

**ASSESSMENT OF DIAGNOSTIC REFERENCE
LEVELS AND RADIATION-INDUCED LIFETIME
CANCER RISK FROM COMPUTED
TOMOGRAPHY EXAMINATIONS IN SELECTED
SOUTH-WESTERN NIGERIAN TEACHING
HOSPITALS.**

OLAWUNI Caroline Olayemi

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**A DISSERTATION SUBMITTED IN THE DEPARTMENT OF
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ABSTRACT

The growing utilisation of computed tomography (CT) has prompted greater attention to exposure of radiation and its potential health risk coupled with the lack of nationally established diagnostic reference levels (DRLs) in Nigeria. This study was therefore aimed at assessing DRLs and estimating lifetime attributable cancer risks (LAR) among population involved in CT examinations at the participated teaching hospitals in South-western Nigeria.

A retrospective study was adopted using CT examination data obtained from two University teaching hospitals in South-western Nigeria; Babcock and Obafemi University Teaching Hospitals. CT records from 266 patients who underwent CT examinations were analyzed. $CTDI_{vol}$ and DLP were recorded directly from CT scanner and size-specific conversion factor published by Romanyukha *et al.* (2016) was used to estimate effective doses. 75th percentile value of $CTDI_{vol}$ and DLP was adopted as local Diagnostic Reference Levels (DRLs). LAR was estimated using online X-ray risk software. Data were analysed using IBM SPSS.

The results showed considerable variability across anatomical regions and examination protocols, indicating a wide spread of patient doses. In centre A, the mean $CTDI_{vol}$ for non-contrast head examinations was 49.7 ± 19.4 mGy, while contrast-enhanced head examinations recorded 69.7 ± 32.8 mGy. Similarly, abdominal examinations showed substantial variation, with $CTDI_{vol}$ and DLP values of 31.3 ± 23.8 mGy and 1304.0 ± 905.9 mGy.cm respectively. In centre B, head examinations exhibited $CTDI_{vol}$ values of 58.5 ± 19.4 mGy and DLP values of 1219.6 ± 431.0 mGy.cm. The adult local DRLs estimated

for head CT showed CTDI_{vol} values ranged from 57.6 – 65.3 mGy, while DLP ranged from 1393.5 – 2050.1 mGy.cm. Chest CT recorded CTDI_{vol} values between 6.9 and 15.4 mGy while DLP recorded 495.6 and 819.0 mGy.cm. Abdomen examinations showed CTDI_{vol} values 8.6 – 42.0 mGy and DLP values of 1621.9 – 1730.2 mGy.cm. some of the values recorded were within the ICRP recommended limits while some were greater than the ICRP CTDI_{vol} and DLP values which are 60 mGy, 1050 mGy.cm, 30 mGy, 650 mGy.cm, and 35 mGy, 780 mGy.cm for head, chest, and abdomen respectively.

Among pediatric patients, head CTDI_{vol} (30.6 - 45.8) mGy were below the ICRP reference levels of 70 mGy. However, pediatric head DLP values reached 1515.4 mGy.cm in centre A and 872.9 mGy.cm in centre B, exceeding the recommended value of 750 mGy.cm. The lifetime cancer risk ranged from 10 to 275 cases per 100,000 population and the highest recorded in the study (275 cases per 100,000 population) was associated with contrast-enhanced CT examinations while the lowest LAR (10 cases per 100,000 population) was observed among patients > 60 years. The statistical test employed demonstrated significant differences in LAR across gender, age groups, region, and contrast status ($P < 0.001$).

CT examinations contributed significantly to patient radiation exposure and potential cancer risk, particularly when the recommended DRLs were consistently exceeded. Young patients, females, and patients that underwent contrast CT examinations exhibited LAR. Consequent to the findings, the study recommends establishment of separate national DRLs for adults, pediatrics, and contrast-enhanced CT examinations in Nigeria.

Key Words: Cancer, Contrast-enhanced, Diagnostics, patient, pediatrics,

Word counts: 493

CERTIFICATION

I certified that this research work was carried out by OLAWUNI, CAROLINE OLAYEMI with matriculation number PSC/F/24/25/0016, under our supervision in the Department of Physics, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.

Dr. Abayomi E. Ajetunmobi,

B.Sc. (Ogun), M.Sc. Ph, (Ibadan), Ph.D. (Abeokuta)

Supervisor.

Date

Dr. Timothy W. David

B.Sc., M.Sc. (Ogun), Ph.D. (Leicester)

Head of Department

Date

DEDICATION

I dedicated this dissertation to the Almighty God, Saviour of my soul, Keeper, Shield and Sufficiency who made it possible for me to complete my course in this University (Olabisi Onabanjo University Ago-Iwoye Ogun State).

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TABLE OF CONTENTS

Content	Page
Abstract	ii
Certification	iv
Dedication	v
Acknowledgments	vi
Table of Contents	vii
List of Tables	xi
List of Figures	xii
List of Plates	xiii
List of Abbreviations	xiv
List of Acronym	xv
Chapter One: Introduction	1
1.1 Background to the Study	1
1.2 Statement of the Problem	5
1.3 Aim and Objectives of the Study	6
1.4 Significant of the Study	6
1.5 Scope of the Study	7
1.6 Operational Definition of Terms	7
CHAPTER TWO: LITRATURE REVIEW	12
2.1 Background to Computed Tomography	12
2.2 Radiation Exposure in Medical Imaging	13
2.3 Concept of Diagnostic Reference Levels	15

2.4 Cancer Risk Estimation Method from CT Radiation	17
2.5 CT Dose Metrics and Measurement	18
2.6 Summary of Empirical Studies	19
2.7 Radiation Protection Regulation	21
2.8 Research Gaps	23
CHAPTER THREE: MATERIALS AND METHODS	24
3.1 Ethical Considerations	24
3.2 Study Design	24
3.3 Study Area	24
3.4 Study Sites and Population	25
3.5 Sample Size and Sampling Techniques	25
3.5.1 Population	25
3.5.2 Inclusion Criteria	25
3.5.3 Exclusion Criteria	26
3.6 Research Materials	26
3.7 Variables and Measurement	31
3.8 Data Collection Procedure	31
3.9 Estimation of Effective Dose	31
3.10 Lifetime Cancer Risk Estimation	33
3.11 Determination of Diagnostic Reference Levels	35
3.12 Analysis of Data for the Study	35
3.12.1 Comparative Statistics for Radiographic Parameters	35
3.12.2 Graphical Presentation of the Result of the Study	36

CHAPTER FOUR: RESULTS AND DISCUSSION	37
4.1 Demographic Characteristics of Patients in Center A	37
4.2 Demographic Characteristics of Patients in Center B	38
4.3 Estimation of CT Dose Metrics for Centre A	39
4.4 Estimation of CT Dose Metrics for Centre B	40
4.5 Establishment of Diagnostic Reference Levels	41
4.6 Estimation of Effective Dose	44
4.7 Estimation of Lifetime Attributable Risk	48
4.8 Characteristics of Exposure Parameters for Centre A and B	53
4.9 Comparative Statistical Analysis	55
4.10 Discussion of the Results	59
CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATION	71
5.1 Summary	71
5.2 Conclusion	81
5.3 Recommendations	73
References	76

LIST OF TABLES

Table	Description	Page
3.1	Description of CT Scanner for Center A	27
3.2	Description of CT Scanner for Center B	29
3.3	Specific Size Conversion Factor	32
4.1	Demographic Details of the Patients for Center A	37
4.2	Demographic Details of the Patients for Center B	38
4.3	Radiation Dose Metrics by Body Region and Contrast for Centre A	39
4.4	Radiation Dose Metrics by Body Region and Contrast for Centre B	40
4.5	Comparison of Adult Local DRLs with International DRLs	41
4.6	Comparison of Local Pediatric DRLs with ICRP	42
4.7	Comparison of Adult DRLs between Centres A and B	43
4.8	The Estimated (mean) Effective Dose	44
4.9	Comparison of Effective Dose with other Studies	46
4.10	Estimated of LAR per 100,000 population for Gender and Region	48
4.11	Estimation LAR per 100,000 Population (age group)	49
4.12	Estimation of Exposure Parameters for Centre A	53
4.13	Estimation of Exposure Parameters for Centre B	54
4.14	Statistical Comparison of LAR for Gender and Contrast Status	56
4.15	Statistical Comparison of LAR for Age-group and Scan Region	57
4.16	Statistical Comparison of CT Dose and LAR between Centre A and B	58

LIST OF FIGURES

Figure	Description	Page
3.1.	X- Ray risk Calculator	34
4.1	Boxplot for Effective Dose Distribution between Centre A and B	45
4.2	Bar Chart Comparing Effective Doses with other Studies	47
4.3	Bar Chart Comparing LAR among Region	50
4.4	Bar Chart Comparing LAR among age groups	51
4.5	Bar Chart Comparing LAR between Male and Female	52

LIST OF PLATES

Plate	Description	Page
3.1.	160-slice Prime Aquilium CT Scanner for Center A	28
3.2	16-slice GE Revolution A CT CT Scanner for Center B	30

LIST OF ABBREVIATIONS

m A - Milliampere

kVp – Peak Kilovoltage

SD – Standard Deviation

kV – Kilovolt

mAs – Millianpere-Second

mSv – Millisievert

mGy – Milligray

Gy - Gray

LIST OF ACRONYMS

CT – Computed Tomography.

CTDI_{vol} – Volume Computed Tomography Dose Index.

CTDI – Computed Tomography Dose Index.

DLP – Dose Length Product.

DRLs – Diagnostic Reference Levels.

LAR – Lifetime Attributable Risk.

ALARA – As Low As Reasonably Achievable.

ICRP – International Commission on Radiological Protection.

CTDI_w – Weighted Computed Tomography Dose Index.

SSDE – Size Specific Dose Estimate.

BEIR – Biologic Effect of Ionising Radiation.

DNA – Deoxyribonucleic Acid.

UNSCEAR – United Nation Scientific Committee on the Effect of Atomic Radiation.

PET – Positron Emission Tomography.

NNRA – Nigeria Nuclear Regulatory Authority.

SPSS – Statistical Package for the Social Sciences.

IDL – International Diagnostic Reference Levels

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Computed Tomography (CT) scan refers to a sophisticated diagnostic imaging techniques that employs ionising radiation to detect the problems that may require medical attention within the human body. Since its introduction into clinical practice, CT has revolutionised medical diagnosis by providing rapid and accurate visualisation of the anatomical structures thereby facilitating early disease detection, treatment planning and patient management. In 2021, Computed tomography marked 50 years of clinical application, highlighting its remarkable contribution to modern health care (Hsieh, 2022).

The practice of CT technology using ionising radiation in medical diagnostics has substantially spread across the globe largely due to the expanding application of CT examinations. Mettler *et al.* (2009) estimated that approximately 3.6 medical procedures involving ionising radiation are performed annually worldwide, comprising about 3.1 billion radiological examinations. The exposure to ionising radiation could be recognised as the potential risk indicator for negative biological alterations like the development of benign and malignant tumour as well as various forms of cancer. Evidence reported by Goyes *et al.* (2018) demonstrated the occurrence of brain tumours among physicians exposed to ionising radiation, while Cao *et al.* (2022) showed that cancer risk in adults increased when radiation dose also increased following CT examinations.

Since its development in the early 1970`s CT has become a dependable diagnostic facility for disease diagnosis with improved image quality and scanning speed. Consequently, CT can be regarded as one of the commonly utilised scanning techniques worldwide. United States recorded 62 million CT in 2006 and 70 million in 2007 (Metler *et al.*, 2008; De Gonzalez *et al.*, 2009). Despite these advances and the substantial diagnostic benefits offered by CT, it contributes largely to patient`s exposure following CT radiation. the largest contributor to patient radiation exposure among diagnostic imaging modalities due to the relatively high radiation doses required for image acquisition.

