facility where size and age-specific protocols are available, a good relationship should be expected between DLP and anthropo-technical parameters. The researchers would like to recommend, in view of findings in the correlation analysis carried out, that for head CT scan in adults, tube current and tube potential (which generate CTDIvol) rather than age and other anthropometric parameters should be put into consideration. The radiologists and radiographers should also have image quality and justifiable patient dose as a dual goal at all times.

5.6 Summary of findings

The summary of findings from this work are as follows:

i. There was considerable variation in $CTDI_{vol}$ (24–94 mGy) and DLP (337– 1982) outputs amongst CT centres in Anambra State.

ii. The derived mean and 75^{th} percentile of the $CTDI_{vol}$ and DLP for Anambra State are 58/67 mGy and 1155/1500 mGy.cm, respectively.

iii. Dose output was influenced more by appropriate/inappropriate protocol selection than by model of scanner.

iv. The relationship of DLP with $CTDI_{vol)}$ was good ($r = 0.770$) but weak with other anthropo-technical parameters ($r \leq 0.241$, $p > 0.05$).

5.7 Conclusions

In conclusion**,** the diagnostic reference levels for adult head CT scans for the population are 67 mGy and 1500 mGy.cm. Centres with fairly lower values of the DLP are more adept at optimization of patient protection and should retain their values. A DRL that is exactly comparable to international recommendations is achievable in our locality if regular dose audits are carried out. The justification for optimizing the $CTDI_{vol}$ and DLP from this locality to a comparable level with foreign ones is clear. Achieving this comparable dose levels would need the synergy of requesting Physicians, Radiologists and Radiographers. They should by all means desire optimum image quality, but that interest should go *parri passu* with the radiation dose to their patients.

5.8 Area for further research

This work should be replicated in the same locality in the nearest future with a medical physicist nearby. This is to ensure that the calibration of the CT scanners are reliable. Also, future works should include excluded centres to see if the dose output will significantly vary from our values.

5.9 Recommendations

The observed inter-centre variations in the same locality calls for standardization of training and, or regular peer review of procedures with other centres. Also, referring physicians and radiologists should demand for dose output as a slide in the printed films to place an obligation on Radiographers to undertake due and regular optimization of radiation dose.

Also, referring physicians and reporting radiologists are also advised to minimize their desire for lengthy adjoining anatomy to be captured during scan. A maximum adjoining anatomy of 10 mm is advised. Furthermore, a national diagnostic reference level that will place an ethical obligation on the CT community is strongly recommended.

Furthermore, computed tomography centres within and outside Anambra State should endeavour to calculate the mean of the $CTDI_{vol}$ and DLP for a sizeable number of patients, and where the dose output deviates significantly from our values, protocol correction should be initiated. This is particularly needful now that the general public in our locality are becoming increasingly aware of radiation carcinogenesis.

5.10 Contribution to knowledge

In Nigeria, no regional or national diagnostic reference levels have been documented in online databases. A few centre-specific and isolated studies however, exists and show CT dose output to range between 38–77 mGy (CTDIvol) and 985–1477 mGy-cm (DLP). This result of this work corroborates the justification to have a common template.

Previous studies (Santos, 2013; Foley, 2012; Treier, 2010; Brix, 2003) have gone a long way to establish the research methodologies for establishing DRLs. In addition, the values reported have become a reference point for other researchers.

The replication of the work in our locality indicates that the methodologies are reliable, and the results, dependable.

For a keen Nigerian CT Radiographer, the DRLs in the literature have been a tentative guide on dose optimization. The present study adds to the body of knowledge on CT dose, particularly in Nigeria, and in Anambra State, specifically.

References

Acquah GF, Schiestl B,Cofie AY, Nkansah JO, Gustavsson M (2014). Radiation dose reduction without degrading image quality during computed tomography examinations: Dosimetry and quality control study. *International Journal of Cancer Therapy and Oncology,* 2(3):20-29.

Adejoh T, Nzotta CC (2016). Head computed tomography: dose output & relationship with anthropotechnical parameters. *West African Journal of Radiology,* 23(2):113-117.

Aroua A, BesancËon A, Buchillier I, Trueb P, Valley JF, Verdun F.R. & Zeller W (2004). Adult reference levels in diagnostic & interventional radiology for temporary use in Switzerland. *Radiation Protection Dosimetry,*111(3):289 – 295

Aweda M.A. & Arogundade R.A (2007). Patient dose reduction methods in computerized tomography procedures: A review. *International Journal of Physical Sciences*, 2(1):1-9

Bauhs JA, Vrieze TJ, Primak AN, Bruesewitz MR, McCollough CH (2008). CT dosimetry: comparison of measurement techniques and devices. *Radiographics,* 28:245–253.

Blaivas M & Lyon M (2007).Frequency of radiology self-referral in abdominal computed tomographic scans and the implied cost. *American Journal of Emergency Medicine,* 25(4):396-9.

Boone JM, Hendee WR, McNitt-Gray MF, and Seltzer SE (2012). Radiation Exposure from CT Scans: How to Close Our Knowledge Gaps, Monitor and Safeguard Exposure—Proceedings and Recommendations of the Radiation Dose Summit, Sponsored by NIBIB, February 24–25, 2011**.** *Radiology,* 265(2): 544–554

Brenner DJ and Hall EJ (2007). Computed Tomography - An Increasing Source of Radiation Exposure. *New England Journal of Medicine*, 357(22):2277-2284

Brink JA and Miller DL (2015). U.S. National Diagnostic Reference Levels: Closing the Gap.*Radiology,* 277(1):3-6.

Brisse HJ, Robilliard M, Savignoni A (2009). Assessment of organ absorbed doses and estimation of effective doses from pediatric anthropomorphic phantom measurements for multi-detector row CT with and without automatic exposure control. Health *Phys.*, 97(4):303–14

Chan VO, McDermott S, Buckley O, Allen S, Casey M, O'Laoide R, Torreggiani WC (2012). The Relationship of Body Mass Index and Abdominal Fat on the Radiation Dose Received During Routine Computed Tomographic Imaging of the Abdomen and Pelvis. *Canadian Association of Radiologists Journal*, 63(4): 260-266

Chiegwu Hyacienth U., Enweani Ifeoma B., Ogbu Sylvester O.I., Onyema Andrew E., Ugwuanyi Daniel C., & Eze Joseph C (2014). Brain and Lenses of the Eyes Doses from Head Computed Tomography: A Study of Selected Computed Tomography Centres in Enugu, Enugu State, Southeast and Nigeria. *International Journal of Health Sciences and Research,* 4(12): 133-138

Christner, JA; Kofler, JM; McCollough, CH (2010). Estimating Effective Dose for CT Using Dose–Length Product Compared With Using Organ Doses: Consequences of Adopting International Commission on Radiological Protection Publication 103 or Dual-Energy Scanning. *AJR*, 194:881–889

Donnelly F, Emery KH, Brody AS, Laor T, Gylys-Morin M, Anton CG, Thomas SR, Frush DP (2001). Minimizing Radiation Dose for Paediatric Body Applications of Single-Detector Helical CT. *American Journal of Roentgenology*, 176:30-306

Ekpo EU, Hoban AC, and McEntee MF (2014). Optimisation of direct digital chest radiography using Cu filtration. *Radiography*, 20(4):346-350.

European Commission (1997). European Guidelines for Quality Criteria for Computed Tomography. EUR16262EN. Luxembourg: European Commission

Eze, KC & Eze,EU (2012). Brain computed tomography of patients with HIV/ AIDS before the advent of subsidized treatment program in Nigeria. *Nigerian Medical Journal*, 53 (4): 231-235

Foley S.J., McEntee M.F., & Rainford L.A (2012). Establishment of CT diagnostic reference levels in Ireland. *British Journal of Radiology*, 85(1018): 1390 –1397.

Gail, FW (2012). Dental Examiners. *Radiation Biology, Safety* and *Protection* for *Today's Dental Team*. 5.https://www.adaausa.org/. Accessed 10 April, 2017

Garba I., Engel-Hills P., Davidson F. & Tabari A.M (2015). Computed Tomography Dose Index For Head CT in Northern Nigeria. *Radiation Protection Dosimetry,165(1-4):98-101.*

Gedel Ahmed Mohammed & Gablah Paul Goddey (2014). Management of Radiation Dose to Pediatric Patients undergoing CT Examination at Korle-Bu Teaching Hospital, Accra-Ghana. *Advances in Physics Theories and Applications*, 37:30-37

Goel A. and Mudgal P (2015).X-Ray Production. http://radiopaedia.org /articles/x-ray-production-2. Accessed October, 2015.

Goo HW, Suh DS (2006). The influences of tube voltage and scan direction on combined tube current modulation: a phantom study. *Pediatric Radiology*, 36(8):833-840

Hall, E. J., & Giaccia, A. J. (2011). Radiobiology for the radiologist (7th ed.). Philadelphia: Lippincott Williams & Wilkins.

Hart D, Jones D.G., & Wall, B.F. (1994). Estimation of Effective Dose in Diagnostic Radiology from Entrance Surface Dose and Dose-Area Product Measurement. National Radiological Protection Board. ICPB - R262..

Hart D, Hillier MC, Shrimpton PC (2012). *Doses to patients from radiographic and fluoroscopic X-ray imaging procedures in the UK : 2010 review*. Didcot: Health Protection Agency

Hayward RW, Naeser MA, and Zatz LM, M.D (1977). Cranial Computed Tomography in Aphasia: Correlation of Anatomical Lesions with Functional Deficits. RSNA Radiology, 123(3): 353 – 362

Hendee WR and O'Connor MK (2012). Radiation Risks of Medical Imaging: Separating Fact from Fantasy. *Radiology*, 264(2):312-321.

http://nsspi.tamu.edu/nsep/courses/basic-nuclear-and-atomicphysics/particle-and-eletromagneticradiation. Accessed October, 2015.

http://www. epa.gov/radiation/understand/). Accessed October, 2015.

http://www www.anambrastate.gov.ng/ history.html. Information about Anambra State: accessed on 16 September, 2015

Huda W & Vance A (2007). Patient radiation doses from adult and pediatric CT. *American Journal of Roentgenology*, 188(2):540-546.

Huda W, Lieberman KA, Chang J, Roskopf ML (2004). Patient size and x-ray technique factors in head computed tomography examinations. Med Phys., 31: 588-94.

Huda W, Lieberman KA, Chang J, & Roskopf ML (2004). Patient size and x-ray technique factors in head computed tomography examinations. *Medical Physics*, 31(3): 588-594

IAEA,(2012). IAEA Annual Report for 2005.https://www.iaea.org/publications/ reports/ annual-report-2005

ICRP (1996). Radiological protection and safety in medicine. A report of the International Commission on Radiological Protection.*Annals of the ICRP*,26:1-47

ICRP (2007). The 2007 ecommendations of the International Commission on Radiological Protection. ICRP publication 103.*Ann ICRP*, 37(2-4):1-332.

International Electro-technical Commission (2002). Medical electrical equipment-part 244: particular requirements for the safety of X-ray equipment for computed tomography. Geneva, Switzerland: IEC

Inyang SO, Egbe, NO, and Ekpo, EU (2015). Challenges in Setting Up Quality Control in Diagnostic Radiology Facilities In Nigeria. *Niger J Med*., 24 (4):344-347.

Johnson, R.; Kuby, P. (2007). Applied Example 2.15, The 85th Percentile Speed Limit: Going With 85% of the Flow", *Elementary Statistics* (10th ed.), Cengage Learning, p. 102, *ISBN 9781111802493.*

Kalra N, Vyas S, Gupta A, Bhalla A, Suri S, and Khandelwal N (2012). Comparison of helical and axial mode indirect computed tomographic venography in patients with pulmonary thromboembolism. *Lung India*, 29(2): 131–136.

Khawaja Ranish Deedar Ali, Singh Sarabjeet, Vettiyil Beth, Lim Ruth, Gee Michael, Westra Sjirk & Kalra Mannudeep K (2015). Simplifying Size-Specific Radiation Dose Estimates in Pediatric CT. *Pediatric Imaging*, 204 (1):167-176

Khursheed A., Hillier M.C., Shrimpton P.C., & Wall B.F (2002). Influence of patient age on normalized effective doses calculated for CT examinations. *British Journal of Radiology*,75 (898):819–830

Klink T, Obmann V, Heverhagen J, Stork A, Adam G, and Begemann P (2014). Reducing CT radiation dose with iterative reconstruction algorithms: The influence of scan and reconstruction parameters on image quality and CTDIvol. *European Journal of Radiology*, 83(9):1645-1654.

Mazrani W, McHugh K, & Marsden P.J (2007). The radiation burden of radiological investigations. *Archives of Disease in Childhood*, 92(12): 1127–1131.

McCollough CH, Leng S, Yu L, Cody DD, Boone JM, and McNitt-Gray MF (2011). CT Dose Index and Patient Dose: They Are *Not* the Same Thing. *Radiology*, 259(2):311–316

McCollough CH, Zink FE. (1999). Performance evaluation of a multi-slice CT system. *Med Phys* 26:2223−2230.

McNitt-Gray M. F., Solberg T. D., and Chetty I (1999). Radiation dose in spiral CT: The relative effects of collimation and pitch. *Medical Physics*, 26, 409–414

Mettler AF, Huda W, Yoshizumi TT & Mahesh M (2008). Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog. *Radiology*, 248(1): 254-63

Miller L. Donald, Kwon Deukwoo, & Bonavia H. Grant (2009). Reference Levels for Patient Radiation Doses in Interventional Radiology: Proposed Initial Values for U.S. Practice. *Radiology*, 253(3): 753–764

Molen A. J. van der, Schilham A, Stoop P, Prokop M. and Geleijns J (2013). A national survey on radiation dose in CT in The Netherlands. *Insights Imaging*, 4:383–390

Muhogora WE, Ahmed NA, Beganovic A, Benider A, Ciraj - Bjelac O, Gershan V, et al (2009). Patient doses in CT examinations in 18 countries: Initial results from Internation Atomic Energy Agency projects. Radiat Prot Dosimetry, 136:118 – 126

Mundi A, Hammed S, Joseph D, Aribisala AJ, Eshiett P, Itopa R & Kpaku G (2015). Diagnostic Reference Level for Adult Brain Computed Tomography Scans: A Case Study of a Tertiary Health Care Center in Nigeria. *IOSR Journal of Dental and Medical Sciences*,14(1):66-75

National Radiological Protection Board, NRPB (1993). Radiation Exposure of the U.K Population" NRPB Report R263. Review. NRPB, Chilton, U.K.

NCRP (2009). National Council on Radiological Protection Report 160 Pie Charts. Bethesda, MD 20814-3095.

Newton TD, Mehrez H, Wong K, Menezes R, Wintersperger BJ, Crean A, Nguyen E, & Paul N (2011). Radiation dose threshold for coronary artery calcium score with MDCT: how low can you go? *European Radiology*, 21(10):2121-2129.

Ngaile JE, Msaki PK (2006).Estimation of patient organ doses from CT examinations in Tanzania. Journal of Applied Clinical Medical Physics, 7(3):80-94

Ogbole GI & Obed R (2014). Radiation doses in computed tomography:Need for optimization and application of dose reference levels in Nigeria. *West African Journal of Radiology*, 21(1):1-6

Ogundare F.O., Olarinoye, I. O., & Obed, R. I (2008). Estimation of patients' organ doses and conceptus doses from selected X-ray examinations in two Nigeria X-ray centres. *Radiation Protection Dosimetry*, 132(4):395-402

Olarinoye, I. O. & Sharifat, I. (2010). A protocol for setting dose reference level for medical radiography in Nigeria: a review. *Bayero Journal of Pure and Applied Sciences,* 3(1):138–141

O'Leary D, Rainford L (2013). A comparison of mean glandular dose diagnostic reference levels within the all-digital Irish National Breast Screening Programme and the Irish Symptomatic Breast Services. *Radiation Protection Dosimetry,* 153: 300–8.

Olowookere C.J; Babalola I.A.; Jibiri N.N.; Obed R.I.; Bamidele L.; & Ajetumobi E.O., (2012).A Preliminary Radiation Dose Audit in some Nigerian Hospitals: Need for Determination of National Diagnostic Reference Levels (NDRLs). *The Pacific Journal of Science and Technology*; 13(1): 487-495

Osei EK & Darko JA (2013). Survey of Organ Equivalent and Effective Doses from Diagnostic Radiology Procedures. *ISRN Radiology*:1-9; http://dx.doi.org/ 10.5402/ 2013/204346

Pickard R, Starr K, MacLennan G, Lam T, Thomas R, Burr J, et al. (2015). Medical expulsive therapy in adults with ureteric colic: a multicentre, randomised, placebo-controlled trial. *Lancet*. 25;386(9991):341-349

Pitman A. G., Budd R. S., and McKenzie A. F. (1997), "Radiation dose in computed tomography of the pelvis: Comparison of helical and axial scanning. *Australasian Radiology*; 41, 329–335

Radiological protection and safety in medicine (1996). A report of the International Commission on Radiological Protection. *Annals of ICRP*, 26(2):1–47

Santos, J., Foley, S., Paulo, G., McEntee, M.F., Rainford, L. (2013). The Establishment of Computed Tomography Diagnostic Reference Levels in Portugal. Journal of Radiation Protection Dosimetry, 2(26):1 – 11.

