COMPUTER TOMOGRAPHY DOSE INDEX FOR HEAD CT IN NORTHERN NIGERIA

By

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Thesis submitted in fulfilment of the requirements for the degree Master of Technology: Diagnostic Radiography, Department of Nursing and Radiography in the Faculty of Health Wellness Sciences at Cape Peninsula University of Technology

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January, 2014

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DECLARATION

I, Idris Garba declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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Sign Date

ABSTRACT

Aim: The aim of this study was to record the values of $CTDI_w$ and DLP displayed on the Computed Tomography (CT) scanner monitors of patients undergoing CT examinations of the head as Diagnostic Reference Levels (DRL) for dose optimisation in Northern Nigeria.

Background: A brain CT scan is the most common CT examination performed, and this modality is recognized as delivering a high dose. CT, therefore, contributes significantly to the total collective effective dose to the population. Elimination of unnecessary or unproductive radiation exposure is necessary. To achieve this, practitioners must adhere to the principles of the justification of practices, and optimisation of radiation protection. Furthermore, the development of DRLs for the local context is advised. These reference doses are a guide to the expected exposure dose from a procedure and are useful as an investigation tool to identify incidences where patient doses are unusually high.

Methodology: The study was conducted in three radiology departments with CT centres in Northern Nigeria. Data was collected, using a purposive sampling technique, from 60 consenting adult participants (weighing 70 ±3 kg) that had brain CT scans on seventh generations 4&16-slice GE and 16-slice Philips CT scanners. Prior to commencement of the study the CT scanners were certified by the medical physicists. For each brain scan, patient information, exposure factors, weighted computed tomography dose index (CTDIw), volume computed tomography dose index (CTDIvol) and dose length product (DLP) values were recorded. The data were analysed using SPSS version (16) statistical software. The mean, standard deviation and third quartile values of the $CTDI_w$ and DLP were calculated. An inter-comparison of the measured doses from the three research sites was conducted. A combined dose for the three centres was calculated, and compared with the reported data from the international communities where there are established DRLs.

Results: The mean CTDIw and DLP values were: centre A (88 mGy and 713 mGy.cm), centre B (68 mGy and 1098 mGy.cm), and centre C (70 mGy and 59 mGy.cm). Comparison of CTDIw and DLP for the scanners of the same manufacturers showed statistically significant differences ($p=0.003$) and $(p=0.03)$ respectively. In the case of the scanners of a different model but the same number of slices, the comparison of DLP was statistically significant ($p=0.005$) while no significant difference was noted in the measured CTDIw. Third quartile values of the cumulative doses of CTDIw and DLP, for Northern Nigeria were determined as 77 mGy and 985 mGy.cm respectively.

Conclusion: The study has established Local DRLs (LDRLs) which are significantly higher than most of the reported data in the literature. Also dose variation between centres was noted. Optimization is thus recommended.

Keywords: Head Imaging, Radiation Dose, Dose optimization, Computed Tomography, Local Diagnostic Reference Levels, Radiation Protection

AKNOWLEDGEMENTS

Thanks be to almighty God who created me from nothing for allowing me to complete this piece of work.

I would like to extend my heart-felt gratitude to the following persons who have inspired and assisted me during this research:

- Professor Penelope Engel-Hills and Mrs Florence Davidson, my internal supervisors at CPUT for their expertise, constructive and positive influence.
- Professor Abdulkadir Musa Tabari my external supervisor at Bayero University Kano, Nigeria for his wonderful support and guidance.
- The entire staff of the CT units of all the participating hospitals for their assistance in the data collection processes.
- The Ethics committee of the participating hospitals and REC of the CPUT for allowing the research to proceed.
- My mother and my wife for their love, encouragement and support.

PLAGIARISM DECLARATION

I……. Idris Garba…….

Declare that the thesis is my own original work, compiled without assistance. All sources used, or quoted, have been indicated and acknowledge by means of using the Harvard system of in-text and end-of text referencing, i.e. I have **NOT PRACTICED ANY FORM OF PLAGIARISM**

COURSE: MTech DIAGNOSTIC RADIOGRAPHY

TITLE: DIAGNOSTIC REFERENCE DOSE LEVEL AND COMPUTED TOMOGRAPHY DOSE INDEX FOR HEAD COMPUTED TOMOGRAPHY SCANS IN NORTHERN NIGERIA

Signed: Monday 20th of January, 2014

Student Full Name & Surname: Idris Garba

Student Number: 209151803

Student Signature:

Recipient Signature:

DEDICATION

This work is dedicated to my late father in the person of Mal. Muhammad Inuwa. May his soul rest in peace. Amen.

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GLOSSARY

Absorbed Dose: the mean energy, imparted by ionizing radiation to some materials per unit mass of that material, with a unit the Gray (Gy) (Graham & Frances, 1992).

Computed Tomography Dose Index (CTDI): an estimate of the average dose to a standard CT dosimetry phantom from an axial CT slice, i.e. total dose per slice or per tube rotation measured in Gray (Gy) (Yates, Pike & Goldstone, 2004).

Dose Length Product (DLP): the $CTDI_{vol}$ multiplied by the scanning length expressed in centimetres. It gives an indication of the energy imparted to organs and can be used to assess overall radiation burden associated with a CT study. Its unit is milligray centimetre (mGy x cm) (Smith, Dillon, Gould & Wintermark, 2007).

Diagnostic Reference Levels (DRLs): the recommended values for those radiological examinations which are most frequently performed or those involving the use of higher radiation dose such as CT. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied (European Commission, 1999).

Effective Dose: the biological effect of radiation dose received. It also reflects the non-uniform radiation absorption of partial body exposures relative to a whole body radiation dose, and allows comparison of risk among different CT examination protocols. The SI unit of measurement is the Sievert (Sv) or millisievert (mSv) (Graham & Frances, 1992; Morin, Gerber & McCollough, 2003).

Multiple Scan Average Dose (MSAD): the dose from all slices in a particular procedure, measured in Gray (Gy) (Morin *et al*., 2003; Goldman, 2007).

Optimisation: the dose of radiation which is delivered must be kept as low as reasonably achievable (ALARA), but high enough to obtain the required diagnostic information, taking into account economic and social factors (European Commission, 1999).

Volume CT Dose Index (CTDIvol): an estimate of the amount of radiation dose delivered to the scan volume for a specific examination (Russels, Fink, Rebeles, Kanal, Ramos, & Anzai, 2008). It is based on the same concept as the MSAD, but is derived from the weighted CT dose index ($CTDI_w$) which is easier to measure. $CTDI_{vol}$ is measured in Gray (Gy) (Morin *et al*., 2003).

Weighted CT Dose Index (CTDIw): the weighted average of the $CTDI_{100}$ measured at the center and the peripheral locations of the phantom. This parameter reflects the average absorbed dose for a single cross sectional image of the patient's body (Koller, Eatou & Bettridge, 2003; Morin *et al*., 2003).

CHAPTER ONE: INTRODUCTION

1.1 Introduction

X-ray Computed Tomography (CT) is a non-invasive method of acquiring the images of the inside of the human body without superimposition of distinct anatomical structures, from a mathematical reconstruction of x-ray attenuation measurements made through a thin axial slice of the patient (Yates, Pike & Goldstone, 2004; Buzug, 2008).

After the launch of CT into clinical practice more than 30 years ago, scanner technology has developed, and its uses have become more widespread (Lewis & Edyvean, 2005; Seeram, 2009).

CT has being recognised as administering a high radiation dose to the patient, when compared to other diagnostic imaging modalities, and this has raised concern over patient radiation doses (Lewis & Edyvean, 2005; Aroua, Samara, Bochud, Meuli & Verdun, 2013). Recent surveys in large medical institutions in countries such as; Canada, Greece, India, Poland, Thailand and UK have shown that CT examinations account for an ever-increasing fraction of radiological radiation dose. In some centres, it contributes up to 60 to 80% of patient radiation dose (IAEA TECDOC, 2009, Aroua *et al*., 2013). In the United Kingdom (UK) CT accounts for only 3-5% of all examinations performed using X-rays, but radiation doses from it account for approximately 40 to 47% of the collective radiation dose arising from medical exposures (Yates *et al*., 2004; Brandberg, Lonn, Bergelin, Sostrom, Forssell-Aronsson & Starck, 2008). Similarly, in Germany CT represents 2-5% of all radiological examinations, yet contributes up to 33% of the collective radiation dose. Worldwide, CT contributes 5% of radiological examinations but contributes up to 34% of the collective radiation dose (Zarb, McEntee & Rainford, 2012).

However, no published data from the African continent, specifically Nigeria, has identified the collective dose arising from CT procedures.

The head CT scan is the most common CT examination performed in Europe (30-40%), and also significantly contributes total collective effective dose of the population (Smith, Shah & Kron, 1998; Mulkens, Salgado & Bellinck, 2007). This contribution is inevitable, as it results from a combination of high dose per examination and frequent use of CT examinations in diagnoses of head trauma and pathology. Increased use of this high dose procedure has been of great concern globally because of the high possibility of inducing undesired health effects in patients, such as cancer. Furthermore, the significant radiation dose delivered to superficial radiosensitive organs such as the lens of the eye, which is often irradiated during radiological procedures of the head, is of great concern (Ngaile & Msaki, 2006).

The absorbed radiation dose to adult patients, for one head CT examination has been reported as being equivalent to the radiation dose for 100-150 conventional chest radiographs. This is 2 mSv for head CT against 0.02 mSv for conventional chest radiograph (Wall & Hart, 1997), or 60 mGy compared to 0.4 mGy (Mayo, Aldrich & Müller, 2003). The typical range of exposure factors for the adult chest x-ray is reported by Liu, Zhuo, Chen, Yi and Li (2008) to be 62-85 kVp, and 10-30 mAs. Whereas, for a standard head CT scan the exposure factors are reported to be 120-140 kVp, and 200-350 mAs (Smith, Dillon, Gould & Wintermark, 2007).

Computed Tomography plays important role in diagnostic radiology. Even though, MRI is widely used in brain imaging, CT continues to be on the rise due to its varied advantages such as fast image acquisition with wide clinical applications (Livingstone, Eapen, Dip & Hubert, 2006).

The following sections focus on radiation protection against the harmful effects of ionizing radiation resulting from CT examinations and methods of radiation dose measurement. These are followed by the statement of the research problem, rationale

and significance of the study. The overview of the methodology and delimitation of the study are also highlighted. The chapter closes with an introduction to the thesis.

1.2 Radiation protection

Radiation protection is concerned with the protection of individual and the environment against the effects of ionizing radiation. Ionizing radiation sources cause harm to both humans and the environment (Munro, 2004). The radiation used in medicine for diagnostic and therapeutic purposes is the main source of ionizing radiation. Several international organizations have published guidelines addressing this aspect of ionizing radiation such as International Atomic Energy Agency (IAEA), World Health Organization (WHO), International Commission on Radiological Protection (ICRP) and International Labour Organization (ILO) (IAEA, 2011).

1.3 Radiation dosimetry

Radiation dosimetry is the process of measuring radiation dose. A dosimeter is a device used to measure external radiation sources. The Thermoluminescent Dosimeter (TLD) is the most common dosimeter used to measure radiation dose (University of California Santa Cruz, 2000). In CT, the dose parameter used is known as Computed Tomography Dose Index (CTDI) measured in mGy to a standard phantom. The dose can be measured in air or in a phantom using an ionization chamber or TLDs (Aweda & Arogundade, 2007).

1.4 Diagnostic reference levels (DRLs)

DRLs are defined in the council directive 97/43 EURATOM as dose levels in medical diagnostic practice, for typical examinations, for groups of standard-size patients or standard phantoms, for broadly defined types of equipment. The values are expected to not be exceeded when good and normal practice regarding diagnostic and technical performance is applied. DRLs are only applied in diagnostic imaging (Michel, 2008).

1.5 Brain CT in Nigeria and its role in imaging

Nigeria is one of the developing countries where the technology of CT is not widespread compared to developed nations like the UK and the United States of America (USA). This is because, with a population of 120 million only 30 CT machines are actively working based on the Nigeria Nuclear Regulatory Authority 2009 report (Erondu, Okoro, Aniemeke & Ugwu, 2011). Also awareness of the clinical applications of CT is rather poor among general physicians and other healthcare providers (Erondu *et al.*, 2011). Despite the limited number of CT scanners, according to a study conducted by Adeyekun and Obi-Egbedi-Ejakpovi (2013), CT is referred to as the first line investigative modality of choice for patients with severe head injury. Although brain CT is the most common, to date, no literature has been found documenting the rate of brain CT in Nigeria.

Even though CT has been of great value since its inception in diagnostic radiology, other imaging modalities like MRI is also widely used in brain imaging. However, CT is on the increase due to its wide applications (Livingstone *et al.*, 2006).

A study conducted by Dzialowski and Kummer (2005) has described CT as the standard imaging modality for management of patients with brain lesion such as acute stroke. This is due to its availability, its speed and great practicality. Therefore, it is feasible for routine clinical use. In other clinical conditions, like trauma, a strong association was also noted between the clinical history and the resultant CT findings (Tabari & Garba, 2007) which makes CT an invaluable tool for brain trauma patients. Advances in CT like invention of helical and multi-detector CT with rapid acquisition times have paved the way for more complex procedures such as CT angiography and perfusion (Mulkens, Salgado & Bellinck, 2007).

1.6 Distribution of CT equipment globally

The use of CT has increased rapidly, both in the USA and other parts of the world, notably in Japan (Brenner & Hall, 2007). A survey conducted in 1996 has shown that,

the number of CT scanners per 1 million populations was 26 in the USA and 64 in Japan. It is estimated that more than 62 million CT scans are currently conducted each year in the United States, as compared with about 3 million in 1980 (Brenner & Hall, 2007). Nevertheless, there is paucity of literature documenting the statistics of CT scanners in the African community.

The sharp increase in the distribution of CT scanners has been driven largely by advances in CT technology that make it extremely user-friendly for both the patient and the physician (Brenner & Hall, 2007), coupled with improved radiation efficiency. Table (1.1) below shows the distribution of CT scanners in the study sites, and this serves about 80, 000,000 population in the country (Index Mundi, 2013).

Table 1.1: Distribution of functional CT scanners at the study site

Regions/CT scanners	GE 2-slice	GE 4-slice	GE 16-slice	Philips 16-slice
North West	1	1	0	0
North Central	0	0	0	1
North East	0	0	1	0

1.7 Rationale of the study

Even though there are non-ionizing imaging modalities such as MRI that are currently being used for imaging of the brain, CT imaging continues to be on the rise due to its wide availability and clinical applications. This is despite the large radiation dose imparted to patients (Livingstone, Eapen, Dip & Hubert, 2006).

In Nigeria there are only a few centres with an MRI scanner, and the number is grossly inadequate for the ever growing population. The number of CT scanners in the region is also not enough, but is higher than the number of MRI scanners. Moreover, the CT scan is faster in terms of image acquisition and more affordable for people. Unfortunately CT is a high radiation dose imaging modality compared to other x-ray emitting equipment. As in any other country, brain CT in Nigeria is the

most common request and represents the largest fraction (80%) of CT examinations performed (Adeyekun & Obi-Egbedi-Ejakpovi, 2013) and ultimately, the total collective dose to the population will be high as reported by Smith, Shah & Kron (1998).

There is a lack of awareness amongst CT radiographers and referring physicians of the dose associated with CT scanning, and the factors contributing to variations in dose. This is because based on the researcher's experience, most of the CT radiographers and referring physicians in the region lack adequate knowledge of operation of this imaging modality.

According to reports of some studies, brain CT protocols routinely used at different scanning facilities depend on choices made by the radiographer. This is because pre-set protocols in most CT scanners do not apply to other groups of people around the globe due to their physique differences. The choices include: selection of kV, mAs, table increment/pitch and scan length. These parameters affect the dose delivered to the patient. Equally, certain inherent features of the different CT scanner designs which include detector type, geometric efficiency and size of the gantry, may also cause a variation in dose from one type of scanner to another (Smith *et al*., 1998; Simone, Helen, Marcus, Rosangela, Larissa & Mecca, 2010).

Therefore, based on the issues raised, the study aimed to measure the dose delivered to patients undergoing CT examinations of the head in three Northern States of Nigeria for the purpose of developing a Local Diagnostic Reference Level (LDRL) as a tool for dose optimisation.

The results of this study were compared with the international data of established DRLs such as UK, Council of European Commission (CEC) and International Commission on Radiological Protection (ICRP) (ICRP, 1991; European Commission,

1999; Ngaile, 2006). Conclusions were drawn and a DRL is recommended for head CT scans in this country.

1.9 Research Question

The research question is thus, what is the estimated mean and third quartile values of $CTDI_w$ and DLP received by a patient undergoing head CT in Nigeria?

1.10 Statement of the research problem

CT examinations are high radiation dose procedures. The implication of some of these exposures, for example during head CT is the exposure to radiosensitive organs such as the lens of the eyes, which may potentially increase cataract formation and other related health effects in the population (Adams, Brettle, Jones, Hounsell & Mott, 1997; Ngaile & Msaki, 2006). Yet, estimated doses of radiation to patients for head CT have not been determined at the research site.

To answer the research question the following sub-problems were developed:

Sub-problem I

Measure the $CTDI_w$ and DLP values delivered to patients for head CT and establish DRL values for the head CT scan for Northern Nigeria.

Sub-problem II

Compare the DRL values of this study with the data from countries where there are established DRLs.

Sub-problem III

Determine whether $CTDI_w$ variation between CT centres exists, correlate scan parameters namely the kV, mAs, slice thickness with $CTDI_w$ values, and determine the factors responsible for $CTDI_w$ variations.

1.11 Significance of the study

This study has established LDRL values that can be used in formulating national DRLs with which individual hospitals may compare their doses, for the purpose of dose optimisation in CT scan of the head. DRL has proven to be an excellent method for optimising the medical X-ray practices in several countries (Edmonds, 2009). The establishment of DRL requires data from the medical X-ray practices to be compared to the standard values. Because there is no study reported on patient doses undergoing CT examinations in Nigeria, it is essential to begin with a national study in order to provide comprehensive data of head CT doses in Nigeria.

The result is a useful review of the patient's dose assessment in CT examination in Northern Nigeria, which will aid CT radiographers, radiologists, and radiation safety officers to determine whether the radiation dose given to patients is within the standard local practice or not.

Other countries have already started establishing DRLs for more complicated CT procedures such as for paediatrics, coronary angiography and CT fluoroscopy. This study will initiate the process of Nigeria and will provide measurement of radiation doses for CT examinations of the head in Northern Nigeria. This study will also contribute to staff awareness with regards to patient dose in medical imaging. Furthermore, the Radiation-control unit may be encouraged to focus in developing DRLs for all common procedures in future.

The numerical values of DRLs are advisory, and not implemented by an individual, but rather by an authority or organisation responsible for the protection of human beings against the harmful effects of ionizing radiation at local, regional or national level. Therefore, the results of the study will be forwarded to our national authority (Nigeria Nuclear Regulatory Authority) for further scrutiny and possible implementation.