Several studies have highlighted the contribution of CT to overall medical radiation exposure. Aloufi (2024) reported that CT is among the most commonly performed diagnostic examinations and it`s it contributes mostly to radiation doses. Journy *et al.* (2014) observed that CT contributes largely to the total radiation dose from CT examinations. The relatively high radiation delivered during CT examinations increase the potential risk of radiation associated carcinogenesis, and this emphasises the importance of radiation protection principles, including justification, optimisation, and dose minimisation (Foley *et al.*, 2012).

Growing concern regarding the health risk of CT radiation exposure has prompted extensive research into radiation-induced cancer risk. Smoll *et al.* (2023) reported that approximately 3.7 % of pediatric brain cancers in Australia were attributable to CT examinations. Mhagama *et al.* (2021) also reported that CT examinations accounted for almost 34% of the entire radiation received during CT examination yearly. Smith-Bindman

et al. (2009) demonstrated that CT donates majorly to radiation exposure in medical diagnosis, while De Gonzalez *et al.* (2012) estimated that CT could contributes 2% to cancers in the United States in the future. Likewise, Malik *et al.* (2024) reported that CT examinations contribute about 25% of total radiographic examinations. and account for 34% of the overall doses received during diagnostic examination. Chaparian and Zarchi (2018) noted that 29% of cancers were traced to CT scans in the U.S. The discoveries highlight the necessity for regular monitoring and optimisation of radiation doses during CT examinations.

The biological effects of ionising radiation have been extensively investigated using epidemiological evidence from populations exposed to radiation. Findings from survivors of the Hiroshima and Nagasaki atomic bombings, who absorbed radiation doses of about 10 to 100 mSv, demonstrated a measurable increase in the incidence of radiation-induced cancers. Smith-Bindman *et al.* (2009) noted that a single CT examination may deliver radiation doses within this range, suggesting that repeated or unnecessary CT examinations may result to higher lifetime cancer risk. These findings underscore the necessity of implementing appropriate radiation protection measures during CT examinations.

An important approach for assessing the health implications of radiation exposure is the estimation of Lifetime cancer risk which refers to the probability that a patient may develop cancer during the remainder of his or her lifetime following radiation exposure, depending on age at exposure and sex (Noor *et al.*, 2025). Estimating LAR provides valuable information for evaluating the potential health risk associated with CT examinations and

supports evidenced-based decision making in radiation protection and dose optimisation. Previous studies conducted in Nigeria have highlighted the necessity of regular monitoring and optimisation of CT doses. Adejoh *et al.* (2017) found that the computed tomography dose index volume (CTDI_{vol}) recorded from centres in Anambra States was within the limit of the European Commission standard. However, the dose-length product (DLP) values were considerably greater than the recommended limits, indicating opportunities for further optimisation of CT protocols.

The International Atomic Energy Agency (IAEA) recommends patients radiation exposure be kept as low as reasonably achievable (ALARA) and sufficient image quality must be maintained to accomplish the intended diagnostic or interventional purpose in CT practice, this requires careful selection of scanning parameters and adherence to established dose guidance levels, commonly referred to as Diagnostic Reference Levels (DRLs) which serves as control tools to identify abnormally high or low radiation doses and promote optimisation of imaging protocols(Arfat *et al.*, 2024).

Optimisation of radiation dose is the basic principle of regulating radiation in order to achieve the maximum diagnostic benefits while minimising unnecessary patient exposure. Generating information such as radiation dose levels, diagnostic reference levels, and associated lifetime attributable risk of cancer in many healthcare facilities within Southwestern Nigeria is essential for evaluating current practice, improving safety, and establishing local and national DRLs. Therefore, this project focuses on the assessment of

patient radiation doses, evaluation of DRLs and estimating LAR in the selected CT centres in South-western Nigeria.

1.2 Statement of the Problem

CT has become a frequently used diagnostic tool worldwide because of its high diagnostic accuracy. According to (UNSCEAR), about 4.2 billion radiological examinations are conducted yearly across the world, with more than one billion being CT examinations. Although CT accounts for just about 10% of all radiological practices, it results into almost 62.2% of total radiation dose received from radiographic procedures.

In Africa, an increasing use of CT has been accompanied by considerable variations in imaging protocols and patient radiation doses. An international Atomic Energy Agency (IAEA) multi-centre study involving 13 hospitals in 10 African countries reported significant differences in CT practices, with median dose values for abdomen-pelvis, chest, and head examinations exceeding recommended diagnostic reference levels in several centres.

In Nigeria, access to CT services has expanded steadily, with 183 CT scanners installed across the countries as of 2018, of which about 83% were functional. However, absence of nationally established diagnostic reference levels and consequent differences in examination techniques may result in unnecessary radiation exposure and increased lifetime cancer risk among patients.

1.3 Aim and Objectives of the Study

Aim: To assess the (DRLs) and estimate the lifetime cancer risks from (CT) examinations in the designated centres in South-western Nigeria. Specific objectives are:

- i. to ascertain the quantity of effective doses absorbed by patients during the CT scans.
- ii. to estimate the lifetime cancer risk that may be accrued during the CT scans procedures at the selected centres.
- iii. to evaluate the compliance of the selected CT centres with the established diagnostic reference levels.

1.4 Significance of the Study

The study produces useful information on patient radiation doses, diagnostic (DRLs), and the attributable cancer risk in computed tomography examinations in Southwestern Nigeria. The findings will support the previous knowledge on CT dose assessment and provide valuable evidence needed to protect and optimise exposure of radiation in clinical practice. The findings of this study will benefit patients by promoting safe CT practices through the identification of opportunities useful for optimization with desirable image quality.

Ultimately, the integration of radiation dose assessment, diagnostic reference levels, and lifetime risk estimation provides a more comprehensive evaluation of CT practice than assessing these parameters independently, consequently, the study will produce facts

leading to improving patient safety, strengthening radiation protection practices and supporting evidence-based policy development for CT imaging in Nigeria.

1.5 Scope of the Study

The study was carried out at two University Teaching Hospitals (Osun State and Ogun State, Southwestern Nigeria). The CT doses considered in this study were obtained from the examinations performed on head, abdomen, and chest. Patients of all age categories were involved in the overall dose assessment but adult above 18 years and above were used for the evaluation of local adult diagnostic reference levels while patients aged below 18 years were assessed for pediatric DRLs.

1.6 Operational Definition of Terms

The key terms associated with CT procedures used in this work are as follows;

Radiation Dose

This means the quantity of ionising radiation energy used by a particular tissue mass, measured in millisieverts (mSv) for effective dose or milli gray (mGy) for absorbed dose. In this study, effective doses were derived as the product of DLP and standardised conversion factor for different regions in the body.

Computed Tomography CT Imaging

Computed Tomography means diagnostic imaging technique adopted to generate a comprehensive internal structure of the body. It applies X-ray method to reveal the internal structure of human body for treatment, diagnosis, monitoring or planning.

Lifetime Attributable Risk

This means estimated probability that suggests an exposed individual is at risk of developing cancer over his or her remaining lifetime due to radiation exposure during CT imaging. It is calculated either by using models from the BEIR VII phase 2 reports, adjusted for age, sex and organ sensitivity to radiation or online X-ray risk calculator made by X-ray risk .com

Radiation-Induced Cancer

This refers to malignancies that develop through the radiation exposure during a diagnostic procedure. The probability of radiation-induced cancer was assessed under this study using the X-ray risk calculator.

Dose Length Product

This is obtained from computed tomography volume dose index and the entire length scanned. DLP represents the quantity of radiation taken by a patient and directly determines patient stochastic risk.

Effective Dose

This can be used for the estimation of cancer induction risk from diagnostic exposure. It considers the sensitivity of different organs and is expressed in millisieverts (mSv). Effective dose was estimated in this study from DLP using region-specific conversion factors.

BEIR An acronym for Biological Effects of Ionising Radiation. It refers to reports that provide scientific models for assessing the health risk, particularly cancer risk due to exposure to ionising radiation. It confirmed the linear no threshold risk model after the reviewing biophysical and biological data. The risk model suggests that cancer risk begins in a linear form with no threshold, and the smallest is capable of causing a small increase to humans.

X-Risk Calculator

X-risk calculator by an X-risk. Com is an online tool that estimates patient lifetime cancer risk from radiation exposure through CT examinations. this study estimated LAR using X-risk calculator by inputting effective dose, patient age, DLP, anatomical region and sex, using BEIR as its frame work.

Ionising Radiation

Ionising radiation refers to an electromagnetic energy that is sufficiently capable of removing molecules and atoms from the body tissue and disrupt chemical reaction in the body transforming molecules partially or fully to ions and conversely non-ionising radiation does not e.g radio waves and microwaves. It consists of gamma rays and x-rays capable of causing damage to the body tissue. (Chaturvedi and Jain, 2019).

Gray

Gray is used to express the absorbed radiation dose. when ionising radiation interacts with substance or matter it deposits an amount of energy to the substance. The energy is

measured per unit mass. The SI unit of dose used in form of 1J/ KG is Gray and the quantities of absorbed CT dose per kilogram is expressed in milli-Gray

Tube Current (mAs)

Tube current refers to the quantity of electrons per seconds and it determines the quantity or intensity of x-rays. It is measured in milliamperes (mA). The lower the tube current, the lower the radiation dose.

Tube Voltage (kVp)

This refers to the range of Kilo-volts and the energy and intensity of the electrons depend on the tube voltage. Previous studies showed that the application of low kVp can lead to reduction in examination dose with better image quality. According to the general rule, when the tube voltage rises the radiation dose increases.

Diagnostic Reference Levels

This serves as a control tool to optimize examination dose to protect patients from over or under exposure during interventional and diagnostic procedures. It identifies an unusually high or low radiation dose to effect appropriate measures for proper optimisation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background to CT imaging

CT is a developed imaging modality that applies ionising radiation to generate a comprehensive internal structure of human body. Since its introduction into clinical practice, CT has transformed diagnostic imaging by enabling accurate visualisation of anatomical structures and pathological conditions that may not be adequately demonstrated using conventional radiography. The first successful CT examination was performed in 1971, when images of the human brain were reconstructed using computer processing techniques, marking a revolutionary breakthrough in radiographic procedure (Schulz *et al.*, 2021).

The adoption of CT has increased considerably in Nigeria. According to Adejoh *et al.* (2018), the first CT scanner was installed in 1987 in southwestern Nigeria. Since then, several CT systems manufactured by companies such as General Electric (GE), Toshiba, Philips, Siemens, and Neusoft have been installed across numerous healthcare institutions in the country. Despite its numerous clinical advantages, CT contributes largely to patient radiation exposure among imaging modalities because it employs relatively high doses of ionising radiation. Although, individual risk from a single CT diagnosis is generally low, but the increase in CT procedures performed globally has raised concern regarding the cumulative health effects of exposure to radiation. (Shao *et al.*, 2019).

The indispensable role of CT in modern medicine continues to drive its widespread utilisation across healthcare systems worldwide. Advances in CT technology have improved diagnostic performance, reduced scanning time, and enhanced image quality, making CT an essential tool in emergency medicine, oncology, neurology, cardiovascular imaging, and trauma management. However, the high demand for CT has also intensified concerns regarding patient exposure and the relative risk of radiation-induced diseases. Smith-Bindman *et al.* (2025) emphasised that CT contributes majorly to medical radiation exposure, while Alashban and Shubayr (2023) reported that the continuous increase in CT utilisation has heightened concerns about radiation-induced cancer and other biological adverse health effects. Given the indispensable role of CT in contemporary medical practice, there is an increasing need to ensure that patient doses are optimised with consideration for effective diagnostic image quality. Achieving this balance is fundamental to radiation protection and forms the basis of implementing optimisation strategies, including the establishing DRLs and the evaluation of radiation-related cancer risk.

