UNIVERSITY OF NAIROBI

ASSESSMENT OF RADIOLOGICAL PATIENT EXPOSURE FOR COMPUTED TOMOGRAPHY SCANNING EXAMINATIONS: A CASE STUDY AT THE NAIROBI HOSPITAL, KENYA.

By

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of degree, or publication. Where other people's work has been used, this has properly been acknowledged and referenced per the University of Nairobi's requirements.

Kibet, Gedion Kiprotich, S56/70230/2013

Signature:  Date: 22/11/2023

APPROVAL

This thesis has been submitted for examination with our approval as University supervisors:

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DEDICATION

"The secret of life, though, is to fall seven times, and to get up eight times."

— Paulo Coelho, The Alchemist-

To my late mother Lucyianna, for supporting my studies.

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ABSTRACT

The Nairobi Hospital is recognised in the region as an advanced diagnostic, treatment, and referral centre in medical expertise and services. The hospital has a Brilliance 64-slice CT scanner with an estimated diagnostic output of approximately 3000 to 5000 scans per annum. This research investigation was conducted on available records of all patients to identify radiation protection dosimetry for the optimization of patient-specific CT protocols. A total of two hundred and fifteen CT scans examined were distributed as follows; head with no contrast, head with contrast, chest non-contrast, chest contrast, neck non-contrast, abdomen non-contrast, abdomen contrast, cervical spine non-contrast, cervical spine contrast, lumbar spine contrast, angiography, angiography non-contrast, and paranasal sinuses. The record of the age distribution of patients was 13 to 87 years, 113 female and 102 male patients. An areal background radiation measurement of the CT facility room was performed using a RAD 60^{TM} dosimeter. The radiation dose exposure rate values measured at various localities varied from 0.01 to 0.20 μSv/hr and were within the 0.25 μSv/hr ICRP limits. Quality assurance of the 64-slice CT Scanner was assessed for radiological compliance with 60601-2-44 standard by the International Electro-Technical Commission using 2-part PMMA Phantoms for Computed Tomography Dose Index measurements. For the QA/QC of the CT scanner, there was an observable significant difference (> ± 20%) in all CT practices, between the certified $CTDI_{vol}$ and measured and for both the abdomen and head examinations. The $CTDI_w$ values obtained from measurements with anthropomorphic phantoms for both head (92.04 ± 0.08) mGy and abdomen (52.89 ± 0.7) mGy examination protocols, were above EC values; 60 mGy and 35 mGy, respectively. Seventy-two out of 215 patients underwent two or more CT scans, and the cumulative effective dose values for patients with repeated examinations ranged between 3.68 to 83.48 mSv, representing an overall increase by factors 2 to 3. The results for the 75th percentile of the Dose Length Product values for head non-contrast (1134.72 vs. 1050 mGy.cm), abdomen with contrast (2865.4 vs. 800 mGy.cm), and chest non-contrast (773.7 vs. 650 mGy.cm) were all higher than the European Commission guidelines. In conclusion, there is a need for re-evaluation for optimizations of various CT examinations, to obtain gender-specific protocols, to reduce exposure levels to an achievable level following the International Commission on Radiological Protection publications 60 and 87.

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ABBREVIATIONS AND ACRONYMS

AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
AEA	Anterior Ethmoidal Artery
AEC	Automatic Exposure Control
ALARA	(As Low As Reasonable Achievable) Principle
BEIR	Biological Effects from Ionizing Radiations
B.S.S	Basic Safety Standards
CBD	Central Business District
CBF	Cerebral Blood Flow
CED	Cumulative Effective Dose
CNR	Contrast-to-Noise Ratio
CT	Computed Tomography
CTA	Coronary Computed Tomography Angiography
CTDI	Computed Tomography Dose Index
$CTDI_{vol}$	Volume Computed Tomography Dose index
$CTDI_{w}$	Weighted Computed Tomography Dose index
DLP	Dose-Length Product
DNA	Deoxyribonucleic Acid
DRL	Diagnostic Reference Level
EC	European Commission
ED	Effective Dose
EG	European Guidelines
ERCP	Endoscopic Retrograde Chalangio Pancretology
ESD	Entrance Surface Dose
FOV	Field of View
Gbps	Giga bytes per second
GLOBOCAN	Global Cancer Observatory
GM	Geiger Muller
Gy	Gray