1.12 Overview of the methodology

A sample of CT scanners was identified from the entire Northern part of Nigeria. The study approval was obtained from the research ethics committee of the participating hospitals as well as the Research Ethics Committee (REC) of Cape Peninsula University of Technology South Africa. Three CT scanners were chosen using stratified and judgement sampling technique from the three geopolitical zones of the region (that is North central, North west and North east).

A data collection sheet was designed and sent to all the participating hospitals together with the consent forms for patients that were willing to participate in the study. Twenty (20) consenting adult participants that came for brain CT were included at each of the study sites based on European Commission criteria (European Commission, 1999), and meeting the weight requirement of (70 ±3 kg).

Information gathered from the patients included, the exposure parameters such as kV, & mAs, and the dose description parameters namely the CTDI and DLP were recorded.

Statistical evaluations were performed with Statistical Package for Social Sciences (SPSS) version (16) for Windows. Scanner information and patient data were presented as descriptive statistics and comparisons were made. Quartile values for CTDI and DLP were calculated. Inferential statistical analyses were carried out to answer the research question. Pearson's tests were used to find correlation between the exposure parameters (kV & mAs) and the calculated CTDI and DLP from the scanner.

The t-test was used to determine any significant difference in terms of dose between CT scanners of different models but the same number of slices, the same model and equal number of slices, and the same models, but different number of slices. The third quartile values of the CTDI and DLP obtained were also compared with that published in the literature from African and European countries.

1.14 Delimitations of the Study

The study was conducted in three (3) Northern States of Nigeria, and was carried out for a period of 6 months from 22nd June 2011- December 2011.

Only adult patients that came for routine head CT examinations and weighed 70 ±3 kg were included in the study.

1.15 Thesis structure

To have a better understanding of radiation dose to patients undergoing brain CT in Nigeria, the next chapters explain CT equipment and CT dosimetry in detail. The methodology, results and discussion are also presented.

Chapter two: CT Equipment and CT dosimetry

This chapter deals with the following: Generations of CT scanners, radiation protection and radiation dose in CT examinations. CT dosimetry, the concept of Diagnostic Reference Levels and CT dose measurement parameters are equally discussed. Factors affecting radiation dose in CT, methods of dose optimization in brain CT imaging and quality control & quality assuarance for CT scanners are highlighted.

Chapter three: Methodology

This chapter explains the methodology involved in the conduct of this study. This includes the type of research, sample size, method of sample selection, method of data collection, data organization, and data analysis. Ethical issues regarding the study were also discussed.

Chapter four: Results

This chapter presents the results and interpretation of the findings based on the research question.

Chapter five: Discussion

The chapter contains a discussion of the important findings. The results are discussed in comparison with studies from the literature. Conclusions, suggestions and recommendations for possible future investigations which would expand the findings presented in this thesis are provided.

CHAPTER TWO: CT EQUIPMENT AND CT DOSIMETRY

2.1 Introduction

This chapter discusses the followings: Generations of CT scanner, radiation protection, and CT dosimetry/CT dose measurement parameters. The concept of Diagnostic Reference Levels, factors affecting radiation dose in CT, methods of dose optimization in brain CT imaging and quality assuarance & quality control for CT scanners are equally discussed.

2.2 Generations of CT scanners

Computed Tomography (CT) scanners have gone through a series of improvements since the introduction of first scanner in the market, and each stage of development of the CT machine is termed "generation". The first CT scanner was produced in 1970 by Sir Godfrey Hounsfield, and made available in the year 1972. Since then, there has been remarkable improvement of the scanner from generation to generation. The modern day CT scanner is known as the seventh generation CT scanner, and was first produced in the year 1998 (Abdullah, 2009).

Early CT scanners acquired images, a single slice at a time (sequential scanning). However, during the 1980s significant advancements in technology heralded the development of slip ring technology, which enabled the X-ray tube to rotate continuously in one direction around the patient. This has contributed to the development of helical or spiral CT (Seeram, 2009).

The next generation of CT scanners is now commercially available. These multi-slice or multi-detector machines utilise the principles of the helical scanner but incorporate multiple rows of detector rings. They can therefore acquire multiple slices per tube rotation, thereby increasing the area of the patient that can be covered in a given time by the X-ray beam (Seeram, 2009).

New advancements of the CT have also led to great increase in the radiation dose to the patients (Abdullah, 2009). The use of multi-slice computed tomography (MSCT) has aggravated the scenario with the increasing collective dose of CT examinations. This is because the MSCT produces higher doses to the patients compared to a single slice CT (SSCT), due to its increased capability (Abdullah, 2009).

Generation of CT scanner in Nigeria

In Nigeria, the initial scanner installed was a 3rd generation CT machine, but it is no longer in use. With technological advancement most of the centers have upgraded to sixth generation CT scanners which are mostly 16-slice scanners. Therefore, the scanners involved in this study are all of the sixth generation type.

The following sections introduce the generation of CT scanners as they are directly linked to increased radiation dose based on their technological advancement and clinical applications (Lewis & Edyvean, 2005).

2.2.1 First generation CT scanner

First generation scanner was commercially developed in 1970, and it had the following features; rotate-translate system, single pencil beam, single detector, together translate through 180 steps and then rotate 1^{o} at a time. It took 3-5 min to produce a slice (Cunningham & Judy, 2000).

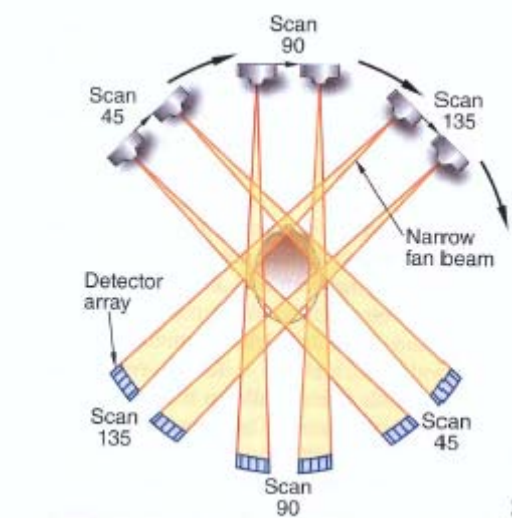

Figure 2.1: First generation CT scanner
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2.2.2 Second generation CT scanner

The second generation CT scanner was introduced in 1972, and possessed the following features; rotate-translate system, narrow fan beam, small curved array of detectors and scan time of 30 sec/slice (Cunningham & Judy, 2000).

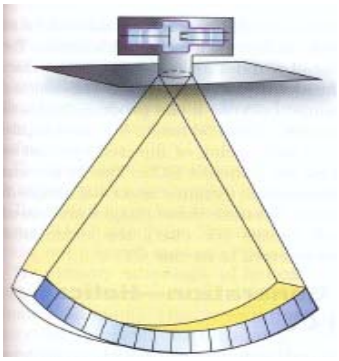

Figure 2.2: Second generation CT scanner
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2.2.3 Third generation CT scanner

The third generation came into existence in the year 1976. Its main features were: rotate-rotate system, wide fan beam, larger curvilinear array of hundreds of detectors, and reduced scan time of 1sec/slice. The tube and detectors are always in the scan

geometry thus, allowing better pre-detector collimation, but making the image susceptible to ring artifacts. The third generation scanner is the most commonly used (Cunningham & Judy, 2000). This was the type of scanner that was installed at the study site and is the scanner that was first installed before the advent of multi-slice scanners.

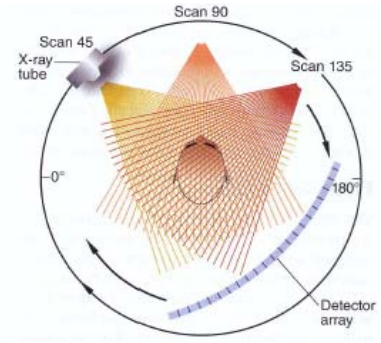

Figure 2.3: Third generation CT scanner
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2.2.4 Fourth generation scanner

The Fourth generation CT scanner was introduced the same year as the third generation scanner, however, the features were slightly different. The features included; rotate-fixed systems i.e. only the tube rotates through 360^{o} around the patient). The units had wide fan beam, with a continuous ring of thousands of detectors. The main advantage over the third generation units was that ring artifacts were avoided. The tube however was closer to the patient which resulted in an increased radiation dose to patients (Cunningham & Judy, 2000).

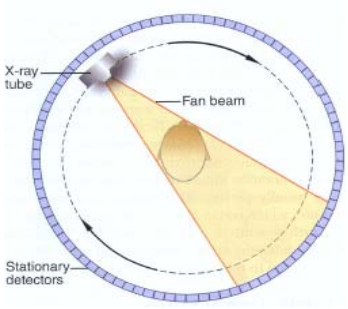

Figure 2.4: Fourth generation CT scanner
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2.2.5 Fifth generation CT scanner

The Fifth generation CT scanner was produced in 1984. Two scanners were produced, namely: the Electron beam CT and the Dynamic spatial reconstruction scanners. They are unique in construction because they have no moving parts; a stationary x-ray tube and detector. Projection data can be acquired in approximately 50 ms which is excellent for cardiac imaging (Seeram, 2009)

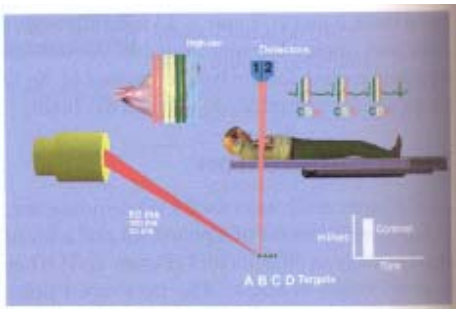

Figure 2.5: Fifth generation CT scanner
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From the fifth generation CT scanner there has since been no common definition of the generations of the development of the CT scanner (Buzug, 2008). Some literature reported Dual Source CT (DSCT) and Cone-Beam CT (CBCT) as the sixth and seventh generation CT scanners respectively (Seeram, 2009), while some reported spiral CT scanner and CBCT scanner as the sixth and seventh generations

respectively (Buzug, 2008). Meanwhile, other literature reported spiral, multi-slice, and PET-CT scanners as the sixth, seventh and eighth generations respectively (Abdullah, 2009).

In this thesis the spiral scanner is considered as the sixth generation and CBCT (Flat-panel) as the seventh generation CT scanner for easy understanding. Meanwhile, multi-slice CT scanner is considered to be part of the spiral generation of CT scanners in that they work on the same principle. In the case of DSCT and PET-CT, we have not convincingly seen where they belong even though they have different features from the rest of the scanners mentioned. Authors named them differently.

2.2.6 Sixth Generation CT scanner

Sixth generation CT scanner was developed in 1990. The scanner possessed the following features: slip ring device produced by Kalender that allows continuous rotation of the x-ray tube as the table traverses through the gantry tracing the beam geometry in the form of spiral or helical pattern (Buzug, 2008). The sixth generation scanner is what is found at the research sites, and employed for the study.

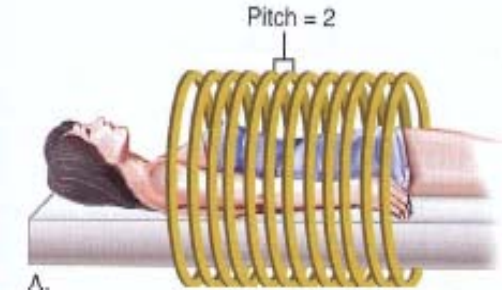

Figure 2.6: Sixth generation CT scanner
From Carlton/Adler. *Radiographic Imaging Concepts and Principles*. *International Edition,* 5E © 2013 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions

2.2.7 Seventh generation CT scanner

Although there is no standard convention for naming of scanner generations in the development of CT, a scanner equipped with cone-shaped x-ray beam and a flat panel

detector is named as the seventh generation scanner. This generation scanner uses a flat panel detector similar to that used in digital radiography.

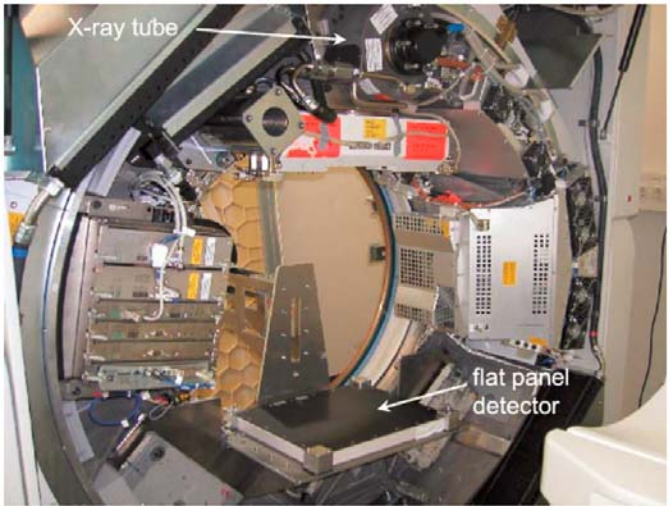

Figure 2.7: Prototype of seventh generation CT scanner
From Seeram. *Computed Tomography: Physical Principles, Clinical Applications, and Quality Control.*3rd Ed. © 2009. Reproduced by permission from Saunders Elsevier

2.2.8 Multi-slice CT scanner

The multi-slice CT was introduced in 1991 (Buzug, 2008). This scanner is capable of producing more than one image per tube rotation. The difference between the MSCT and the SSCT is that it has multiple rows of detectors (Abdullah, 2009). The latest MSCT is capable of producing up to 320 slices per tube rotation (Seeram, 2009).

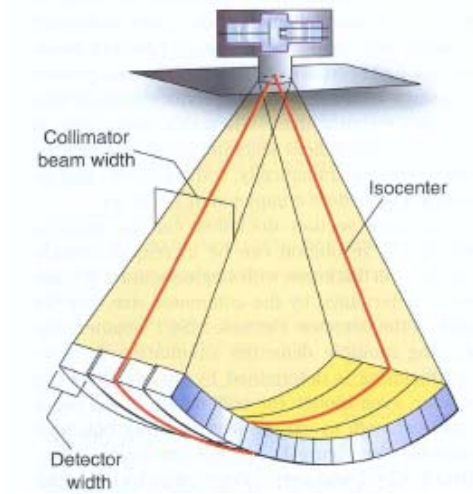

Figure 2.8: Scan pattern of multi-slice CT scanner
From Carlton/Adler. *Radiographic Imaging Concepts and Principles*. *International Edition,* 5E © 2013 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions

2.2.9 Latest development in CT technology

2.2.9.1 Dual source CT

The dual source CT scanner was introduced in 2006 by the Siemens Company. The scanner has two X-ray sources and two curved detectors. In addition it possessed the following features: increased temporal resolution, double speed, while lowering dose even further (Seeram, 2009).

Figure 2.9: schematic diagram of DSCT
From Seeram. *Computed Tomography: Physical Principles, Clinical Applications, and Quality Control.*3rd Ed. © 2009. Reproduced by permission from Saunders Elsevier

2.2.9.2 PET-CT scanner

The PET-CT scanner combines two imaging modalities namely the CT scanner and the positron emission tomography (PET) scanners. PET scanners show metabolism and uptake of radiopharmaceutical as hot spots, while the CT shows detailed anatomy. The combination of PET and CT give the best image quality required for diagnosis (Buzug, 2008).

Table (2.1) gives a summarised description of common generations of CT scanners as described by various authors (Subbarao, Banerjee, Aggarwal, & Bhargava, 1997; Cunningham & Judy, 2000; Karthikeyan & Chegu, 2005; Buzug, 2008; Abdullah, 2009; Seeram, 2009).

Table 2.1: Generations of CT scanners

Generation	Year introduced	Number of detectors	Scan time	Type of Movement	Degree of rotation of the tube	Beam Dimension
First	1970	Single detector	3-5min/slice	Translate-Rotate	1º at a time together translate through 180º	Pencil beam
Second	1972	Curved array of more than 30 detectors	30sec/slice	Translate-Rotate	Rotate through 180º	Fan beam
Third	1976	Large curvelinear row of hundred of detectors	1sec/slice	Rotate-Rotate	Rotate through 360º	Wider fan beam
Fourth	1976	Ring of thousand detectors	1sec/slice	Rotate-Fixed	Rotates through 360º	Wider fan beam
Fifth	1984	Hundred curved detectors	Millisecond/slice	No moving part	No rotation	Wider fan beam
Sixth (Spiral scanner)	1990	Hundreds of Curved detectors	Sub-second	Rotate-Rotate	Rotates through 360º or 90º for dual source CT scanner	Wider fan beam
Seventh	1998 & 2001	Flat panel detector	Sub-second	Rotate-Rotate	360º degree angle of rotation	Cone beam

2.3 Background to Radiation Protection

This section introduces radiation protection in diagnostic radiology and the likely radiation injury an individual may suffer as a result of exposure to ionizing radiation. Therefore, CT scan being a high dose modality, it is imperative to have a better understanding of this topic so as to put measures in place for adequate protection of patients undergoing CT procedures.

2.3.1 Effects of ionizing radiation on human tissues

Radiation injury is an injury an individual suffers as a result of exposure to ionizing radiation. The injury is classified into two groups namely the stochastic and deterministic radiation injuries (Bushong, 2008).

2.3.2 Stochastic effects of radiation

Stochastic effect of radiation occurs at low dose of radiation. These effects are called non-deterministic or probabilistic effect of radiation. Principally, late effects of low-dose of radiation occurring over a long period consist of radiation-induced malignancy and genetic effects. Late effects include the followings: carcinogenesis, non-specific life shortening, and genetic effect. These radiation effects have a linear non-threshold dose-response relationship (Bushong, 2008:550-551).

2.3.3 Deterministic effects of radiation

Deterministic effects of radiation occur at high doses of radiation. Different organs at different radiation dose levels are affected, therefore there is a threshold dose below which effects are not seen. Above the threshold the probability and the severity of the effect increases as the radiation dose increases. In some deterministic effects, death occurs within days or weeks. Acute effects include: hematologic syndrome,

gastrointestinal syndrome, and Central Nervous System (CNS) syndrome (Bushong, 2008).

2.3.4 Radiation protection

Radiation protection is concerned with prevention of stochastic and deterministic effects by setting dose equivalent limits well below the threshold values for these effects, such that the limits cannot be reached even for the total period of one working life. This would limit the risk of stochastic disease to a frequency not greater than the risks of non-radiation workers (Bushong, 2008).

2.4 Radiation dosimetry

In this section, methods of radiation measurement are discussed with emphasis on CT dose measurement.

Radiation dosimetry is the method of measuring radiation dose. A dosimeter is a device used to measure external radiation sources. Thermoluminescence dosimeter (TLD) was the most common dosimeter used to measure dose (University of California Santa Cruz, 2000). In CT, the dose parameter used is known as CTDI measured in mGy. The dose can be measured in air or in a phantom using ionization chamber or TLDs (Aweda & Arogundade, 2007; IAEA, 2007).

2.4.1 CT dosimetry

Radiation dose and image quality in CT have been a matter of concern since the introduction of the first CT scanner in clinical practice. This is because CT is a relatively high dose procedure that contributes disproportionately to the overall radiation dose from radiologic sources (Seeram, 2009).