2.2 Radiation Exposure in Medical Imaging

Many diagnostic imaging modalities, particularly Computed tomography, Conventional radiography, fluoroscopy, and nuclear medicine, utilise ionising radiation to produce diagnostic images. Ionising radiation is characterised by its ability to transfer sufficient energy to atoms or molecules to strip off electrons, leading to the formation of ions. X-rays and gamma rays are the major ionising radiation applied in imaging procedure. When ionising radiation interacts with biological tissues, It may directly or indirectly damage

Cellular DNA by the formation of free radicals. If the cellular mechanism cannot repair the damage, it may result in genetic mutations, chromosomal abnormalities or malignant transformations of affected cells (Chaturvedi and Jain, 2019).

The biological risks of ionising radiation are divided into deterministic and stochastic effects. Deterministic effects occur only after exceeding threshold dose and the risk increases when radiation dose also increases. Stochastic effects do not have threshold dose limits. Instead, the risk may probably occur with increase in radiation dose. Radiation-caused cancers and hereditary genetic mutations are the principal stochastic effects associated with medical exposure (Goyes *et al.*, 2018)

Extensive epidemiological evidence has established ionising radiation as a significant risk factor for several malignancies, including Leukaemia, brain tumours, thyroid cancer, breast cancer, bone and tissue sarcoma. De Gonzalez *et al.* (2012) identified radiation exposure as one of the recognised causes of soft tissue and bone sarcomas, particularly among children, who are more susceptible because their cells are radiosensitive and dividing rapidly coupled with longer life expectancy. Following exposure. Similarly, Matthew *et al.* (2013) reported population of 608 for cancer cases among individuals diagnosed through CT examinations during childhood or adolescence, including brain tumors, solid cancers, leukaemia and lymphoid malignancies. Chen *et al.* (2025) observed that repeated CT scanning can contribute to protracted health effects, including cardiovascular diseases and malignancies. De Gonzalez (2009) emphasised that age at exposure mostly determines

radiation-induced cancer risk with children exhibiting substantially greater susceptibility than adults

The increasing use of ionising radiation in healthcare has reinforced the importance of maintaining balance between diagnostic benefits and potential radiation risks. Kashecheev and Pryakhin (2018) reported that although CT and radionuclide imaging institute a relatively small proportion of radiological procedures, they constitute a disproportionately large share of the collective radiation dose. Consequently, international radiation safety standards recommend that patients must be intimated with the knowledge of benefits and risks associated with radiological examinations.

2.3 Concept of Diagnostic Reference Levels (DRLs)

DRLs are standardised dose investigation levels applied to control radiation exposure from diagnostic imaging. They are control tools to identify unusually high or low doses for standard imaging examinations with consideration for qualitative diagnostic image. DRLs were first introduced by ICRP in publication 73 (1996) which were further refined in ICRP publication 135, which provides guidance on the appropriate dose quantities for different imaging techniques which include CT, pediatric imaging and interventional radiology (Vano *et al.*, 2017)

The introduction of DRLs forms the basic component of protecting exposure from radiation and ensuring quality assurance in CT practice. The ICRP recommends that each country establish national organisations responsible for collecting patient dose data and developing

national DRLs based on local practice (Vano *et al.*, 2017). In most countries DRLs were obtained using 75th percentile of the median radiation dose for standard examinations (O'Hara *et al.*, 2024). In countries where national DRLs have not yet been established, such as Nigeria, regional DRLs may serve as practical reference standards until sufficient data become available for the development of national benchmarks (Achuka *et al.*, 2021).

The application of DRLs has significantly improved radiation dose optimisation worldwide by encouraging periodic dose audits and the review of imaging protocols. According to Foley *et al.* (2012), adherence to radiation protection principles, particularly justification and optimisation, ensures diagnostic advantage of CT examinations higher than the relative radiation risks. Similarly, Meyer *et al.* (2016) emphasised the importance of DRLs in low and middle-income countries that uses ageing imaging facilities and shortages of competent personnel may contribute to unnecessary patient radiation exposure. Although, Nigeria currently adopts international recommendations because nationally established DRLs are unavailable, the development of local and national DRLs remains essential for standardising CT practice, improving patient safety and supporting evidence-based radiation dose optimisation.

2.4 Cancer Risk Estimation Methods from CT Radiation

This posited that an individual may probably develop cancer during the remainder of his or her lifetime following exposure to ionising radiation through CT.

The most widely accepted approach for estimating LAR is based on the (BEIR VII report (2006)) which provides risk coefficient based on age and sex for cancer cases and death per 100,000 individuals that received 100 mSv (0.1 Gy). Where specific age categories are unavailable, linear interpolation is recommended to estimate the corresponding LAR values. The BEIR model consistently demonstrates that females and younger patients have higher lifetime attributable cancer risk because of their cells and tissues are highly radiosensitive coupled with longer post-exposure life span (Aloufi, 2024).

In addition to the BEIR model, several computer-based tools have been developed to estimate cancer risk from CT examinations. Smith-Bindman *et al.* (2025) predicted future radiation-induced cancers using the National Cancer Institute Radiation Risk Assessment Tool (RadRAT), while Mansour *et al.* (2025) employed the X-Ray Risk.com calculator to estimate LAR from CT radiation exposure. These tools integrate patient age, sex, organ dose, and effective dose to estimate individual cancer risk and have become valuable resources for radiation protection research and dose optimisation.

2.5 CT Dose Metrics and Measurements

The Patient's dose administered for imaging largely determined by the pitch, the site and the scan length. $CTDI_w$ (CTDI weighted) refers to both the radiation dose at the centre and the periphery or edges and the assumption is that radiation declines linearly from outside to the centre. The $CTDI_w$ will be divided by scan length to obtain CTDI for a single slice. $CTDI_{vol}$ is estimated when $CTDI_w$ is divided by the pitch. $CTDI_{vol}$ refers to the

radiation dose output by CT scanner which determines the quantity of actual dose absorbed by a patient. When the pitch increases, the dose decreases. Equations 2.1 and 2.2 present the formular for $CTDI_{vol}$ and DLP as adopted by Artifafat *et al.*, 2014.

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \quad 2.1$$

$$DLP = CTDI_{vol} \times \text{scan length} \quad 2.2$$

DLP allows better estimation or measurements of stochastic risk to the patient while Pitch describes table movement following 360 degrees rotation (Devi *et al.*, 2024; Arfat *et al.*, 2024). Similar $CTDI_{vol}$ figures for brain CT may result into different doses absorbed, taking into consideration the size of the head of patients. The larger the head, the more the attenuation of the scanning region and how the quantity of absorbed x-ray by the distant tissues from the imaging site diminishes, thereby reducing dose absorbed. The size-specific dose estimate (SSDE) considers the variation in attenuation that exist between dosimetry phantom and the patient (Mitsui *et al.*, 2024). $CTDI_{vol}$ estimated radiation exposure to the scan site using scan parameters like rotation time, pitch and a dosimetry phantom to measure the absorbed dose. DLP refers to the entire exposure from imaging procedure. (Inoue *et al.*, 2023). Effective dose determines the associated stochastic effects of low-level radiological exposure. ICRP describes effective dose as the value of stochastic risk after receiving a low-dose exposure which represents a total dose taken by a patient through a specific exposure. It should also be considered that cancer risk depends on age at exposure, population group and gender. (Harrison *et al.*, 2021; Harrison *et al.*, 2023). Organ dose

represents the specific dose absorbed by a particular organ before multiplying by weighing factor

2.6 Summary of Empirical Studies

International studies have shown that abdomen-pelvis and multiphase CT examinations generally produce the highest radiation doses and corresponding lifetime cancer risks. Alhuyaili *et al.* (2025) established proposed national DRLs for Saudi Arabia. Also reported that females and children exhibits higher LAR than males. Similarly, (Smith-Bindman *et al.*, 2009; Smith-Bindman *et al.*, 2025) observed substantial variations in effective dose among various CT examinations, and projected that continued increase in CT utilisation could contribute significantly to future cancer incidence.

Studies by Brenner *et al.* (2001), De Gonzalez (2009), Miglioreti *et al.* (2013), Meulepas *et al.* (2013), Kiani and Chaparian (2023), Shubayr and Alashban (2023), and Mansour *et al.* (2025) consistently reported that age, sex, examination type, and the organs exposed are the major determinants of radiation-induced cancer risk. These studies further demonstrated that pediatric patients and females are more radiosensitive than adults and males, while examinations involving the abdomen, pelvis, chest, and multiphase protocols are associated with the highest effective doses and LAR values. In addition, Hall *et al.* (2006) and Little *et al.* (2025) emphasised the importance of cumulative radiation exposure, particularly among patients undergoing repeated CT examinations.

Within Africa, available evidence remains limited but demonstrates similar trends. Uushona *et al.* (2022) established adult CT diagnostic reference levels for several African countries, including Ghana, Senegal, Namibia, and Kenya, and reported noticeable variations in CTDI_{vol} and DLP between countries, highlighting the need for harmonised regional DRLs. Likewise, Mokubangele *et al.* (2024) evaluated radiation dose and lifetime cancer risk from CT was relatively low, females and younger patients consistently exhibited higher LAR estimates than males and older adults.

In Nigeria, empirical studies have primarily focused on radiation dose assessment and the establishment of DRLs. Ikubo and Tobi (2022) estimated the lifetime attributable risk from head CT examinations in the Niger delta region and reported generally low cancer risks despite variations in effective dose between centres. Kabeer *et al.* (2024) established local DRLs for abdomen-pelvis, chest, and head. CT examinations in Northern Nigeria and observed variations in comparison with international reference limits, indicating the necessity for continuous protocol optimisation. Similarly, M and S (2021) reported relatively high abdominal and chest CTDI_{vol} and DLP in CT examinations while Ibe *et al.* (2025) highlighted inadequate implementation of radiation protection practices and recommended stronger optimisation strategies and policy interventions. Overall, the reviewed literature demonstrates that patient age, sex, examination protocol, scan region, and CT scanner characteristics significantly influence radiation dose and LAR.

2.7 Radiation Protection Regulations

- i. The organization or individual who is responsible for the practice or activities involving radiation risk will be responsible for the safety.
- ii. Government must establish and maintain a result-oriented legal and governmental authority for the purpose of safety.
- iii. Efficient leadership and management must be assigned and sustained for the safety of the organization, facilities or practice involving radiation risk.
- iv. The activity or occupation that generate radiation risk must have associated benefits.
- v. There is need to optimise protection so that maximum safety can be achieved reasonably.
- vi. The strategy to control radiation risk must be safe for all individuals and free of any danger or damage.
- vii. Everybody must be protected from radiation risk either at present or in the future and there must be adequate effort to prevent and mitigate radiation or nuclear accident.
- viii. There must be arrangements for emergency, preparation and prompt response to prevent radiation or nuclear accidents.
- ix. Justification and optimisation of protective measure to reduce unregulated or existing radiation risk should be maintained. (European Commission *et al.*, 2014).

ICRP publication 135 Recommendation:

- x. CTDI_{vol} and DLP are to be used in determining DRLs using reference phantom measured 16 and 32 cm diameter for head and body respectively.
- xi. There must be consideration for adjustment in nuclear medicine and pediatric imaging.
- xii. Both national and regional established DRLs should be subject to frequent revision like three to five years or more.
- xiii. The median value of DRLs must be compared with regional, national, or local DRLs to ensure a significantly lower than the set DRLs which will consequently affect the image quality adversely.
- xiv. The regional values are to be established as the median value of national DRLs based on 75th percentile.
- xv. The national DRLs must be established using 75th percentile of median value of represented samples from the centres.
- xvi. NNRA recommended that the applicant seeking license to operate radiotherapy in Nigeria must ensure the availability of all the required personnel such as medical physicist, Radiographers, Radiotherapist, Oncology Nurses, and Biomedical Engineer with professional training and installation of facilities must be ensured.
- xvii. NNRA required radiation warning signs to be posted at strategic places and radiation warning lights must be installed within the radiography units.