Saravanakumar A, Vaideki K, Govindarajan KN, & Jayakumar S (2014). Establishment of diagnostic reference levels in computed tomography for select procedures in Pudhuchery, India. *Journal of Medical Physics*, 39(1): 50–55.

Sharifat, I. & Olarinoye I.O (2009). Patient Entrance Doses at Minna and Ibadan for Common Diagnostic Radiological Examinations. *Bayero Journal of Pure and Applied Sciences,* 2(1):1-5.

Shah KH, Slovis BH, Runde D, Godbout B, Newman DH, and Lee J (2013). Radiation exposure among patients with the highest CT scan utilization in the emergency department. *Emerg Radiol.,* 20(6):485-91

Seeram E, Brennan PC (2006). Diagnostic reference levels in radiology. Radiol Technol 2006, 77: 373–84.

Smith-Bindman R, Moghadassi M, Wilson N, Nelson TR, Boone JM, Cagnon CH et al. (2015). Radiation Doses in Consecutive CT Examinations from Five University of California Medical Centers. *Radiology*, 277(1):134-41.

Sohaib SA, Peppercorn PD, Horrocks J.A, Keene MH, Kenyon GS , Reznek RH (2001).The Effect of Decreasing mAs on Image Quality and Patient Dose in Sinus CT. *British Journal of Radiology*, 74: 157–161

Shrimpton, P.C., Hillier, M.C., Lewis, M.A. & M. Dunn (2006). National survey of doses from CT in the UK: 2003. *The British Journal of Radiology,* 79: 968-980

Stephen AE. Jr, Priscilla FB, Kimberly EA, Steven BB, Libby FB, James MH, et al. (2007). American College of Radiology White Paper on Radiation Dose in Medicine. *Journal of American College of Radiology*, 4:272-284

Thomas F, Huchen X, Jason YC, Holly N, Ying Z, Robert WM (2011). Patient-specific CT dosimetry calculation: a feasibility study. *Journal of Applied Clinical Medical Physics*, 12 (4):313 – 321

Tipnis S, Thampy R, Rumboldt Z, Spampinato M, Matheus G, Huda W (2016). Radiation intensity ($CTDI_{vol}$) and visibility of anatomical structures in head CT examinations. *Journal of Applied Clinical Medical Physics*,17(1):293-300

Treier A., Aroua A., Verdun FR., Samara E., Stuessi A., Trueb R.(2010). Patient doses in CT Examinations in Switzerland: Implementation of National Diagnostic Reference Levels. Journal of Radiation Protection Dosimetry, 142(2–4):244–254.

Tsalafoutas IA & Koukourakis GV (2010). Patient dose considerations in computed tomography examinations. World Journal of Radiology, 28; 2(7): 262–268.

Tsalafoutas IA, Tsapaki V, Triantopoulou C, Gorantonaki A, Papailiou J (2007). CT-guided interventional procedures without CT fluoroscopy assistance: patient effective dose and absorbed dose considerations. *American Journal of Roentgenology*, 188:1479–1484

Tubiana M,(1996).WilhelmConrad Röntgen and the discovery of X-rays. *Bulletin of the Academy of Natural Medicine*, 180(1):97-108.

Ujah FO, Akaagerger NB, Agba EH, Iortile T.J (2012). A comparative study of patients radiation levels with standard diagnostic reference levels in federal medical centre and Bishop Murray hospitals in Makurdi. *Archives of Applied Science Research*, 4 (2):800-804

Uzoagulu, A.E. (2011). Practical guide to writing research project report in tertiary institutions. Enugu, Nigeria:Cheston Publishers, p.57

Vassileva J, Rehani MM, Al-Dhuhli H, Al-Naemi HM, Al-Suwaidi JS, Appelgate K (2012). IAEA survey of pediatric CT practice in 40 countries in Asia, Europe, Latin America, & Africa: Part 1,frequency and appropriateness. *American Journal of Roentgenology*, 198(5):1021-31.

Verdun FR, Bochud F, Gudinchet F (2008). Radiation risk: what you should know to tell your patient. *Radiographics*, 28:1807-1816

Wall B.F & Shrimpton P.C. (1995). Patient dose protocol and trend in the U.K. *Radiation Protection Dosimetry*, 57:359-362.

Wambani, J. S., Korir, G. K., Onditi, E. G., Korir, I. K (2010). A survey of Computed Tomography Imaging Techniques and Patient Dose in Kenya. *East African Medical Journal*, 87 (10): 400 – 407.

Weisbrot D, Lin H, Ye L, Blank M, Goodman R. (2003), Effects of mobile phone radiation on reproduction and development in Drosophila melanogaster. *J Cell Biochem*. 89(1): 48-55.

Wildberger JE, Mahnken AH, Schmitz-Rode T (2001). Individually adapted examination protocols for reduction of radiation exposure in chest CT. *Investigative Radiology,* 36(10):604-11

Williams Jacqueline P. , Brown Stephen L. , Georges E. Georges, Hauer-Jensen Martin ,Hill Richard P. , Huser Amy K. (2010). Animal Models for Medical Countermeasures to Radiation Exposure. *Radiation Research,* 173(4): 557–578

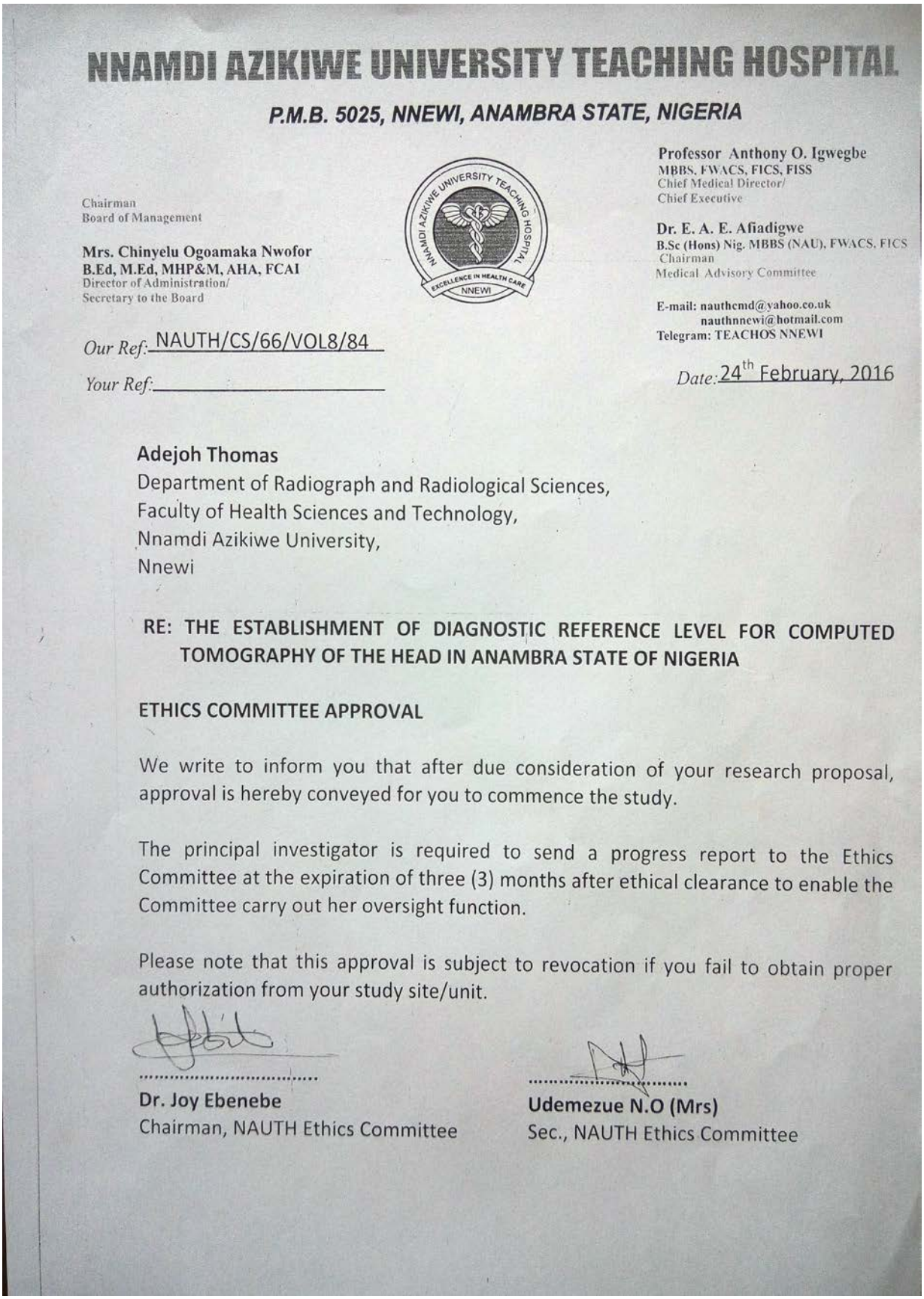
WHO (2016). What is Ionizing Radiation? http://www.who.int/ionizing_radiation/ about/ what_ is_ ir/en/ Accessed 08 June, 2017

Yamani, Taro (1967). Statistics, an introductory analysis, 2nd Ed., New York:Harper and Row, pg 172

Yu L, Liu X, Leng S, Kofler MJ, Ramirez-Giraldo JC, Qu M, Christner J, Fletcher JG, and McCollough CH (2009). Radiation dose reduction in computed tomography: techniques and future perspective. Imaging Med., 1(1): 65–84.

Appendixes

Ia: Ethical approval from NAUTH, Nnewi (centre A)



NNAMDI AZIKIWE UNIVERSITY TEACHING HOSPITAL

P.M.B. 5025, NNEWI, ANAMBRA STATE, NIGERIA

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Secretary to the Board

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Chief Medical Director/
Chief Executive

Dr. E. A. E. Afiadigwe
B.Sc (Hons) Nig. MBBS (NAU), FWACS, FICS
Chairman
Medical Advisory Committee

E-mail: nauthcmd@yahoo.co.uk
nauthnnewi@hotmail.com
Telegram: TEACHOS NNEWI

Our Ref: NAUTH/CS/66/VOL8/84

Your Ref: _____

Date: 24th February, 2016

Adejoh Thomas
Department of Radiograph and Radiological Sciences,
Faculty of Health Sciences and Technology,
Nnamdi Azikiwe University,
Nnewi

RE: THE ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVEL FOR COMPUTED TOMOGRAPHY OF THE HEAD IN ANAMBRA STATE OF NIGERIA

ETHICS COMMITTEE APPROVAL

We write to inform you that after due consideration of your research proposal, approval is hereby conveyed for you to commence the study.

The principal investigator is required to send a progress report to the Ethics Committee at the expiration of three (3) months after ethical clearance to enable the Committee carry out her oversight function.

Please note that this approval is subject to revocation if you fail to obtain proper authorization from your study site/unit.

.....
Dr. Joy Ebenebe
Chairman, NAUTH Ethics Committee

.....
Udemezue N.O (Mrs)
Sec., NAUTH Ethics Committee

Ib: Ethical approval from the Nnamdi Azikiwe University (FHST)

FACULTY OF HEALTH SCIENCES AND TECHNOLOGY
COLLEGE OF HEALTH SCIENCES
NNAMDI AZIKIWE UNIVERSITY, NNEWI CAMPUS
P.M.B 5001, NNEWI, ANAMBRA STATE -NIGERIA

OFFICE OF THE DEAN

*Our Ref:*_____ *Your Ref:*_____ *Date:* 8th December, 2015

ADEJOH THOMAS
Department of Radiography/Radiological Science
Nnamdi Azikiwe University
Nnewi Campus.

Dear Thomas,

ETHICS COMMITTEE APPROVAL
RE: THE ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVEL FOR COMPUTED TOMOGRAPHY OF THE HEAD IN ANAMBRA STATE OF NOGERIA

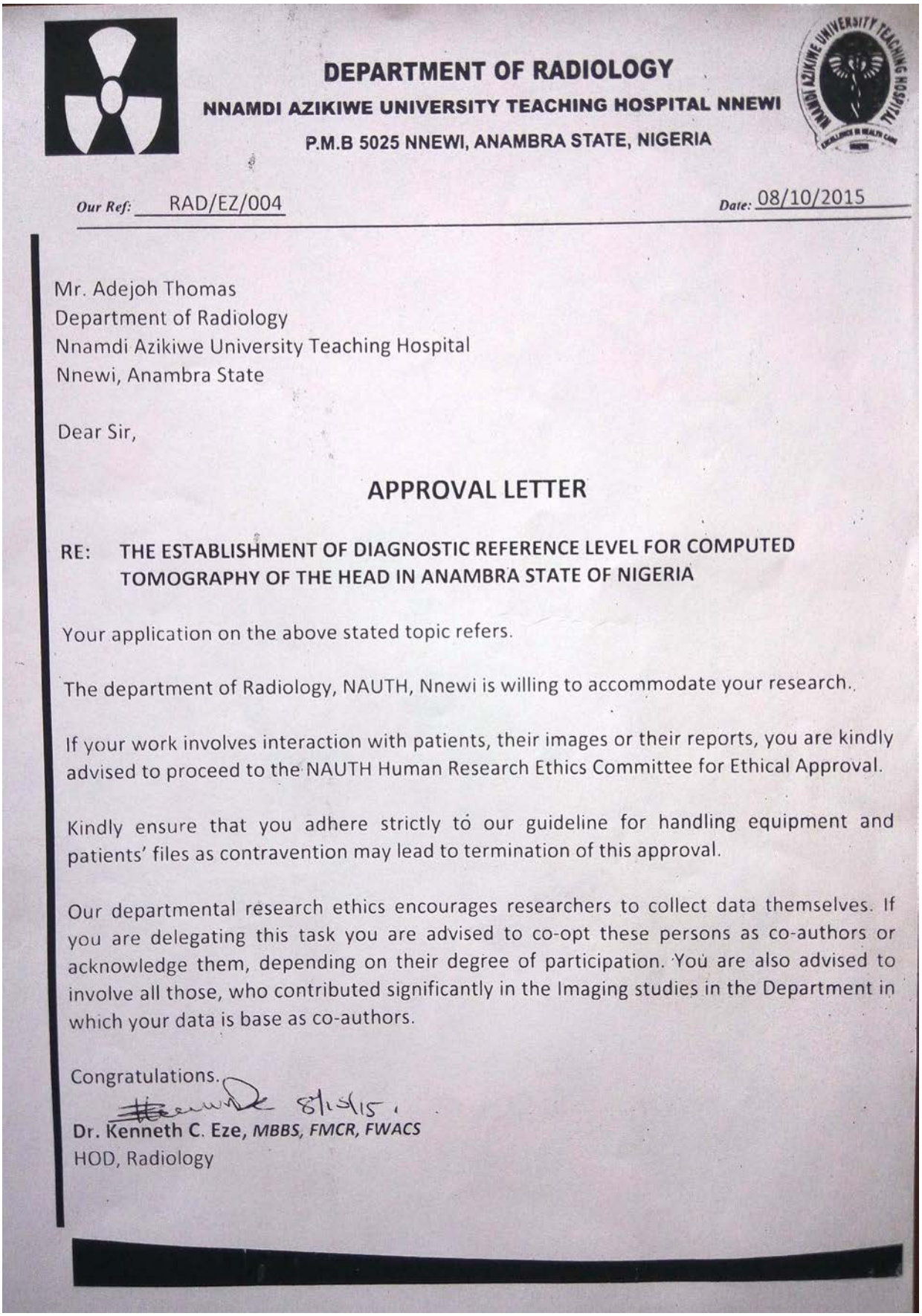
We write to inform you that after due consideration of your research proposal, approval is hereby conveyed for you to commence the study.

Best wishes in your research endeavours.

Yours Sincerely,

Christopher O. Akosile (PT, Ph.D)
Chairman
For FHST Ethical Committee

Ic: Approval from Radiology Department, NAUTH, Nnewi (centre A)



DEPARTMENT OF RADIOLOGY
NNAMDI AZIKIWE UNIVERSITY TEACHING HOSPITAL NNEWI
P.M.B 5025 NNEWI, ANAMBRA STATE, NIGERIA

Our Ref: RAD/EZ/004 *Date:* 08/10/2015

Mr. Adejoh Thomas
Department of Radiology
Nnamdi Azikiwe University Teaching Hospital
Nnewi, Anambra State

Dear Sir,

APPROVAL LETTER

RE: THE ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVEL FOR COMPUTED TOMOGRAPHY OF THE HEAD IN ANAMBRA STATE OF NIGERIA

Your application on the above stated topic refers.

The department of Radiology, NAUTH, Nnewi is willing to accommodate your research.

If your work involves interaction with patients, their images or their reports, you are kindly advised to proceed to the NAUTH Human Research Ethics Committee for Ethical Approval.

Kindly ensure that you adhere strictly to our guideline for handling equipment and patients' files as contravention may lead to termination of this approval.

Our departmental research ethics encourages researchers to collect data themselves. If you are delegating this task you are advised to co-opt these persons as co-authors or acknowledge them, depending on their degree of participation. You are also advised to involve all those, who contributed significantly in the Imaging studies in the Department in which your data is base as co-authors.