In conventional radiography most of the radiation dose is received at the skin level, therefore, a parameter known as the Entrance Skin Dose (ESD) is used to determine the amount of radiation absorbed by the irradiated body. In the case of CT, the situation is different in the sense that, the dose at the periphery and at the center of the traversed tissue is more or less the same unlike in conventional radiography. This is because the beam is heavily filtered as it exits the tube, and the exposure comes from different directions as opposed to conventional radiography thus necessitating the use of a different approach such as the use of CT Dose Index (CTDI) and Dose Length Product (DLP) to estimate the patient dose (Seeram, 2009).

2.4.2 Concept of CT dosimetry

CT dosimetry remains an important concept for Radiographers and Radiologists based on the following reasons; Radiographers and Radiologists can compare CT doses of their patients with national values to know whether their doses are comparable or not. Radiographers and Radiologists can participate effectively in informing both the public and other hospital personnel such as physicians about the dose in CT. CT radiographers and Radiologists can assist the medical physicist in performing the actual dose measurements. Radiographers and Radiologists can be an integral part of CT acceptance testing, at the same time conducting the quality control procedures. Finally a knowledge of CT dosimetry will assist the radiographers and Radiologists to carry out dose measurements themselves where there is no medical physicist to perform the task (Seeram, 2009).

2.4.3 CT dose measurement parameters

Measurements of patient dose undergoing CT examinations can be done directly on patients using thermoluminescent dosimeters (TLDs) or on phantoms using either an ionization chamber or TLDs. It can as well be carried out indirectly through the measurement of CT Dose Index (CTDI), Volume CT Dose Index ($CTDI_{vol}$), Dose Length

Product (DLP) or Multiple-Scan Average Dose (MSAD) (Rothenberg & Pentlow, 1992; Ngaile & Msaki, 2006).

Dose measurements to determine CTDI and MSAD require the use of TLDs, and this is difficult and time-consuming for a wide survey of patient's doses. Therefore, it is rarely performed (Morin *et al*., 2003). However, the use of $CTDI_{vol}$ and DLP has been proposed as the appropriate dose quantities for the establishment of diagnostic reference levels for optimising patient exposure (GE Medical System, 2001; AAPM, 2008). The DLP plays an important role as an indicator of the radiation dose of the patient, because it takes into account the extent of the body region being irradiated (GE Medical System, 2001; Livingstone *et al*., 2006). Equally, $CTDI_{vol}$ and DLP are dose parameters which can readily be recorded from the display units of most modern CT scanners since around 2001 (AAPM, 2008).

I. CT dose index (CTDI)

CTDI is a measure of dose from a single slice of irradiation (Huang, Wu, Su, Chen, Hung & Lee, 2004). It is also, an important fundamental radiation dose parameter that increases dose awareness, and dose optimisation in a CT examination (Lewis & Edyvean, 2005). The CTDI is measured, and other radiation dose parameters like DLP and CTDIvol are derived from it. It is usually measured with thermoluminiscence dosimeters or an ion chamber. This measurement is labour-intensive, hence is rarely performed (Morin *et al*., 2003). The measured results represent absorbed dose, and the SI unit of measurement is Gray (Gy). CTDI represents the integral under the radiation dose profile in the Z-axis of a single slice scanner that would produce 1 tomographic image per tube rotation (Morin *et al*., 2003; IAEA, 2007).

II. $CTDI_{100}$

The $CTDI_{100}$ is a measured parameter of radiation exposure. It is obtained with an ionization chamber that integrates the radiation exposure of a single axial scan over a length of 100 mm. The ionization events occurring in the chamber produce a current that is proportional to the number of ionization events. The measured exposure can be converted to dose. This measurement is more convenient than the CTDI, and is the measurement of choice performed by the medical physicists in the clinical setting. The SI unit of exposure measurement is Coulomb/kg (C/kg) (Morin *et al*., 2003).

III. $CTDI_w$

The $CTDI_w$ is the weighted average of the $CTDI_{100}$ measured at the center and the peripheral locations of the phantom. This parameter reflects the average absorbed dose for a single cross sectional image of the patient's body. The $CTDI_w$ is calculated using the equation:

$$CTDI_W = [2/3\,CTDI_{100}(Periphery) + 1/3\,CTDI_{100}(Center)] \times f \text{.....(1)}$$

"*The term f reflects the difference between the absorption of radiation in air and the absorption in another media. It is used to convert radiation exposure, expressed in* C/kg *, into absorbed dose, expressed in* Gy *(the SI unit for* $CTDI_w$*). For the calculation of* $CTDI_w$*, the appropriate value for f is* $33.7\,Gy \times C^{-1} \times kg^{-1}$*,*" (Koller, Eatough & Bettridge, 2003; Morin *et al*., 2003).

IV. Dose length product (DLP)

DLP is an indicator of the integrated radiation dose of the entire CT examination. The DLP incorporates the number of slices and the scan width (total scan length). The DLP indicates most closely the radiation dose for a specific CT examination, and its numeric value is affected by variances in patient anatomy (the value of DLP is higher for taller patients because of their height). So, "*the* $CTDI_{vol}$ *is more useful in designing CT imaging protocols and comparing radiation doses among different protocols*" (Morin *et al*., 2003;

Russels, Fink, Rebeles, Kanal, Ramos & Anzai, 2008). The DLP is directly related to the patient (stochastic) risk, and may be used to set reference values for a given type of CT examination to help ensure patient doses at CT are as low as reasonably achievable (Walter, Kent & Mohammad, 2008). According to Edmond (2009), "*DLP is found on the console of the CT scanners as required by law in many countries in Europe*."

The DLP is expressed as $CTDI_{vol} \times ScanLength$. Therefore, DLP increases with an increase in total scan length or with variables that affect the $CTDI_w$ or $CTDI_{vol}$ such as tube voltage, tube current or pitch. Because scan length is expressed in centimeters, the SI unit of DLP is $mGy \times cm$ (Morin *et al*., 2003)

V. Multiple scan average dose (MSAD)

MSAD is the average radiation dose over the central scan of a CT procedure consisting of multiple parallel scans. The MSAD describes the average patient dose only if the scan protocol uses more than just a few parallel scans. Like the CTDI, the MSAD requires thermoluminescent dosimeters for measurement and is rarely performed (Morin *et al.*, 2003).

The MSAD for non-spiral scans can be estimated from the CTDI in the equation below:

$$MSAD = \frac{N \times T}{I}(CTDI) \text{.....(2)}$$

(Morin *et al*. 2003)

Where *N* is the number of scans, *T* is the nominal scan width (mm), and *I* is the distance between scans (mm). For MSCT systems, $N \times T$ is the total nominal scan width, and *I* corresponds to the patient table movement during 1 gantry rotation. Therefore, given the definition of pitch as the table movement per gantry rotation to beam collimation (Karthikeyan & Chegu, 2005), the MSAD for spiral scans can be expressed as:

$$MSAD = \frac{I}{Pitch}(CTDI) \text{.....(3)}$$

(Morin *et al*., 2003)

VI. $CTDI_{vol}$

Volume Computed Tomography Dose Index ($CTDI_{vol}$) is expressed as the average dose delivered to the scan volume for a specific examination. It is derived from the CTDI. $CTDI_{vol}$ is also considered as a new radiation dose parameter agreed by the International Electrotechnical Commission (Russels *et al*., 2008).

According to Morin *et al.* (2003) $CTDI_{vol}$ for single-slice scanners is defined as:

$$CTDI_{vol} = \frac{N \times T}{I}\left(CTDI_{w}\right) \text{.....(4)}$$

Where *N* is the number of scans, *T* is the nominal scan width (mm), and *I* is the distance between scans (mm).

Also, $CTDI_{vol}$ for MSCT is defined as:

$$CTDI_{vol} = \frac{I}{Pitch}\left(CTDI_{w}\right) \text{.....(5)}$$

The $CTDI_{vol}$ is now the preferred expression of radiation dose in CT dosimetry and is considered more useful in comparing radiation doses to critical organs such as the thyroid and lens for CT examination of the neck (Morin *et al.*, 2003; Russels *et al*., 2008).

VII. Effective dose

Effective dose quantifies the risk from partial-body exposure to that from an equivalent whole-body exposure. The term is used to take into account the type of radiation and the sensitivity of tissues to ionizing radiation (Seeram, 2009)

In CT, effective dose is expressed as:

$$E = E_{DLP} \times DLP \text{.....(6)}$$

(Ling, 2009)

Where E= Effective dose

E_{DLP}= Normalised effective dose

DLP= Dose length product

2.4.4 Radiation dose in CT examinations

Even though CT delivers some of the highest dose during radiological examinations (Rothenberg & Pentlow, 1992), CT vendors do not believe that radiation exposure from CT scans present a significant health hazard (Mozumdar, 2003). This is because, measured effective doses, from CT examinations are well below the recommended limits of exposure (Mozumdar, 2003). Despite this, CT examinations are dose-limited imaging techniques, which can produce better images with increased radiation dose (Rothenberg & Pentlow, 1992). Unlike conventional film screen radiography whereby higher exposure gives over exposed radiographs and low exposure gives under exposed radiography. To enhance optimization of patients exposures and image quality, the use of DRLs and adjustment of exposure parameters such as mAs & kV are necessary (Rothenberg & Pentlow, 1992; Seeram, 2009).

2.4.5 Factors affecting radiation dose in CT

In this section, factors that affect radiation dose in CT are discussed. These include the operating parameters such as the kV, mAs & slice thickness and indirect factors such as the reconstruction filter. The indirect factors have a direct effect on the image quality, but no direct influence on the radiation dose (Seeram, 2009).

2.4.5.1 CT scanner design

Scanner design features affect radiation dose to the patient. Most of the features of CT scanners that affect dose, and dose efficiency are similar in both single and multi-slice systems. Features of CT scanners that affect patient's dose include: tube filtration, beam shaping filters, collimator design, and focus to axis distance. Those that affect dose efficiency include: detector materials, number, width and spacing. Indeed, some manufacturers have a range of systems from single to 16-slice which are identical in terms of most of the features. The only difference is that the single bank of detectors of a single slice scanner is replaced by multiple detector banks along the z-axis. It is this

factor which primarily causes differences in dose efficiency between single and multi-slice scanners (Lewis & Edyvean, 2005; Goldman, 2007). Also the difference in number of detector rows affects the DLP due to an increase in area coverage but not the $CTDI_{vol}$ if parameters like kV and mAs are kept constant.

2.4.5.2 Operating parameters for head CT scan

Various changes in selectable scan operating parameters affect patients radiation dose. These include: changes in source collimation, section thickness, section spacing, and number of adjacent sections. Some scanners have a much wider choice of operating parameters than others (Rothenberg & Pentlow, 1992). Previous studies have suggested that it is feasible to reduce tube current without marked deterioration of image quality in CT of the head (Karabulut & Ariyurek, 2006).

Other operating parameters that significantly affect radiation dose to patients are:

X-ray tube voltage: Is the electrical potential applied across the x-ray tube to accelerate electrons toward the target material. Radiation dose increases approximately proportional to the percentage change in tube voltage (AAPM, 2013)**.** Tube voltage values for routine brain CT scan for adult patients are shown in Table (2.2).

Table 2.2: Typical tube voltage for routine brain CT scan for adults patients

Kv	References
110	(Livingstone *et al.*, 2006)
120-140	(Smith *et al*., 2007)
120	(Tsapaki *et al*., 2006)

X-ray tube current: increasing the current (mA) increases the dose proportionately (Ling, 2009). Typical mAs values for routine brain CT scan for adult patients are shown in Table (2.3).

Table 2.3: Typical tube current for routine brain CT scan for adult patients

mAs	References
100	(Livingstone *et al.*, 2006)
200-350	(Smith *et al*., 2007)
250-270	(Tsapaki *et al*., 2006)

Scan time: in a complete rotation of 360^0, dose is directly proportional to scan time. If incomplete rotations are employed, there is a complex spatial relationship between dose and scan time because of variations in rotation angle. The exposure time may be significantly less than the set scan time for scanners that employ a pulsed x-ray beam. Therefore, a longer scan time leads to more radiation dose to patients (Rothenberg & Pentlow, 1992). Thin slice sections give more dose to patient because the CT scanner will take more time to cover the desired area of interest.

Scanner rotation angle: The desirable reconstruction angle for CT image is 180^0. Data acquisition over 360^0 (or 360^0 plus overscan) is widely used for third and fourth generation scanners. Overscan of 15^0-45^0 is often used to reduce patient motion artefacts. Some scanners may irradiate patients over a larger angle than that used for data collection as the tube accelerates and decelerates before and after the scan. Any rotation other than 360^0 will result in an asymmetric dose distribution. This is most marked for 180^0 scans, which may be employed when scanners operate in the fast-scanning modes such as that used for dynamic studies (Rothenberg & Pentlow, 1992). A rotation angle of 360^0 produces more radiation dose (Karthikeyan & Chegu, 2005). Equally, additional rotation generally contributes a greater percentage to the radiation dose more especially in a multi-slice CT scanner (Lewis, 2005).

Filtration: is the scanner component that shapes the energy of the x-ray spectrum. Beam shaping is done using either a bow tie filter and/or flat filters. The radiation output from the x-ray tube ($CTDI_w$) is affected by a change in beam shaping filters. The relationship is vendor and filter specific (AAPM, 2013).

Patient orientation: patient orientation (supine or prone positions) may significantly affect the dose to critical organs such as the eyes when acquiring the scanogram (Ling, 2009). The chance of the effect becomes higher when the x-ray tube is at the fronto-occipital position. This is because the critical organ (the eye) is closer to the source of radiation. Unfortunately this is less importance in brain CT scan, because in modern CT scanners the orientation of the x-ray tube could be changed from fronto-occipital to occipito-frontal position. In addition, the gantry could be angled to minimize dose to the lens of the eyes without changing the patient position.

Source collimation: x-ray beam collimation define the beam width for examination. wider beam collimation however, more penumbra which does not contribute in image formation but rather affect the radiation dose (Seeram, 2009).

Section thickness: increasing the slice thickness yields a slightly lower dose per scan as well as decreased noise. Decreasing the section thickness while keeping noise constant results in higher radiation doses (Rothenberg & Pentlow, 1992; Lewis & Edyvean, 2005). Common slice thickness employed for routine brain CT scan are shown in Table (2.4). Equally, the local protocol used for routine brain CT scan at the study site is found on page 50.

Table 2.4: Common section thickness for routine brain CT scan

CT scanners	Slice thickness	References
GE 9800	10mm	(Smith *et l*., 1998)
Toshiba Asteion	2mm	(Koller, Eatough & Bettridge, 2003)
Siemens AR	10mm	(Tsapaki, Kottou & Papadimitriou, 2001)
Philips brilliance	3mm	(Zarb *et al*., 2013)
GE brightspeed	2.5-5mm	(Zarb *et al*., 2013)

Section spacing: decreasing section spacing increases multiple-scan dose (Rothenberg & Pentlow1992).

Pitch: defined based on the International Electrotechnical Commission standards, as the table travel divided by the total active detector length in the Z-axis (GE Medical System,

2001). Most manufacturers give pitch value with respect to the nominal slice thickness instead of the total active collimated length in the Z-direction. This definition of pitch is easier to use in both single and multi-slice systems. In helical CT, selecting a higher pitch will reduce the DLP of the patient but not the CTDI, by reducing the number of rotations over the same plane (GE Medical System, 2001; Seeram, 2009).

Number of adjacent sections: increasing the number of adjacent sections increases the volume of tissue irradiated, and increases the dose to any individual region of the patient when the dose profiles overlap (Seeram, 2009).

Repeat scans: repeat scans of the same region increase radiation dose to patient (Seeram, 2009).

Image parameters: selectable image parameters such as pixel size and reconstruction filter do not affect dose directly. The dose however, varies when a change in these parameters requires a different milliamperage or scan time to obtain the desired image quality (Rothenberg & Pentlow, 1992; Ling, 2009).

Standard scan examination: outline of scanning procedure for a particular clinical indication that is generally accepted as being able to provide adequate clinical information in most of the patients examined. Radiation doses are usually lower than that of special techniques (Karthikeyan & Chegu, 2005). In a study conducted by Seifert, Hagen, Bartylla and Bla (1997) they stated that dose reduction from 0.9 mSv to 0.7 mSv without significant change to image quality is possible if the scan is done with standard exposure factors such as 120 kV, 250 mAs, 5 mm norminal slice thickness and with distal slice increment less than one instead of scanning with 120 kV, 250 mAs, 0.5 mm or 1mm slice thickness with slice increment greater than one.

The patient: dose distribution depends on the size, shape, tissue density, and elemental composition of the patient cross section. The same scanner types with the same operating

technique would have different dose distributions for different body parts. A thicker patient section or denser tissue results in more attenuation of the primary beam and more build-up of scattered radiation. The dose at any point in the section is the sum of contributions from many beams, which may have undergone different amounts of attenuation (Rothenberg & Pentlow, 1992). To establish DRLs for different body parts, the European Commission (1996) recommended that measurements be performed on standard-sized patients or patients close to standard size, preferably with an average weight, that is 70 ± 3 kg.

2.4.6 Dose optimisation in CT

Radiation dose optimisation strategies involve modulation of scanning parameters, especially the tube current, on the basis of patient weight and cross-sectional dimensions of the area of interest (Kalra *et al*., 2004). Another important parameter is the X-ray beam pre-collimation which determines the area covered on the patient. The greater the area covered the greater the radiation dose to the patient. All these parameters such as the mA, kV must be carefully selected so that the given diagnostic requirements are met at the optimum level of radiation dose. In addition to the scan parameters, the reconstruction parameters such as the reconstruction matrix, reconstruction field of view and reconstruction algorithm must be considered. Although these do not affect dose directly, they may have an indirect effect by altering the image characteristics (Lewis & Edyvean, 2005; Ling, 2009).

Therefore, under this section the following sub topics are discussed: the automatic tube current modulation, body part based strategies, patient-based strategies, and appropriate image quality.

2.4.6.1 Automatic modulation of tube current

A key parameter affecting dose to the patient is the selected tube current-time product (mAs). Tube current modulation is a technical innovation that can substantially reduce radiation dose. The concept of automatic tube current modulation is based on the premise that pixel noise on a CT scan is attributable to quantum noise in the projections. By adjusting the

tube current to follow the changing patient anatomy, quantum noise in the projections can be adjusted to maintain a desired noise level on the image and to improve dose efficiency (Kalra *et al*., 2004; Lewis & Edyvean, 2005). This parameter is used for imaging different body parts including the brain. The tube current is modulated when the tube is in the fronto-occipital or occipito-frontal position and when it is in the lateral aspect of the skull.

2.4.6.2 Automatic modulation of tube potential

A large potential exists for dose reduction in optimizing the x-ray tube kV setting. Voltage reduction from 140 kV to 80 results in 78% dose reduction. This is because most of the low energy radiation cannot be able to reach the patient. Therefore, they must have been filtered off. Also, the use of 100 kV tube voltage is associated with a 53% dose reduction compared to conventional 120 kV scan protocols. Unfortunately, this radiation dose reduction will be at the expense of image quality. The higher the radiation energy, the more it reaches the detector thus reduced image noise and improved image quality. At the moment the dose reduction software is available in Siemens CT scanners and is known as CARE kV (Grant & Schmidt, 2011)

2.4.6.3 Body part-based strategies

The body part being examined is also important in the optimization of CT scanning parameters. CT radiation dose can be substantially reduced particularly in those structures with a high inherent contrast, such as CT of the chest and paranasal sinuses, CT colonography and CT for urolithiasis, without severely compromising the image quality necessary to maintain a diagnostic standard (Karabulut & Ariyurek, 2006). More so, modern CT scanners come with the protocols build based on the nature of the area under examination as well as, the clinical indication. The protocol for head CT scan with a clinical indication of brain lesion is different from that of head CT scan with emphasis on the paranasal sinuses for example.