2.8 Research Gaps

Although numerous studies have evaluated radiation doses from CT examinations and established DRL, while others have focused on estimating radiation-induced Lifetime Attributable Risk (LAR), these aspects have largely been investigated independently. Consequently, there is limited evidence linking optimization of radiation dose through DRLs with the corresponding estimation of potential lifetime cancer risk in the same patient population. This lack of an integrated approach limits comprehensive evaluation of CT practice and the ability to maintain balance between qualitative diagnostic image and patient's radiation dose. Therefore, this study addresses the gap by integrating radiation dose assessment, assessing local DRLs, and estimating lifetime Attributable Risk from CT examinations, thereby providing evidence to support dose optimization and radiation protection in clinical practice.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Ethical Considerations

Ethical clearance was obtained from the Health Research Ethics Committee of Obafemi Awolowo Teaching Hospital. In addition, an approval letter permitting data collection was obtained from the Chief Medical Director (CMD) of Babcock University Teaching Hospital. All information obtained during the study was treated with confidentiality.

3.2 Study Design

A retrospective study design was adopted. Patient dose data were obtained from CT procedures performed between October, 2025 and March, 2026 from the CT centres. The study design allowed the collection of large number of patient's dose records across different ages, gender, and scan sites for comprehensive analyses.

3.3 Study Area

Data for this study were collected from Babcock University Teaching Hospital Ilisan, Ogun state (hospital A) and Obafemi Awolowo University Teaching Hospitals Complex Ile-Ife Osun State (hospital B). Both centres are located in Nigeria. These study locations were selected because they are University teaching hospitals with adequate facilities and personnels where diagnoses of different diseases and radiotherapy treatment will be consistently conducted in order to arrive at evidence-based results.

3.4 Study Sites and Population

A total of 141 patients CT scan data were collected from Babcock teaching hospital while 125 Patients CT data were obtained from Obafemi Awolowo University Teaching hospitals complex.

3.5 Sample Size and Sampling Technique

3.5.1 Population

266 CT scans examinations performed on head, chest and abdomen conducted within six months. (October, 2025 – March, 2026) at Babcock University Teaching Hospital Ilisan Ogun State, using Toshiba Aquilion 160-slice CT scanner and Obafemi Awolowo University Teaching Hospitals Complex Ile-Ife, Osun State, using GE Revolution ACT 16-slice CT scanner. 141 CT records were obtained from Babcock University Teaching Hospital. (centre A) and 125 was obtained from Obafemi Awolowo University Teaching Hospitals Complex. (centre B).

3.5.2 Inclusion Criteria

Male and female Patients including both adults and children who underwent CT scan performed on abdomen, chest, and head are grouped as follows: 0-20, 21-40, 41-60, 60 and above. Complete dose-report data ($CTDI_{vol}$ & DLP) were collected at the selected CT scan centers. All patients within the following age groups are included: 0-20 years, 21-40 years, 41-60 years, and > 60years. The age categories were chosen to distinguish pediatric patients from adults and to evaluate the well-established decline in radiation-induced cancer risk with increasing age as observed in the empirical studies.

3.5.3 Exclusion Criteria:

Missing or incomplete dose report and scans involving multiple regions were excluded from the study.

3.6 Research Materials (CT Scanners)

Center A operates with Toshiba Prime Aquilion CT scanner that is 160-slice CT scanner while center B uses a GE Revolution ACT which is 16-slice CT scanner. Tables 3.1, 3.2, plates 3.1, and 3.2 present the details of the CT scanners and images at the selected study centers.

Table 3.1: Description of CT scanner for Center A

SPECIFICATION	DETAILS
Model and type of scanner	PRIME Aquillion
CT scanner Manufacturer	Toshiba
System Type	Multi-Slice
Number of detector rows	80.0
Year of Installation	2015
Automatic Exposure Control (Yes/No)	YES



Plate 3.1: 160-slice Prime Aquilion used for computed Tomography scanning at Centre A.
Source: Babcock University Teaching Hospital CT scanner (Photo by the Author)

Table 3.2: Description of CT Scanner for Center B

SPECIFICATION	DETAILS
Model and type of Scanner	G E Revolution ACT
CT Scanner Manufacturer	G E Health Care
System Type	Multi -slice
Number of detector rows	16.000
Year of Installation	2019
Automatic Exposure control (Yes/No)	YES



Plate 3.2:16-slice GE Revolution ACT used for computed Tomography scanning a
Centre B

Source: Obafemi Awolowo University Teaching Hospitals Complex CT scanner
(Photo by the Author)

3.7 Variables and Measurement

The primary variables, which include the $CTDI_{vol}$ was recorded from the CT console and the DLP (Dose Length Product) obtained directly from the CT console. Also, the patients' demographics (Age and sex) were obtained directly from CT console. Effective Dose was calculated from the product of DLP and conversion factor (k) published by Romanyukhal *et al.* (2016). The secondary variables, which include the scanner parameters such as kVp and mA were obtained directly from the CT console.

3.8 Data Collection Procedure

Ethical approval and permission were obtained from CT centres, and all eligible data within the study period were obtained. The $CTDI_{vol}$ was automatically generated by the CT console and does not require manual calculation. The DLP (mGy, cm) and the patient's demographic records were also obtained directly from the CT console.

3.9 Effective Dose Estimation

Effective dose (E) was calculated using equation 3.1 below. The conversion factor (k) adopted for the study was derived from body size-specific k factors published by Romanyukhal *et al.*, (2016) as expressed in equation 3.2, and l connotes dose length.

$$E = DLP \times k(mSv) \quad (3.1)$$

$$k = \frac{E}{DLP} = \frac{E}{CTDI_{vol}} \times l \quad (3.2)$$

Table 3.3: Size-specific conversion factors.

Region	< year old	1 year old	5 years old	10 years old	Adult
Head	0.009	0.006	0.004	0.003	0.002
Chest	0.099	0.064	0.047	0.033	0.021
Abdomen	0.088	0.063	0.043	0.032	0.022

Source: (Romanyukha *et al.*, 2016).

3.10 Lifetime Attributable Cancer Risk Estimation

The lifetime Cancer risk was estimated using X-ray risk software by X-ray risk.com. The software is user's friendly and permits parameters such as patient's age at exposure, patient's gender, estimated effective dose, DLP (mGy) and the type of examination/region to be entered at its interacting interface. Figure 3.3 presents the software for LAR estimation.



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Risk Calculator

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Plain Films (x-rays)

- Chest x-ray (2 views)
- Abdomen x-rays
- Pelvis x-rays
- Hip x-rays (unilateral)
- Neck x-rays
- Upper Back x-rays
- Lower Back x-rays
- Extremity x-rays (Hands, Feet, etc)
- Mammogram (unilateral)
- Dental x-ray (panoramic)
- Dental x-ray (4 intraoral bitewings)
- Skull x-rays
- DEXA Scan (Bone Density)

Dose is based on multiple views

CT Scans

Study: First, select a study on the left.

Gender: Male ☒ Female ☐

Age at Time of Study: (years)

Number of Exams:

Effective Dose: (mSv)

DLP (Optional for CT): (mGy · cm)

Total Effective Dose:	0	(mSv)
Additional Cancer Risk:	0.000000	(%)
Baseline Cancer Risk:		(%)
Baseline + Additional Risk:		(%)

Source: X-Ray risk. com

Figure 3.1: X-ray Risk Calculator for Cancer Risk Estimation

3.11 Diagnostic Reference Levels (DRLs) Determination

The CTDI_{vol} and DLP values were collected for each examination type and their median values were obtained using SPSS version 27. The local DRLs was estimated for both adults (18 years and above) and pediatrics (below 18 years) adopted 75th percentile value. The DRLs was estimated based on ICRP recommendation.

3.12 Analysis of Data

A statistical software, IBM SPSS version 27 was used for the estimation of basic statistical variables, such as median, percentile, minimum, and maximum. Normality of radiation dose parameters was assessed using the Shapiro-Wilk test which showed that the data were predominantly not normally distributed as $p < 0.001$. The descriptive statistics were summarised using mean + standard deviation, median, minimum and maximum.

3.12.1 Comparative Statistics of the Result of the study

The Mann-Whitney U test was used to compare differences in lifetime attributable risk between two independent groups. The analysis was done using non-parametric and the Statistical significance level was set at $p < 0.05$. The Man-Witney U test was used to compare lifetime cancer risk between male and female patients and between contrast and non- contrast CT examinations while Kruskal-Wallis H test was used to compare lifetime cancer risk among anatomical regions (Head, Chest, and Abdomen), and among age groups. The DRLs were assessed based on the 75th percentile of CTDI_{vol} and DLP.

3.12.2 Graphical Presentation of the Result of the Study

Graphical representations, including Pie Charts, bar charts and box plots, were used as visual assessment of the study variables. The graphs were used to illustrate variations in radiation dose metrics and LAR across anatomical regions, contrast status, gender, and age groups, thereby enhancing interpretation of the statistical findings.

CHAPTER FOUR

RESULTS AND DISSCUSSION

4.1 Demographic Characteristics of Patients for Centre A

Table 4.1: Demographic and Examination details of the study population for Centre A

Variables	Categories	Frequency	Percentage (%)
Sex	Male	88	62.4
	Female	53	37.6
Total		141	100.0
Age Group	0–20	18	12.8
	21–40	30	21.3
	41–60	46	32.6
	>60	47	33.3
Total		141	100.0
Contrast status	Contrast	58	41.1
	Non- contrast	83	58.9
Total		141	100.0
Scan Region	Head	108	76.6
	Chest	23	16.3
	Abdomen	10	7.1
Total		141	100.0

4.2 Demographic Characteristics of Patients in Centre B

Table 4.2: Demographic and Examination details of the study population for Centre B

Variables	Categories	Frequencies	Percentages
Sex	Male	61	49.6
	Female	63	50.4
Total		125	100.0
Age-Group	0–20	13	10.4
	21–40	25	20.0
	41–60	40	32.0
	>60	47	37.6
Total		125	100.0
Contrast status	Contrast	49	39.2
	Non-contrast	76	60.8
Total		125	100.0
Scan Region	Head	84	67.2
	Chest	16	12.8
	Abdomen	25	20.0
Total		125	100.0

4.3 Estimation of CT Dose Metrics for Centre A

Table 4.3: Radiation dose metrics by body region for centre A

Scan region	Dose metrics	Mean± SD	Median	Min	Max
Head					
C-	CTDI _{vol}	49.7± 19.4	59.5	4.2	119.0
C+		69.7± 32.8	59.5	22.9	130.8
C-	DLP	1267± 503.4	1246.0	97.0	2707.1
C+		1695.5± 1041.3	1246.2	54.8	4409.4
Chest					
C-	CTDI _{vol}	11.5 ± 5.5	11.5	7.6	15.4
C+		22.4 ± 36.3	12.6	2.2	165.0
C-	DLP	542. ± 391.7	542.0	265.0	819.0
C+		371.7 ± 148.3	426.1	69.1	629.8
Abdomen					
C+	CTDI _{vol}	31.3± 23.8	22.8	9.4	84.9
C+	DLP	1304.0 ± 905.9	791.9	515.7	2943.6

C+ With Contrast C- without contrast Centre A- Babcock University Teaching Hospital

4.4 Estimation of CT Dose Metrics for Centre B

Table 4.4: Radiation dose metrics by body region for centre B

Scan Region	Dose Metrics	Mean± SD	Median	Min	Max
Head					
C-	CTDI _{vol}	53.5 ± 19.4	57.6	22.3	69.1
C+		50.8 ± 17.8	53.7	7.9	69.1
C-	DLP	1219.6± 431.0	1151.8	537.6	2441.7
C+		2023.4 ± 691.6	1888.8	1011.6	3317.1
Chest					
C-	CTDI _{vol}	6.5± 0.6	6.5	6.0	6.9
C+		7.9 ± 1.9	7.7	5.2	11.6
C-	DLP	422.4 ± 214.2	422.4	270.9	573.9
C+		546.2 ± 262.2	462.9	251.9	1354.4
Abdomen					
C+	CTDI _{vol}	7.6 ± 1.4	7.8	5.3	10.2
C+	DLP	1443.6± 286.2	1548.7	885.8	1932.9

C+ with Contrast C- without contrast Centre B- Obafemi Awolowo University Teaching Hospitals Complex

4.5 Estimated DRLs for the Study

Table 4.5: Comparison of Adult Local DRLs with (ICRP) and other Countries.