Congratulations.

8/10/15

Dr. Kenneth C. Eze, ***MBBS, FMCR, FWACS***
HOD, Radiology

Id: Approval from centre B

DIOCESE ON THE NIGER
IYI ENU MISSION HOSPITAL

Tel: 08188859440, E-mail:iyienuhospital@yahoo.com Website: www.iyienuhospital.org
P. O. Box 67, Onitsha. P.M.B. 4 Ogidi, Anambra State Nigeria.

7th January, 2016

Mr. Adejoh Thomas,
PHD(in-view),
Radiation Protection & Dosimetry
Department of Radiography,
Nnamdi Azikiwe University,
Nnewi Campus.

RE: THE ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVEL FOR COMPUTED TOMOGRAPHY OF THE HEAD IN ANAMBRA STATE OF NIGERIA

This is to convey the approval of the management of this hospital to you, to use our CT-scan unit for your data collection.

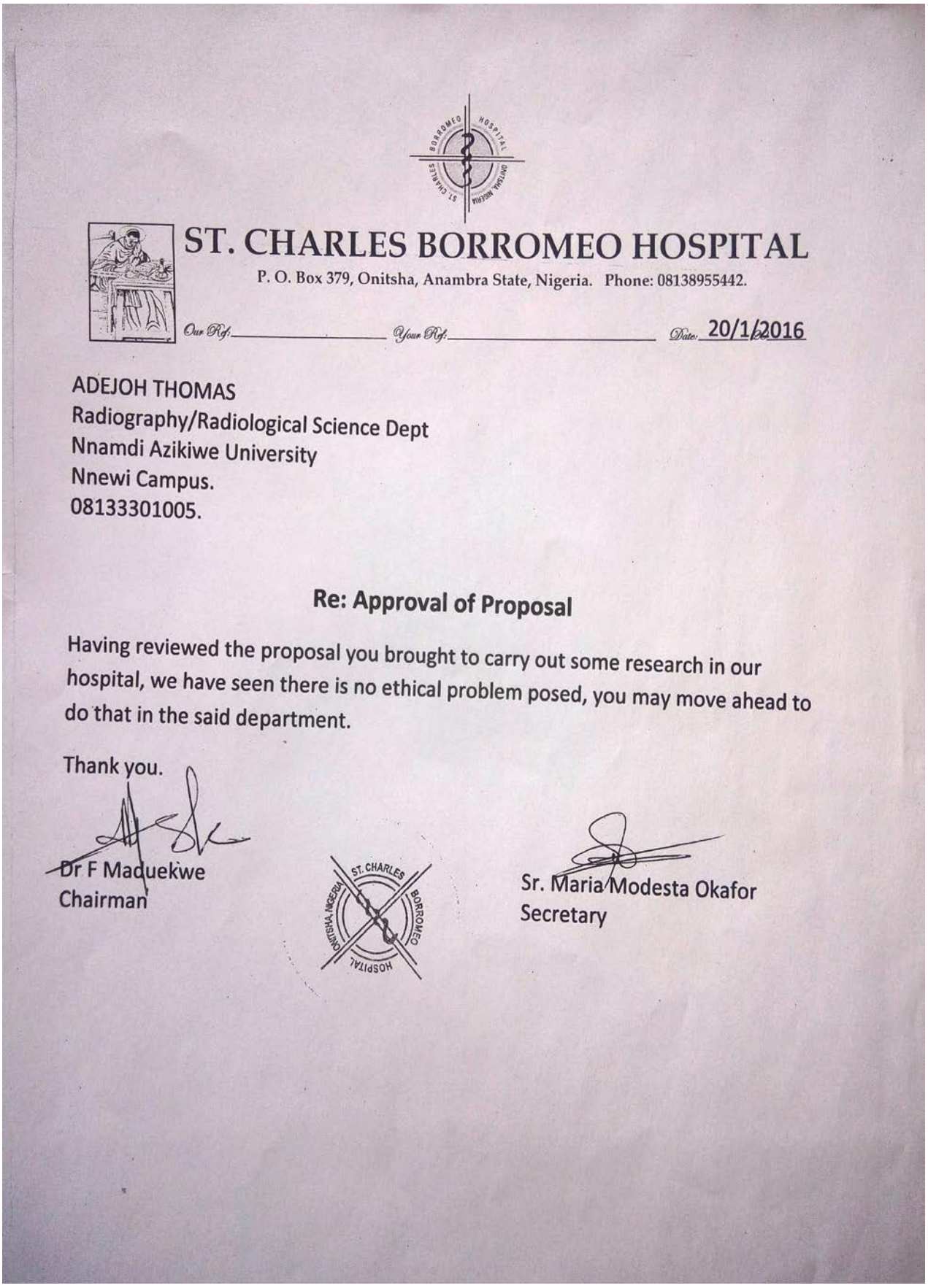
Congratulations.

Yours in His Service,

.....
Rev. Canon **Ikechukwu Okwuosa** AHAN
Hospital Administrator

"To Preach and To Heal"

Ie: Approval from centre C



ST. CHARLES BORROMEO HOSPITAL

P. O. Box 379, Onitsha, Anambra State, Nigeria. Phone: 08138955442.

Our Ref. _____ Your Ref. _____ Date: 20/1/2016

ADEJOH THOMAS
Radiography/Radiological Science Dept
Nnamdi Azikiwe University
Nnewi Campus.
08133301005.

Re: Approval of Proposal

Having reviewed the proposal you brought to carry out some research in our hospital, we have seen there is no ethical problem posed, you may move ahead to do that in the said department.

Thank you.

Dr F Maduekwe
Chairman

ST. CHARLES BORROMEO HOSPITAL ONITSHA, NIGERIA

Sr. Maria Modesta Okafor
Secretary

1f: Approval from centre D

HOPE SPECIALIST MEDICAL CENTRE

104 MODEBE AVENUE, ONITSHA

16TH October, 2015

Mr Adejoh, Thomas
PhD (in-view) Radiation/Environmental
Protection and Dosimetry
Department of Radiography
Nnamdi Azikiwe University
Nnewi Campus

Sir,

RE-THE ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVEL FOR COMPUTED TOMOGRAPHY OF THE HEAD IN ANAMBRA STATE OF NIGERIA

I write to convey the approval of the Management of this Medical Centre to you to collect your data on your PhD work from our CT Unit.

Our vision and mission are centred on dedicated clinical services to humanity, training as well as research. So, your research is in line with our goals.

In line with medical research ethics, kindly ensure that patients' confidentiality are strictly maintained in the course of your data collection.

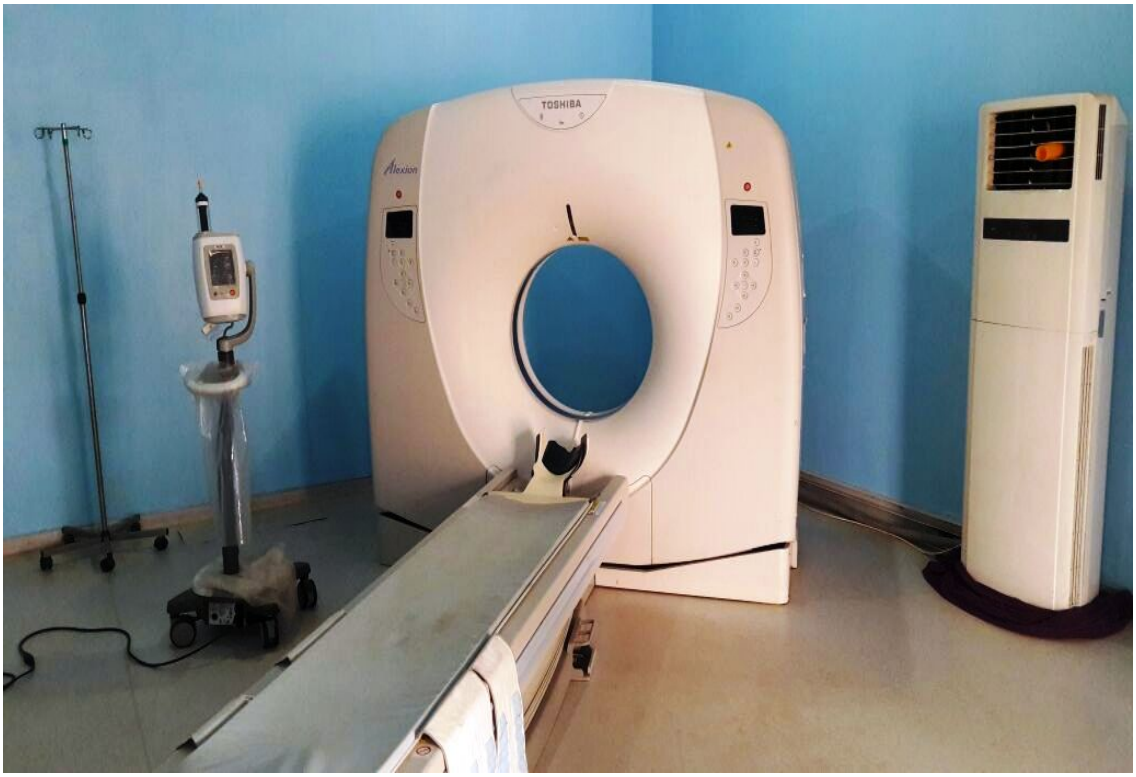
Congratulations.

Mrs Chibueze, B. N.
Manager

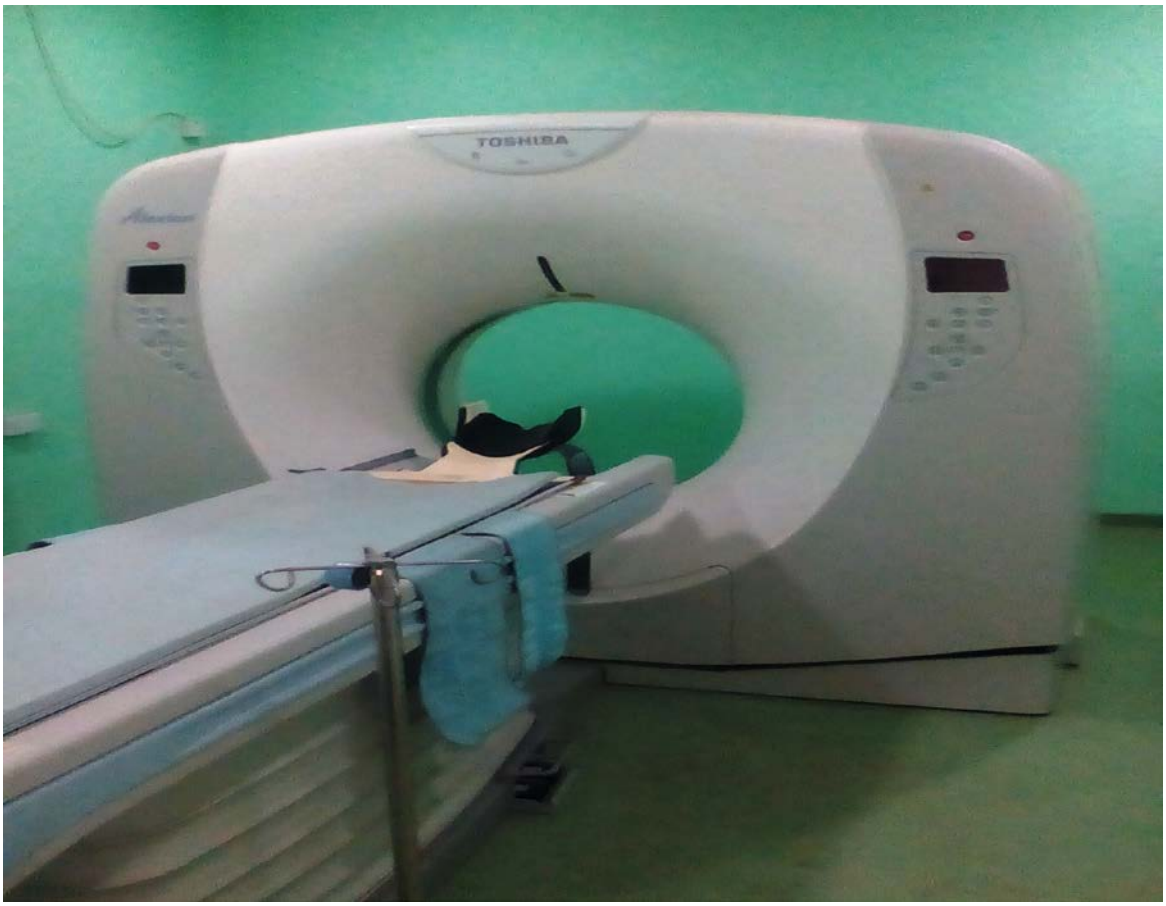
HOPE CLINIC/DIALYSIS CENTRE
SIGN
DATE
104 MODEBE AVENUE