2.4.6.4 Patient-based strategies

It has been shown that children, particularly girls, are 10 times more sensitive than adults to the risk of cancer induction from the same effective dose of ionizing radiation. The effective dose is up to 50% greater when adult protocols are used in neonates or young children (Karabulut & Ariyurek, 2006). Furthermore, previous studies have documented that CT images of acceptable quality can be obtained with 50% less radiation (Karabulut & Ariyurek, 2006). Therefore, the protocols are designed based on the age of the patients. Protocols for brain CT scan for adults are different from that of paediatrics in most of the CT scanners.

2.4.6.5 Use of modified exposure parameters for brain CT

A study conducted by Nsoor (2009) has shown that 50% dose reduction using reduced adult protocols for paediatric brain CT is possible if personnel are well educated and exposure parameters are modified. Recommendations have been made in some studies as regard to the use of dose modulation technique, which has shown dose reduction in brain CT (Livingstone *et al*., 2006; Smith *et al*., 2008).

2.4.6.6 Appropriate image quality

Fundamentally, image quality in CT, as in all medical imaging, depends on four basic factors: patients contrast, spatial resolution, image noise, and artefacts. Depending on the diagnostic task, these factors interact to determine sensitivity and visibility of details (Goldman, 2007). Automatic exposure of tube current is an invaluable tool for dose reduction, but relies on the radiographer selecting either the mA for a standard patient or required level of noise for a given examination. Using the automatic tube current, the mA is automatically regulated based on the thickness of the area under examination. Because CT does not carry an image quality penalty for over-exposure, there has been a tendency to aim for lower than necessary noise levels and hence higher doses. The current challenge in CT is to identify an appropriate image quality. This is the optimal value of noise for an examination (the level at which a diagnosis can reliably be made at a

minimum dose level). A relatively new approach to determining these optimal noise levels is through the addition of simulated noise to images obtained at higher mAs values. Images from the same patient at a range of noise levels can then be viewed and scored for diagnostic quality, without subjecting the patient to multiple exposures. A number of studies using this approach have been undertaken and suggest that, in some cases, it is possible to significantly reduce mAs values without affecting the diagnostic quality of the scan (Lewis & Edyvean, 2005).

2.4.7 Diagnostic Reference Levels (DRLs)

"DRLs are reference dose levels in medical radio diagnostic practices, for typical examinations, or groups of standard-sized patients or a standard phantom, and broadly defined types of equipment. These levels are expected not to be exceeded, for standard procedures when good and normal practice regarding diagnostic and technical performance is applied (European Commission, 1999)."

There is no dose limit for patients when applying ionizing radiation in medicine, but, X-ray examinations must be justified and optimized (Treier *et al*., 2009). The concept of the DRL as a tool to identify situations where patient doses are unusually high, and in most urgent need of reduction, was therefore adopted by the International Commission on Radiological Protection in ICRP Publications 60 and 73, and by the European Directive 97/43 Euratom (ICRP, 1991; Drouet, 2007).

A similar idea tagged ''reference doses'' for common CT examinations was initiated in the UK in 1990, in a joint document by the Royal College of Radiologists (RCR), and the National Radiological Protection Board (NRPB) titled: Patient Dose Reduction in Diagnostic Radiology (Barry, 2001).

In 1999, a European Commission document proposed another set of reference dose values for nine common CT examinations. Many of the reference values were based on doses from the 1991 UK audit. The most recent NRPB summary of medical radiation

exposures of the UK population still bases the majority of its CT data on the 1991 audit (Yates *et al*., 2004).

Table (2.5) shows different DRL values for head CT scan from different parts of the world. The values reported are based on the 3rd quartile value.

Table 2.5: DRLs values for head CT scan

Locations	**$CTDI_{vol}$** (mGy)	**MSAD** (mGy)	**DLP** $(mGy \cdot cm)$	**References**
United Kingdom (UK)	60	-	1050	(Hull & East Yorkshire (n.d)
European Commission	60	-	1050	(Tsapaki *et al.,* 2001)
India	-	50	-	(Chougule, 2005)
East Anglia	-	-	760 (360-1180) (range of DLP)	(Yates *et al*., 2004)
Vienna	-	-	900 (494-1781)	(Barnes, 2010)
Switzerland	60	-	1000	(Treier *et al*., 2009)

Because of the high doses involved in CT examinations relative to the majority of diagnostic radiological examinations, the potential risk to the sensitive organs is considered to be high. Hence, it is useful to be able to calculate the dose from potentially high dose examinations before they are carried out. A computer model was developed to assist in routine calculation of doses during CT examinations. This model could also be used to provide information for routine patient dose estimation, as well as allowing different protocols to be evaluated prior to the examination (Adams, Brettle, Jones, Hounsell & Mott, 1997).

There has been a significant increase in patient dose due to high-resolution imaging, and the application of more complex scan techniques (Treier *et al*., 2009). Although, CT procedure represents a small fraction (5%) of the total number of procedures performed worldwide, it contributes about 34% of the annual collective dose from all medical X-ray

examinations to the population (Ngaile & Msaki, 2006). Table (2.6) shows dose contribution from radiological procedures including CT scan.

Table 2.6: Radiation dose contribution from different radiological examinations (Seabourn, 2010)

Examinations	Percentage of Diagnostic imaging studies	Percentage of Radiation exposure
Radiography	74%	11%
Nuclear Medicine	5%	26%
Interventional	4%	14%
CT	**17%**	**49%**

The amount of radiation dose a patient receives from a CT scan depends upon two key factors i.e. the design of the scanner and also on the way the scanner is used. The features of the CT scanner that influence the dose delivered to patients are similar in both single slice and multi-slice scanners, but multi-slice scanning can potentially result in higher radiation risk to the patient because is used for more complex procedures like cardiac CT or CT perfusion which require longer scan time (Lewis & Edyvean, 2005).

Table (2.7) shows different design of CT scanners with the radiation dose produced for CT scan of the brain.

Table 2.7: Radiation doses for head CT scans from different CT scanners

Scanner type	Generation	Slice thickness	Number of slice	$CTDI_{vol}$ (mGy)	DLP (mGy-cm)	References
GE 9800	3rd	10mm	1	33.9	NR	(Smith *et l.*, 1998)
Toshiba Asteion	NR	2mm	Multi-slice	60	NR	(Koller, Eatough & Bettridge, 2003)
Siemens AR	NR	10mm	1	44	576	(Tsapaki, Kottou & Papadimitriou, 2001)
NR	NR	2.5mm	4	55	825	(AAPM, 2008)

NR= Not Recorded

2.5 Quality assurance (QA) and quality control (QC) for CT

"Quality assuarance (QA) is defined as a plan for the systematic observation and assessment of the different aspects of a facility to make certain that standards of quality are being met whereas, Quality control (QC) is defined as a comprehensive set of activities designed to monitor and maintain systems that produce a product" (Carter &

Veal, 2008). QC also lays out the necessary testing to ensure that all parameters during the examination procedure are in accordance with the standard operating protocol, thus resulting in images with diagnostic value, without exposing the patient to unnecessary risk (Seeram, 2009).

The following sections describe quality control for CT scanners, and quality control recommended by the manufacturers to be carried out on the CT scanners at the study sites.

2.5.1 Quality Control for CT scanners

Quality control as it relates to CT is a programme that periodically tests the performance of a CT scanner and compares it with the standard. It is recommended that a qualified medical physicist supervises the image quality control test on the CT scanner. Documents indicating that performance test was completed at the time of installation will be provided in the form of an attestation signed by the qualified medical physicist who performed the acceptance test. The performance tests should include assessments on the following: Alignment light accuracy, slice thickness, spatial resolution, low contrast resolution, image uniformity, noise, artefacts evaluation, CT number accuracy and display monitors. In addition, the medical physicist must perform dose measurements using CTDI phantoms. Prior to scanning the phantom, the physicist should perform tube warm-up and any necessary daily calibration scans such as air scans or water scans (Seeram, 2009).

2.5.2 Method of quality control at the study sites

At the study sites two types of CT scanners were used the GE and Philips CT scanners, and each scanner has specified QC tests recommended by the manufactures. The tests have different names but are similar. For both CT scanners the manual recommends that the QC tests are to be done by the radiographer before any procedure is performed. This is considered to be part of routine maintenance tests.

QC for the GE CT scanner

In the General Electric (GE) CT scanner the manufacturers recommend fast calibration and tube warm-up to be done. The fast calibration is recommended to be done on daily basis before any procedure is performed. The calibration is done when there is no object in the gantry. It checks for detector efficiency in order to achieve accuracy of the CT number. The tube warm-up is performed whenever the CT scanner is idle for at least two hour after the initial calibration or after a day's work.

QC for the Philips CT scanner

For the Philips CT scanner, the manufacturers recommend air calibration and tube conditioning. The tube conditioning is recommended to be carried out on a daily basis before performing any procedure. Meanwhile, the air calibration which is similar to fast calibration in GE scanner, is recommended once a month.

The QC tests are mandatory on both scanners before the radiographer embarks on any procedure so as to increase the life span of the CT scanner as well as not to compromise the image quality.

The use of different terminologies for QC by CT scanner manufactures have been noted. "Tube warm up" in the GE units is referred to as "tube conditioning" in the Philips units, and "fast calibration" in the GE units is referred to as "air calibration" in the Philips units.

Ideally, the two scans should be accompanied by a water phantom scan to ensure that the relative CT numbers to water remain within acceptable limits based on the American College of Radiology recommendation (ACR Quality Control Manual, 2012). The water phantom test is not done at the study site because is not part of what the vendors recommend for daily QC.

Table (2.9) shows the quality control tests that are recommended by the manufacturers to be performed on the CT scanners at the study sites.

Table 2.8: Frequency of QC at the study sites

CT Scanner QC / CT Scanner Tests	Daily Prep (Tube warm-up)	Tube Conditioning	Fast Calibration	Air Calibration
GE 4-Sice	Daily	Not Applicable	Daily	Not Applicable
GE 16-Slice	Daily	Not Applicable	Daily	Not Applicable
Philips 16-Slice	Not Applicable	Daily	Not Applicable	Monthly

2.6 Summary of the chapter on CT Equipment and CT dosimetry

This chapter discusses the generations of CT scanners; the generations range from first to latest development in CT technology (Cone-beam CT). Other categories of CT scanners that do not fall into any of the generations such as PET/CT scanner are equally included. Radiation protection of patient which includes stochastic and deterministic effects is discussed. Radiation dosimetry, CT dosimetry, and radiation dose in CT examinations are introduced. Dose description parameters namely the CTDI and DLP are well explained. DRL in brain CT imaging and the reason of its introduction as one of the best methods of minimizing patient radiation dose is highlighted. Factors affecting radiation dose in CT namely the kV, mA, & slice thickness are included. Dose optimization strategies in CT which include size based technique, scanning based on the patient age or clinical task are provided. Quality assuarance & quality control for CT are included. Reports of the use of different scan parameters for adult brain, and the radiation dose associated with adult brain CT from different vendors are also included. The subsequent chapter is on the research methodology.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The chapter describes the methods involved in the selection of participants, data collection, analysis, organisation and interpretation. The study involved comparison with the standard doses established in the literature, therefore, the values measured in the present study were derived with the same methods and with comparable accuracy to the ones in the existing regulations.

The methodology described attempts to answer the research question raised in the study: what is the estimated $CTDI_w$ value patients receive while undergoing head CT scans in Northern Nigeria?

3.2 Research methodology

3.2.1 Prospective quantitative research

This study adopted a prospective, quantitative and cross sectional research design to determine the absorbed radiation dose to patients undergoing CT scan of the head. A quantitative design was appropriate because the study involved the use of numerical data, and was conducted prospectively to ensure more reliable and valid data (Punch, 2006). Based on the guidelines stipulated in the literature, the data could be obtained either from standard-size patients or a phantom (European Commission, 1999). At the study sites, there are dosimetry phantoms, but no ionization chamber or TLD chips to carry out the direct measurement. Therefore, we had to employ the use of standard-size patients.

3.2.2 Site selection

The Northern region of Nigeria was selected because this kind of study has never been conducted there. Moreover, this is where the researcher lives and works. The region consists of three regions as shown in figure (3.1) namely the North West as centre A, North central as centre B, and North East as center C. The sites were selected through a physical visit to some of the areas in the region, or contact via telephone. All the scanners assessed were equipped with dose description parameters. The number of patient scans per day/week was also determined. A total of three (3) centres were identified in the region. A stratified method of sampling was used to select a center from each of the zones. The centres chosen had made a substantial sample in Northern Nigeria with reasonable spread in terms of population, geography and technology which is sufficiently representative for the purpose of setting preliminary DRLs.

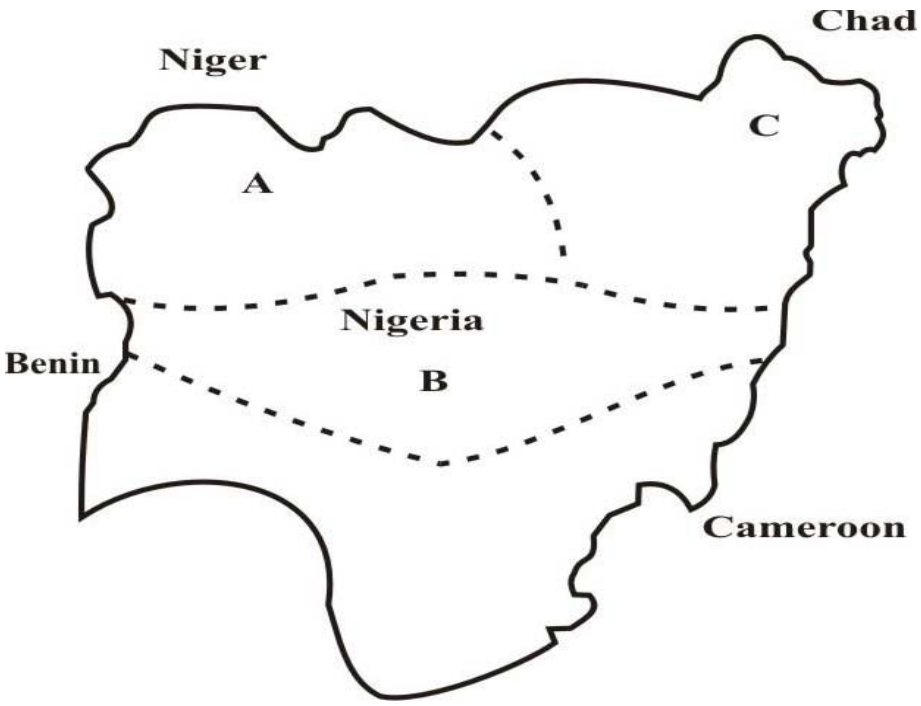

Figure 3.1: Map of Nigeria adopted from Google map, 2013

3.2.3 Selection of CT scanners

From each of the three zones identified namely the North West (center A), North central (center B) and North East (centre C), a CT scanner was selected. In a zone where there are more than one CT scanner a judgement sampling technique was used for the selection. The criteria used for the judgement selection include: looking at the target population, as well as number of patients who were referred for routine brain scans.

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At the time of the study there were only four functional CT scanners installed in the Northern region. All four scanners are in government hospitals, and that was where most of the patients go for their CT investigations because this is more affordable.

The CT scanners in the region are: General Electric (GE) Healthcare (2), (4) & (16)-slice and Philips 16-slice CT scanners. Both CT scanners were considered in order to have a true reflection of what is being done in the area. The inclusion of different manufacturers also made the study more comprehensive, because dose contribution from each of the scanner types was evaluated and a recommendation as to which scanner to be used was drawn-up. In addition, the scanners are equipped with dose description parameters namely: the CTDI and DLP. Figure (3.1) and figure (3.2) show images of CT scanners from the study area.

Previous studies have confirmed that available CT scanners in the study area could be used to develop DRLs whether they are from the same manufacturer or not. Moreover, a single slice CT scanner could also be used to develop DRLs (European Commission, 1999; Gray, Archer, Hobbs, Mettler, Pizzutiello, Schueler, Strauss, Suleiman & Yaffe, 2005; Shrimpton, Hillier, Lewis & Dunn, 2006). Furthermore, similar studies conducted in Sudan by Elameen (2010) and Estonia by Nosach (2006) have included CT scanners from different manufacturers that are from different slices. Table (3.1) below shows detail of CT scanners at the study sites

Table 3.1: Detail of the CT scanners selected

Name of scanner model	Number of slice	Centres	Number of head CT done per week
General electric Brightspeed Excel	4-slice	A	50
Philips Brilliance	16-slice	B	15
General electric Brightspeed Delight	16-slice	C	10

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Figure 3.2: Philips 16-slice CT scanner from on the of the study sites

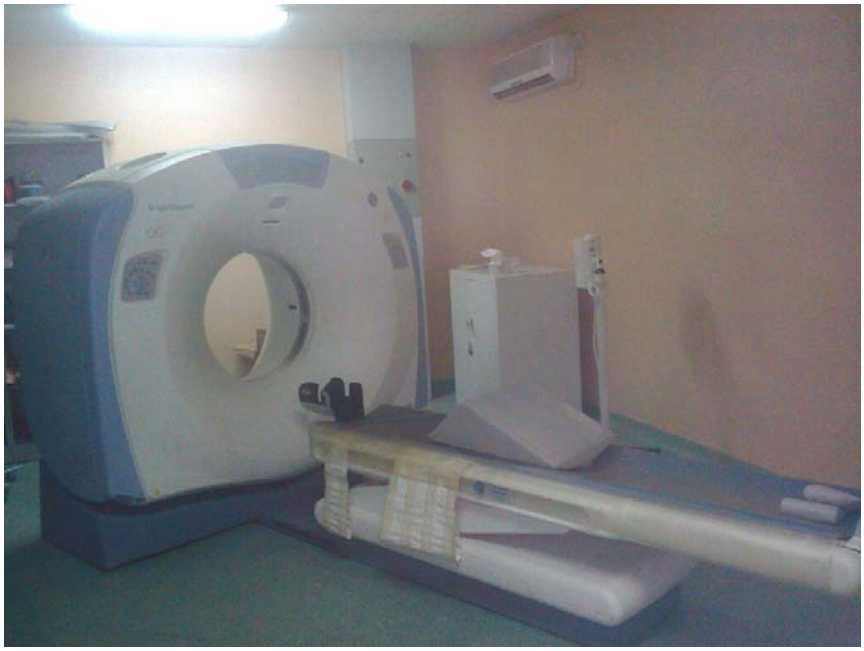

Figure 3.3: General Electric (GE) 4-slice CT scanner from one of the study sites

3.2.4 Study population

The study population comprised of all patients that came for CT examinations of the head in the study areas from June, 2011-December, 2011.