Country	Head		Chest		Abdomen		References
	CTDI _{vol}	DLP	CTDI _{vol}	DLP	CTDI _{vol}	DLP	
Centre A	59.5	1446.6	15.4	819.0	–	–	Present study C-
Centre B	65.3	1393.5	6.9	573.9	–	–	Present study C-
Centre A	92.2	2373.6	14.6	495.6	42.0	1730.2	Present study C+
Centre B	57.6	2050.1	7.9	593.6	8.6	1621.9	Present study C+
Nigeria	61.0	1310.0	17.0	735.0	20.0	1486.0	Ekpo (2018)
Morocco	40.0	1445.0	11.0	700.0	9.0	788.0	Khajimi <i>et al.</i> (2024)
French	46.0	850.0	10.0	350.0	13.0	650.0	Roch <i>et al.</i> (2018)
USA	62.0	1120.0	17.0	610.0	17.0	860.0	Smith-Bindman <i>et al.</i> (2015)
Japan	77.0	1350.0	13.0	510.0	18.0	880.0	Kanda <i>et al.</i> (2021)
Ethiopia	43.0	1364.0	8.0	369.0	11.0	1569.0	Zewdu <i>et al.</i> (2021)
China	50.0	818.0	8.0	302.0	10.0	442.0	Li <i>et al.</i> (2020)
Sudan	41.0	461.0	9.0	165.0	8.0	270.0	Bashier <i>et al.</i> (2018)
Ireland	66.0	940.0	11.0	390.0	13.0	1120	Foley <i>et al.</i> (2012)
Kenya	61.0	1612.0	19.0	895.0	20.0	1842.0	Korir <i>et al.</i> (2015)
ICRP	60.0	1050.0	30.0	650.0	35.0	780.0	ICRP publication 87, (2000)

Note: CTDI_{vol} (mGy) DLP (mGy.cm)

Table 4.6: Comparison of local pediatrics DRLs with ICRP (10 years old pediatric)

Scan Region	Centre	ICRP CTDI _{vol}	ICRP DLP	This study CTDI _{vol}	This study DLP
HEAD	Centre A				
	C-	70.0	750.0	45.80	1515.40
	C+			30.60	549.30
	Centre B				
	C-			33.60	872.90
	C+			—	—
CHEST	Centre A				
	C-	30.00	600.00	—	—
	C+			79.30	133.50
	Centre B				
	C-			—	—
	C+			7.90	418.20

Note: C+ = with Contrast, C- = without Contrast, CTDI_{vol} (mGy), DLP (mGy.cm). ICRP Publication 87, 2000

Table 4.7: Comparison of Adults DRLs between Centre A and B based on 75th percentile.

Scan Region	Parameters	Centre A	Centre B
Head	CTDI _{vol} (C-)	59.5	65.3
	CTDI _{vol} (C+)	92.2	57.6
	DLP (C-)	1446.6	1393.5
	DLP (C+)	2373.6	2050.1
Chest	CTDI _{vol} (C-)	15.4	6.9
	CTDI _{vol} (C+)	14.6	7.9
	DLP (C-)	819.0	573.9
	DLP C+)	495.6	684.1
Abdomen	CTDI _{vol} (C+)	42.0	8.6
	DLP (C+)	1730.2	1621.9

Note: C- = without contrast media C+ =with contrast media CTDI_{vol} (mGy) and DLP (mGy.cm)

4.6 Effective Dose Estimation

Table 4.8: The Estimated (mean) Effective Dose in mSv for Centre A and B

Scan Region		Centre A	Centre B
Head	C-	2.7 (0.6–5.9)	2.5 (1.1–4.9)
	C+	3.7 (1.8–8.3)	4.0 (2.0–6.6)
Chest	C-	11.4 (3.6–10.7)	12.4 (12.1–12.7)
	C+	7.9 (1.2–8.3)	12.1 (8.5–19.0)
Abdomen	C+	28.7 (7.0–43.6)	30.8 (9.4–42.5)

Note: C- = without contrast media, C+ = with contrast media. No routine CT examination for abdominal CT. The range (minimum – maximum) is inside the parenthesis and the mean effective dose is outside.

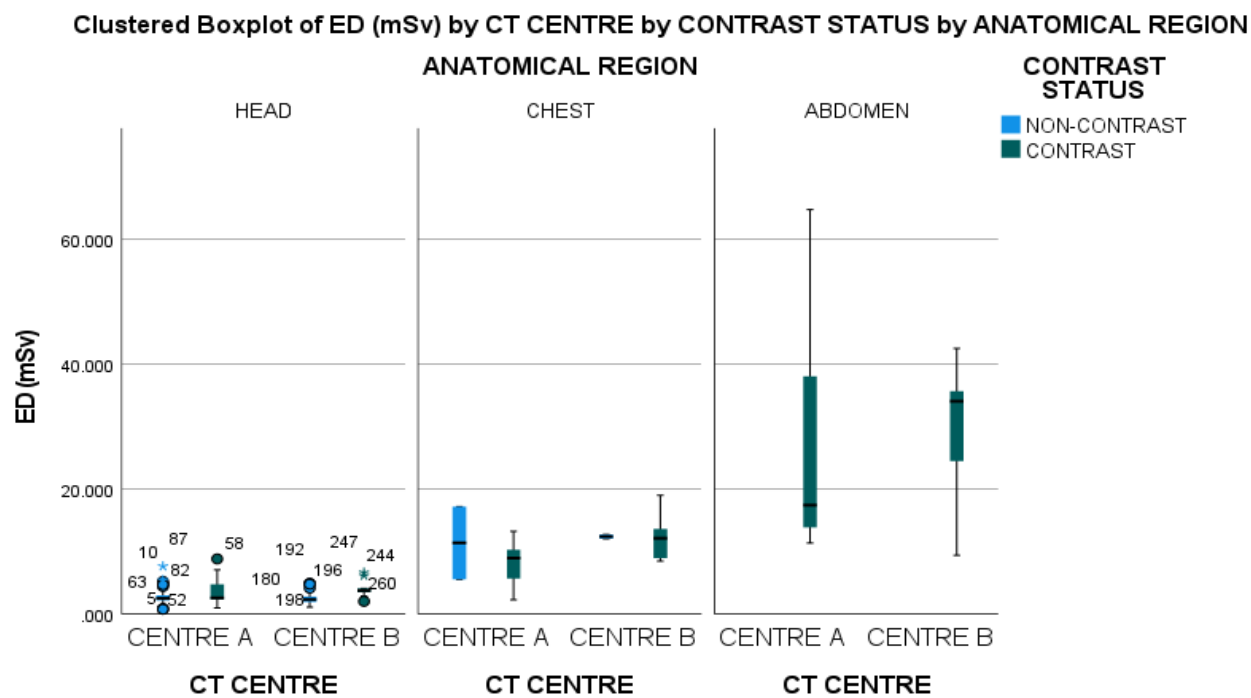


Figure 4.1: Distribution of Effective Doses between Centre A and B across the CT Region by Contrast Status.

Table 4.9: Comparison of Overall (contrast and routine) Effective Dose of Present Study with National and International Studies.

AUTHORS	HEAD	CHEST	ABDOMEN
Present Study: Centre A	2.9	8.2	28.7
Centre B	2.6	12.2	30.8
Ekpo (2018)	6.6	8.2	24.9
Osei and Darko (2013)	1.8	7.9	–
Clarke <i>et al.</i> (2000)	1.3	5.6	5.8
Origgi <i>et al.</i> (2005)	7.9	8.4	7.4
Tsai <i>et al.</i> (2007)	1.6	8.4	7.4
Aldrich <i>et al.</i> (2006)	2.8	9.3	10.1
Mokubangele <i>et al.</i> (2024)	1.7	3.9	6.5
Albadaneh & Ewaidat. (2026)	2.4	17.6	4.9

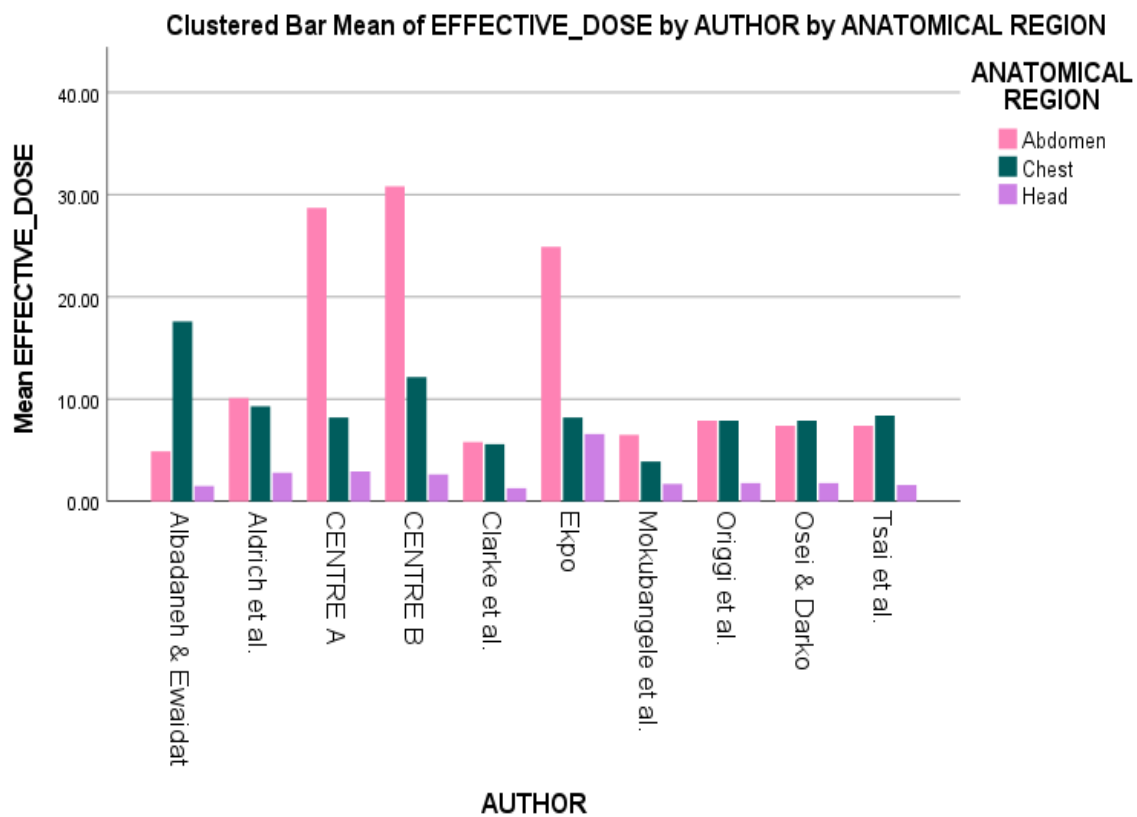


Figure 4.2: Comparison of Effective Dose of the Present Study with National and International Studies.

4.7 Estimation of Lifetime Attributable Risk (LAR)

Table 4.10: Estimation of life time cancer risk per 100,000 population for gender and anatomical.