Appendix IIa: CT scan suite in NAUTH

Appendix IIb: CT scanner at Iyi-Enu hospital

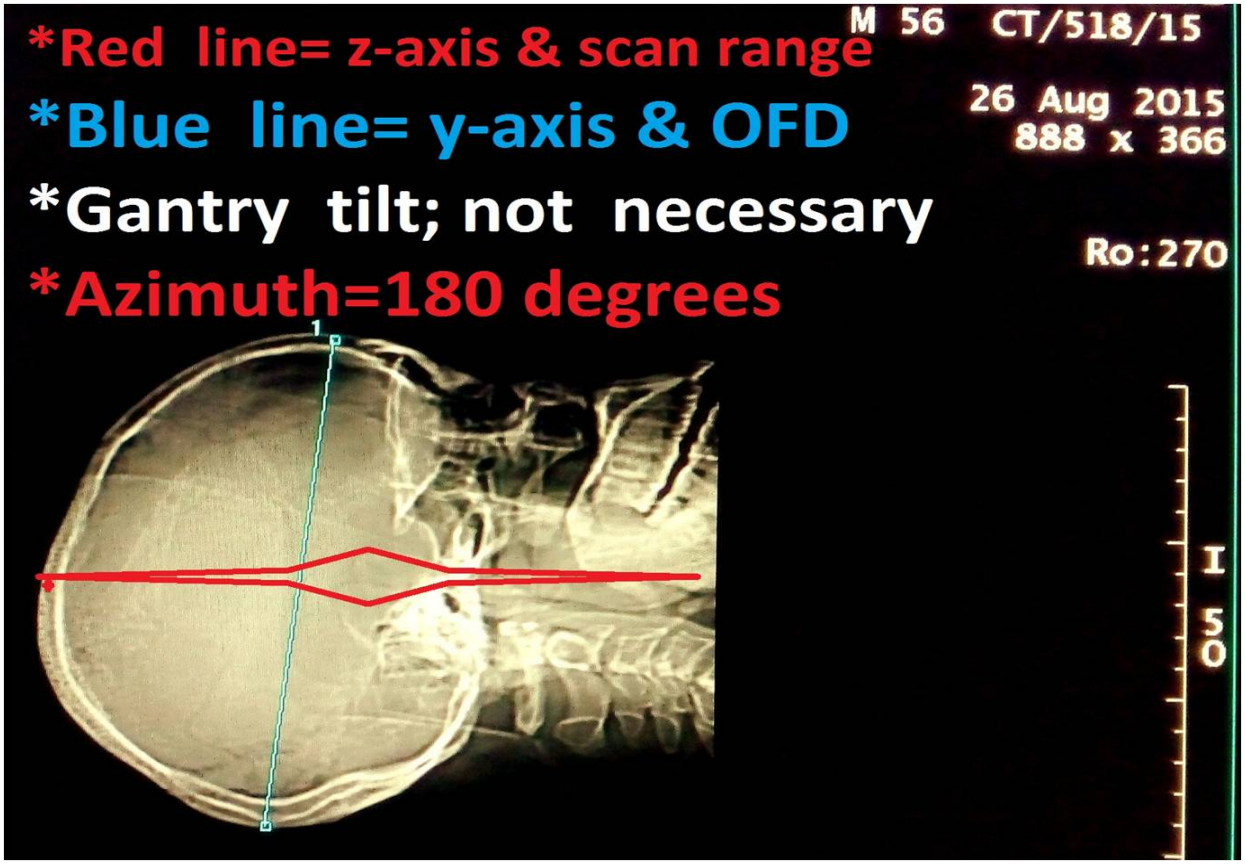


Appendix IIc: CT scanner at Borromeo hospital

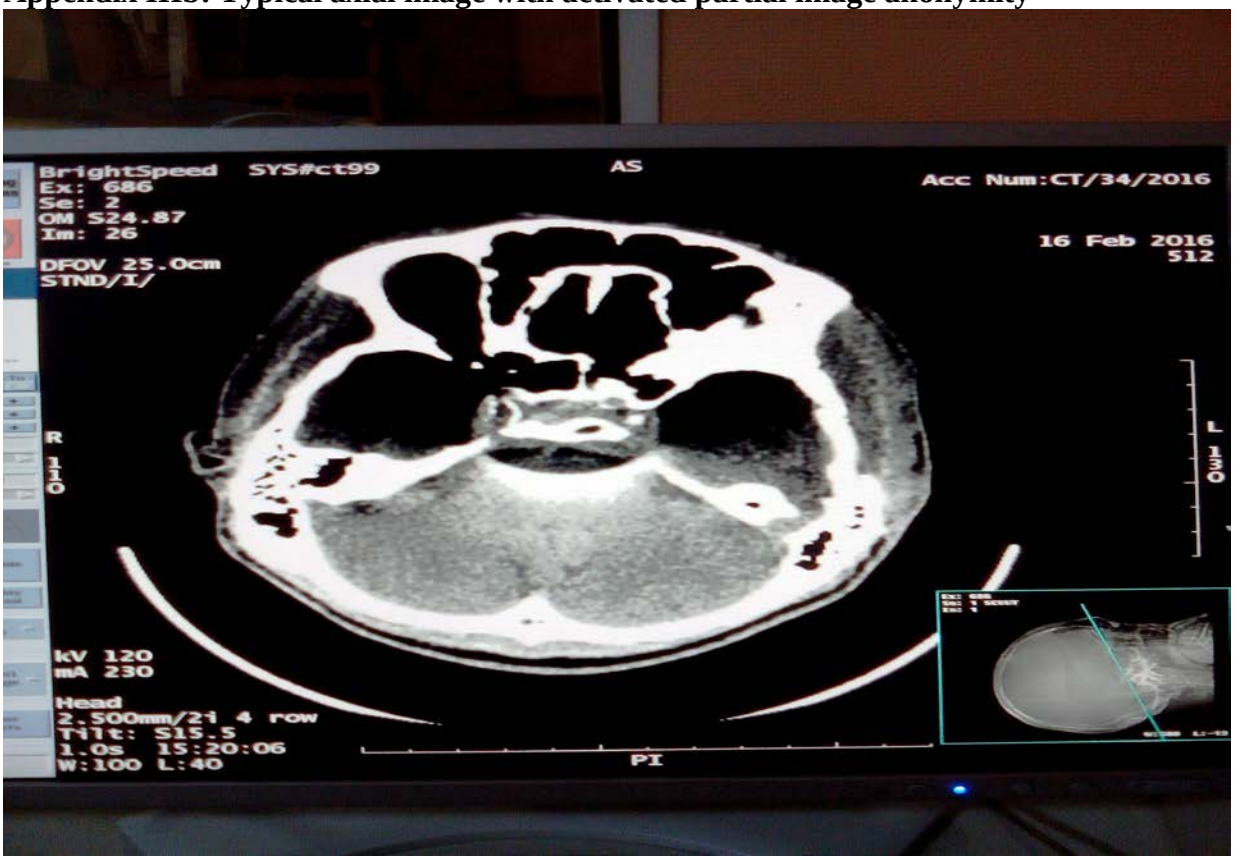


Appendix IId: CT scanner at New Hope Medical Centre

Appendix IIIa: Typical non-rotated scanogram of the head showing name anonymity



Appendix IIIb: Typical axial image with activated partial image anonymity



Appendix IV

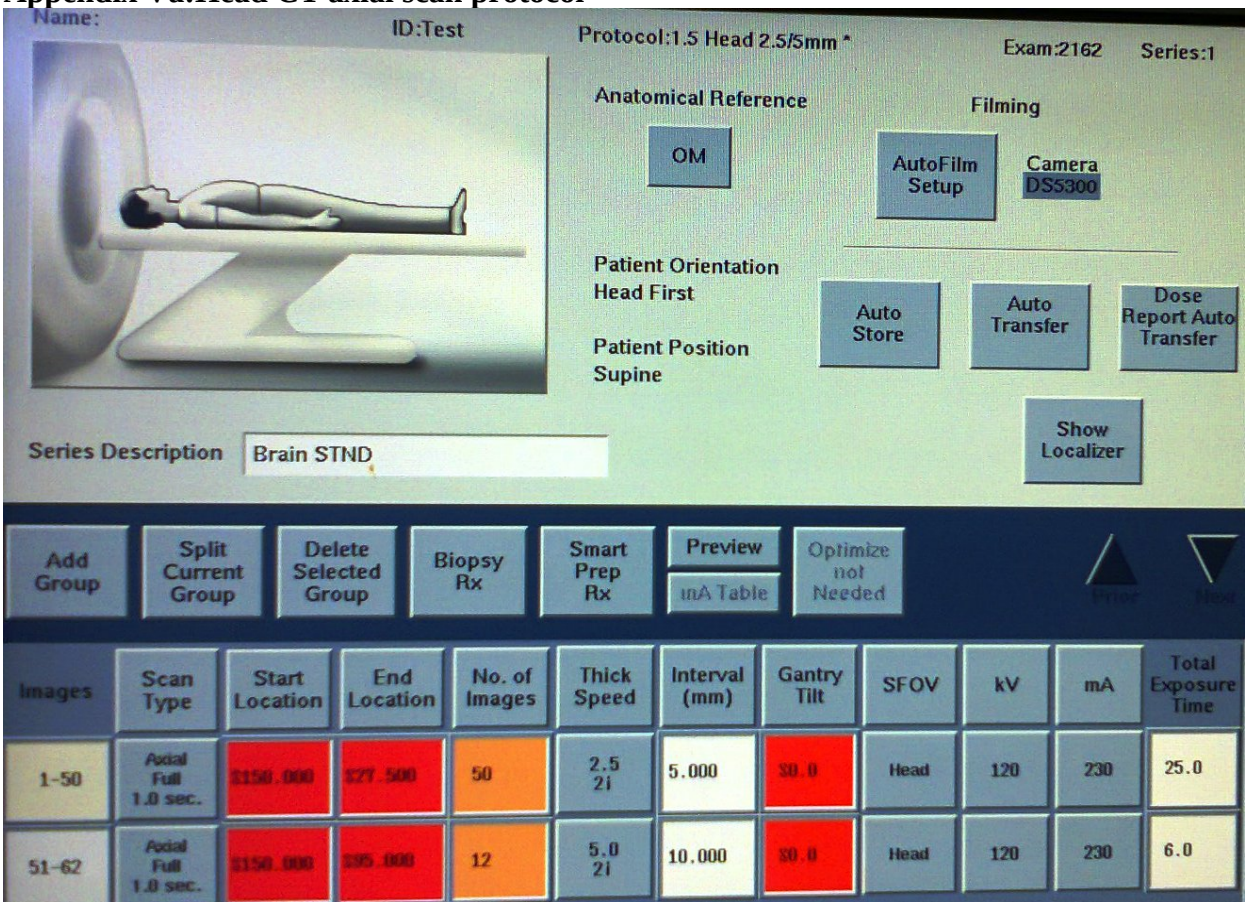
(a). Distribution of CT centres in Southeast Nigeria as at December, 2016

S/ No	Name of Diagnostic centre	Ownership	Model	Slice	Manufactured	Installed	Functional
Anambra State							
1.	GRA Diagnostic centre, Onitsha	Private	GE	32	?	2016	Yes
2.	Eldorado Diagnostic centre, Awka	Private	GE	16	?	2016	Yes
3.	Onitsha Med. Diagn. Centre	Private	Siemens	16	2015	2015	Yes
4.	General Hospital, Onitsha	PPP	GE	4	2007	2015	Yes
5.	Borromeo Hospital, Onitsha	Catholic	Toshiba	16	2013	2014	Yes
6.	Iyi-Enu Missions Hosp, Ogidi	Anglican	Toshiba	16	2013	2014	Yes
7.	Conquest Imaging, Nnewi	Private	GE	1	1998	2011	Yes
8.	NAUTH, Nnewi	FG	GE	4	2007	2011	Yes
9.	Chukwuemeka OOTH, Awka	State	?	?	?	**Not installed**	
Imo State							
10.	Digital Imaging, Owerri	Private	?	?	?	2016	Yes
11.	FMC, Owerri	FG	GE	16	?	2015	No
12.	Human Race, Owerri	Private	Philips	4	?	2015	Yes
13	Ochiedike Diagnostic C, Owerri	Private	GE	16	?	2014	No
14.	St John's Cath Hosp, Owerri	Catholic	?	?	?	2014	No
15.	IMSUTH, Orlu	State	?	?	?	**Not installed**	
Enugu State							
16.	Hansa Clinics, Independence Lay Out, Enugu	Private	GE	4	?	2016	No
17.	Hansa Clinics, Independence Lay Out, Enugu	Private	GE	8	?	2014	Yes
18.	Memphys Neuro Hospital, Trans-Ekulu, Enugu	Private	Philips	64	?	2014	Yes
19.	Memphys Neuro Hospital, Trans-Ekulu, Enugu	Private	CereTom	8	2007	2009	Yes
20.	Conquest, Trans-Ekulu, Enugu	Private	GE	16	2009	2009	Yes
21.	UNTH, Ituku-Ozalla, Enugu	FG	GE	2	2003	2006	No
Abia State							
22.	Livingworld Hospital, Aba	Private	?	?	?	2016	Yes
23.	Mecure, Umuahia	PPP	Yes	1	< 1999	2014	Yes
24.	Mecure, Aba	Private	Yes	1	< 1999	2014	Yes
25.	FMC, Umuahia	FG	GE	4	2007	2014	Yes
Ebonyi State							
26.	Diagnostic centre, Abakaliki	Private	?	?	?	2016	No
27.	FETHA, Abakaliki	FG	GE	1	1998	2012	No

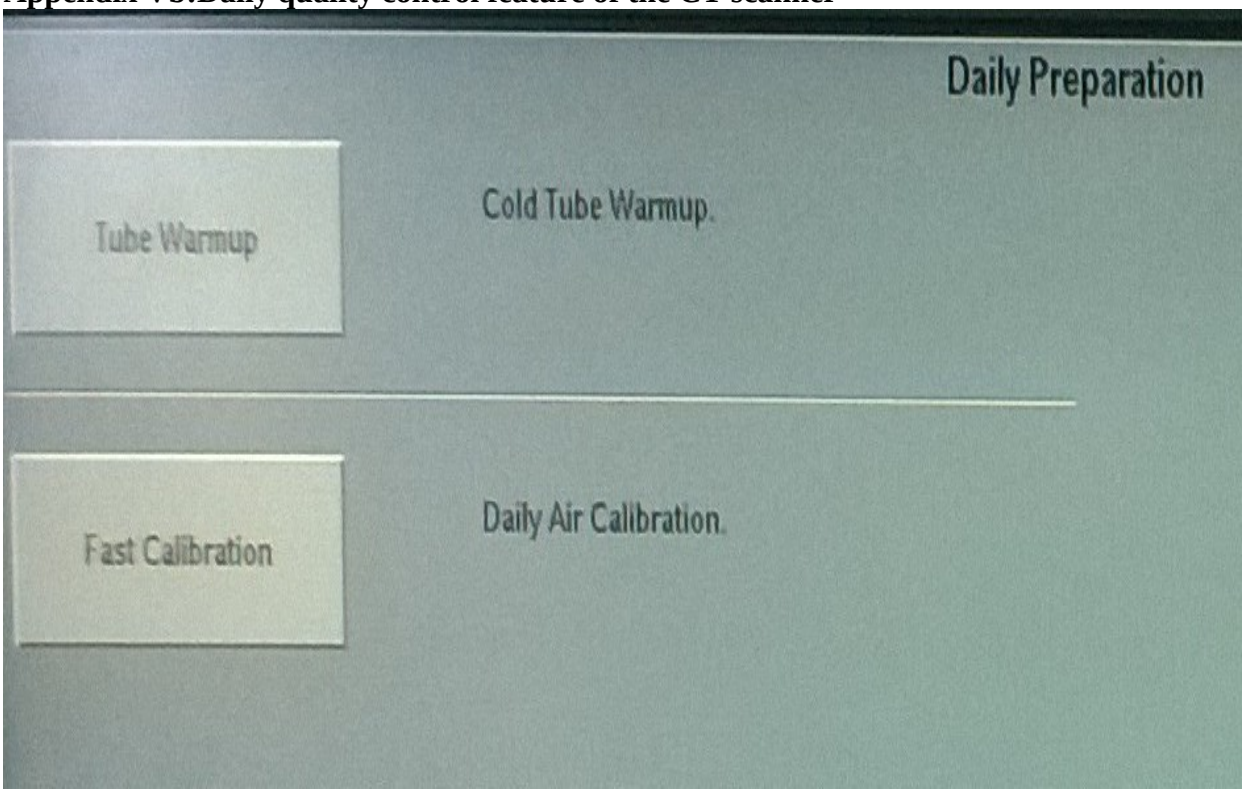
(b). Distribution of CT centres in Anambra State as at December, 2016

S/ No	Name of centre	Location	Ownership	Model	Slice	Manufac-tured	Installed	Function -ality
1.	Conquest Imaging	Nnewi	Private	GE	1	1998	2012	Up
2.	NAUTH	Nnewi	Federal government			2007	2011	Up
3.	General Hospital	Onitsha	PPP	GE	4	2007	2013	Up
4.	Iyi-Enu Missions Hospital	Ogidi	Anglican	Toshiba	16	2013	2014	Up
5.	Borromeo Hospital	Onitsha	Catholic	Toshiba	16	2013	2014	Up
6.	New Hope Diagnostic Centre	Onitsha	Private	Siemens	16	2015	2015	Up
7.	Eldorado Diagnostic centre	Awka	Private	GE	16		2016	Up
8	GRA Diagnostic centre	Onitsha	Private	GE	16		2016	Down
9.	COOTH, Amaku	Awka	State government	?	?			Down

Appendix Va:Head CT axial scan protocol



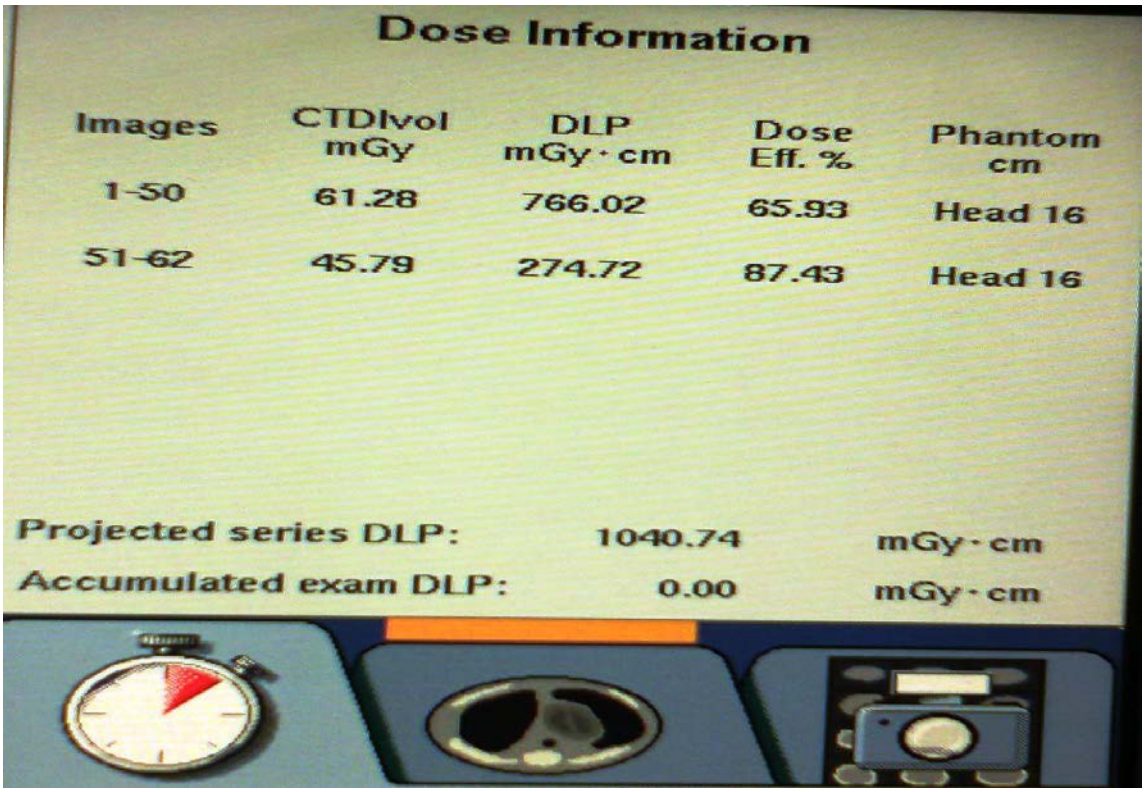
Appendix Vb:Daily quality control feature of the CT scanner