3.2.5 Sample Size

A sample size of 60 participants was used in the study. This was obtained through selection of 20 participants that came for CT examinations of the head in each of the three participating centres using a purposive method of sampling (Tongco, 2007). Purposive sampling technique was considered as the most appropriate, as standard-sized patients are essential to the design. Twenty participants were selected based on the recommendation made by the European Commission which says a minimum of 10 participants shall be recruited for each body part under examination (European Commission, 1999). More so, the larger a sample, the more representative it will be of the population from which it has been taken (Willis, 2004). All patients that met the inclusion criteria and agreed to participate in the study were weighed, and were within the weight limits of standard size patient which is 70 ±3 kg for the European population

(European Commission 1996). The European weight limit was adopted to make comparison with published values easier because a standard-size patient for Nigerian population could not be found in the literature.

3.2.6 Participants selection

3.2.6.1 Inclusion criteria

I. Only adult patients weighing in the range of 67 to 73 kg were included in the study (European Commission, 1999)

II. Patients presenting for routine CT examination of the head (patients that did not require special technique like CT angiography, CT perfusion or helical CT scan)

III. Data was only acquired on a CT scanner that was calibrated by the Nigerian Nuclear Regulatory Authority (NNRA)

3.2.6.2 Exclusion Criteria

I. Patients with weight above or below the specified limits

II. Patients who were too sick, and or their weight could not be measured

III. Patients for non-routine scan of the head (Post neurosurgical cases and psychiatric patients, and patients undergoing special CT examination of the head such as CT perfusion, CT angiography that involves the use of special techniques such as dynamic study or acquisition of thinner sections).

3.2.7 Data Collection

The data were collected by the researcher assisted by the CT radiographers. The CT radiographers were well trained on how to collect the data. The data collection sheet used for the study was adopted from the IAEA survey form (Appendix B) and has the

following sections: participant demographic information, scan parameters and dose parameters.

I. Patient demographic information

The demographic information included in the study were: i) age, to make sure only adult patients were included in the study; ii) gender of the patients; iii) weight to ensure that only standard size patients were included (70 kg ±3), and iv) body region which indicates only patients coming for head CT were included in the study.

II. Scan parameters

The exposure parameters were: tube current time product (mAs) and kV.

Other information recorded were: slice thickness, pitch, scan length, number of slices, scan mode, and field of view (FOV).

III. Dose parameters

After each head CT scan, the $CTDI_w$ and DLP values obtained from the visual display unit of the CT scanners were recorded on a data capture sheet. These are the parameters found in all of the CT scanners in the study.

The scans were done using the existing protocols. This gave a reasonable reflection of what was happening at the study site.

Weighing scales were provided by the researcher in all the participating centres. The Radiographers in-charge of the CT units were responsible for explaining the procedure and weighing of all the participants. Hence, the radiographers were properly trained to be able to administer the consent information to all the participants. They were also able to determine whether the patient could be included in the study or not.

Predominantly the people in the study environment are Hausa speaking therefore, the consent form was translated into Hausa language. Meanwhile, an English consent form was only given to those that could speak English fluently (Appendix A).

3.3 GE Protocol for routine adult head CT at the study site

The protocol for routine adult head CT is designed to be in sequential (Axial) mode. The slice group is usually in two batches, namely, batch A for the posterior fossa, and batch B for the cerebrum. The kilovoltage used is normally in the range of 120 kV with 250 mA for the GE 4-slice, and 120 kV and 160 mA for the GE 16-slice. The time used for GE 4-slice is 1 sec per slice, and 2 sec per slice for the 16-slice GE scanner. In most cases automatic mA is prescribed due to its dose saving effect. The slice thickness in both scanners is 2.5 mm for the posterior fossa, and 5 mm for the cerebrum. A single value for the DLP is obtained by simple adding up the two DLP values displayed on the CT console for the two sections, however this does not apply to $CTDI_w$. The $CTDI_w$ was obtained using the formula adopted from (Zarb *et al*., 2012):

$$CTDI_w(average) = \frac{[CTDI_w(1) \times length(1)] + [CTDI_w(2) \times length(2)]}{length(1) + length(2)} \quad \text{.....(7)}$$

$CTDI_w(1)$ = Is the displayed $CTDI_w$ for the posterior fossa

$CTDI_w(2)$ = Is the displayed $CTDI_w$ for the cerebrum

Length (1) = Is the scan length for the posterior fossa

Length (2) = Is the scan length for the cerebrum

3.4 Philips protocol for routine adult head CT at the study site

For Philips CT scanners, the protocol is slightly different. A sequential (Axial) mode is also maintained for routine adult head CT scans. The slice group is single as opposed to the GE protocol which has two groups. The kilovoltage used is 130 kV. In the Philips machine, the tube current time product (mAs) is recorded instead of tube current (mA) as in the case of the GE machine. The average mAs prescribed is 450. A uniform slice

thickness of 3 mm is used for the entire scan length. Single values for DLP and $CTDI_w$ were recorded since only one slice group is used.

Table 3.2: A summary of protocols for routine head CT at the study sites

CT scanners/Scan parameters	Scan mode	Centres	kV	mA	mAs	ST (sec)	FOV (cm)	Slice Thickness (mm)
GE 4-Slice	Axial	A	120	250	NR	1	25	2.5, 5
Philips 16-slice	Axial	B	130	NR	450	1.75	25	3
GE 16-Slice	Axial	C	120	160	NR	2	25	2.5, 5

NR= Not Recorded ST= Scan Time

3.5 Data Analysis

The data obtained were saved on an excel spread sheet (appendix J, K, & L). The data contain the followings: the demographic information (age, gender, & weight), the scan parameters (kV, mA, slice thickness & FOV)) and dose parameters ($CTDI_w$ & DLP). The data were analysed to provide answers to the research problems itemised in chapter one.

Two statistical methods were employed for the data analysis namely: descriptive and inferential analysis.

The descriptive analysis was employed to summarise the data for this study. They are used to give a description of the data by determining the measures of location (mean, median and mode) and to express its variability (range, standard deviation, and standard error) (Willis, 2004).

Inferential statistical analysis was employed to measure the significance (whether any difference between two samples is due to chance or a real effect of a test result. It is represented using p values (Willis, 2004).

Data was analysed using SPSS version 16 statistical software. The mean, standard deviation and third quartile values at 95% confidence interval was used. Comparison was made between the measured doses and reported data from the European countries where there are established DRLs. Statistically significant results of dose values between CT

centres were determined using chi-square and student t-test at 0.05 level of significance (Willis, 2004).

I. T-test

The "t-test" is a statistical tool used to compare paired but independent samples. It is used when the sample size is less than 30 (Willis, 2004). In this study the sample taken from each of the centers is less than 30.

II. Level of significance

In a statistical analysis one must test the certainty of accepting the null hypothesis. Before this is done the level of significance for the rejection of the null hypothesis must be determined (Willis, 2004). Although the level of significance could be set at any value, it is usually set at *5%, $p<0.05$*. This means the likelihood the event occurs by chance alone is 5 or less in 100 (therefore, there is 95% probability that the null hypothesis is correct). The lower the level of significance that is adopted the less likely that the null hypothesis will be rejected (Willis, 2004).

3.5.1 Sub-problem I

Measuring the $CTDI_w$ and DLP values delivered to patients for head CT, and establishing DRLs values for the head CT scan for Nigeria. In order to answer this, the mean values of CTDIw and DLP of the head CT scans displayed on the scanner monitor were recorded. Thereafter, the 3rd quartile values were obtained which were used to establish the Local Diagnostic Reference Levels.

I. The mean

The mean summarizes all of the data. It is calculated by adding all of the values and dividing the sum by the number of observations (Willis, 2004).

II. Third Quartile

The DRL must be set at approximately the level of the third quartile in the dose distribution. The third quartile value is chosen as an appropriate investigation level on the grounds that if 75% of X-ray departments can operate satisfactorily below this dose level, the remaining 25% should be made aware of their potentially less than optimal performance. They should then be encouraged to alter their radiographic equipment or techniques to bring their doses in line with the majority (European Commission, 1999).

3.5.2 Sub-problem II

Comparing the DRL values of this study with the data from countries where there are established DRLs.

The answer to sub-problem (II) was determined by comparing the CTDIw & DLP values with what were established in the literature.

3.5.3 Sub-problem III

Determine whether $CTDI_w$ variation between CT centres exists, correlate scan parameters namely the kV, mAs, slice thickness with $CTDI_w$ and DLP values, and determine the factors responsible for $CTDI_w$ and DLP variations.

Sub-problem (III) was answered using a t-test to compare the mean CTDIw & DLP values for head CT from one center to another. Statistically significant results at 95% confidence interval were documented which determine whether the answer obtained will be accepted or rejected. Correlations were also used to determine the relationship between the scan parameters and dose values.

III. Correlation

In order to determine statistically whether a correlation exists between two variables x and y, the correlation coefficient represented by r must be used. For the two variables to be correlated, they do not need to demonstrate a linear relationship between them (Willis, 2004).

IV. Linear correlating coefficient

A regression line was drawn comparing CTDIw & DLP with kV, mAs, mA, scan length slice thickness, and number of slices. SPSS software was used to determine the linear correlation coefficient. The correlation coefficient *(r)* is used to measure the strength and direction of the linear relationship between two variables. The correlation coefficient *(r)* takes on values greater than or equal to negative 1 and less than or equal to positive 1 ($-1 \leq r \leq +1$). A positive correlation suggests that as values of x increase, the y values increase, or x values decrease as y values decrease. A negative correlation suggests that as the values of x increase, the values of y decrease or as the x values decrease, the y values increase. There is a strong linear correlation between two variables when *r* is either positive or negative 1. When the *r* value tends towards zero, then there is a weak or no linear correlation between the two variables being compared. A linear correlation coefficient *r* that is greater than 0.8 is described as strong, whereas *r* at 0.5 is described as weak. It is usually considered that there is no linear correlation when *r* is less than 0.5 (Willis, 2004).

V. Coefficient of determination r^2

The coefficient r^2 is a measure of how well the regression line represents the data on the scatter graph. When r^2 is greater than or equal to 0 and less than or equal to 1 ($0 \leq r^2 \leq 1$), then the regression line passes through all the data points on the scatter graph. Therefore, this suggests a strong linear correlation between x and y values (Willis, 2004).

VI. Significance of the linear correlation coefficient

The statistical significance of the linear correlation coefficient was ascertained by calculating the probability levels (*p-value*). When the *p-value* is less than *0.05*, then the correlation between the variables compared was statistically significant. When the *p-value* is greater than 0.05, the linear correlation between the two variables is not considered to be statistically significant (Willis, 2004).

3.6 Validity and reliability

The validity and reliability of the instrument, procedure for recording weight, QC and data capturing sheet were determined.

I. Instrument

The CT scanners were thoroughly checked by performing the daily QC, and ensured to be in good working condition. The number of CT scans performed per day/week in all the study sites was determined. Based on the outcome, the researcher was confident that the equipment was functional and that the radiographers on site were capable of recording the data.

II. Procedure for recording weight

The site radiographers are well trained to be able to weigh the patient accurately. Weighing scales in all the centers were always on zero before readings were taken.

III. Quality Control

To ensure the equipment works satisfactorily, QC is performed on a daily basis prior to any CT procedure. The frequency of the QC is documented in table (2.9).

IV. Data Capture sheet

The data collection sheet used was adopted from the IAEA document (IAEA, 2007), and it had been tested in other countries like Canada, Greece, and India where similar studies had been conducted (IAEA TECDOC, 2009). The recorded data were thoroughly checked (i.e. data were entered into an excel spreadsheet. Each entry was then checked by the researcher to ensure that no mistakes were made during data capture) by the researcher before entered in the software for processing.

3.7 Ethical Clearance

Ethical clearance is the process that requires researchers to give due consideration to a participant in a research study. Researchers are asked to consider and document ethical clearance for any study involving human research participants. A researcher's ethical responsibilities include the principle of academic integrity and honesty, and respect for other people. There are ethical issues in research which relate to patient access, consent and protection. For this reason, researchers are required to obtain permission to conduct their research (Punch, 2006). Refer to the permission from the study sites as appendix C.

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Therefore, in this study ethical clearance to conduct the study was obtained from the chairperson responsible for the research in the participating hospitals (appendix C) as well as the Research Ethics Committee of the Faculty of Health and Wellness Science, Cape Peninsula University of Technology (CPUT) (appendix F). Data was only collected from the consenting adult participants (See consent form: Appendix A). During the study period, the researcher adhered to the following ethical principles:

i. Patient's participation was voluntary.

ii. The patient and a witness signed the consent form.

iii. Patients who could not sign indicated with a thumb print.

iv. Patients were not coerced or threatened to participate in the study.

v. Data obtained was kept confidential.

vi. Data will be kept safe for five years after study in a safely locked cupboard.

vii. Results did not contain the name or any biographical details of the patient or hospital involved in the study.

Table 3.3: Summary of analysis

Sub-problems	**Analysis**
Sub-problem I	Mean and 3rd quartile of the absorbed dose (CTDIw & DLP) were obtained, and determined the Local Diagnostic Reference Level.
Sub-problem II	Table and bar chart were used to compare the dose values obtained with the established results from literature
Sub-problem III	A t-test was used to determine whether there was statistically significant results of the dose value between centres, and linear regression analysis compares CTDI + DLP with scan parameters

CHAPTER FOUR: RESULTS

4.1 Introduction

A total of 20 participants were included from each study site. This consisted of 41 (68.3%) males and 19 (31.7%) females. The participants' age range was from 16 to 80 years (40.72±16.84). Sixteen years of age is considered as an adult based on the hospital age classification in Nigeria (Mundi, 2013).

For head CT, only sequential scanning is considered to be a routine scan. In this study, both sequential and helical scanning were included by the CT radiographers. The helical scans were done probably due to lack of patient cooperation. The helical scan is not usually recommended because it is a faster acquisition mode and is associated with higher radiation dose if noise is to be kept minimal (Smith *et al.*, 2007).

Ninety percent of the patients were scanned using the sequential mode, namely: 20 participants from centre A, 16 participants from centre B and 18 participants from centre C. The remaining 6 (10%) were scanned using the helical mode. Table (4.1) shows the number of sequential and helical scans taken at each study site.

Table 4.1: Rate of sequential and helical scans at the study sites

Centres	Sequential scan (Axial)	Helical scan (Spiral)
Centre A	20	NIL
Centre B	16	4
Centre C	18	2
Total	54	6

4.2 Results of scan parameters

Analysis of the scan parameters (kV, mA, mAs, slice thickness, FOV, number of slices, pitch, & scan mode) is presented in Table 4.2 and 4.3 for sequential and helical modes respectively.

Table 4.2: Mean scan parameters for sequential mode

Scan parameters	kV	mA	mAs	Scan time (sec)	Number of Slices	ST (mm)	FOV (cm)
Centre (A) GE Brightspeed 4-slice	120 (±0.00)	218 (±46.5)	NR	1	44 (±7.3)	2.5-5	23 (±1.5)
Centre (B) Philips Brilliance 16-slice	120 (±0.00)	NR	450 (±0.00)	1.75	52 (±8.3)	3.0 (±0.0)	21 (±1.4)
Centre (C) GE Brightspeed 16-slice	131 (±10.2)	149 (±17.7)	NR	2	45 (±8.6)	2.5-5	24 (±1.9)
Combine Results (A+B+C)	127 (±7.84)	185 (±49.5)	450 (±0.00)		47 (±8.6)		23 (±1.9)

ST=Slice thickness
FOV=Field Of View
NR= Not Recorded

When recording and reporting data, care must be taken to ensure that the 'measured' value and 'uncertainty' should be presented with the same significant number. This practice ensures the precision of the data. In practice, experimental data should be approximated to either one or two decimal places (uncertainty digits). (Data Analysis Australia, 2013). There is however no penalty if someone decides to report the data with more than two decimal places. The recorded data in this study for the parameter 'scan length' was reported to the nearest whole number while parameters such as 'FOV' and '$CTD1_W$' were recorded to one and two decimal places respectively.

Table 4.3: Mean scan parameters for helical mode

Scan parameters	kV	mA	mAs	Scan time (sec)	Number of Slices	ST	FOV	Pitch
Centre (B) Philips Brilliance 16-slice	120 (±0)	NR	313 (±75)	15	104 (±14.4)	3 (±0)	21 (±3)	0.69 (±0.01)
Centre (C) GE Brightspeed 16-slice	130 (±14)	253 (±11)	NR	1	36 (±0.7)	5 (±0)	23 (±3)	0.56 (±0.01)
Combine Results (B+C)	123 (±8)	253 (±11)	313 (±75)		82 (±37)	4 (±1)	22 (±3)	0.65 (±0.07)

ST=Slice thickness
FOV=Field Of View
NR= Not Recorded

The mean kV values in both acquisition modes are nearly the same, whereas the mA is higher for helical mode. However, sequential mode has higher mAs value (Figure 4.1).

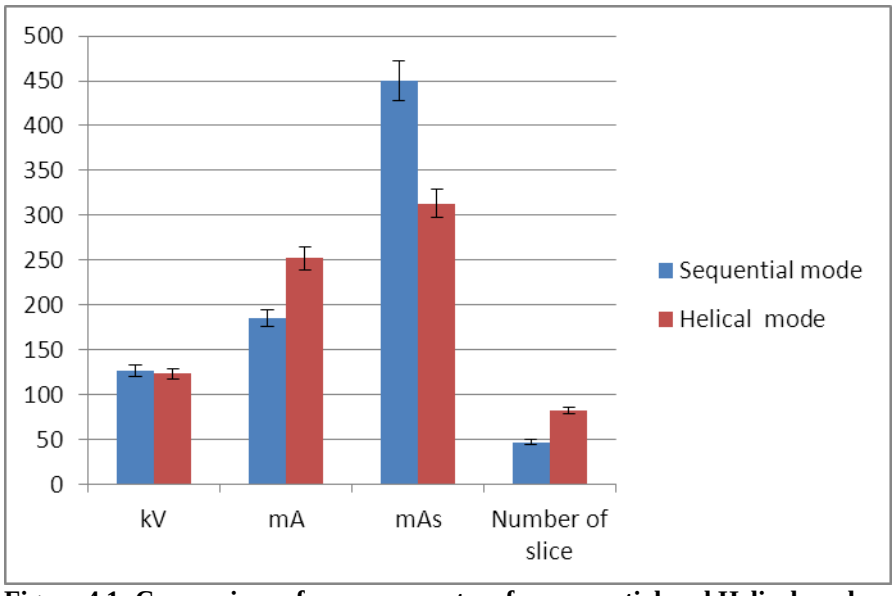


Figure 4.1: Comparison of scan parameters for sequential and Helical modes

Figures 4.2-4.4 show the number of slices acquired plotted for each participant with error bars inserted at 95% confidence interval. The error bars indicate the standard error of the mean. It is an estimate of the standard deviation of the distribution of the mean. It describes how spread out the distribution of the population from which the sample was taken. When the standard error is low, it is more likely that the sample mean is a good reflector of the value for the true population mean (Willis, 2006).