Parameters		Mean estimated effective dose (mSv) (centre A)	Mean LAR per 100,000 population (centre A)	Mean estimated effective dose (mSv) (centre B)	Mean LAR per 100,000 population (centre B)
Head	C-	2.7	20.0 (0.020%)	2.5	18.0 (0.018%)
	C+	3.7	24.0 (0.024%)	4.0	27.0 (0.027%)
Chest	C-	11.4	64.0 (0.064%)	12.4	111.0 (0.111%)
	C+	7.9	38.0 (0.038%)	12.1	105.0 (0.105%)
Abdomen	C+	28.7	275.0 (0.275%)	30.8	159.0 (0.159%)
Male	C-	2.9	19.0(0.019%)	2.6	18.0 (0.018%)
	C+	10.0	82.0 (0.082%)	16.3	80.0 (0.080%)
Female	C-	3.0	25.0 (0.025%)	2.9	25.0 (0.025%)
	C+	3.7	58.0 (0.058%)	22.6	142.0 (0.142%)

Note: The LAR percentage given by x-ray risk calculator is inside the parenthesis while LAR per 100,000 population is outside.

Table 4.11: Estimation of lifetime cancer risk per 100.000 population for age groups

Parameters		Mean estimated effective dose (mSv) (Centre A)	Mean LAR per 100.000 population. A	Mean estimated effective dose (mSv) (centre B)	Mean LAR per 100,000 population (centre A)
0–20	C-	3.2	36.0 (0.036%)	4.1	53.0 (0.053%)
	C+	3.5	46.0 (0.046%)	13.3	143.0 (0.143%)
21–40	C-	3.0	35.0 (0.035%)	2.8	31.0 (0.031%)
	C+	16.2	178.0 (0.178%)	14.3	154.0 (0.154%)
41–60	C-	2.7	19.0 (0.019%)	2.9	16.0 (0.016%)
	C+	8.8	48.0 (0.048%)	23.7	132.0 (0.132%)
>60	C-	2.9	10.0 (0.010%)	2.3	12.0 (0.012%)
	C+	6.7	20.0 (0.020%)	21.4	60.0 (0.060%)

Note: The LAR percentage given by x-ray risk calculator is inside the parenthesis while LAR per 100,000 population is outside.

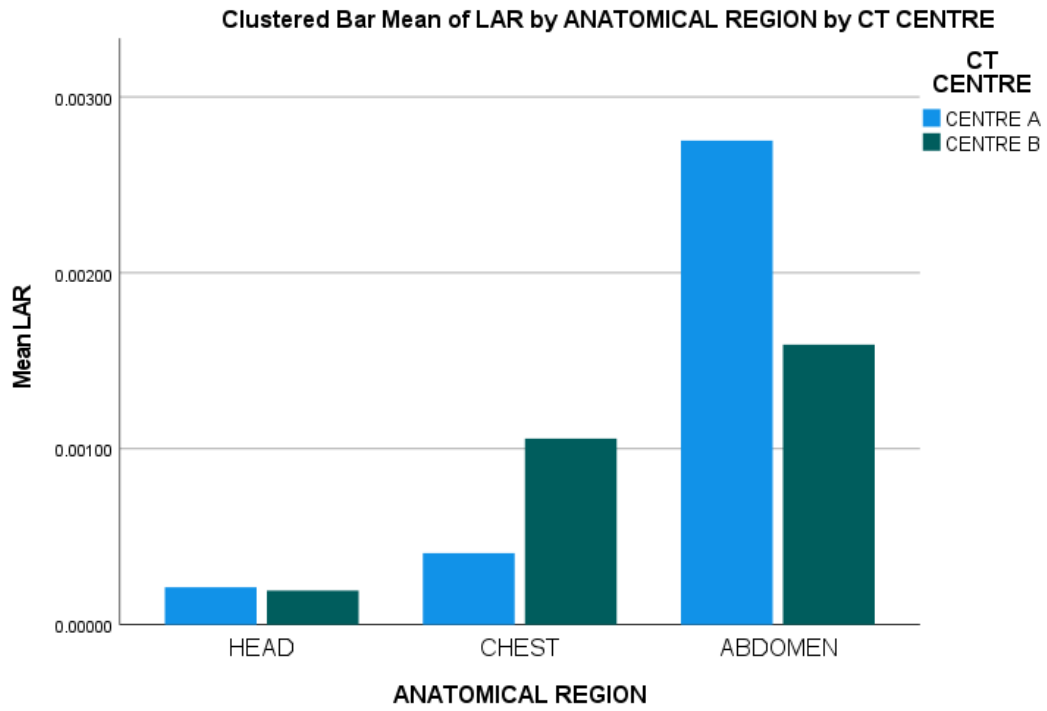


Figure 4.3: Comparison of LAR among Anatomical Region between Centre A and B.

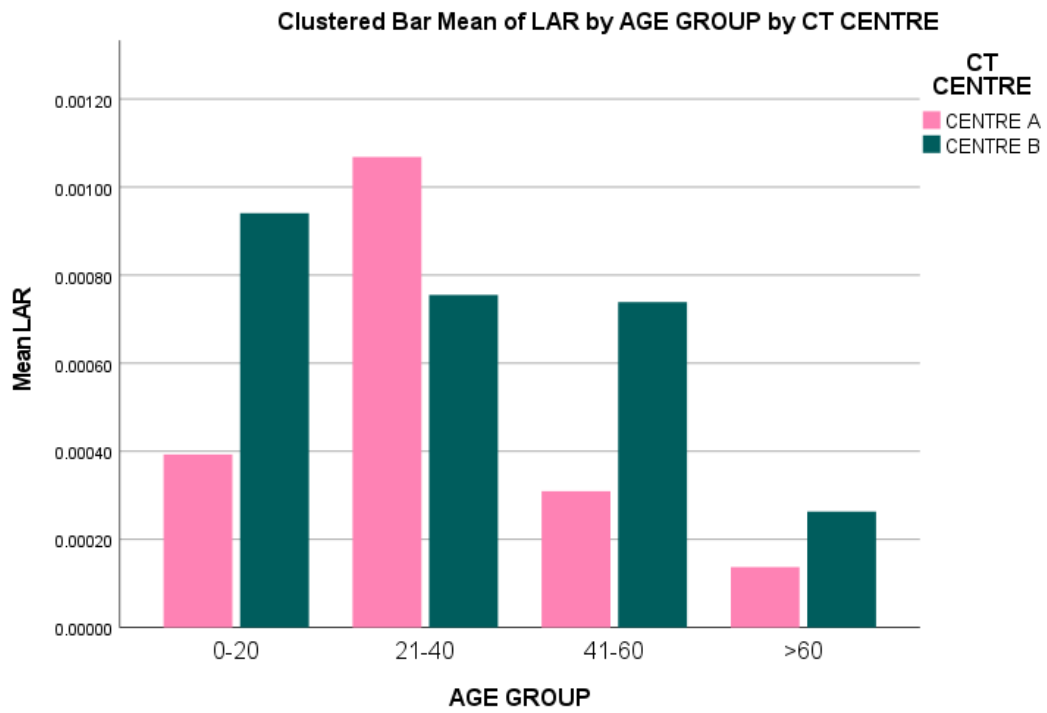


Figure 4.4: LAR Comparison across Age groups for Centres A and B.

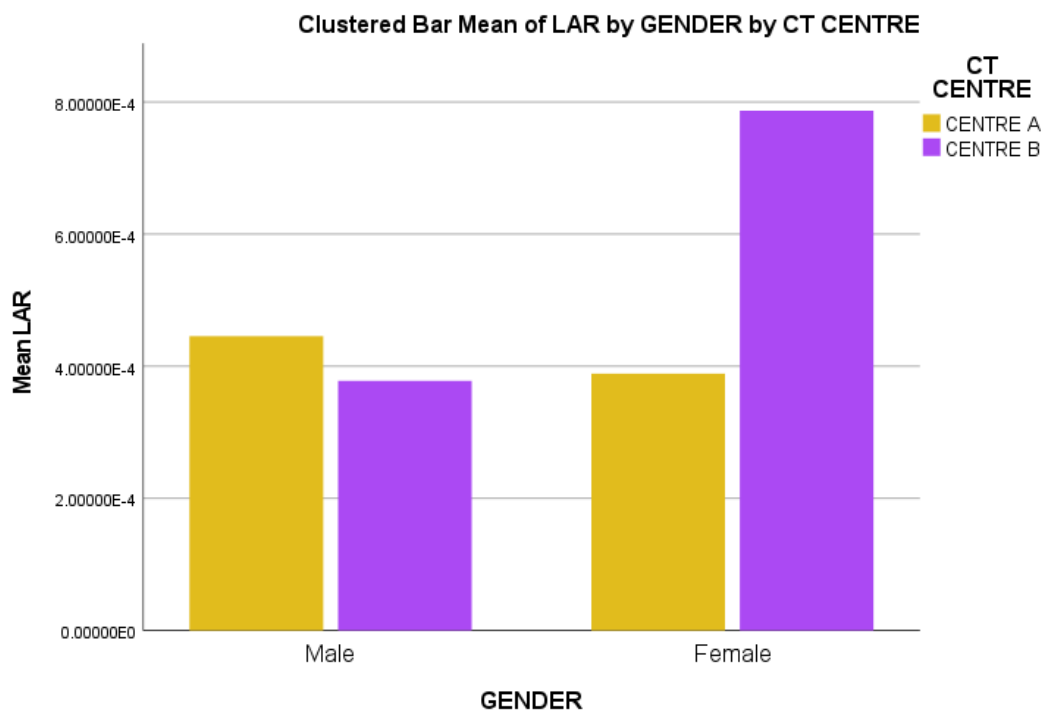


Figure 4.5: LAR Comparison between Male and Female across CT Centres.

4.8 Characteristics of Exposure Parameters for Centre A and B.

Table 4.12: CT Exposure Parameter Settings for Centre A

Exposure parameter	Body region	Median	Mean $\pm$ SD	Min	Max
Tube voltage (kVp)	Head	120.0	119.0 $\pm$ 5.8	80.0	120.0
	Chest	120.0	123.0 $\pm$ 17.7	100.0	176.0
	Abdomen	120.0	117.1 $\pm$ 7.6	100.0	120.0
Tube current (mA)	Head	162.5	176.6 $\pm$ 58.9	100.0	350.0
	Chest	155.5	190.2 $\pm$ 86.4	114.0	385.0
	Abdomen	330.0	296.1 $\pm$ 78.6	123.0	345.0

Table 4.13: CT Exposure Parameter Settings for Centre B

Exposure parameter		Body region	Median	Mean $\pm$ SD	Min.	Max.
Tube (kVp)	voltage	Head	120.0	118.8 ± 4.8	100.0	120.0
		Chest	120.0	120.0 ± 0.0	120.0	120.0
		Abdomen	120.0	119.2 ± 4.0	100.0	120.0
Tube (mA)	Current	Head	160.0	157.9 ± 20.4	83.0	180.0
		Chest	120.0	120.3 ± 30.1	80.0	180.0
		Abdomen	108.0	122.6 ± 33.3	80.0	180.0

4.9 Comparative Statistical Analysis

Statistical analysis was performed to test for significant differences and relationships between selected variables. at 95% confidence level and $p\text{-value} < 0.05$. Non- parametric test was adopted because the CT dose data in this study were predominantly not normally distributed as Shapiro-wilk value from test of normality showed $p\text{-value} < 0.05$.

Table 4.14: Statistical Analysis of LAR for Gender and Contrast Status using Mann - Whitney U Test for Centres A and B.