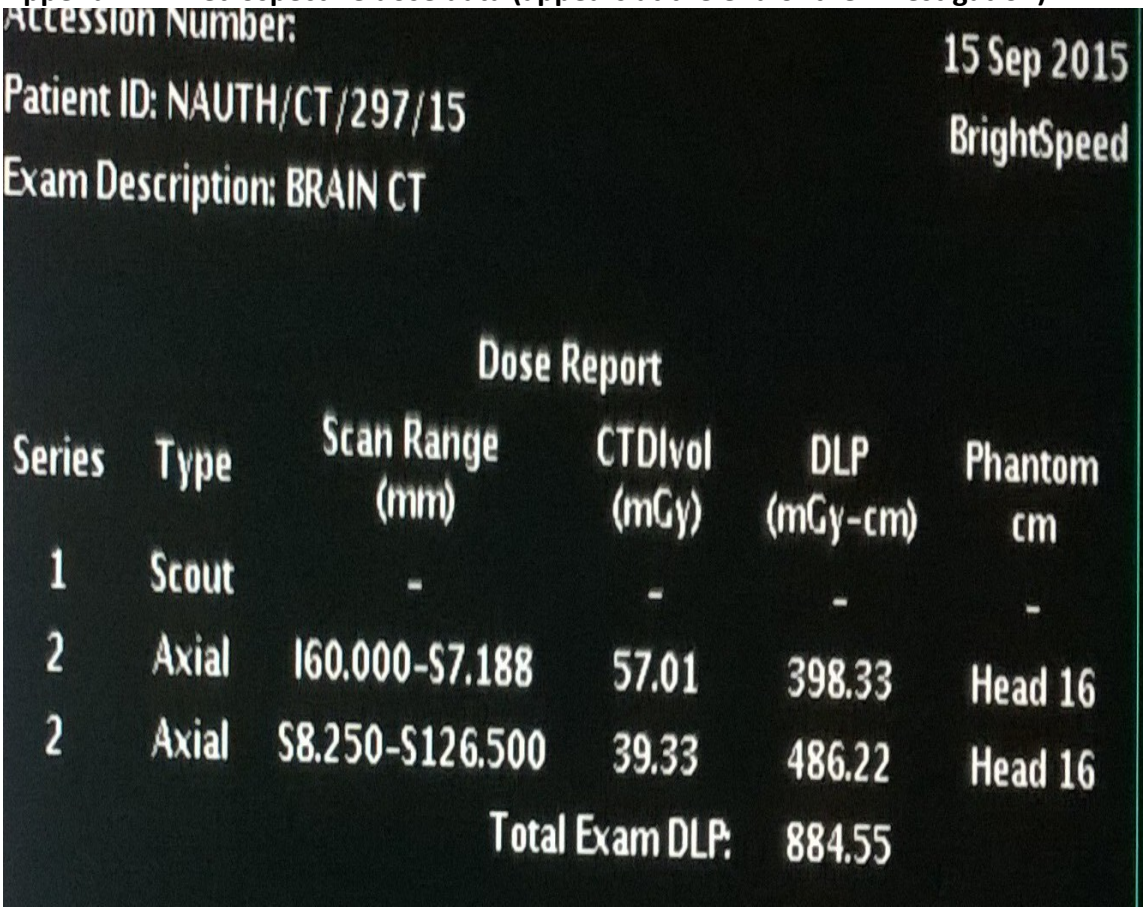
Appendix Vc: 90 degree azimuthal image of quality control phantom (centre A)

Appendix Vd:180 degree azimuthal image of quality control phantom (centre A)

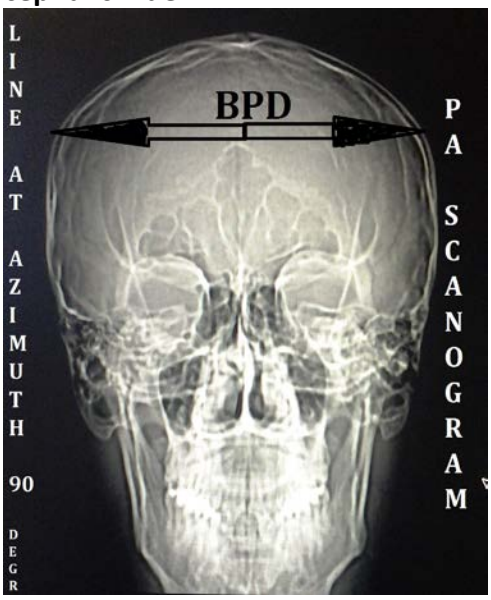
Appendix Ve: Prospective dose data (appears during planning of the investigation)

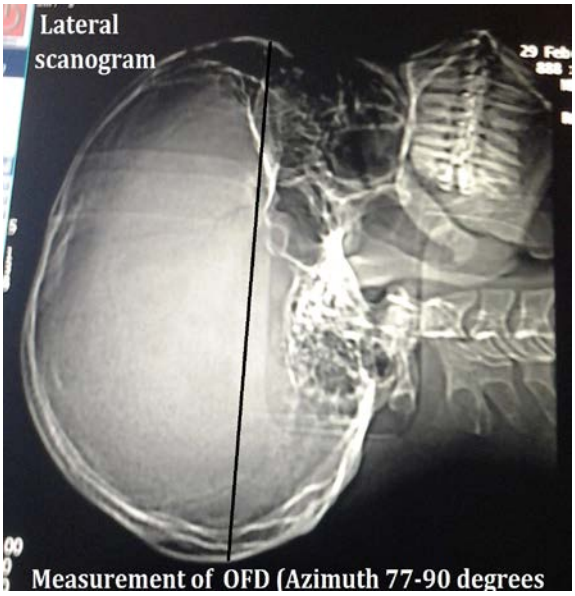


Appendix Vf: Retrospective dose data (appears at the end of the investigation)

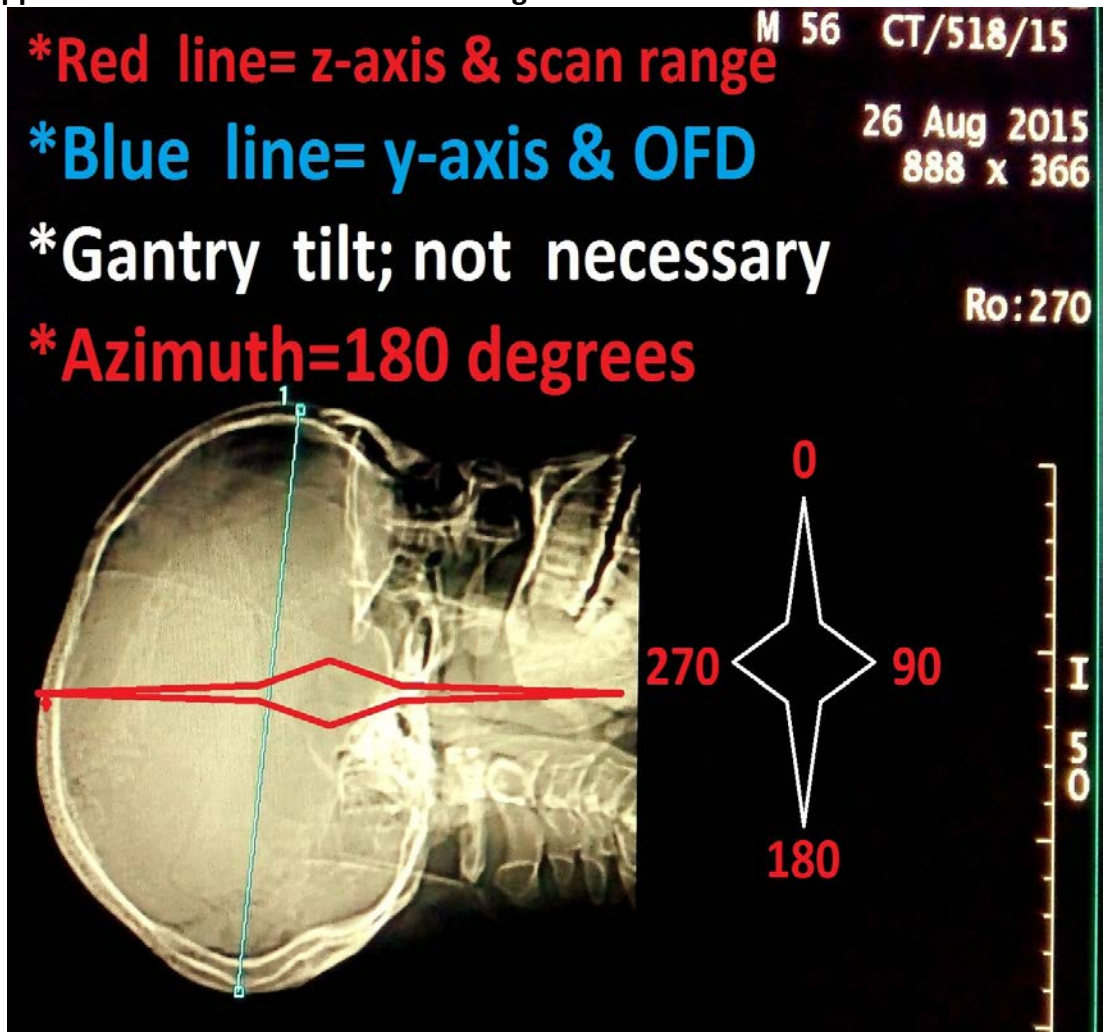


Appendix Vg: Posterio-anterior (left) and lateral (right) scanograms for the measurement of bi-parietal and occipito-frontal diameter in the calculation of cephalic index





Appendix Vh: Landmarks on head scanogram for biometric assessments



Appendix VI:Data capture sheet

Nnamdi Azikiwe University Teaching Hospital, Nnewi (A)

GE Brightspeed Excel, 4-slice, manufactured:2007; installed:2011; manual mA; aperture:70 cm; pitch:1.5; scan mode: axial; scanogram:2; azimuth:90/180; slice row:2; slice cm:2/5;gap:yes

S/No	Age	Gender	CTDI	DLP	kg	cm	BMI	OFD	BPD	CI	kVp	mA	DGR	Range	Tilt	Anatomy
1	18	M	94	1393	80	183	24.5	184	137	75	120	230	1	17	13.5	Cranium
2	18	M	54	520	67	172	22.7	195	140	72	120	230	1	20	20	Sinuses
3	25	F	60	1500	73	180	22.5	176	150	85	120	90	2	15	15.5	Cranium
4	29	M	67	908	72	166	26.1	174	139	80	120	230	1	20	15	Sinuses
5	29	F	59	719	79	180	28.1	197	136	69	120	230	1	26	17.5	Facial
6	36	F	40	824	80	186	26.6	188	139	74	120	180	2	16	19	Cranium
7	38	M	59	1699	67	167	24.0	177	133	75	120	180	2	19	21	Cranium
8	38	F	54	1279	80	168	28.4	185	133	72	120	200	1	18	16	Sinuses
9	45	F	61	1011	75	173	30.7	192	134	70	100	120	0.7	15	20	Facial
10	46	F	59	1500	60	173	19.7	184	143	78	120	230	1	23	20	Sinuses
11	46	M	64	1560	76	176	24.5	203	139	69	120	230	1	20	17.5	Sinuses
12	46	M	57	710	65	157	26.4	183	128	70	140	150	2	15	12.5	Cranium
13	54	F	41	570	80	180	28.4	196	138	70	100	100	1	15	17	Cranium
14	55	M	58	1150	71	167	25.5	196	144	74	100	120	0.7	11	24	Sinuses
15	56	F	60	428	60	167	21.5	195	142	73	120	100	1	16	17.5	Cranium
16	56	M	63	1282	61	159	23.3	194	135	70	120	230	1	13	20	Cranium
17	56	F	56	1050	65	163	19.6	182	133	73	120	230	1	15	21.5	Facial
18	56	F	57	1359	70	160	27.3	182	137	75	120	230	1	15	20.5	Sinuses
19	57	M	48	1000	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
20	57	M	94	1393	67	167	24.0	189	140	74	120	180	1	18	21	Sinuses
21	58	F	61	1738	79	183	24.5	176	129	73	120	230	1	17	13.5	Facial
22	58	F	60	1746	62	170	21.5	190	152	80	120	180	1	14	14.5	Cranium
23	58	F	45	400	69	168	24.5	194	143	74	120	240	1	18	19.5	Sinuses
24	59	M	59	950	72	167	25.8	187	133	71	120	240	1	17	16.5	Cranium
25	60	M	58	936	80	168	32.2	190	134	71	120	240	1	18	20.5	Cranium
26	63	M	58	1051	75	146	35.2	182	129	71	120	278	1	15	20	Sinuses
27	65	F	58	1042	82	146	43.2	184	145	79	100	70	0.7	20	24.5	Sinuses
28	66	M	59	1500	62	151	27.2	175	142	81	120	230	1	16	16.5	Cranium
29	67	M	57	1359	77	154	41.0	185	120	65	120	160	2	17	8	Facial
30	68	F	48	1000	70	168	24.8	188	134	71	120	230	1	17	10.5	Sinuses
31	68	F	61	1738	78	174	32.3	189	148	78	120	200	1	19	8	Facial
32	71	M	60	1746	74	165	34.5	178	139	78	120	230	1	15	12	Cranium
33	71	F	61	1738	72	163	27.1	182	144	79	120	230	1	15	18	Cranium
34	73	M	60	1746	66	162	25.2	191	130	68	120	230	1	18	17.5	Facial
35	73	M	55	658	79	151	34.7	180	141	78	120	278	1	13	15.5	Sinuses
36	76	F	59	1102	80	180	26.1	182	154	85	120	230	1	15	28	Cranium
37	76	M	62	1000	74	152	19.0	189	135	71	120	180	1	15	16.5	Cranium
38	77	F	58	1051	80	169	34.0	174	136	78	120	230	1	12	12	Cranium
39	78	M	41	570	78	144	23.1	180	124	69	120	230	1	12	17.5	Cranium
40	78	M	57	710	77	161	29.7	182	140	77	100	70	0.7	10	18	Cranium
41	78	M	60	428	80	180	25.0	183	145	79	120	230	1	16	24.5	Sinuses
42	78	F	45	400	71	156	21.0	185	124	67	120	230	1	13	16	Facial
43	78	M	59	950	80	159	33.6	186	135	73	120	180	1	19	20.5	Cranium
44	78	F	58	936	70	168	24.8	182	138	76	120	230	1	18	10.5	Facial
45	79	M	40	824	72	163	27.1	184	130	71	100	200	1	22	8	Sinuses

46	79	M	58	1042	80	151	35.1	184	148	80	120	240	1	17	11	Cranium
47	79	F	64	1560	75	168	33.7	176	134	76	120	220	0.7	23	14.5	Cranium
48	79	M	58	1150	62	162	23.6	184	137	75	120	240	1	18	20	Facial
49	80	M	50	551	67	147	31.0	184	128	70	120	250	1	14	20	Cranium
50	82	F	63	1282	81	180	28.1	197	136	69	120	230	1	26	17.5	Cranium
51	82	F	60	1390	80	186	26.6	188	139	74	120	180	2	16	19	Sinuses
52	82	M	56	1050	67	167	24.0	177	133	75	120	180	2	19	21	Cranium
53	83	M	63	1282	80	168	28.4	185	133	72	120	200	1	18	16	Facial
54	83	F	60	1270	82	173	30.7	192	134	70	100	120	0.7	15	20	Cranium
55	84	M	54	1279	79	173	19.7	184	143	78	120	230	1	23	20	Facial
56	84	M	57	1838	76	176	24.5	203	139	69	120	230	1	20	17.5	Cranium
57	84	F	45	846	75	157	26.4	183	128	70	140	150	2	15	12.5	Cranium
58	85	F	55	1500	82	180	28.4	196	138	70	100	100	1	15	17	Facial
59	85	M	58	719	71	167	25.5	196	144	74	100	120	0.7	11	24	Cranium
60	85	M	61	1011	60	167	21.5	195	142	73	120	100	1	16	17.5	Cranium
61	86	F	41	1183	79	159	23.3	194	135	70	120	230	1	13	20	Sinuses
62	86	F	60	500	82	163	19.6	182	133	73	120	230	1	15	21.5	Cranium
63	86	M	67	908	70	160	27.3	182	137	75	120	230	1	15	20.5	Cranium
64	86	M	60	1500	80	168	28.3	185	132	71	120	200	1	18	16	Facial
65	87	F	54	520	77	167	24.0	189	140	74	120	180	1	18	21	Facial
66	87	M	50	980	80	183	24.5	176	129	73	120	230	1	17	13.5	Sinuses
67	87	F	74	1982	80	170	21.5	190	152	80	120	180	1	14	14.5	Cranium
68	88	M	40	939	69	168	24.5	194	143	74	120	240	1	18	19.5	Cranium
69	89	F	60	1005	72	167	25.8	187	133	71	120	240	1	17	16.5	Sinuses
70	89	M	58	1185	81	168	32.2	190	134	71	120	240	1	18	20.5	Cranium
71	91	F	58	1053	75	146	35.2	182	129	71	120	278	1	15	20	Sinuses
72	91	F	41	1060	80	146	43.2	184	145	79	100	70	0.7	20	24.5	Cranium
73	91	F	59	337	69	151	27.2	175	142	81	120	230	1	16	16.5	Sinuses
74	92	M	58	1213	78	168	24.5	194	143	74	120	240	1	18	19.5	Cranium
75	92	M	63	830	80	167	25.8	187	133	71	120	240	1	17	16.5	Sinuses

Iyi Enu Mission Hospital, Ogidi (centre B)