In centres A & C, the number of slices is almost the same for all the patients. Only in a few patients, the number of slices was higher than usual. These are patients who were scanned with helical mode and with a large scan field of view.

In centre B where the Philips scanner is installed, more slices were generated because a thinner slice width is prescribed in the protocol. However, there were a few patients with an unusually high number of slices. Those patients were scanned using helical mode.

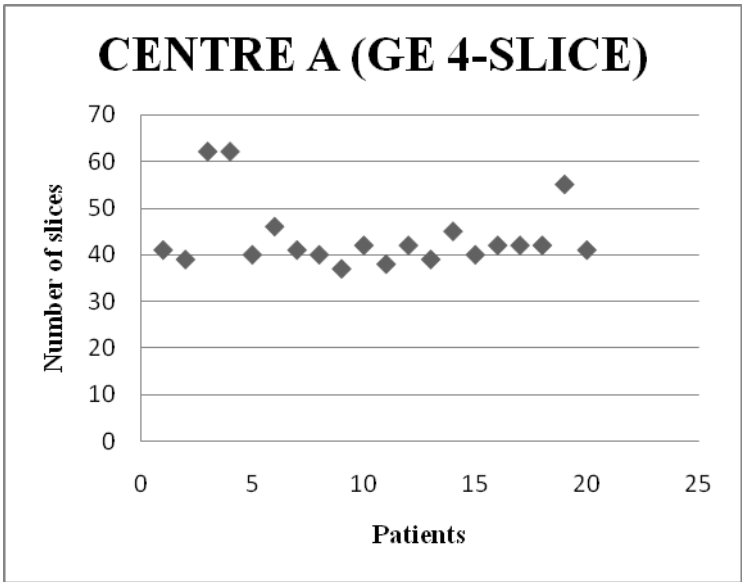


Figure 4.2: Number of slices acquired per patient at centre A

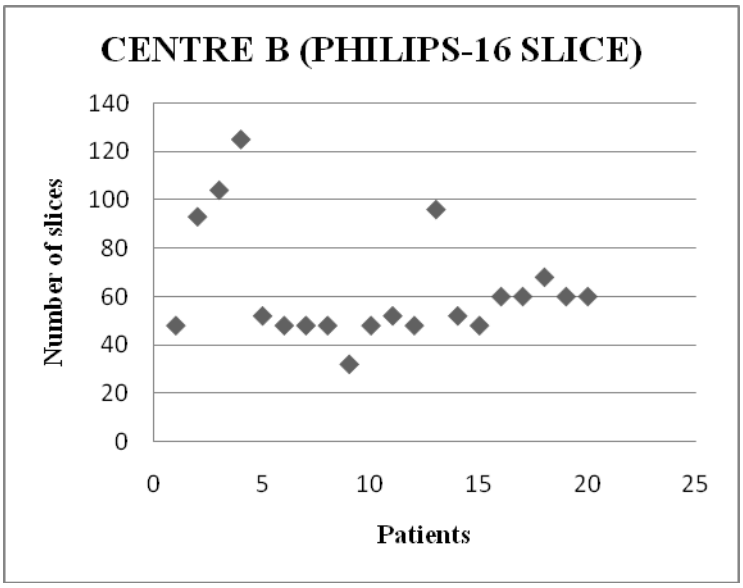


Figure 4.3: Number of slices acquired per patient at centre B

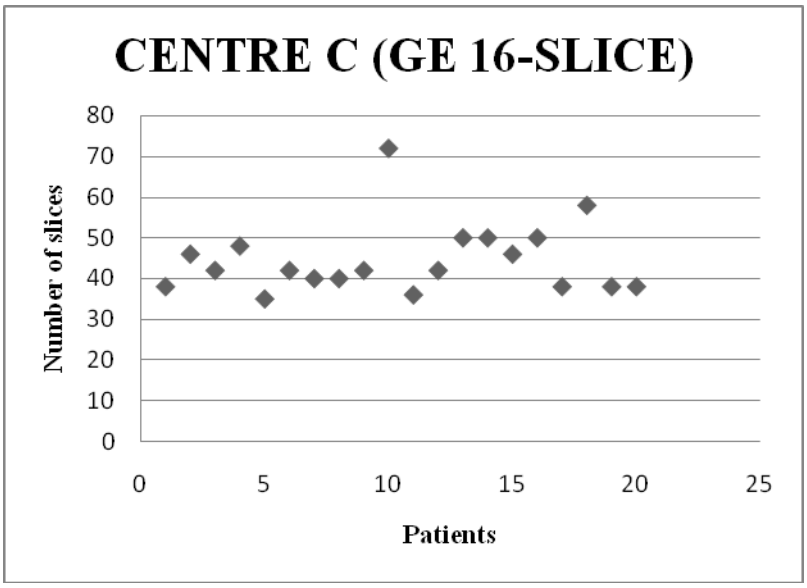


Figure 4.4: Number of slices acquired per patient at centre C

4.3 Results of measured parameters

Summary statistics for the measured parameters which include: the patient' weight, CTDIw, CTDIvol, DLP and scan length for sequential and helical modes, are shown in Table 4.4 and 4.5.

The sequential mode has higher CTDIw for brain CT in centre (A) followed by centre (C), 88 mGy and 70 mGy respectively. Meanwhile, highest DLP value is noted in centre (B) as1099 mGy.cm (Table 4.4). The reason for the higher $CTDI_w$ in centre A & C is due to the higher mA value used, and the higher DLP value in centre C is attributed to the number of slices acquired.

In the case of helical mode, the measured $CTDI_{vol}$ in centre B is lower than that of centre C, so also are the DLP values (Table 4.5). This is because the tube current used for centre C is on the high side, and thus it affects the $CTDI_{vol}$. The DLP value in centre C is also higher because is directly affected by the $CTDI_{vol}$ value.

The standard deviation for the $CTDI_w$ in centre (B) is much less because the exposure parameters used for the scan were almost uniform, whereas in centre (A) and (C) wide variation in exposure parameters was noted (Table 4.4).

Figure 4.2 shows comparison of measured parameters namely the CTDI, DLP and scan length for sequential and helical modes

Table 4.4: Average measured parameters for sequential mode

Centers	Weight (kg)	CTDIw (mGy)	DLP (mGy.cm)	Scan length (mm)
Center A (N:20)	70 (±2.3)	88 (±19)	713 (±203)	156 (±12.2)
Center B (N:16)	70 (±2.8)	68 (±0.6)	1099 (±130.3)	162 (±18.4)
Center C (N:18)	70 (±2.6)	71 (±15)	597 (±98.9)	172 (±32.0)
Summated results (A+B+C)	70 (±2.6)	76 (±17)	789 (±258)	163 (±22.8)

Table 4.5: Average Measured parameters for helical mode

Centers	Weight (kg)	CTDIvol (mGy)	DLP (mGy.cm)	Scan length (mm)
Center B (N:4)	70 (±2.8)	47 (±11)	840 (±246)	232 (±75.9)
Center C (N:2)	70 (±2.6)	100 (±4.23)	1925 (±116.6)	178 (±3.54)
Summated results (B+C)	70 (±2.6)	65 (±29)	1202 (±594.3)	214 (±65.2)

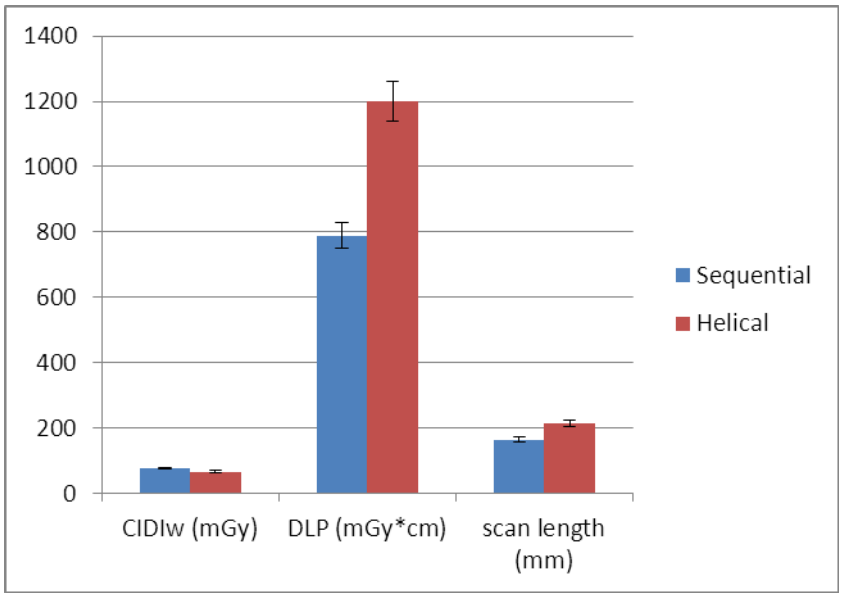


Figure 4.5: Comparison of measured parameters for sequential and helical modes

4.4 Analyses for establishing DRLs

To establish DRLs, only routine procedures ought to have been included, and for head CT only sequential scan is considered to be a routine (Zarb *et al.*, 2012).

Analysis of the absorbed dose in CTDIw and DLP for head CT acquired with sequential mode was carried out.

Mean and third quartile values of the measured doses in CTDIw, and DLP are shown in Table (4.4). Figure (4.4) and (4.5) are bar charts of mean absorbed dose in CTDIw and DLP for brain CT across all centres with third quartile values of CTDIw (77 mGy) and DLP (985 mGy.cm).

Sub-problem 1

Recording the radiation output of CT scanners to patients for head CT, and establishing DRLs values for the head CT scan for Northern Nigeria. The answer to this problem is shown in table 4.6 & 4.7.

Table 4.6: Measured CT scanner output with 3rd quartile values

Centres	Statistical quantities	CTDIw (mGy)	DLP (mGy.cm)
Center A (n=20)	Mean	88	713
	3Q	110	827
Center B (n=16)	Mean	68	1098
	3Q	68	1231
Center C (n=18)	Mean	70	597
	3Q	77	648
Combined average results (A+B+C)	Mean	76	789
	3Q	77	985

3Q=3rd quartile values

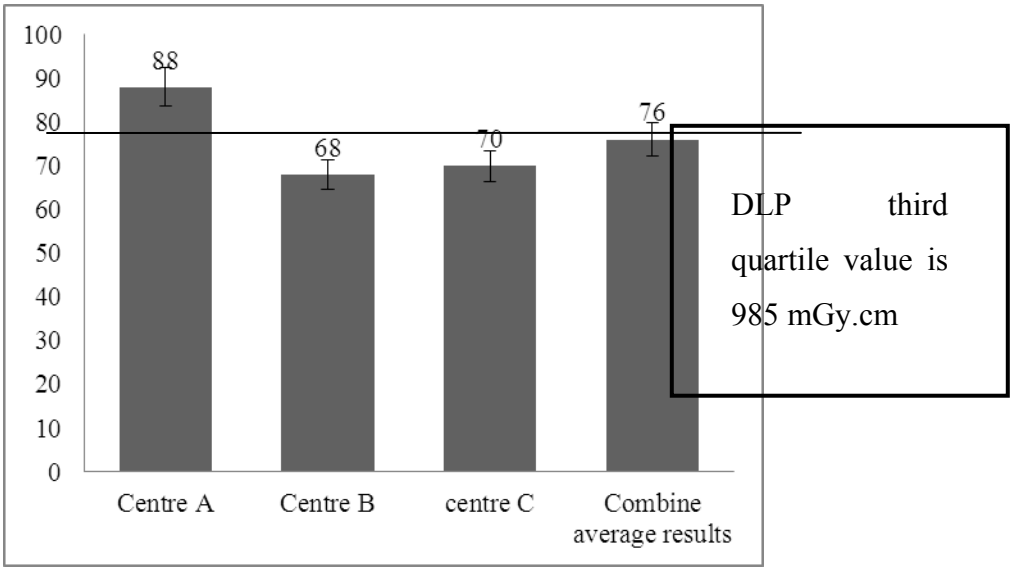


Figure 4.6: Mean CTDIw

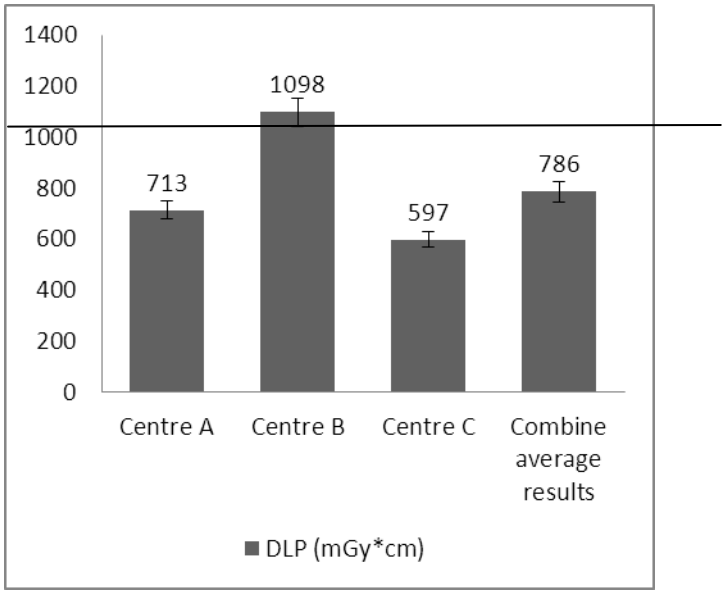


Figure 4.7: Mean DLP

Sub-problem II: Comparison of study DRLs to international values

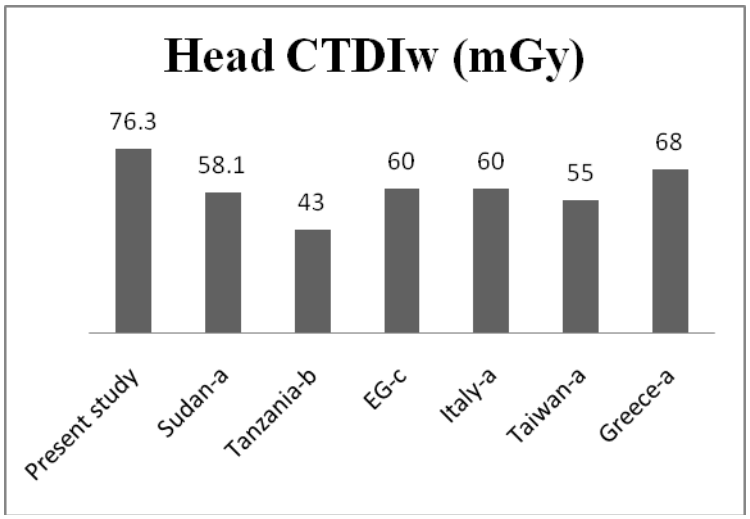
The mean CTDIw and DLP in the study centres were compared to the European Commission guidelines. The mean CTDIw in all three centres is higher than that of the

European Guidelines. The DLP values in centre A and C are lower than that of EG, whereas, the DLP value in centre B is higher (Table 4.7).

Table 4.7: Mean CTDIw (mGy) and DLP (mGy.cm) for Head CT scans

Dose quantities	Range	Centre A (GE 4-slice) (n=20)	Centre B (Philips 16-sclice) (n=16)	Centre C (GE 16-slice) (n=18)	Cumulative average results (A+B+C)	EG (EC, 1996)
CTDIw (mGy)	(17-117)	88	68	70	76	60
DLP (mGy.cm)	(462-2007)	713	1098	597	789	1024

The CTDIw results for the present study were compared with published data for brain CT scans from the international community. The CTDIw for brain CT in Nigeria is higher than the value reported in Europe and African countries where data is identified (Figure 4.8).



a: Elameen, 2010; **b**: Ngaile, 2006; **c**: EC, 1996

Figure 4.8: Mean adult brain CTDIw for Nigeria and some African and European countries

Sub-problem III: Comparison of dose results between centres

CTDIw + DLP against scan parameters

The student t-test was used for CTDI and DLP comparison between centres. Linear regression analysis was used to compare scan parameters namely: the kV, mA, mAs, number of slices with CTDIw and DLP values.

A comparison was made between the two scanners of the same model. Statistically significant results were noted in the measured CTDIw and DLP (*p=0.003 & p=0.03*) respectively (Table 4.8). The comparison between the two scanners of a different model, but the same number of slices, showed statistically significant results in the measured DLP (*P=0.005*). No significant result was noted in the measured CTDIw (Table 4.9).

Table 4.8: Dose comparison for the same scanner model

Dose parameters	**Centre A (GE 4-slice)**	**Centre C (GE 16-slice)**	***P-value***
CTDIw (mGy)	88	70	0.003
DLP (mGy.cm)	713	597	0.03

Table 4.9: Dose comparison for different type of scanner models

Dose parameters	**Center B (Philips 16-slice)**	**Centre C (GE 16-slice)**	***P-value***
CTDIw (mGy)	68	70	0.47
DLP (mGy.cm)	1098	597	0.0005

In cross correlation analysis, positive correlations were noted between mA & CTDIw, and mAs & DLP. Positive correlations were also seen between number of slices & DLP, and scan length & DLP. A negative correlation is also noted between mA & DLP and kV & $CTDI_w$ (Table 4.10). The correlation graphs are shown in figure 4.9, 4.10, 4.11, 4.12, 4.13 & 4.14. No correlation was observed between mAs & CTDIw and slice thickness & CTDIw.