LAR	Category	Centre	Frequency	Mean rank	U	Z	p-value
Gender	Male	A	88.0	68.9			
	Female	A	53.0	74.6	2139.0	-0.8	0.411
	Male	B	62.0	55.6			
	Female	B	63.0	70.3	1495.0	-2.3	0.024
Contrast	Contrast	A	58.0	90.3			
	Non-contrast	A	83.0	57.5	1288.0	-4.7	< .001
Contrast	Contrast	B	49.0	91.7			
	Non-contrast	B	76.0	44.5	458.0	-7.1	< .001

Significant at $P < 0.05$.

Table 4.15: Statistical Analysis of Differences in LAR for Age groups and Anatomical Region using Kruskal- Wallis H Test.

LAR	Category	Centre	Frequency	Mean rank	Df	H	P- value
Age group	0 -20	A	18.0	90.1	3.0	49.5	< .001
	21 – 40	A	30.0	101.0			
	41 – 60	A	46.0	76.4			
	>60	A	47.0	39.2			
	0-20	B	13.0	90.4	3.0	35.5	< .001
	21 – 40	B	25.0	77.4			
	41 -60	B	40.0	73.4			
	>60	B	47.0	38.9			
Region	Head	A	108.0	59.4	2.0	41.8	< .001
	Chest	A	23.0	99.0			
	Abdomen	A	10.0	131.9			
Region	Head	B	84.0	44.0	2.0	71.3	< .001
	Chest	B	16.0	96.1			
	Abdomen	B	25.0	105.0			

Significant at $p < 0.05$.

Table 4.16: Mann-Whitney U Test for Comparison of Radiation Dose Indices and LAR between Centres A and B.

Parameters	Centre A Mean Rank	Centre B Mean Rank	P -value
CTDI _{vol} (mGy)	142.5	123.4	0.040
DLP (mGy.cm)	130.7	136.7	0.527
Effective Dose (mSv)	128.6	139.0	0.270
LAR	128.0	139.7	0.216

Significant at $p < 0.05$

4.10 Discussion of the Results

The selected center A for the study, as presented in Table 4.1, the percentages of male and female adopted for the study are 62.4% and 37.6 %, respectively. The centre,s age distribution shows that the majority of adopted patients are over 40 years old (65.9%), with the highest age group being over 60 years (33.3%). The non-contrast scan used for the center is 58.9%, while the contrast scan is 41.1%. Head scan for the center is 76.6%, followed by the chest scan (16.3%, and then the abdomen scan (7.1%). The is consistent with the pediatrics study by Syrgiamiotis *et al.* (2025) who recorded 64%, 23%, and 13% for head, chest and abdomen.

The prominence of the head CT scan in both centers suggests a neurological emergency such as stroke or any other health trauma. which also correlates with the patterns found in Nigerian hospitals, where the records of patients having a stroke are high, as reported by Adeloye *et al* (2019), who submitted that the crude incidence of stroke in Nigeria ranged from 12.8–39.0 per hundred thousand persons per year. Secondly, the bad states of Nigerian roads, where there is a high rate of occurrence of accidents that may involve head injuries.

Similarly, in Table 4.2, at centre B, the percentages of male and female adopted for the study are nearly equal with 49.6% for the males, and 50.4 % for the females. The center's age distribution shows that the majority of adopted patients are over 40 years old (65.9%), with the highest ages to be above group being over 60 years (37.6%). The non- contrast CT for center (B) was 60.8%. while contrast-enhanced CT was 39.2%. The percentages of head, chest, and abdomen scans are 67.2%, 12.8%, and 20.0 % respectively. Similar

explanation applies to center B, the reason for prevalence of head scan as explained for center A.

Table 4.3 and Table 4.4 presented the radiation dose metrics, specifically CTDI_{vol} and DLP for CT examinations performed in centre A and B across different anatomical regions and contrast phases. The findings showed variations in radiation dose between the two centres and among the various CT procedures evaluated but not statistically significant except CTDI_{vol} which higher in centre A than B. The CT dose indices demonstrated that the CTDI values were within acceptable limits, indicating appropriate scanner output and adherence to protocol settings. However, the DLP was comparatively high, suggesting that although the radiation intensity per slice was appropriate, the overall patient exposure was increased due to scan coverage.

For head CT examinations, the CTDI_{vol} values were relatively high in both centres, particularly during contrast-enhanced studies. Contrast-enhanced head CT recorded substantially elevated CTDI_{vol} and DLP values compared with non-contrast examinations. Chest CT examinations demonstrated moderate CTDI_{vol} values but relatively increased DLP values, especially in contrast-enhanced procedures. Abdominal CT examinations recorded some of the highest radiation dose metrics among all procedures evaluated. The increased dose values may be attributed to multi-phase scanning protocols, repeated image acquisitions and prolonged scan duration commonly associated with contrast-enhanced CT studies.

Table 4.5 compared the adult local DRLs obtained in this study with values set by the ICRP and DRLs reported from different countries. The comparison was based on CTDI_{vol} and DLP values for head, chest, and abdominal CT examinations. For head CT examinations, the non-contrast CTDI_{vol} values obtained in the present study were 59.5 mGy for centre A and 65.3 mGy for centre B, while contrast-enhanced CTDI_{vol} values were 92.2 mGy and 57.5 mGy for centre A and B respectively.

The routine head CTDI_{vol} value for centre A was comparable to ICRP recommended value of 60 mGy whereas Centre B slightly exceeded the ICRP value. The values were also similar to those reported in the United States (62 mGy), Japan (77 mGy), Kenya ((61 mGy), and Nigeria (61 mGy). However, the contrast-enhanced CTDI_{vol} value of 92.2 mGy recorded in centre A was substantially higher than all international reference values. This suggests multi-phase acquisition protocols or inadequate optimisation during contrast-enhanced head CT examinations.

The values obtained for DLP head CT in the present study were also considerably elevated. Non-contrast DLP values of 1446.6 mGy.cm and 1393.5 mGy.cm for centres A and B exceeded the ICRP standard of 1050 mGy.cm. Also, the contrast-enhanced DLP of 2373.6 mGy.cm and 2050.1 were markedly higher than values reported in other countries and European Commission. This indicates that although CTDI_{vol} values were relatively comparable to international standards, scan length and acquisition coverage may not have been adequately controlled.

For chest CT examinations, non-contrast chest CTDI_{vol} value for centre A was 15.4 mGy and 6.9 for centre B while contrast-enhanced values were 14.6 mGy and 7.9 mGy for Centres A and B respectively. These values were lower than ICRP value of 30 mGy and comparable to values reported in Morocco (11 mGy), France (10 mGy), Japan (13 mGy), Kenya (19 mGy) and Nigeria (17 mGy). This suggests relatively acceptable optimisation of tube current and voltage parameters for chest imaging within the study centres.

The DLP values for routine chest CT were 819.0 mGy.cm and 573.9 mGy.cm while contrast-enhanced values were 489.6 mGy.cm and 593.6 mGy.cm for centres A and B. Chest CT values were lower than the ICRP standard of 650 mGy.cm except DLP value for routine test in centre A. (819 mGy.cm) but higher than the values obtained in China (302 mGy.cm) and France (350 mGy.cm), but comparable to Morocco and the United States (610 mGy.cm). The obtained values may differ due to scan coverage, patient body habitus, and use of contrast-enhanced scan protocols.

Abdominal CT examinations demonstrated the greatest variation and highest radiation burden in the present study. Contrast-enhanced CTDI_{vol} values were 42.0 mGy for centre A and 8.6 mGy for centre B. Centre A value exceeded the ICRP recommended value of 35 mGy and also considerably higher than values reported in Morocco (9 mGy), France (13 mGy), Chinna (10 mGy), Ethiopia (11 mGy), and the United States (17 mGy). However, centre B recorded lower values than most international references suggesting better optimisation practices for abdominal imaging in that centre. Similarly, abdominal DLP

values in the present study were markedly elevated. Centre A recorded 1730.2 mGy.cm, while centre B recorded 1621.9 mGy.cm.

These values exceeded ICRP recommended value of 780 mGy .cm and other countries but slightly lower than Kenya (1842 mGy.cm). This may be attributed to wider scan coverage, multi-phase imaging, increased tube current settings, and prolonged acquisition time. The DRLs estimated in this study were higher than estimated DRLs from Alhuyaili *et al.* (2025) who reported DRLs value of 10.9 mGy, 394 mGy.cm (chest) and 12.5 mGy, 638 mGy.cm (Abdominal-pelvic CT) for CTDI_{vol} and DLP respectively in Saudi Arabia in establishing diagnostic reference levels.

The DRLs obtained from African study by Uushona *et al.* (2022) for Namibia, Senegal, Ghana and Kenya, 60.9 mGy for head and 15.5 mGy, 544 mGy.cm for chest were comparable with estimated DRLs in this study but abdominal CTDI_{vol} and DLP estimated in the present study were higher than values from African study of 15.7 mGy and 737 mGy.cm. The CTDI_{vol} and DRLs recorded by a Nigerian study (M & S, 2021) in Northern part of Nigeria (17.25 mGy, 735) for chest CT were higher than the value obtained in this study. The DLP for abdominal examination of 1670.75 mGy.cm was relatively comparable with values obtained in this study except abdominal CTDI_{vol} of 19.25 mGy which was lower than value obtained in centre A.

Table 4.6 presented the pediatric DRLs with ICRP at 75th percentile with ICRP standard for 10 years old pediatric. The non-contrast head CTDI_{vol} values were 45.8 mGy and 33.6 mGy for centre A and B. These values were below the ICRP value of 70 mGy, suggesting

acceptable pediatric CT optimisation practice in the study centres. Similarly, contrast-enhanced $CTDI_{vol}$ recorded in centre A (30.6 mGy) was also below ICRP value. Centre B did not record contrast-enhanced CT for pediatric CT examination. The head DLP values for non-contrast CT of 1515.4 mGy.cm and 872.3 mGy.cm for centre A and B were higher than ICRP recommended value of 750 mGy.cm but centre A contrast-enhanced DLP of 549.3 mGy. cm was below ICRP recommended value. For chest CT examination, only contrast-enhanced CT examinations were available. The $CTDI_{vol}$ were 79.3 mGy and 7.9 mGy. centre A exceeded ICRP recommended value of 30.0 mGy while centre B was below the ICRP recommended value.

The DLP of 133.5 mGy.cm and 418.2 mGy.cm for centre A and B respectively were below the ICRP recommended value of 600.0 mGy indicating efficient CT optimisation protocol for pediatric chest examination in the study centres. Table 4.7 presented the comparison of adults DRLs between Centre A and B based on 75th percentile. Centre A recorded higher DRLs majorly in all the examinations except in chest examination where Centre B recorded higher value than centre B.

Table 4.8 presented estimated effective dose of the study for both centres A and B. The mean, maximum and minimum were recorded. The highest effective dose was observed in abdominal CT examination, followed by chest CT while head CT demonstrated the lowest effective dose among the evaluated procedures. Routine CT estimated in this study recorded the mean value of 2.7 mSv, 2.5 mSv (head CT), 11.4 mSv, 12.4 mSv (chest CT), while contrast-enhanced CT recorded mean value of 3.7 mSv, 4.0 mSv (head CT), 7.9 mSv,

12.1 mSv (chest CT), 28.7 mSv, 30.8 mSv (abdominal CT) for centre A and centre B. The effective doses estimated in this study were higher than values recorded by Khata *et al* (2026) where abdominal CT had the highest mean effective dose of 12.8 ± 3.5 mSv, Chest CT was 10.2 ± 2.1 mSv and head CT with the lowest mean effective dose of 2.1 ± 0.6 mSv. In comparison with the pediatric CT study conducted by Aborisade *et al.* (2019) at OAUTHC which is centre B who recorded equivalent doses that ranged from 23.49–55.26 mSv for abdominal CT scan, 10.07–69.94 mSv for skull and 8.60–31.94 mSv for chest CT scan. This showed that there is an improvement in CT optimisation protocol in centre B due to lower effective doses recorded in this study.