Toshiba-Alexion, 16-slice, manufactured (Germany):2013; installed:2014; auto mA; aperture:75cm; pitch:0.75; scan mode: helical; scanogram:2; azimuth:0/90; slice row:1; slice cm:0.75;gap:0																
S/ No	Age	Gender	CTDI	DLP	kg	cm	BMI	OFD	BPD	CI	kVp	mA	DGR	Range	Tilt	Anatomy
1	20	M	58.8	1068	80	186	26.6	188	139	74	120	180	2	16	19	Sinuses
2	23	F	58.8	1068	67	167	24.0	177	133	75	120	180	2	19	21	Cranium
3	26	M	58.8	963	80	168	28.4	185	133	72	120	200	1	18	16	Cranium
4	26	F	58.8	1951	82	173	30.7	192	134	70	100	120	0.7	15	20	Sinuses
5	28	F	58.8	1097	79	173	19.7	184	143	78	120	230	1	23	20	Cranium
6	28	M	58.8	664	76	176	24.5	203	139	69	120	230	1	20	17.5	Sinuses
7	28	M	58.8	1068	75	157	26.4	183	128	70	140	150	2	15	12.5	Cranium
8	30	M	58.8	1421	82	180	28.4	196	138	70	100	100	1	15	17	Sinuses
9	35	F	48.2	1560	71	167	25.5	196	144	74	100	120	0.7	11	24	Cranium
10	35	F	58.8	1201	60	167	21.5	195	142	73	120	100	1	16	17.5	Sinuses
11	35	M	58.8	1215	79	159	23.3	194	135	70	120	230	1	13	20	Cranium
12	42	M	58.8	1097	82	163	19.6	182	133	73	120	230	1	15	21.5	Cranium
13	42	F	58.8	1421	70	160	27.3	182	137	75	120	230	1	15	20.5	Facial
14	45	M	49.8	913	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
15	45	F	58.8	1539	77	167	24.0	189	140	74	120	180	1	18	21	Cranium
16	45	M	58.8	1039	80	183	24.5	176	129	73	120	230	1	17	13.5	Sinuses
17	48	F	58.8	980	80	170	21.5	190	152	80	120	180	1	14	14.5	Cranium
18	48	F	58.8	1157	69	168	24.5	194	143	74	120	240	1	18	19.5	Cranium
19	48	F	58.8	1187	72	167	25.8	187	133	71	120	240	1	17	16.5	Facial
20	48	M	58.8	1421	81	168	32.2	190	134	71	120	240	1	18	20.5	Facial
21	55	M	44.1	1163	75	146	35.2	182	129	71	120	278	1	15	20	Sinuses
22	55	M	44.1	1163	80	146	43.2	184	145	79	100	70	0.7	20	24.5	Cranium
23	59	F	58.8	1421	69	151	27.2	175	142	81	120	230	1	16	16.5	Cranium
24	59	M	58.8	1215	78	168	24.5	194	143	74	120	240	1	18	19.5	Facial
25	59	F	58.8	1039	80	167	25.8	187	133	71	120	240	1	17	16.5	Cranium
26	63	F	58.8	1585	75	146	35.2	182	129	71	120	278	1	15	20	Cranium
27	63	M	49.8	913	82	146	43.2	184	145	79	100	70	0.7	20	24.5	Sinuses
28	63	M	58.8	1127	62	151	27.2	175	142	81	120	230	1	16	16.5	Cranium
29	63	F	58.8	980	77	154	41.0	185	120	65	120	160	2	17	8	Facial
30	66	M	58.8	1034	70	168	24.8	188	134	71	120	230	1	17	10.5	Cranium
31	68	M	58.8	1538	78	174	32.3	189	148	78	120	200	1	19	8	Sinuses
32	68	M	49.8	913	74	165	34.5	178	139	78	120	230	1	15	12	Facial
33	68	F	49.8	980	72	163	27.1	182	144	79	120	230	1	15	18	Cranium
34	70	M	58.8	1186	66	162	25.2	191	130	68	120	230	1	18	17.5	Cranium
35	70	F	58.8	1039	79	151	34.7	180	141	78	120	278	1	13	15.5	Facial
36	70	F	58.8	980	80	180	26.1	182	154	85	120	230	1	15	28	Sinuses
37	72	M	58.8	1539	74	152	19.0	189	135	71	120	180	1	15	16.5	Cranium
38	72	M	58.8	1186	80	169	34.0	174	136	78	120	230	1	12	12	Cranium
39	73	M	58.8	1039	78	144	23.1	180	124	69	120	230	1	12	17.5	Cranium
40	73	M	58.8	1204	77	161	29.7	182	140	77	100	70	0.7	10	18	Cranium
41	74	F	58.8	1450	80	180	25.0	183	145	79	120	230	1	16	24.5	Cranium
42	75	F	49.8	1302	71	156	21.0	185	124	67	120	230	1	13	16	Sinuses
43	75	M	49.8	1005	80	159	33.6	186	135	73	120	180	1	19	20.5	Facial
44	76	M	58.8	1245	70	168	24.8	182	138	76	120	230	1	18	10.5	Cranium
45	76	F	58.8	1109	72	163	27.1	184	130	71	100	200	1	22	8	Facial

46	78	M	58.8	1412	80	151	35.1	184	148	80	120	240	1	17	11	Cranium
47	78	M	49.8	975	75	168	33.7	176	134	76	120	220	0.7	23	14.5	Sinuses
48	78	F	49.8	1121	62	162	23.6	184	137	75	120	240	1	18	20	Cranium
49	79	F	58.8	947	67	147	31.0	184	128	70	120	250	1	14	20	Cranium
50	79	F	58.8	1034	81	180	28.1	197	136	69	120	230	1	26	17.5	Sinuses
51	80	M	58.8	1068	80	183	24.5	184	137	75	120	230	1	17	13.5	Sinuses
52	80	M	58.8	1068	67	172	22.7	195	140	72	120	230	1	20	20	Cranium
53	80	F	58.8	963	73	180	22.5	176	150	85	120	90	2	15	15.5	Facial
54	80	F	58.8	1421	72	166	26.1	174	139	80	120	230	1	20	15	Cranium
55	81	M	48.2	1560	79	180	28.1	197	136	69	120	230	1	26	17.5	Sinuses
56	82	M	58.8	1201	80	186	26.6	188	139	74	120	180	2	16	19	Cranium
57	83	M	58.8	1215	67	167	24.0	177	133	75	120	180	2	19	21	Sinuses
58	83	M	58.8	1097	80	168	28.4	185	133	72	120	200	1	18	16	Facial
59	83	F	58.8	1421	75	173	30.7	192	134	70	100	120	0.7	15	20	Cranium
60	83	M	49.8	913	60	173	19.7	184	143	78	120	230	1	23	20	Cranium
61	84	M	58.8	1539	76	176	24.5	203	139	69	120	230	1	20	17.5	Sinuses
62	84	F	58.8	1039	65	157	26.4	183	128	70	140	150	2	15	12.5	Facial
63	84	F	58.8	980	80	180	28.4	196	138	70	100	100	1	15	17	Sinuses
64	85	M	58.8	1157	71	167	25.5	196	144	74	100	120	0.7	11	24	Sinuses
65	85	M	58.8	1187	60	167	21.5	195	142	73	120	100	1	16	17.5	Cranium
66	86	M	58.8	1421	61	159	23.3	194	135	70	120	230	1	13	20	Cranium
67	86	F	58.8	1127	65	163	19.6	182	133	73	120	230	1	15	21.5	Sinuses
68	86	M	58.8	980	70	160	27.3	182	137	75	120	230	1	15	20.5	Cranium
69	87	F	58.8	1034	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
70	88	M	58.8	1538	67	167	24.0	189	140	74	120	180	1	18	21	Facial
71	88	M	49.8	913	79	183	24.5	176	129	73	120	230	1	17	13.5	Sinuses
72	89	F	49.8	980	62	170	21.5	190	152	80	120	180	1	14	14.5	Facial
73	90	M	58.8	1186	69	168	24.5	194	143	74	120	240	1	18	19.5	Cranium
74	90	F	58.8	1039	72	167	25.8	187	133	71	120	240	1	17	16.5	Cranium
75	93	F	58.8	1120	80	168	32.2	190	134	71	120	240	1	18	20.5	Cranium

St Charles Borromeo Hospital, Onitsha (centre C)

Toshiba-Alexion, 16-slice, manufactured (Germany):2013; installed:2014; auto mA; aperture:75cm; pitch:0.75; scan mode: helical; scanogram:2; azimuth:0/90; slice row:1; slice cm:2.5;gap:0																
S/ No	Age	Gender	CTDI	DLP	kg	cm	BMI	OFD	BPD	CI	kVp	mA	DGR	Range	Tilt	Anatomy
1	19	M	68.5	1562	80	180	26.1	182	154	85	120	230	1	15	28	Cranium
2	33	M	65.5	1631	74	152	19.0	189	135	71	120	180	1	15	16.5	Cranium
3	33	M	68.5	1785	80	169	34.0	174	136	78	120	230	1	12	12	Cranium
4	38	F	68.5	1460	78	144	23.1	180	124	69	120	230	1	12	17.5	Sinuses
5	38	F	68.5	1872	77	161	29.7	182	140	77	100	70	0.7	10	18	Cranium
6	43	M	68.5	1613	80	180	25.0	183	145	79	120	230	1	16	24.5	Cranium
7	43	M	68.5	1785	71	156	21.0	185	124	67	120	230	1	13	16	Facial
8	43	M	65.5	1973	80	159	33.6	186	135	73	120	180	1	19	20.5	Sinuses
9	44	F	68.5	1613	70	168	24.8	182	138	76	120	230	1	18	10.5	Cranium
10	44	F	68.5	1785	72	163	27.1	184	130	71	100	200	1	22	8	Cranium
11	45	M	68.5	1562	80	151	35.1	184	148	80	120	240	1	17	11	Cranium
12	46	M	68.5	1785	75	168	33.7	176	134	76	120	220	0.7	23	14.5	Cranium
13	46	F	65.5	1562	62	162	23.6	184	137	75	120	240	1	18	20	Facial
14	47	M	68.5	1494	67	147	31.0	184	128	70	120	250	1	14	20	Cranium
15	50	F	68.5	1391	81	180	28.1	197	136	69	120	230	1	26	17.5	Cranium
16	50	M	68.5	1871	80	183	24.5	184	137	75	120	230	1	17	13.5	Sinuses
17	50	F	68.5	1460	67	172	22.7	195	140	72	120	230	1	20	20	Cranium
18	50	F	86.5	1878	73	180	22.5	176	150	85	120	90	2	15	15.5	Cranium
19	51	F	86.5	1562	72	166	26.1	174	139	80	120	230	1	20	15	Facial
20	52	M	86.5	1872	79	180	28.1	197	136	69	120	230	1	26	17.5	Facial
21	53	M	86.5	1785	80	186	26.6	188	139	74	120	180	2	16	19	Sinuses
22	55	M	86.5	1183	67	167	24.0	177	133	75	120	180	2	19	21	Cranium
23	56	F	86.5	1829	80	168	28.4	185	133	72	120	200	1	18	16	Cranium
24	57	M	86.5	1341	75	173	30.7	192	134	70	100	120	0.7	15	20	Facial
25	59	F	86.5	1785	60	173	19.7	184	143	78	120	230	1	23	20	Cranium
26	59	F	86.5	1870	76	176	24.5	203	139	69	120	230	1	20	17.5	Cranium
27	60	M	68.5	1494	65	157	26.4	183	128	70	140	150	2	15	12.5	Sinuses
28	61	M	68.5	1563	80	180	28.4	196	138	70	100	100	1	15	17	Cranium
29	63	F	68.5	1656	71	167	25.5	196	144	74	100	120	0.7	11	24	Facial
30	63	M	68.5	1256	60	167	21.5	195	142	73	120	100	1	16	17.5	Cranium
31	63	M	68.5	1829	61	159	23.3	194	135	70	120	230	1	13	20	Sinuses
32	66	M	68.5	1494	65	163	19.6	182	133	73	120	230	1	15	21.5	Facial
33	66	F	68.5	1426	70	160	27.3	182	137	75	120	230	1	15	20.5	Cranium
34	69	M	86.4	1742	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
35	69	F	86.4	1656	67	167	24.0	189	140	74	120	180	1	18	21	Facial
36	70	F	68.5	1426	80	183	24.5	184	137	75	120	230	1	17	13.5	Sinuses
37	70	M	68.5	1562	67	172	22.7	195	140	72	120	230	1	20	20	Cranium
38	72	M	65.5	1562	73	180	22.5	176	150	85	120	90	2	15	15.5	Cranium
39	76	M	68.5	921	72	166	26.1	174	139	80	120	230	1	20	15	Cranium
40	76	M	68.5	1562	79	180	28.1	197	136	69	120	230	1	26	17.5	Cranium
41	78	F	68.5	921	80	186	26.6	188	139	74	120	180	2	16	19	Cranium
42	78	M	68.5	1699	67	167	24.0	177	133	75	120	180	2	19	21	Sinuses
43	78	F	65.5	1836	80	168	28.4	185	133	72	120	200	1	18	16	Facial
44	78	M	68.5	1785	75	173	30.7	192	134	70	100	120	0.7	15	20	Cranium
45	78	F	68.5	1960	60	173	19.7	184	143	78	120	230	1	23	20	Facial

46	79	M	68.5	1494	76	176	24.5	203	139	69	120	230	1	20	17.5	Cranium
47	80	M	68.5	1494	65	157	26.4	183	128	70	140	150	2	15	12.5	Sinuses
48	80	F	68.5	1563	80	180	28.4	196	138	70	100	100	1	15	17	Cranium
49	80	F	68.5	1656	71	167	25.5	196	144	74	100	120	0.7	11	24	Cranium
50	80	F	68.5	1256	60	167	21.5	195	142	73	120	100	1	16	17.5	Sinuses
51	80	M	68.5	1829	61	159	23.3	194	135	70	120	230	1	13	20	Sinuses
52	81	M	86.5	1872	65	163	19.6	182	133	73	120	230	1	15	21.5	Cranium
53	81	F	86.5	1785	70	160	27.3	182	137	75	120	230	1	15	20.5	Facial
54	81	F	86.5	1183	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
55	82	F	86.5	1829	67	167	24.0	189	140	74	120	180	1	18	21	Sinuses
56	82	M	86.5	1341	79	183	24.5	176	129	73	120	230	1	17	13.5	Cranium
57	82	M	86.5	1785	62	170	21.5	190	152	80	120	180	1	14	14.5	Sinuses
58	83	F	86.5	1870	69	168	24.5	194	143	74	120	240	1	18	19.5	Facial
59	83	F	68.5	1528	72	167	25.8	187	133	71	120	240	1	17	16.5	Cranium
60	84	M	68.5	1651	80	168	32.2	190	134	71	120	240	1	18	20.5	Cranium
61	86	M	86.5	1785	75	146	35.2	182	129	71	120	278	1	15	20	Sinuses
62	86	F	86.5	1785	82	146	43.2	184	145	79	100	70	0.7	20	24.5	Facial
63	78	F	68.5	1547	62	151	27.2	175	142	81	120	230	1	16	16.5	Sinuses
64	86	F	68.5	1785	77	154	41.0	185	120	65	120	160	2	17	8	Sinuses
65	86	M	68.5	1562	70	168	24.8	188	134	71	120	230	1	17	10.5	Cranium
66	87	M	68.5	1785	78	174	32.3	189	148	78	120	200	1	19	8	Cranium
67	87	F	65.5	1562	74	165	34.5	178	139	78	120	230	1	15	12	Sinuses
68	88	M	68.5	1494	72	163	27.1	182	144	79	120	230	1	15	18	Cranium
69	88	F	68.5	1391	66	162	25.2	191	130	68	120	230	1	18	17.5	Facial
70	89	F	68.5	1871	61	159	23.3	194	135	70	120	230	1	13	20	Sinuses
71	89	M	68.5	1460	65	163	19.6	182	133	73	120	230	1	15	21.5	Sinuses
72	90	M	86.5	1878	70	160	27.3	182	137	75	120	230	1	15	20.5	Facial
73	90	F	86.4	1656	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
74	92	F	68.5	1426	67	167	24.0	189	140	74	120	180	1	18	21	Cranium
75	93	M	68.5	1562	70	168	24.8	188	134	71	120	230	1	17	12.5	Facial

New Hope Medical Diagnostic Centre (centre D)

Siemens Somaton - Perspective, 16-slice, manufactured:2015; installed:2015; auto mA; aperture:80cm; pitch:0.75; scan mode: helical; scanogram:2; azimuth:0/90; slice row:1; slice cm:2.5;gap:0