Table 4.10: Correlations of scan parameters with patients dose descriptors

Correlated parameters	R^2	*P values*
mA and CTDIw	0.76	0.001
mAs and DLP	0.73	0.001
NS and DLP	0.20	0.121
SL and DLP	0.14	0.290
mA and DLP	-0.23	0.095
kV and CTDIw	-0.11	0.420

NS= Number of Slices SL= Scan Length

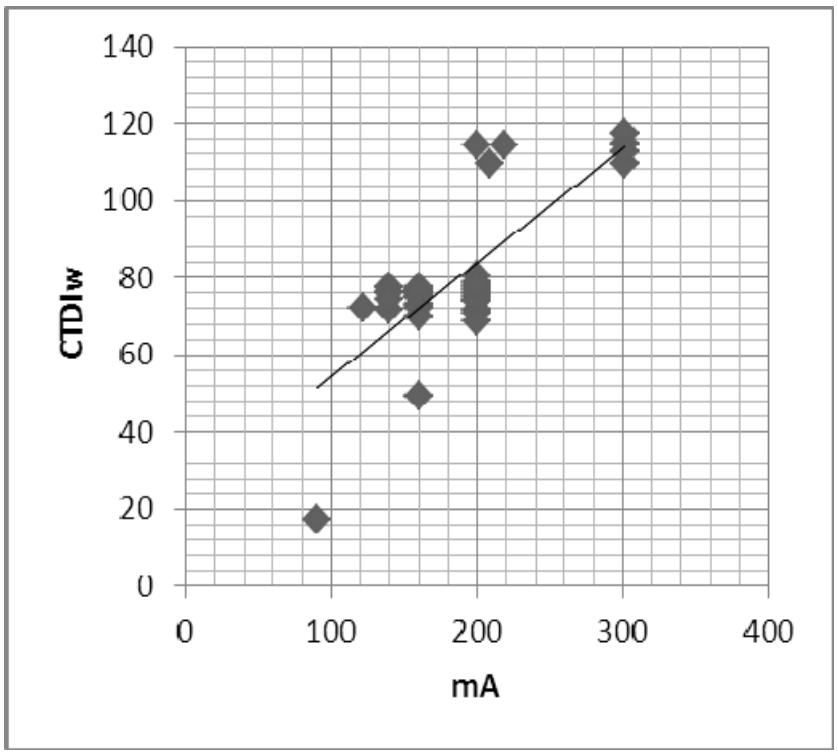


Figure 4.9: Correlation between mA and $CTDI_w$

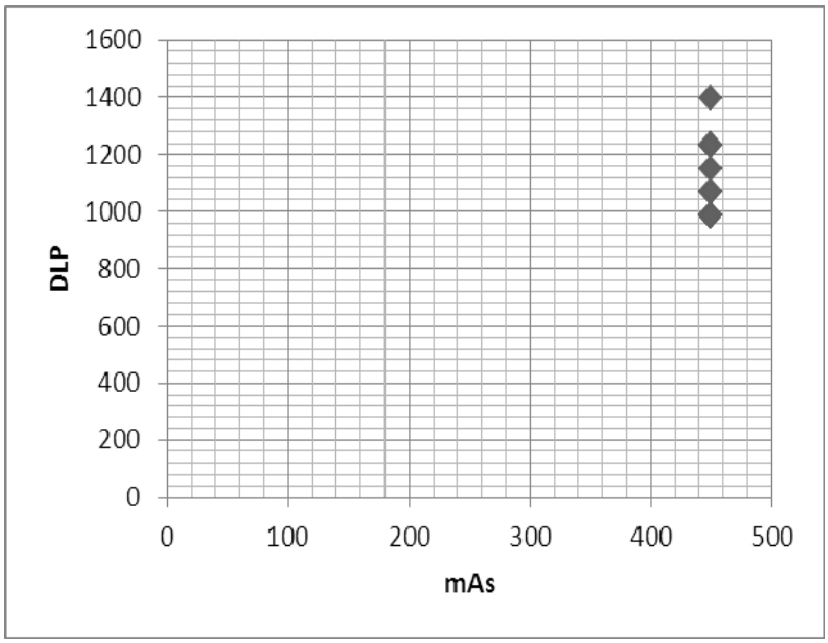


Figure 4.10: Correlation between mAs and DLP

No line of best fit could be inserted in figure 4.10. This is because, the mAs value used in the study was constant.

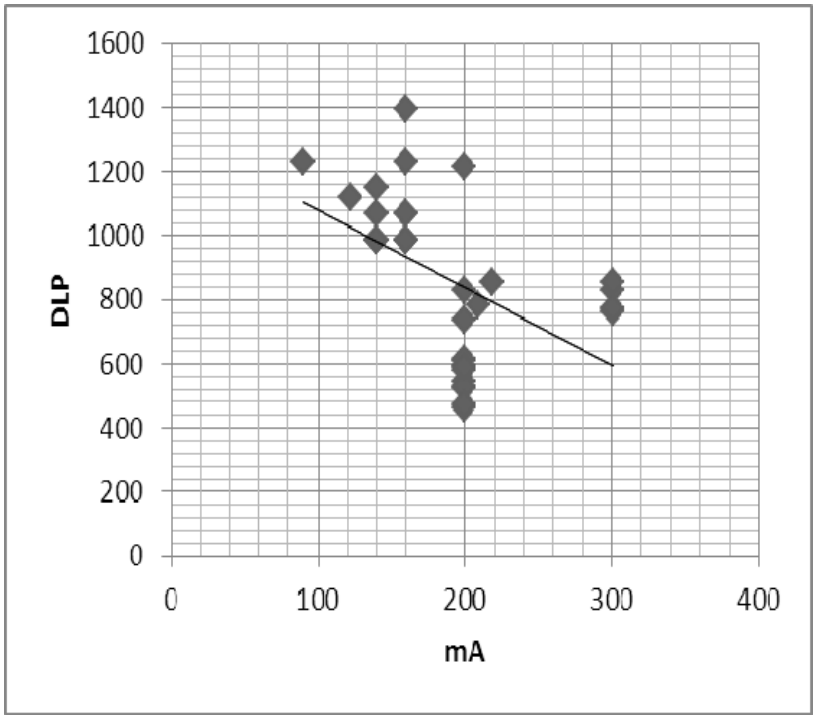


Figure 4.11: Correlation between mA and DLP

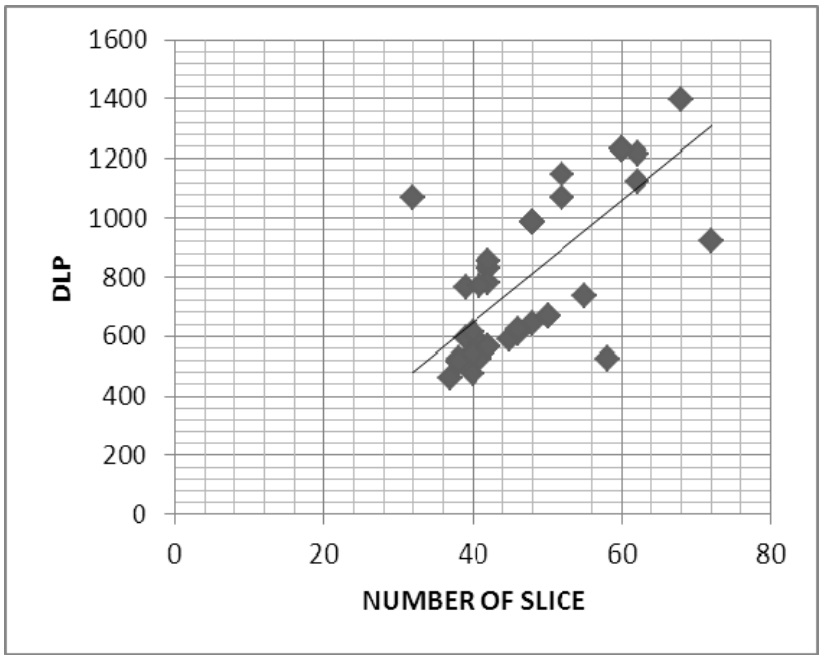


Figure 4.12: Correlation between number of slices and DLP

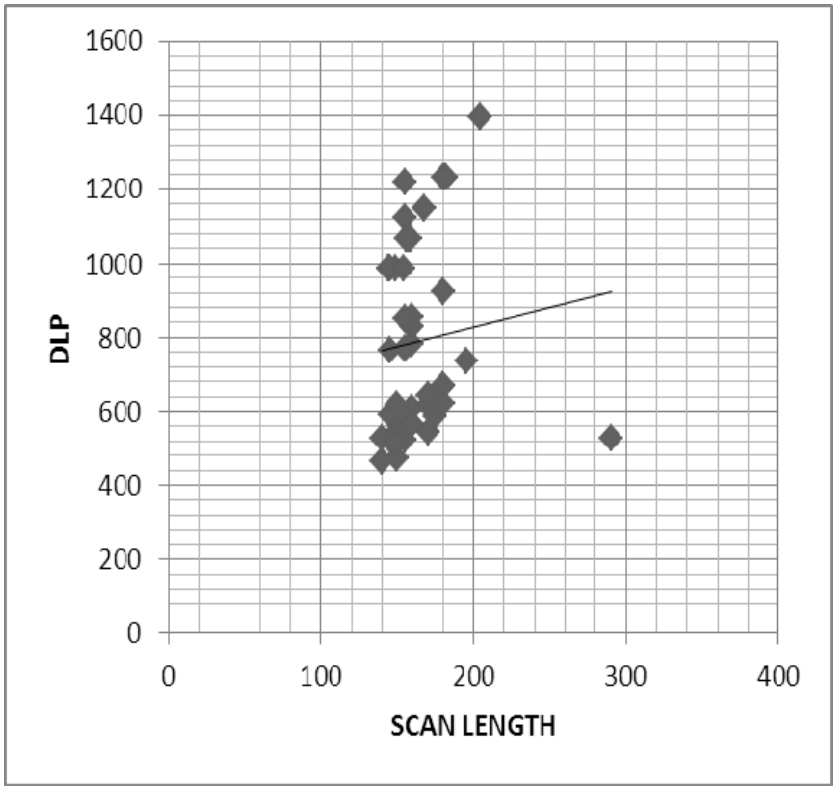


Figure 4.13: Correlation between scan length and DLP

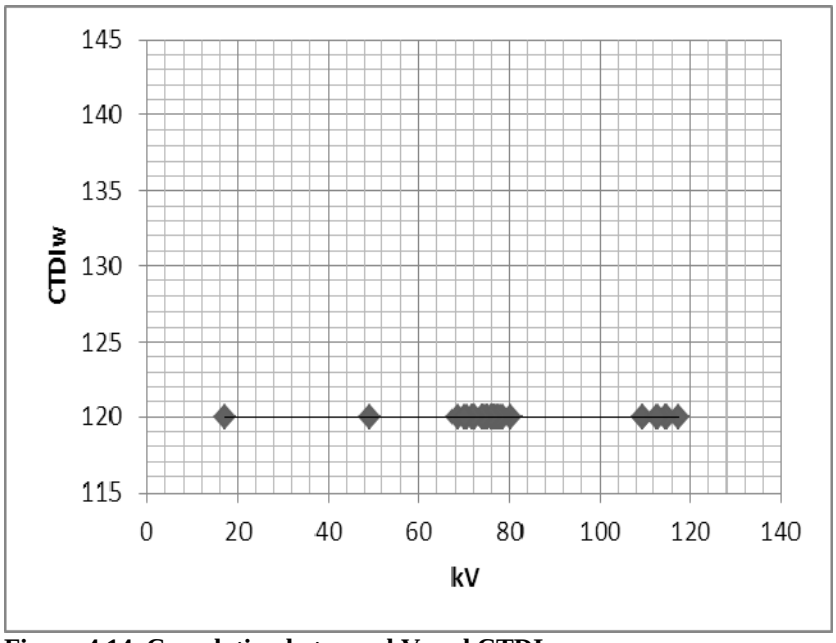


Figure 4.14. Correlation between kV and CTDIw

4.5 Summary of chapter four

This chapter highlighted the major findings in the study. These include establishing local Diagnostic Reference Levels for Northern Nigeria. The reasons for higher DRLs for Nigeria which were because more slices than that recommended for brain CT are acquired usually due to the radiologist influence coupled with the use of higher mA value. There was radiation dose variation due to lack of harmonised protocol for brain CT because every centre has their local protocol. Also, the CT radiographers are not properly trained to understand how the protocol affects radiation dose. Factors responsible for the dose variation were also evaluated through correlating the radiation dose index ($CTDI_w$ and DLP) with scan parameters. The subsequent chapter discusses the findings of this study with similar reported findings in the literature.

CHAPTER FIVE: DISCUSSION

5.1 Discussion

The study determined the $CTDI_w$ and DLP to adult patients undergoing routine head CT scans in three centres located in Northern Nigeria. Potential Local Diagnostic Reference Levels were established. Likewise, factors responsible for CTDI and DLP variation between centres are investigated and discussed in this chapter.

Publications 60 & 73 of the International Commission on Radiological Protection (ICRP) and European Union Directives 93/43 adopted a concept known as Diagnostic Reference Level (DRL) in order to investigate incidences where patient dose during a radiological investigation is unusually high and in urgent need of reduction (Drouet, 2007). The DRLs help to avoid excessive radiation doses to patients and population and that does not contribute to the clinical purpose of a medical imaging task. As such, in recent years it has become an important entity in the management of radiation doses delivered to the patients in diagnostic and interventional radiology. International, regional and national bodies have shown a keen interest in DRLs (Drouet, 2007).

Scan parameters

Studies have reported different dose values in CT imaging due to the variations in applied scan protocols and this limits comparison between studies (Mulkens *et al*., 2007). The findings of the present study also showed that the use of different scan parameters namely kV, mAs, slice thickness, and scan time, being employed at different centres (Table 4.2 & 4.3), resulted in different CTDI and DLP values for the same procedure (Table 4.4 & 4.5).

Measured scan parameters

The measured CTDIw values for all the centres in this study were found to be different

(Table 4.8) and comparably higher than the values reported in Europe (Tsapaki *et al*., 2001). This is due to the different scan parameters employed at each centre, and the fact that dose optimisation strategies are not being observed. Perhaps, the scan parameters are almost the same for adult brain CT for a particular centre. Irrespective of the age, or weight of the patient the adult protocol does not change. What is still being used is the pre-set protocol from the manufacturers. Also it has been reported that setting of scan parameters such as the mAs, tube rotation time, kV, pitch and collimation is a major contributor to the patient dose received during a CT scan procedure (Smith *et al.*, 2007).

Diagnostic Reference Levels (DRLs)

It has been recommended that the DRL should be set at the level of the third quartile in the dose distribution of the measured CTDIw per series and DLP per examination. The third quartile value is chosen as an appropriate investigation level on the grounds that if 75% of the CT units can operate satisfactorily below this dose level, then the remaining 25% should be made aware of their considerably less than optimal performance. Operators of the units should be encouraged to adjust their radiographic protocols by lowering the kV and mA or increasing the slice thickness to bring their doses in line with the 75% majority (Ali, 2005; Elameen, 2010).

DRLs should be established using routine examinations (EC, 1999). Therefore, this study only considered those scans done on sequential (axial) mode as this is the routine protocol at the study site. The few helical scans done were not used to establish the DRLs values for this study.

In this study, the LDRL value for head CT was established as 76.94mGy and 985.48mGy.cm through combining measurements of the absorbed dose in CTDIw and DLP for all participants from the three centres (Table 4.6).

For the measured $CTDI_w$, centre B & C were within the third quartile value but not in centre A where the $CTDI_w$ was found to be higher (Figure 4.6). Whereas the measured

DLP values in centre A & C were below the third quartile value, in centre B it was found to be higher (Figure 4.7). The reason for a high CTDIw in centre A was postulated to be due to the high mA value employed for the scan. The higher DLP in centre B was determined to be due to the increased number of slices (Table 4.2). Even though there is no literature found documenting the required number of slices for a routine adult brain CT, it is apparently clear that what is currently obtained with Philips CT scanner (Figure 4.3) is higher than what is obtained with GE scanners (Figure 4.2 & 4.4). The number of slices performed during CT examinations is one of the parameters that determine the DLP value.

Comparison of LDRL to established international values

The recommended LDRL value for brain CT in Nigeria is 77 mGy. This is higher than the recommended value from the European Commission (60 mGy) and established data from the African countries with published data such as Sudan, and Tanzania (European Commission, 1999; Ngaile, 2006; Elameen, 2010). This is shown in Table 4.7 and Figure 4.8. The reason for the higher value could be attributed to different scanners and scan protocols being used.

Dose Comparison between Centres

A comparison between two scanners of the same model was done. The scanner with a lesser number of slices was found to have a higher absorbed dose in CTDIw and DLP. The difference was statistically significant (*p=0.003*& *p=0.03)* CTDIw and DLP respectively (Table 4.8).

Comparison between two CT scanners of a different model but the same number of slices showed a difference in DLP, that was found to be statistically significant (*p=0.005*) (Table 4.9). The explanation is the anticipated variation in $CTDI_w$ due to the inherent differences in equipment (namely the beam collimation, generator factors, and tube target

angle), and scanning protocol (Smith *et al*., 1998). It is known that manufacturers have specified a ±20% margin of variation of $CTDI_w$ between scanners (Koller *et al*., 2003).

Factors responsible for dose variation

A positive correlation was noted between mA & CTDIw and mAs & DLP with R^2 values of 0.76 and 0.73 respectively (Table 4.10). The correlation graphs are also shown in figure 4.9 and 4.10. This is in line with the reports of Breiki *et al*. (2008) and Nagel (2010) who reported a linear relationship between tube current and patient dose if all other parameters are kept constant.

There is a correlation noted between scan length & DLP, and number of slices & DLP (Table 4.10). The correlation graphs are shown in figure 4.12 & 4.13. This shows that the number of slices determine the scan length. Also, the scan length has a linear relationship with DLP. This finding is consistent with the report documented by GE Medical System (2001) and Seeram (2009).

A negative correlation has been shown between kV and $CTDI_w$. This is because in most of the brain scans performed, the kV was constant (120 kV). Meanwhile, other parameters like tube current-time product were not kept constant. Typically, an increase in kV from 120 to 140 leads to a 47% increase in radiation dose (GE Medical System, 2001; Romans, 2013). Negative correlation is equally noted between mA & DLP. The reason for negative correlation is attributed to the use of non-fixed protocol for brain CT scan at the study sites. Thus, each centre has its own pre-set protocol. Perhaps due to the different CT scanner design.

5.2 Conclusion

Diagnostic reference levels were primarily introduced to avoid situations of high patient absorbed radiation dose. Furthermore, the CTDI's and DRL's should not to be exceeded when departments operate under normal diagnostic and technical practices (ICRP, 1991).

The aim of this study was to establish a Local Diagnostic Reference Level for routine brain CT for the purpose of dose optimisation.

The $CTDI_w$'s and DRL's obtained in the third quartile range for typical brain CT scans for the sample was 76.94 mGy and 985.49 mGy*cm. The CTDI and DLP evaluation was done following EC guidelines. However, variation of $CTDI_w$ and DLP for the same procedure was observed from one centre to another. This is due to the application of different scan protocols at each of the centres. The reason the $CTDI_w$ was higher than in other studies is due to a high tube current and tube current-time product being employed.

5.3 Limitations of the study

I. Relevant apparatus was lacking at the research sites to be able to do direct measurements of dose using a phantom, and to make comparison with dose values displayed on the scanner monitor.

II. The lack of documented standard weight for the Nigerian population, thus European standard-size patient was adopted (70 kg ±3).

III. The derived LDRLs are only applicable to the participating hospitals and are not representative of national DRLs.

5.4 Recommendations

Although the $CTDI_w$ of 77 mGy and DLP of 985 mGy.cm was generally higher compared to published results from other countries these are the recommended initial

LDRLs for Nigeria. We therefore recommend implementation of the established LDRLs across the country. It is furthermore recommended that the tube current-time product be investigated and reduced where possible in order to reduce the absorbed radiation dose, and that the protocol for brain CT is harmonized across all CT centres in Nigeria. The final recommendation is that an audit should be conducted in two (2) years' time to establish revised LDRLs that should be lower than these initial recommended doses.

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LIST OF APPENDICES

Appendix A: Patient information sheet/consent form

A STUDY OF DEVELOPMENT OF A DIAGNOSTIC REFERENCE LEVEL FOR HEAD CT SCANS IN NORTHERN NIGERIA

Investigator: **IDRIS GARBA**
Masters student of the Cape Peninsula University of Technology
Department of Radiography, Groote Schuure Hospital Campus

Contact Details of the investigator:
Radiology department, University of Maiduguri Teaching Hospital, Borno State Nigeria
Phone Number: +2348034532750

Purpose of the study:

The aim of the study is to measure the amount of radiation dose absorbed by your body while undergoing a CT scan of your head for formulating national data with which individual hospitals may compare their doses, for the purpose of dose optimisation.