The high effective dose observed in abdominal CT may be explained by the large scan coverage and the multiple radiosensitive organs within the abdomen. Abdominal CT also frequently require multi-phase acquisitions or contrast-enhanced studies, which substantially increase cumulative radiation exposure. The chest demonstrated the second highest effective dose because it includes radiosensitive organs like breast, lung, tissue, and oesophagus, . Head CT recording the lowest effective dose may be attributed to relatively smaller scan length.

Figure 4.1 explained the visual representation of effective doses across anatomical region for both contrast and non-contrast CT and showed some outliers for head effective doses meaning that a particular patient received a radiation dose that was substantially higher or different from most other patients and longer whisker in centre A for abdominal CT

indicated that some patients received much higher doses than others, although not classified as outliers.

Table 4.9 Compared the overall mean (contrast and non-contrast) effective dose of the present study with the national and international values. The mean head CT effective doses were 2.9 mSv and 2.6 mSv for centre A and B. These values are higher than most international studies but lower than Ekpo, 2018. The chest CT recorded 8.2 mSv and 12.2 mSv for centre A and B respectively. These values are higher than most values in international studies and similarly abdomen CT values were 28.7 mSv and 30.8 mSv for centre A and B.

Although, the recorded values in this study were higher but still lower than estimated values from study conducted at Aminu Kano teaching hospital in Nigeria by Lawal *et al.*, (2019) which recorded mean effective dose of 34.5 mSv and mean DLP of 2320 mGy.cm cancer risk was estimated at 600 per 1,000,000 for computed tomography Urography, indicating necessity for CT optimisation procedure and establishment DRLs in Nigeria. Figure 4.10 showed visual representation of comparison of present study effective dose with other studies as abdominal CT examination in this study showed the highest radiation dose. Table 4.10 and Table 4.11 presented estimation of mean value of lifetime cancer risk per 100,000 population.

The estimated lifetime cancer risk showed a relationship between dose and cancer risk. Abdominal CT recorded the highest LAR values (up to 275 per 100,000 population) followed by chest CT while head CT recorded the lowest risk. Gender- based analysis

indicates that female patients had higher LAR compared to males. Male versus female (19 vs 25, 18 vs 25 per 100,000 population) for centre A and B routine CT examinations. Age groups LAR estimation recorded 0–20 years (36, 53 per 100,000 population), 21–40years (35, 31 per 100.000population), 41–60years (19, 16 per 100.000 population) and > 60 years (10, 12 per 100.000 population).

The findings were consistent with study conducted by Smith-Bindman *et al*, (2009) who recorded the estimated LAR of 1 out of 270 women who did coronary angiography CT at age forty years, and this figure is approximately 370 per 100,000 population. Other results include 1 in 600 men (167 per 100,000 population), and for head CT the results showed 1 in 8100 women (12 per 100,000 population), 1 in 11080 men (9 per 100,000 population. Similarly, research by Alhuyaili *et al*. (2025) estimated LAR values that ranged from approximately 19 to 59 per 100,000 population for chest and abdominal CT which are still comparable with some of the reports obtained for this study.

In comparison with Nigerian studies, some of the LAR values obtained in this study were relatively higher than LAR values recorded by Ikubor and Tobi (2022) that ranged from 0.14 to 26.45 per 100,000 population. Despite the differences, the general trend observed in Nigerian studies is consistent with the present findings, where LAR increases with radiation doses.

The results showed that lifetime cancer risk increased with higher effective dose, younger age, female gender, Use of contrast, and scan region. When compared with African studies, some of the LAR recorded in the study were higher than the values obtained in the study

conducted in Cameroon by Mokubangele *et al.*, (2024) who reported 0.45 to 67.13 per 100,000 population while some values in this study are still below the estimated values depending on the scan protocol, anatomical region and the use of contrast. Generally, the present findings were consistent with the outcome of Kiani and Chaparian, (2022b) pediatrics study in the year 2022. The mean REID (Risk of Exposure-Induced Cancer Death recorded for different age groups in the study were: ≤ 1 year, 14.85 per 100,000 males and 19.93 out of 100,000 females, 2–5years 13.39 out of 100,000 males and 17.24 per 100.000 females, 6–9 years 10.53 per 100,000males and 13.58 per 100,000 females, 10–12 years 8.83 out of 100,000 males and 11.1 out of100,000 females. This confirms that risk decreases as age increases and vice versa.

Table 4.12 and Table 4.13 presents exposure parameters (Tube voltage kvp and Tube current mA) used for the CT examination in the study by centre A and B. The tube voltage is almost consistent across all the examinations across centre A and B but there are variations in tube current. The higher dose values observed in centre A particularly for abdominal and contrast-enhanced CT examinations suggest the use of relatively higher tube current settings and inadequate modulation. The estimated maximum values of tube current for head, chest and abdominal examination were 350 mA, 385 m A, and 345 m A for centre A and 180 m A for head, chest, and abdominal CT scan in centre B.

Table 4.14 and 4.15 presented the statistical analysis to test differences in LAR between gender, age group, anatomical region and contrast status. There was statistically significant difference in LAR between anatomical region, age- group, and contrast examination as

they all exhibit the p-value $< .001$. The mean rank revealed that abdominal scan showed the highest LAR followed by chest CT and lowest risk for head CT scan among the anatomical region. Younger age group had higher LAR than older age group, and contrast-enhanced CT exhibited the higher LAR than routine examination. There was also a statistically significant difference between male and female in centre B as p-value of $0.02 < 0.05$ but there was no statistically significant difference between male and female in centre A as the p-value $0.4 > 0.05$ but females recorded higher mean rank than males suggesting higher trend towards cancer risk than males. The mean rank also confirmed that female demonstrated higher lifetime cancer risk than males. Similar analysis performed showed that there was no statistically significant difference in mean DLP, Effective dose and LAR between centre A and B. The p-values > 0.05 with p-values of 0.52, 0.27 and 0.21 for DLP, Effective dose and LAR respectively. This suggests similar CT procedures between the two centres with slight variation.

Table 4.16 compares radiation dose indices and LAR between Centres A and B using Mann-Whitney U test. $CTDI_{vol}$ was significantly higher in centre A than B ($p=0.040$). Although centre B had higher mean ranks for DLP, Effective Dose, and LAR, these differences were not statistically significant ($P > 0.05$).

The Spearman rank correlation at significant level of 0.01 showed positive significant correlation between effective dose and DLP. The p-values were 0.007 which < 0.001 for centre A and B. There was also positive statistically significant correlation between Effective dose and LAR with p-value of < 0.001 at significant level of 0.01 for centre A

and centre B. This means effective dose increases as DLP increases and LAR increases as effective dose increases.

Figure 4.2 compared overall mean effective dose of this study with mean effective doses of other studies and showed that the result obtained in this study and a study conducted in Nigeria (Ekpo, 2018) had higher values especially for abdominal CT examinations indicating the need for optimization. Figure 4.3 compared lifetime cancer risk between anatomical region and showed that abdomen exhibits the highest lifetime cancer risk. Figure 4.4 compared LAR between age groups and confirmed that LAR increases as age reduces while figure 4.5 compared LAR between male and female and showed that female exhibits higher LAR than males. However centre A had a slight difference that was not statistically significant where males LAR bar was slightly higher than females due to contrast-enhanced CT.

CHAPTER FIVE

Summary, Conclusion and Recommendations

5.1 Summary

The study assessed radiation dose metrics, DRLs and estimated LAR from CT examinations in two selected teaching hospitals. The study was motivated by high usage of CT technology and concerns regarding radiation exposure and its associated health risk, particularly with deficiency of nationally established DRLs in Nigeria.

To achieve the aim of this study, radiation doses were assessed and discovered that $CTDI_{vol}$ values for most of the examinations were within the recommended reference limits, indicating generally acceptable scanner output. However, the DLP values were higher than the set standards in several examinations, suggesting longer scan length, repeated acquisitions, or protocol variations. The reports of this study were consistent with (Ekpo *et al.*, 2018), a study conducted in Nigeria which showed that $CTDI_{vol}$ were comparable to international standards but DLP and effective doses were considerably higher.

The effective doses received by patients during CT examinations were assessed using the dose-length product (DLP) and conversion factors. The findings revealed variations in effective doses across the different anatomical region and CT centres. Generally, abdominal CT examinations recorded higher effective doses than head and chest examinations, while contrast-enhanced CT examinations produced higher doses than non-contrast examinations.

The study also estimated the LAR of cancer from CT procedures at the selected hospitals. The results showed that cancer risk varied according to age, sex, anatomical region, and contrast status. Younger patients exhibited higher cancer risks than older patients, while female patients demonstrated greater lifetime cancer risks than males. Furthermore, abdominal contrast-enhanced CT examinations produced the highest estimated lifetime cancer risk among all the examinations considered.

In addition, the compliance of the selected CT centres with established diagnostic reference levels was evaluated by comparing the estimated local DRLs with international recommendations. The findings showed that some of the estimated DRLs particularly those for head and chest CT examinations were within the recommended limits, whereas abdominal examinations exceeded the international reference values. Similar variations were observed in pediatric examinations. Overall, the study established that CT examinations contribute significantly to patient radiation exposure and may increase the risk of radiation-induced cancer.

5.2 Conclusion

The study concluded that CT examinations contribute significantly to patient radiation exposure and potential cancer risk, particularly when the recommended DRLs are consistently exceeded. Young patients, females, and patients that underwent contrast CT examinations exhibit higher radiation dose and associated lifetime cancer risk. The CTDI_{vol} DRLs values were generally within internationally acceptable limits but DLP values frequently exceeded recommended levels, particularly for head and abdominal CT examinations. This indicated that scan length and multiphase imaging protocols are the major contributors to increased radiation exposure.

There is also a slight variability between centres but not statistically significant. Abdominal CT examinations contributed the highest effective dose and lifetime cancer risk. The study confirmed that radiation-induced cancer risk is higher in females, younger patients, and contrast-enhanced CT examinations. Tube voltage remained consistent across all examinations while tube current varies and it was confirmed that the centre with highest tube current recorded the highest lifetime cancer risk. Overall, the study highlights the need for continuous optimisation of CT practices to minimise radiation exposure with consideration for qualitative diagnostic image. The study identified the following as the contribution to knowledge.

The study identified the clinical significance of exceeding DRLs consistently as it may increase the risk of cancer.

The study provided evidence-based facts that necessitate optimisation in the studied CT centres.

It provided more evidence for policy development in Nigeria.

The study revealed the necessity for protocol optimisation rather than scanner technology alone.

It provided empirical evidence supporting the establishment of separate DRLs for adults, pediatric patients, and contrast-enhanced CT examinations.

5.3 Recommendations

The following are recommended based on the findings of this study.

- i. It is recommended that separate DRLs be established for adult patients, pediatric patients, and contrast-enhanced CT examinations in Nigeria to account for differences in patient characteristics, imaging protocols, and radiation dose requirements, thereby promoting more effective dose optimisation and patient safety.
- ii. CT examinations protocols should be regularly reviewed and standardised to minimise unnecessary radiation exposure, particularly for abdominal and contrast-enhanced studies.
- iii. Efforts should be made to limit scan coverage strictly to the region of clinical interest and avoid unnecessary multiphase acquisitions.

- iv. Radiographers and medical physicists should undergo regular training on radiation protection and dose optimisation techniques.
- v. Application of dose reduction techniques must be adopted
- vi. All CT examinations should be clinically justified, especially for younger patients and females who are more radiosensitive and regular dose audits should be conducted to monitor compliance with established DRLs and improve overall radiation safety practices.
- vii. Ultra-low dose CT should be adopted where necessary as adopted during COVID-19 and produced 90% sharp images without noise and 93.33% high quality image as adopted by Garg *et al.* (2023)

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