S/ No	Age	Gender	CTDI	DLP	kg	cm	BMI	OFD	BPD	CI	kVp	mA	DGR	Range	Tilt	Anatomy
1	24	F	44	765	66	162	25.2	191	130	68	120	230	1	18	17.5	Cranium
2	29	F	42	744	79	151	34.7	180	141	78	120	278	1	13	15.5	Cranium
3	29	F	44	765	80	180	26.1	182	154	85	120	230	1	15	28	Cranium
4	38	F	39.7	659	74	152	19.0	189	135	71	120	180	1	15	16.5	Sinuses
5	38	M	44.3	793	80	169	34.0	174	136	78	120	230	1	12	12	Cranium
6	39	M	39.7	601	78	144	23.1	180	124	69	120	230	1	12	17.5	Sinuses
7	43	M	46.9	773	77	161	29.7	182	140	77	100	70	0.7	10	18	Facial
8	45	M	45.6	782	80	180	25.0	183	145	79	120	230	1	16	24.5	Sinuses
9	49	M	39.8	699	71	156	21.0	185	124	67	120	230	1	13	16	Sinuses
10	54	F	41.7	675	80	159	33.6	186	135	73	120	180	1	19	20.5	Cranium
11	55	M	40	660	70	168	24.8	182	138	76	120	230	1	18	10.5	Sinuses
12	63	M	51.5	844	72	163	27.1	184	130	71	100	200	1	22	8	Cranium
13	63	F	46.3	779	80	151	35.1	184	148	80	120	240	1	17	11	Cranium
14	65	M	44.9	817	75	168	33.7	176	134	76	120	220	0.7	23	14.5	Cranium
15	68	M	44.3	724	62	162	23.6	184	137	75	120	240	1	18	20	Cranium
16	68	M	41.0	800	67	147	31.0	184	128	70	120	250	1	14	20	Sinuses
17	72	F	47.6	708	81	180	28.1	197	136	69	120	230	1	26	17.5	Cranium
18	72	F	24.3	426	80	186	26.6	188	139	74	120	180	2	16	19	Cranium
19	72	M	41.7	685	67	167	24.0	177	133	75	120	180	2	19	21	Facial
20	72	F	41.7	651	80	168	28.4	185	133	72	120	200	1	18	16	Cranium
21	74	M	46.9	705	82	173	30.7	192	134	70	100	120	0.7	15	20	Sinuses
22	74	M	44.5	668	79	173	19.7	184	143	78	120	230	1	23	20	Cranium
23	75	F	73.6	1055	76	176	24.5	203	139	69	120	230	1	20	17.5	Cranium
24	75	M	41.7	743	75	157	26.4	183	128	70	140	150	2	15	12.5	Cranium
25	75	F	45.6	681	82	180	28.4	196	138	70	100	100	1	15	17	Facial
26	76	F	41.0	705	71	167	25.5	196	144	74	100	120	0.7	11	24	Cranium
27	77	M	53.4	1177	60	167	21.5	195	142	73	120	100	1	16	17.5	Sinuses
28	77	F	41.0	742	79	159	23.3	194	135	70	120	230	1	13	20	Cranium
29	78	F	39.0	603	82	163	19.6	182	133	73	120	230	1	15	21.5	Facial
30	79	M	42.0	745	70	160	27.3	182	137	75	120	230	1	15	20.5	Cranium
31	79	M	52.8	845	80	168	28.3	185	132	71	120	200	1	18	16	Sinuses
32	79	F	46.9	768	77	167	24.0	189	140	74	120	180	1	18	21	Facial
33	79	F	37.8	605	80	183	24.5	176	129	73	120	230	1	17	13.5	Cranium
34	79	M	40.4	651	80	170	21.5	190	152	80	120	180	1	14	14.5	Cranium
35	80	F	39.1	656	69	168	24.5	194	143	74	120	240	1	18	19.5	Cranium
36	82	F	44.3	812	80	186	26.6	188	139	74	120	180	2	16	19	Sinuses
37	82	M	44.9	797	67	167	24.0	177	133	75	120	180	2	19	21	Cranium
38	83	M	44.9	806	80	168	28.4	185	133	72	120	200	1	18	16	Cranium
39	84	M	44.3	741	82	173	30.7	192	134	70	100	120	0.7	15	20	Cranium
40	85	M	43.6	350	79	173	19.7	184	143	78	120	230	1	23	20	Facial
41	85	F	44.9	772	76	176	24.5	203	139	69	120	230	1	20	17.5	Cranium
42	85	M	41.0	658	75	157	26.4	183	128	70	140	150	2	15	12.5	Sinuses
43	86	F	47.6	798	82	180	28.4	196	138	70	100	100	1	15	17	Facial
44	86	F	43.7	765	71	167	25.5	196	144	74	100	120	0.7	11	24	Cranium
45	86	F	41.7	743	60	167	21.5	195	142	73	120	100	1	16	17.5	Facial

46	86	M	43.7	765	79	159	23.3	194	135	70	120	230	1	13	20	Cranium
47	86	M	40.1	659	82	163	19.6	182	133	73	120	230	1	15	21.5	Sinuses
48	86	F	44.4	792	70	160	27.3	182	137	75	120	230	1	15	20.5	Cranium
49	87	F	39.8	601	80	168	28.3	185	132	71	120	200	1	18	16	Cranium
50	87	F	46.9	773	77	167	24.0	189	140	74	120	180	1	18	21	Cranium
51	87	M	45.6	781	80	183	24.5	176	129	73	120	230	1	17	13.5	Sinuses
52	88	M	39.8	699	80	170	21.5	190	152	80	120	180	1	14	14.5	Cranium
53	88	F	41.7	675	69	168	24.5	194	143	74	120	240	1	18	19.5	Facial
54	88	F	39.8	659	72	167	25.8	187	133	71	120	240	1	17	16.5	Cranium
55	88	M	51.5	843	81	168	32.2	190	134	71	120	240	1	18	20.5	Facial
56	89	M	46.3	779	75	146	35.2	182	129	71	120	278	1	15	20	Cranium
57	89	M	45	817	80	146	43.2	184	145	79	100	70	0.7	20	24.5	Sinuses
58	89	F	44.3	724	69	151	27.2	175	142	81	120	230	1	16	16.5	Facial
59	89	F	41.1	799	78	168	24.5	194	143	74	120	240	1	18	19.5	Cranium
60	89	M	47.6	708	80	167	25.8	187	133	71	120	240	1	17	16.5	Cranium
61	90	M	24.3	427	75	146	35.2	182	129	71	120	278	1	15	20	Sinuses
62	91	F	41.7	685	82	146	43.2	184	145	79	100	70	0.7	20	24.5	Facial
63	91	F	41.7	651	62	151	27.2	175	142	81	120	230	1	16	16.5	Sinuses
64	91	F	46.9	705	77	154	41.0	185	120	65	120	160	2	17	8	Cranium
65	91	M	44.5	668	70	168	24.8	188	134	71	120	230	1	17	10.5	Cranium
66	91	M	73.7	1055	78	174	32.3	189	148	78	120	200	1	19	8	Cranium
67	91	F	41.7	743.7	80	151	35.1	184	148	80	120	240	1	17	11	Sinuses
68	91	M	45.7	681	75	168	33.7	176	134	76	120	220	0.7	23	14.5	Cranium
69	91	F	41.1	705	62	162	23.6	184	137	75	120	240	1	18	20	Facial
70	91	F	53.5	877	67	147	31.0	184	128	70	120	250	1	14	20	Cranium
71	92	M	41.1	742	81	180	28.1	197	136	69	120	230	1	26	17.5	Cranium
72	92	M	39	603	80	186	26.6	188	139	74	120	180	2	16	19	Cranium
73	92	F	42.0	745	67	167	24.0	177	133	75	120	180	2	19	21	Cranium
74	92	M	52.8	845	80	168	28.4	185	133	72	120	200	1	18	16	Cranium
75	92	M	43.4	856	77	154	41.0	185	120	65	120	160	2	17	8	Craniuml

Appendix VII:
SPSS ANALYSES

Frequencies

```
[DataSet1] C:\Users\User\Desktop\Main PhD Thesis\Ongoing work\Data
collection\AdejohdissertationANTHROPO-DOSEdata2017.sav
```

Statistics on biometrics

	Age	kg	cm	BMI	OFD	BPD	CI
N (Valid)	300	75	75	75	75	75	75
N (Missing)	0	225	225	225	225	225	225
Mean	69.7167	74.0800	166.0400	27.1107	186.2667	137.2267	73.8000
SE Mean	1.09856	.74271	1.19269	.59490	.78805	.77520	.47685
Mode	86.00	80.00	168.00	24.50	182.00	133.00	71.00
Std. Deviation	19.02761	6.43210	10.32897	5.15200	6.82470	6.71339	4.12966
Minimum	18.00	60.00	144.00	19.00	174.00	120.00	65.00
Maximum	93.00	82.00	186.00	43.20	203.00	154.00	85.00

Statistics on $CTDI_{vol}$

	CTDInauth	CTDIiyienu	CTDIboro	CTDInewHope	CTDIall
N (Valid)	75	75	75	300	75
N (Missing)	225	225	225	0	225
Mean	57.4533	56.8053	73.5360	44.1107	57.9763
SE Mean	1.06801	.47448	.97437	.79101	.73927
Mode	58.00	58.80	68.50	41.70	58.80
Std. Deviation	9.24924	4.10915	8.43828	6.85036	12.80445
Minimum	40.00	44.10	65.50	24.30	24.30
Maximum	94.00	58.80	86.50	73.70	94.00
Percentiles 75	60.0000	58.8000	86.5000	67.0000	45.7000

Statistics on DLP

		DLPnauth	DLPiyienu	DLPboro	DLPnewHope	DLPall
N	Valid	75	75	75	75	300
	Missing	225	225	225	225	0
Mean		1095.1867	1173.8800	1617.9200	733.3827	1155.0923
Std. Error of Mean		45.95170	25.66233	25.61289	13.85164	23.55741
Mode		1500.00	980.00[a]	1785.00	705.00[a]	1785.00
Std. Deviation		397.95340	222.24232	221.81413	119.95875	408.02639
Minimum		337.00	664.00	921.00	350.00	337.00
Maximum		1982.00	1951.00	1973.00	1177.00	1982.00
Percentiles	75	1390.0000	1302.0000	1785.0000	792.0000	1500.0000

ANOVA

ONEWAY ANOVA

ANOVAall

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	18197163.629	3	6065721.210	88.918	.000
Within Groups	13165953.805	193	68217.377		
Total	31363117.433	196			

Multiple Comparisons

Tukey HSD

(I) Grouping	(J) Grouping	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	361.39819*	52.24736	.000	225.9963	496.8001
	3	-496.96548*	53.32565	.000	-635.1618	-358.7692
	4	-83.54122	52.50275	.386	-219.6050	52.5225
2	1	-361.39819*	52.24736	.000	-496.8001	-225.9963
	3	-858.36367*	52.81126	.000	-995.2269	-721.5004
	4	-444.93941*	51.98022	.000	-579.6490	-310.2298
3	1	496.96548*	53.32565	.000	358.7692	635.1618
	2	858.36367*	52.81126	.000	721.5004	995.2269
	4	413.42426*	53.06393	.000	275.9062	550.9423
4	1	83.54122	52.50275	.386	-52.5225	219.6050
	2	444.93941*	51.98022	.000	310.2298	579.6490
	3	-413.42426*	53.06393	.000	-550.9423	-275.9062

*. The mean difference is significant at the 0.05 level.

Descriptives

ANOVAall (CTDI)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	75	56.5510	11.42742	1.63249	54.2687	60.8334	41.00	94.00
2	75	57.1394	3.81132	.53369	43.0675	45.2114	37.82	55.00
3	75	73.4957	9.52470	1.38932	67.6992	73.2923	41.00	86.50
4	75	43.5600	4.38378	.61996	55.3141	57.8059	44.10	58.80
Total	300	58.9158	12.19063	.86855	55.2029	58.6287	37.82	94.00

ANOVAall

Tukey HSD

Grouping	N	Subset for alpha = 0.05		
		1	2	3
2	57	43.1394		
4	57		56.5600	
1	74		56.5510	
3	43			74.4957
Sig.		1.000	.925	1.000

Means for groups in homogeneous subsets are displayed.

NORMALITY TESTS

Descriptives

			Statistic	Std. Error
BMIALL	Mean		27.4000	.75734
	95% Confidence Interval for Mean	Lower Bound	25.8773	
		Upper Bound	28.9227	
	5% Trimmed Mean		27.0997	
	Median		26.1000	
	Variance		28.105	
	Std. Deviation		5.30138	
	Minimum		19.00	
	Maximum		43.20	
	Range		24.20	
	Interquartile Range		6.85	
	Skewness		.928	.340
	Kurtosis		.821	.668
ageALL	Mean		45.6327	2.61483
	95% Confidence Interval for Mean	Lower Bound	40.3752	
		Upper Bound	50.8901	
	5% Trimmed Mean		45.2517	
	Median		42.0000	
	Variance		335.029	
	Std. Deviation		18.30380	
	Minimum		18.00	
	Maximum		89.00	
	Range		71.00	
	Interquartile Range		31.00	

	Skewness		.271	.340
	Kurtosis		-1.016	.668
kgALL	Mean		74.7143	1.95354
	95% Confidence Interval for Mean	Lower Bound	70.7864	
		Upper Bound	78.6421	
	5% Trimmed Mean		74.9977	
	Median		72.0000	
	Variance		187.000	
	Std. Deviation		13.67479	
	Minimum		44.00	
	Maximum		98.00	
	Range		54.00	
	Interquartile Range		18.00	
	Skewness		-.095	.340
	Kurtosis		-.576	.668
cmALL	Mean		165.4694	1.50964
	95% Confidence Interval for Mean	Lower Bound	162.4341	
		Upper Bound	168.5047	
	5% Trimmed Mean		165.5544	
	Median		167.0000	
	Variance		111.671	
	Std. Deviation		10.56745	
	Minimum		144.00	
	Maximum		186.00	
	Range		42.00	
	Interquartile Range		13.50	
	Skewness		-.155	.340
	Kurtosis		-.485	.668
ofdALL	Mean		185.3673	.94432
	95% Confidence Interval for Mean	Lower Bound	183.4687	
		Upper Bound	187.2660	
	5% Trimmed Mean		185.2166	
	Median		184.0000	
	Variance		43.696	
	Std. Deviation		6.61026	
	Minimum		174.00	
	Maximum		203.00	
	Range		29.00	
	Interquartile Range		7.50	
	Skewness		.396	.340

	Kurtosis		-.082	.668
bpdALL	Mean		137.2041	1.02808
	95% Confidence Interval for Mean	Lower Bound	135.1370	
		Upper Bound	139.2712	
	5% Trimmed Mean		137.1814	
	Median		137.0000	
	Variance		51.791	
	Std. Deviation		7.19658	
	Minimum		120.00	
	Maximum		154.00	
	Range		34.00	
	Interquartile Range		9.00	
	Skewness		.070	.340
	Kurtosis		.117	.668
ciALL	Mean		74.1429	.64220
	95% Confidence Interval for Mean	Lower Bound	72.8516	
		Upper Bound	75.4341	
	5% Trimmed Mean		74.0125	
	Median		74.0000	
	Variance		20.208	
	Std. Deviation		4.49537	
	Minimum		65.00	
	Maximum		85.00	
	Range		20.00	
	Interquartile Range		7.00	
	Skewness		.427	.340
	Kurtosis		-.207	.668

M-Estimators

	Huber's M-Estimator[a]	Tukey's Biweight[b]	Hampel's M-Estimator[c]	Andrews' Wave[d]
BMIALL	26.4205	25.9828	26.4301	25.9817
ageALL	44.9129	44.9280	45.2624	44.9302
kgALL	74.4793	74.7952	75.0179	74.7901
cmALL	165.9156	166.5632	165.8508	166.5727
ofdALL	184.7144	184.4143	184.7413	184.4173
bpdALL	137.0663	136.9839	137.0809	136.9807
ciALL	73.9586	73.9249	74.0167	73.9258

a. The weighting constant is 1.339.

b. The weighting constant is 4.685.

c. The weighting constants are 1.700, 3.400, and 8.500

d. The weighting constant is 1.340*pi.

Extreme Values

			Case Number	Value
BMIALL	Highest	1	27	43.20
		2	29	41.00
		3	26	35.20
		4	46	35.10
		5	35	34.70
	Lowest	1	37	19.00
		2	17	19.60
		3	10	19.70
		4	42	21.00
		5	22	21.50[a]
ageALL	Highest	1	32	89.00
		2	9	73.00
		3	17	73.00
		4	1	70.00
		5	12	70.00[b]
	Lowest	1	31	18.00
		2	49	19.00
		3	41	19.00
		4	16	22.00
		5	42	23.00
kgALL	Highest	1	31	98.00
		2	29	97.00
		3	38	97.00
		4	47	95.00
		5	32	94.00
	Lowest	1	37	44.00
		2	39	48.00
		3	42	51.00
		4	17	52.00
		5	16	59.00[c]
cmALL	Highest	1	6	186.00
		2	1	183.00
		3	21	183.00

		4	3	180.00
		5	5	180.00[d]
	Lowest	1	39	144.00
		2	27	146.00
		3	26	146.00
		4	49	147.00
		5	46	151.00[e]
ofdALL	Highest	1	11	203.00
		2	5	197.00
		3	13	196.00
		4	14	196.00
		5	2	195.00[f]
	Lowest	1	38	174.00
		2	4	174.00
		3	28	175.00
		4	47	176.00
		5	21	176.00[g]
bpdALL	Highest	1	36	154.00
		2	22	152.00
		3	3	150.00
		4	31	148.00
		5	46	148.00
	Lowest	1	29	120.00
		2	42	124.00
		3	39	124.00
		4	49	128.00
		5	12	128.00
ciALL	Highest	1	3	85.00
		2	36	85.00
		3	28	81.00
		4	4	80.00
		5	22	80.00[h]
	Lowest	1	29	65.00
		2	42	67.00
		3	34	68.00
		4	39	69.00
		5	11	69.00[i]

a. Only a partial list of cases with the value 21.50 are shown in the table of lower extremes.

b. Only a partial list of cases with the value 70.00 are shown in the table of upper extremes.

c. Only a partial list of cases with the value 59.00 are shown in the table of lower extremes.

d. Only a partial list of cases with the value 180.00 are shown in the table of upper extremes.

e. Only a partial list of cases with the value 151.00 are shown in the table of lower extremes.

f. Only a partial list of cases with the value 195.00 are shown in the table of upper extremes.

g. Only a partial list of cases with the value 176.00 are shown in the table of lower extremes.

h. Only a partial list of cases with the value 80.00 are shown in the table of upper extremes.