Procedure involved in the study:

The information and procedures needed for this research project are in no way different to what is normally expected of patient undergoing a CT Head examination.
Your weight will be measured to determine whether you will be included in the study.
You will be required to lie comfortably on the scanner table, after which you will be taken into the machine where a series of images will be acquired.
The machine has a build-in device that will record the amount of radiation you will receive.
The dose will be the same as for the CT scan of the brain you would have normally received.

The key is that readings will be taken for the investigation requested and no additional investigations will be done.

Potential Harm, Risk or Discomfort

It is very unlikely that there will be any discomfort. The only thing, you will be asked to lie on the scanner bed, after which you will be taken into a small tunnel inside the scanner where the images are to be acquired. The whole exam will last for not more than 20 minutes.

Potential Benefits

I hope the amount of absorbed radiation measured will be a useful data that can be used by other local hospitals to compare their doses, for the purpose of dose optimisation.

I also do hope, this will be a useful review of patients' doses for CT examination in Northern Nigeria.

Confidentiality:

You will not be asked to provide your name or any personal information

You and a witness will sign the consent form or indicate with a thumb print as a sign of your willingness to participate in this study.

Your data collected will be kept confidential (The data will be anonymously recorded).

Also, your data will not be released or made known to a third party, and will be kept safe for 5 years after study in a safely locked cupboard.

Reasons for your selection

You are selected to participate in the study, because you fit into the inclusion criteria.

Your participation is entirely voluntary.

Therefore, you have the right to withdraw from the study at any time, and without any explanation, even after signing the consent form. However, any information you have already submitted will be destroyed unless you indicate otherwise.

Information about the study results:

Your data collected may be used in a thesis or publication even though your identity will not be revealed.

Contact for answers about the study:

If you have questions or require more information about the study, please, contact
The investigator: IDRIS GARBA
Phone number: +2348034532750

CONSENT FORM

I have read the information presented in the information letter about a study being conducted by Idris Garba of Cape Peninsula University of Technology. I was given the opportunity to ask questions about my participation in the study, and I did receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so. I also, agree to participate in this study, and I have been given a copy of this form.

.....

Signature or thumb print of the participant

In my opinion, the person who has signed or thumb printed above is agreeing to participate in this study voluntarily, and understands the nature of the study and the consequences of participation in it.

.....

Signature of the witness

Appendix B: Form for capturing patients data/scan parameters

Centre code ☐

Please complete a form for each patient participating in this study.

Patient information: ***Date:*** / /

Age: ☐ ***Gender*** ***Male*** ☐ ***Female*** ☐

CT exam no..... ***Area*** ***Head*** ☐ ***Weight.....*** ☐

Scanning parameters:

KV: ……. ***mAs:*** ……

No. of Slice ***Single*** ☐ ***Multislice*** ☐

Slice thickness: ☐ ***Pitch*** ☐ ***Scan length*** ☐ ***No of slices*** ☐

Table distance ☐ ***Tube rotation speed (ST)*** ☐

Field size ☐ ***Source Collimation*** ☐

Dose parameter:

$CTDI_w$ ☐ ***$CTDI_{vol}$*** ☐ ***DLP*** ☐

CT Radiographer: ……

All forms will be collected by: IDRIS GARBA, contact no: +2348034532750

(Adopted from IAEA Technical report series number 457)

Appendix C: Ethical clearance from the study sites

Dr Abdulkadir Musa Tabari *MBBS, FMCR,FICS*

Consultant & Head, Department of Radiologist, Aminu Kano Teaching Hospital, Kano, Nigeria.
Senior Lecturer & Head, Department of Radiology, Bayero University, Kano, Nigeria.

Department of Radiology,
Aminu Kano Teaching Hospital (AKTH),
PMB 3452,
Kano 700001,
Kano state,
Nigeria.

Tel : +234 802 361 9929
+234 805 438 1482
e-mail : amustabari@yahoo.com

Department of Radiology,
Bayero University,
PMB 3011,
Kano 700001,
Kano state,
Nigeria.

Date : 12th May, 2011.

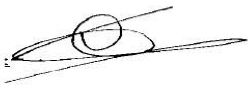
Idris Garba
Department of Radiology,
University of Maiduguri Teaching Hospital
Maiduguri,
Borno State.

Re: APPLICATION OF PERMISSION TO CONDUCT A STUDY TITLED "THE DEVELOPMENT OF DIAGNOSTIC REFERENCE LEVEL FOR HEAD CT SCANS IN NORTHERN NIGERIA"

Sequel to your application on the above subject matter, I would like to inform you that the Department of Radiology, Aminu Kano Teaching Hospital has granted you permission to carry on with your study, subject to approval of your University research ethics committee.

I wish you best of luck in your academic pursue.

Yours sincerely



Dr AM Tabari

Appendix D: Acceptance certificate for Philips brilliance 16-slice

PHILIPS

Philips Healthcare

CUSTOMER ACCEPTANCE CERTIFICATE

It is herewith declared for the equipment as listed.below and being specified in the purchase and sales contract 701-09-020-1 with project 6600087144 between:

Federal Medical Centre Gombe
Ashaka Road, Gombe,
Gombe State, Nigeria

and

PHILIPS MEDICAL SYSTEMS NEDERLAND B.V.

that the specified equipment is (i) handed over in Nigeria to the Federal Medical Centre and (ii) is complete and in good working condition. It is therefore accepted in accordance with the contract and is now ready for [first] patient use. The warranty period of 12 months started on 01-04-2011 and will expire on 01-04-2012.

A. Equipment List per Room

Brilliance 16

On behalf of:
Federal Medical Centre,
Nigeria

Name:
Designation:

Signature: _____

Date: .....

Place: .....

On behalf of:
Philips Medical Systems Nederland B.V.
By its authorized representatives

Name: Floris Brouckaert
Designation: **Project Manager**

Signature: _____

PHILIPS MEDICAL SYSTEMS NEDERLAND B.V.

Floris Brouckaert
Project Manager Indent Business Africa
Philips Healthcare
+31-40-27.82266

Appendix E: Acceptance certificate for GE Brightspeed 16-sclice

GE Healthcare Technologies

ACCEPTANCE CERTIFICATE

FOR:- BrightSpeed Delight 16 CT Scanner

Federal Neuropsychiatric Hospital – Maiduguri

Quotation Number: MH/PROC DPT/CP/09/024 SO Number: 2835975

The following medical equipment has been completely installed to factory specification and found to be operating satisfactorily

OPTION	SERIAL No.
BrightSpeed Delight 16 CT Scanner	
MH/PROC DPT/CP/09/024	

Warranty

Warranty on this unit commences on 04/03/2011 for a 12 month period

The warranty ceases on 03/03/2012

Reserves and Conditions

Sales Manager GE Healthcare Technologies	OTR Manager GE Healthcare Technologies	Service Manager GE Healthcare Technologies
Date		Date

NAME, DATE AND SIGNATURE

FEDERAL NEURO PSYCHIATRIC HOSPITAL MEDICAL DIRECTOR SIGN FOR AND ON BEHALF OF MAIDUGURI

7/3/11

Appendix F: Ethical clearance from the CPUT

Cape Peninsula University of Technology

PDF COPY OF ORIGINAL

20 July 2011
CPUT/HW-REC 2011/H13

P.O. Box 1906 • Bellville 7535 South Africa •Tel: +27 21 442 6162 • Fax +27 21 447 2963
Symphony Road Bellville 7535

OFFICE OF THE CHAIRPERSON:
HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE (HW-REC)
Registration Number NHREC: REC- 230408-014

At the meeting of the Health and Wellness Sciences-REC on 22 June 2011 approval was granted to Idris Garba pending amendments that have now been received and reviewed. This approval is for research activities related to an MTech: Radiography at this institution.

TITLE:

The development of a diagnostic reference level for head ct scans in northern Nigeria

INTERNAL SUPERVISOR: **Ms F Davidson**
INTERNAL CO-SUPERVISOR: **Prof P Engel-Hills**

Comment:

Research activities are restricted to those detailed in the revised proposal and application submitted in June 2011

Approval will not extend beyond 20 July 2012. An extension must be applied for should data collection for this study continue beyond this date.

Prof PENELOPE ENGEL-HILLS
CHAIR: HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE

e-mail*: engelhillsp@cput.ac.za*

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APPENDIX I: CPUT Review results

Review CPUT

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APPENDIX J: Centre (A) data

SN	CT NUMBE	DATE	AGE	WEIGHT	SEX	AREA	CENTRE	kV	kV helical	mA	mA helical	mAs	mAs helical	SCANNER	NUMBER OF SLICES	NS helical	SLICE THICKNESS	ST helical	SCAN MODE	SCAN LENGTH	SL helical	ST	FOV	FOV helical	PITCH	CTDIw	CTDIvol	DLP	DLP HELICAL
1	2525/11	11/8/011	16	69	M	BRAIN	A	120		200				MULTISLIC	41		2.5,5		AXIAL	155		1	25			74.14		523.32	
2	2522/11	9/8/011	45	68	M	BRAIN	A	120		200				MULTISLIC	39		2.5,5		AXIAL	145		1	23.3			80.52		593.29	
3	2587/11	18/8/011	45	70	M	BRAIN	A	120		122				MULTISLIC	62		2.5		AXIAL	155		2	24.5			72.3		1120.63	
4	2753/11	13/10/011	70	67	M	BRAIN	A	120		200				MULTISLIC	62		2.5,5		AXIAL	155		2	25			78.59		1218.22	
5	2744/11	11/10/011	80	68	M	BRAIN	A	120		200				MULTISLIC	40		2.5,5		AXIAL	150		1	22.3			74.3		542.58	
6	2718/011	20/09/011	70	73	M	BRAIN	A	120		200				MULTISLIC	46		2.5,5		AXIAL	160		1	25			75.96		607.56	
7	2715/011	20/09/011	67	73	F	BRAIN	A	120		200				MULTISLIC	41		2.5,5		AXIAL	155		1	21.7			75.14		581.18	
8	2957/011	22/12/011	40	73	M	BRAIN	A	120		200				MULTISLIC	40		2.5,5		AXIAL	150		1	22.3			77.01		614.8	
9	2889/011	15/11/011	20	67	M	BRAIN	A	120		200				MULTISLIC	37		2.5,5		AXIAL	140		1	22.9			71.81		462.29	
10	2868/011	11/11/011	22	69	M	BRAIN	A	120		301				MULTISLIC	42		2.5,5		AXIAL	160		1	23.2			114.75		827.24	
11	2888/011	15/11/011	70	70	F	BRAIN	A	120		200				MULTISLIC	38		2.5,5		AXIAL	140		1	22.4			70.75		526.58	
12	2880/011	14/11/11	49	67	M	BRAIN	A	120		200				MULTISLIC	42		2.5,5		AXIAL	160		1	22			114.42		827.85	
13	2884/011	14/11/11	26	67	M	BRAIN	A	120		301				MULTISLIC	39		2.5,5		AXIAL	145		1	20.5			109.6		764.71	
14	2881/11	14/11/11	65	68	M	BRAIN	A	120		200				MULTISLIC	45		2.5,5		AXIAL	175		1	25			74.11		587.63	
15	2879/11	14/11/11	18	69	F	BRAIN	A	120		200				MULTISLIC	40		2.5,5		AXIAL	150		1	20.7			68.51		473.72	
16	2871/11	12/11/011	50	70	M	BRAIN	A	120		301				MULTISLIC	42		2.5,5		AXIAL	160		1	23.6			117.28		855.61	
17	2991/11	26/11/011	50	73	M	BRAIN	A	120		219				MULTISLIC	42		2.5,5		AXIAL	155		1	21.3			114.52		851.79	
18	2784/11	26/12/11	20	72	M	BRAIN	A	120		209				MULTISLIC	42		2.5,5		AXIAL	160		1	22.9			109.54		781.04	
19	2863/11	9/11/011	29	73	M	BRAIN	A	120		200				MULTISLIC	55		2.5,5		AXIAL	195		1	25			78.09		735.12	
20	2987/11	27/12/011	28	73	M	BRAIN	A	120		301				MULTISLIC	41		2.5,5		AXIAL	155		1	23			112.79		771.73	

APPENDIX J: Centre (B) data

SN	CT NUMBE	DATE	AGE	WEIGHT	SEX	AREA	CENTRE	kV	kV helical	mA	mA helical	mAs	mAs helical	SCANNER	NUMBER OF SLICES	NS helical	SLICE THICKNESS	ST helical	SCAN MODE	SCAN LENGTH	SL helical	ST	FOV	FOV helical	PITCH	CTDIw	CTDIvol	DLP	DLP HELICAL
1	145	18/8/011	33	67	F	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	144		1.75	22			67.3		985.45	
2	152	23/8/011	51	68	F	BRAIN	B		120				350	MULTISLICE		93		3	HELICAL		279	14.3		23	0.69		53.1		837.08
3	148	22/8/011	44	73	M	BRAIN	B		120				350	MULTISLICE		104		3	HELICAL		312	15.8		23	0.69		53.1		924
4	209	20/10/011	35	68	M	BRAIN	B		120				350	MULTISLICE		125		3	HELICAL		188	18.66		20.1	0.688		53.1		1091.87
5	190	04/10/011	26	68	M	BRAIN	B	120				450		MULTISLIC	52		3		AXIAL	157.3		1.75	20.8			67.8		1066.79	
6	188	04/10/011	37	73	M	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	145.3		1.75	20.7			67.8		985.13	
7	193	04/10/011	40	73	F	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	145.3		1.75	18.9			67.8		984.63	
8	194	05/10/011	50	69	M	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	145.3		1.75	20.3			67.9		985.5	
9	192	05/10/011	55	73	M	BRAIN	B	120				450		MULTISLIC	32		3		AXIAL	158.8		1.75	22			67.3		1067.96	
10	204	06/10/011	33	73	F	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	148.9		1.75	21.9			66.2		985.58	
11	208	06/10/011	49	73	F	BRAIN	B	120				450		MULTISLIC	52		3		AXIAL	168		1.75	20			68.4		1149.16	
12	207	06/10/011	40	67	M	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	144		1.75	22			68.5		985.76	
13	205	07/10/011	40	73	F	BRAIN	B		120				200	MULTISLICE		96		3	HELICAL		150	10.08		17.7	0.688		30.4		506
14	218	07/10/011	50	68	F	BRAIN	B	120				450		MULTISLIC	52		3		AXIAL	156		1.75	19.8			68.4		1066.91	
15	214	27/10/011	35	67	M	BRAIN	B	120				450		MULTISLIC	48		3		AXIAL	154		1.75	21.4			68.4		985.34	
16	215	5/12/011	54	67	M	BRAIN	B	120				450		MULTISLIC	60		3		AXIAL	181.5		1.5	25			67.9		1231.94	
17	216	5/12/011	30	73	M	BRAIN	B	120				450		MULTISLIC	60		3		AXIAL	181.6		1.5	21.2			67.8		1230.95	
18	217	5/12/011	16	67	M	BRAIN	B	120				450		MULTISLIC	68		3		AXIAL	204.1		1.5	21.6			68.4		1396	
19	218	7/12/011	25	68	F	BRAIN	B	120				450		MULTISLIC	60		3		AXIAL	180.1		1.5	21.8			68.5		1232.57	
20	219	7/12/011	50	73	M	BRAIN	B	120				450		MULTISLIC	60		3		AXIAL	181.6		1.5	23.2			67.8		1231.19	

APPENDIX J: Centre (C) data

SN	CT NUMBE	DATE	AGE	WEIGHT	SEX	AREA	CENTRE	kV	kV helical	mA	mA helical	mAs	mAs helical	SCANNER	NUMBER OF SLICES	NS helical	SLICE THICKNESS	ST helical	SCAN MODE	SCAN LENGTH	SL helical	ST	FOV	FOV helical	PITCH	CTDIw	CTDIvol	DLP	DLP HELICAL
1	CT0056	16/9/011	50	68	M	BRAIN	C	140		160				MULTISLIC	38		2.5,5		AXIAL	150		2	22.5			75.35		515.19	
2	CT0065/2	30/9/011	23	73	M	BRAIN	C	140		160				MULTISLIC	46		2.5, 5		AXIAL	170		2	26.9			76.36		617.7	
3	CT0064	30/9/011	39	68	F	BRAIN	C	140		160				MULTISLIC	42		2.5,5		AXIAL	160		2	24			72.87		566.45	
4	CT0072/2	30/9/011	27	67	F	BRAIN	C		140	160				MULTISLIC	48		2.5,5		AXIAL	170		2	23.8			77.55		640.77	
5	CT0072	30/9/011	22	70	M	BRAIN	C	120			245			MULTISLICE		35		5	HELICAL		175	1		25	0.562		97.63		1842.52
6	CT0071	30/9/011	60	73	M	BRAIN	C	140		160				MULTISLIC	42		2.5,5		AXIAL	160		2	26.5			76.73		566.4	
7	CT0065	30/9/011	19	67	M	BRAIN	C	140		160				MULTISLIC	40		2.5,5		AXIAL	170		2	26.3			74.88		543.39	
8	CT0080	7/10/011	32	68	F	BRAIN	C	140		160				MULTISLIC	40		2.5,5		AXIAL	150		2	21.8			76.73		538.2	
9	CT0082	7/10/011	23	73	M	BRAIN	C	140		160				MULTISLIC	42		2.5,5		AXIAL	160		2	24.7			76.36		566.45	
10	CT0087	11/10/011	21	67	F	BRAIN	C	140		160				MULTISLIC	72			2.5	AXIAL	180		2	22.1			49.26		922.66	
11	CT0086	11/10/011	54	73	M	BRAIN	C		120		260			MULTISLICE		36		5	HELICAL		180	1		21.3	0.562		103.61		2007.5
12	CT0089	28/10/011	60	73	M	BRAIN	C	120		140				MULTISLIC	42		2.5,5		AXIAL	160		2	24.9			71.71		566.45	
13	CT0090	1/11/011	20	69	M	BRAIN	C	120		140				MULTISLIC	50		2.5,5		AXIAL	180		2	22.5			77.55		668.96	
14	CT0092	1/11/011	35	68	F	BRAIN	C	120		140				MULTISLIC	50		2.5,5		AXIAL	180		2	23.7			77.41		668.96	
15	CT0093	1/11/011	42	73	M	BRAIN	C	120		140				MULTISLIC	46		2.5,5		AXIAL	180		2	22.5			76		622.85	
16	CT0094	1/11/011	34	67	M	BRAIN	C	120		140				MULTISLIC	50		2.5,5		AXIAL	180		2	22.7			76.15		668.96	
17	CT0095	4/11/011	77	68	F	BRAIN	C	120		140				MULTISLIC	38		2.5,5		AXIAL	150		2	21.8			74.19		515.19	
18	CT00100	11/11/011	29	72	M	BRAIN	C	120		90				MULTISLIC	58			5	AXIAL	290		2	27.5			17.29		525.65	
19	CT00101	11/11/011	70	68	F	BRAIN	C	140		160				MULTISLIC	38		2.5,5		AXIAL	147.5		2	22			72.01		515.2	
20	CT00106	15/11/011	33	67	F	BRAIN	C	140		160				MULTISLIC	38		2.5,5		AXIAL	150		2	22.1			70		516.5	