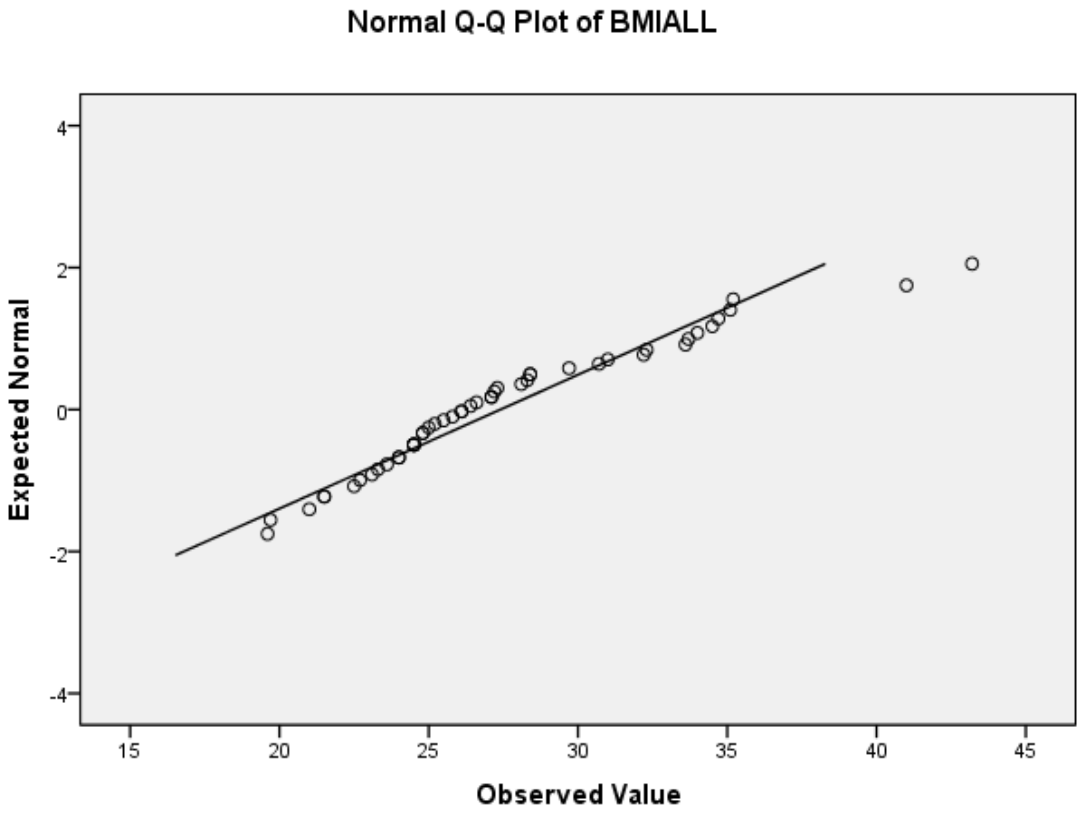
i. Only a partial list of cases with the value 69.00 are shown in the table of lower extremes.

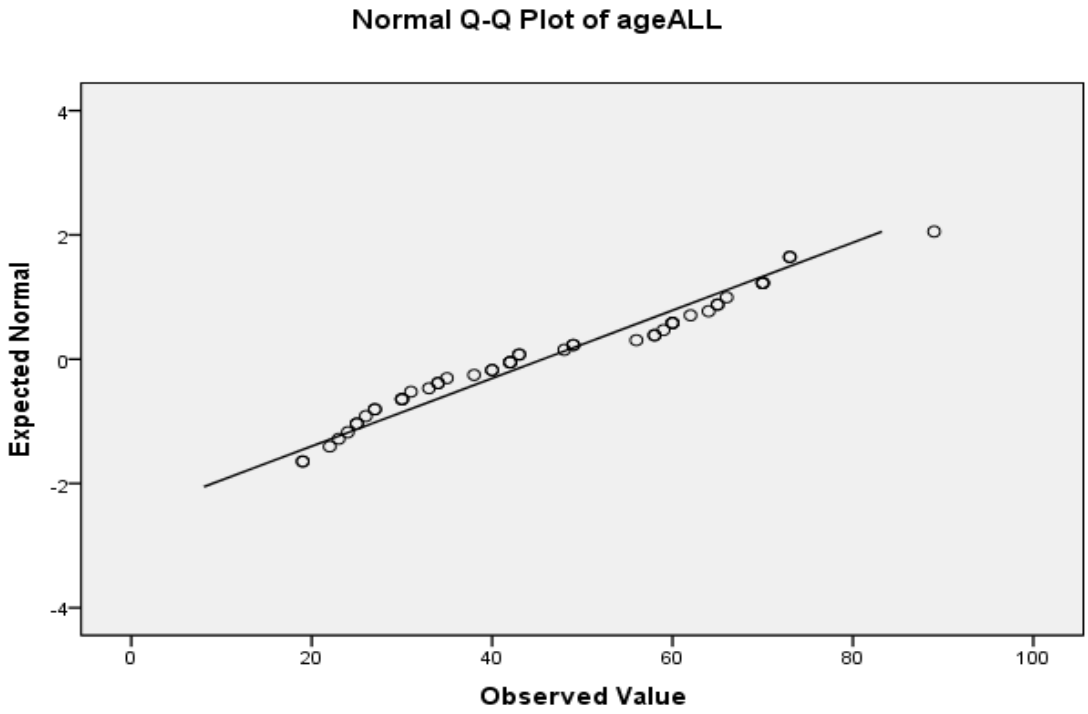
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
BMIALL	.140	49	.017	.935	49	.010
ageALL	.118	49	.087	.945	49	.023
kgALL	.108	49	.200*	.970	49	.250
cmALL	.109	49	.200*	.968	49	.206
ofdALL	.134	49	.027	.967	49	.185
bpdALL	.075	49	.200*	.991	49	.976
ciALL	.125	49	.053	.968	49	.195

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

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Expected Normal
Observed Value
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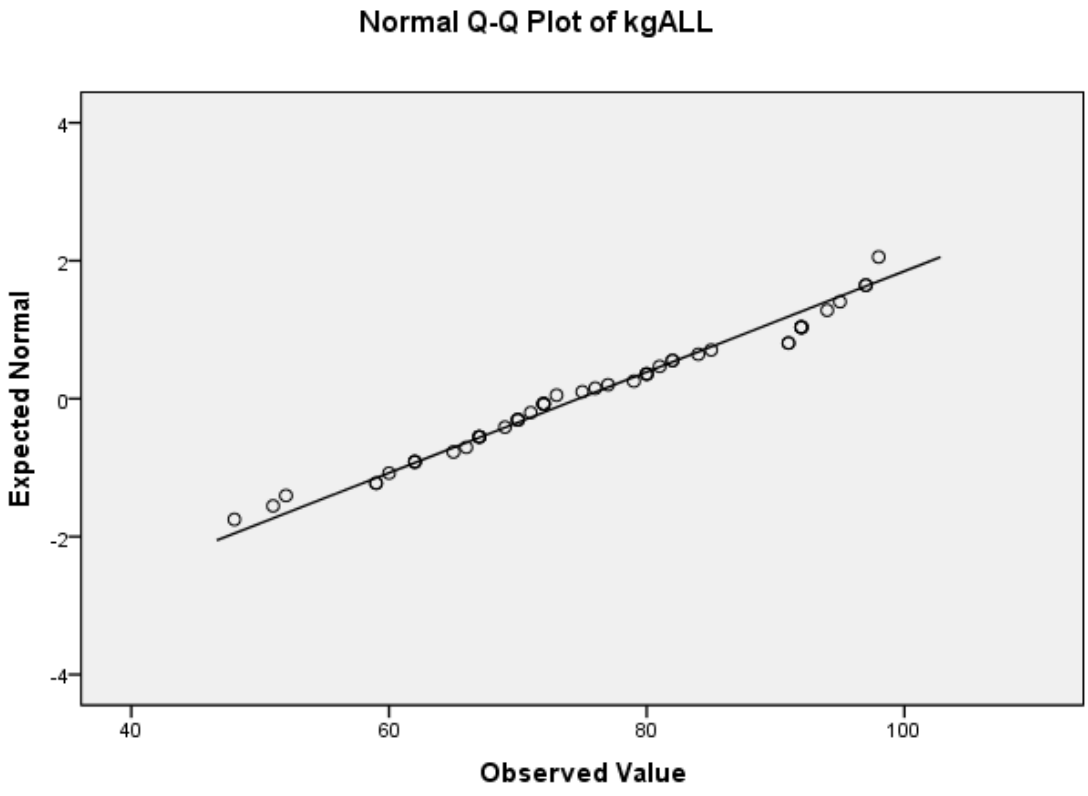
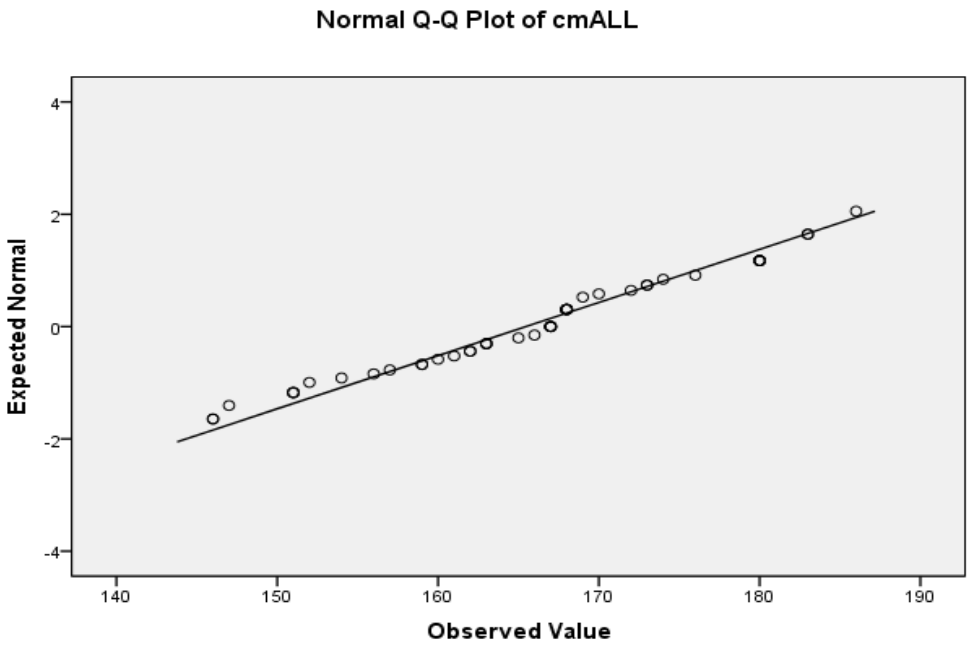
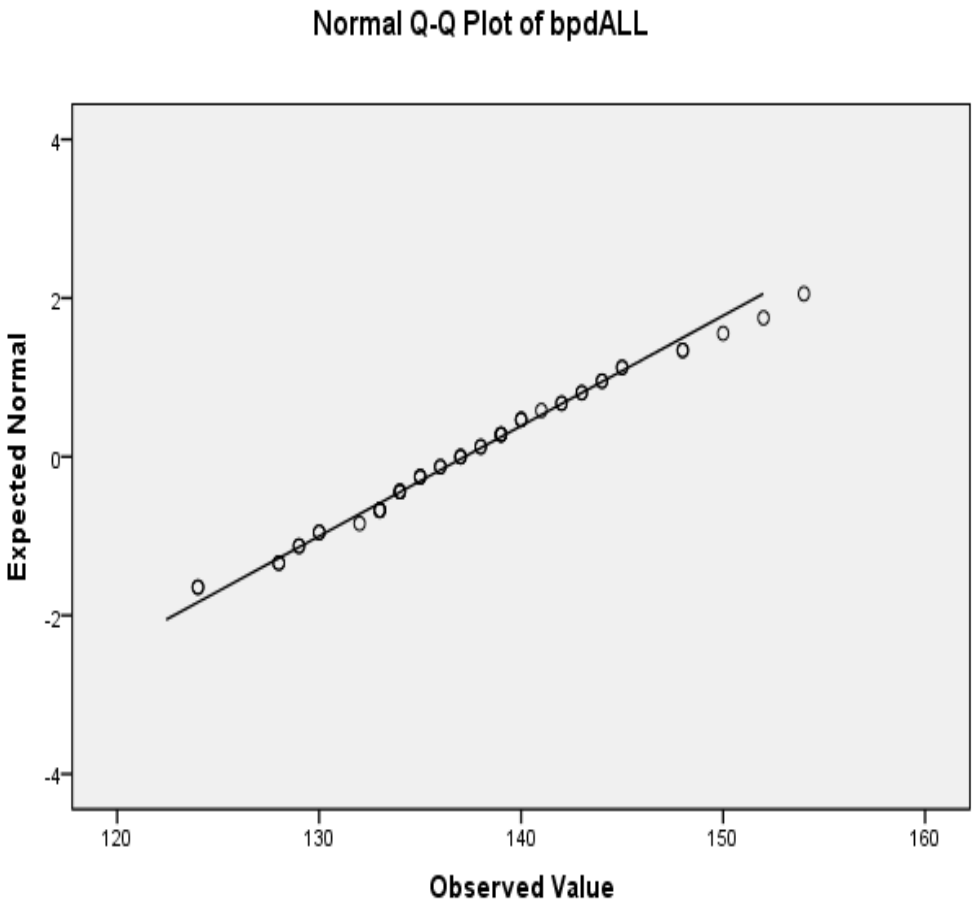
2
0
-2
-4
0
20
40
60
80
100


Normal Q-Q Plot of kgALL
Expected Normal
Observed Value
4
2
0
-2
-4
40
60
80
100


Normal Q-Q Plot of cmALL
Expected Normal
Observed Value
4
2
0
-2
-4
140
150
160
170
180
190


Normal Q-Q Plot of bpdALL
Expected Normal
Observed Value
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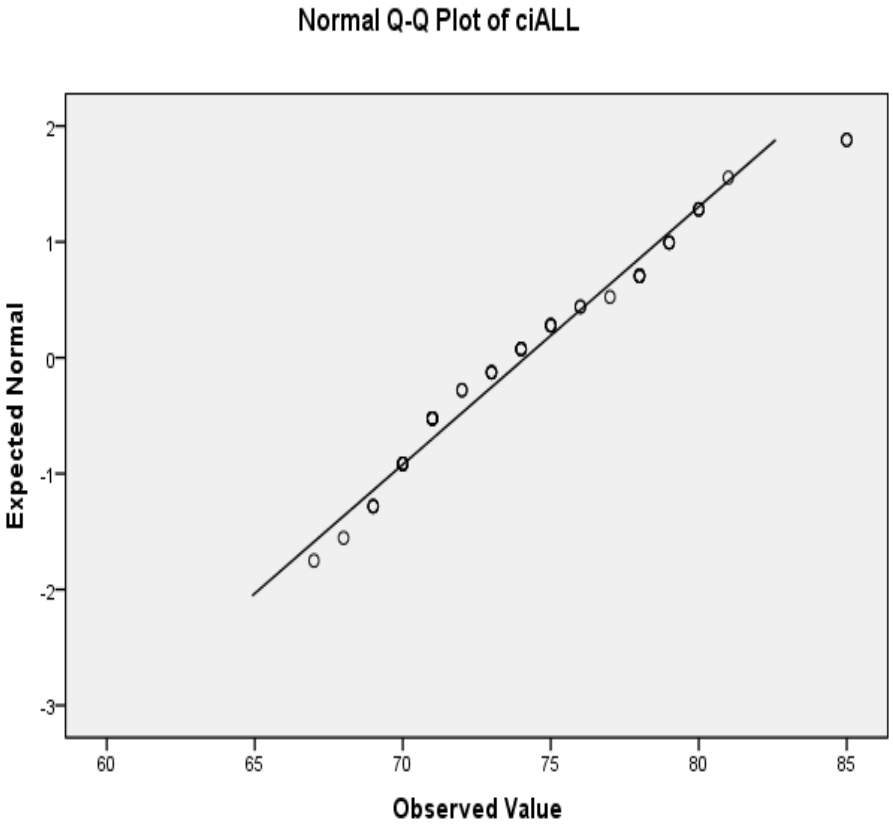
2
0
-2
-4
120
130
140
150
160


Normal Q-Q Plot of ciALL
Expected Normal
2
1
0
-1
-2
-3
60
65
70
75
80
85
Observed Value