HVL	Half-Value Layer
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
IEC	International Electro Technical Commission
ICRP	International Commission on Radiation Protection
IP	Interventional Procedures
IR	Ionizing radiations
KAP	Kerma-Area Product
KERMA	Kinetic Energy Released Per unit Mass
KHU	Kilo Heat Units
KNH	Kenyatta National Hospital
KNRA	Kenya Nuclear Regulatory Authority
kV	Kilo Voltage
kVp	Kilo Voltage Power
kW	Kilo Watts
LCD	Liquid Crystal Display
mA	milli-Amperes
mAs	Milli-Amperes Second
MATLAB	Matrix Laboratory Software
MC	Monte Carlo
MDCT	Multi-Detector Computed Tomography
mGy	milliGray
mGy*cm	milliGray centimetre
MHU	Mega Heat Unit
MRI	Magnetic Resonance Imaging
mSv	milliSievert
NCCS	National Cancer Control Strategy
NRPB	National Radiological Protection Board
PACS	Picture Archiving and Communication System
PMMA	PolyMethylMethAcrylate
PSD	Peak Skin Dose

PU	Processus Uncinatus
OPG	Ortho-Pantoma-Gram
QA/QC	Quality Assurance and Quality Control
SSDE	Size Specific Dose Estimates
Sv	Sievert
TLD	Thermo Luminescent Dosimeter
UL	Upper Limit
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

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CHAPTER 1: INTRODUCTION

1.1 Background to the Study

The widespread use of ionizing radiation in medicine is the most frequent man-made source of radiation exposure [1]. In practice, CT scan examinations, results in much more exposure than other radiographic examinations modalities [2]. Computed Tomography (CT) scanners characteristic to create cross-sectional images of an organ for a patient in the detection of tumours has yielded convincing evidence for many [3]. The medical profession has accepted it on a global scale, and it is used by radiologists. Multi-Detector Computed Tomography (MDCT) scanners have been introduced to many Kenyan hospitals to improve their diagnostic capabilities in order to help with the early detection, treatment, and prevention of cancer as well as other illnesses.

These scanners are therefore significant sources of ionizing radiation exposure. If the radiation level exceeds the necessary dose limits, it can be dangerous for patients, medical staff, and the general public [4].With the use of a wider beam for irradiating the patient and using a large number of detector rows to produce many slices, patients can receive a higher dose when using multi-slice CT scanners. As a result, exposure to medical radiation has increased among the population at large. In real life, a CT scan procedure can result in high levels of patient exposure to improper radio-diagnostic procedures [4].

Effective use of digital imaging is challenging because MDCT scanners have the advantage of producing high-quality images with any amount of radiation complicating the optimization of protocols [5]. To ensure that patients are protected to the fullest extent possible during all radiological procedures, including CT, the International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) have established fundamental safety criteria. They recommend using and implementing DRLs to improve radiological operations. By offering corrective action for any dose that exceeds the necessary levels, DRLs serve as a tool for optimization and thereby improve patient safety [6].

Repeated and unjustified CT scans in patients can cause deterministic harm, stochastic effects, and carcinogenic risks [7]. The majority of patients' cumulative radiation exposure is accounted for by repeated CT scans, which may result in minimal radiation-induced cancer risks [8]. The International Agency for Research on Cancer (IARC) reported that one of the main causes of death and global mortality in the year 2021 was cancer, with an estimated 14 million new cases each year. The IARC also noted that 70% of cancer-related fatalities occur in both middle-income and developing nations. According to the National Cancer Control Strategy (NCCS) for the year 2021, cancer was the third most common cause of death in Kenya, after cardiovascular disease and infectious diseases.

According to the GLOBOCAN report for the year 2019 by the IARC, the number of new cancer cases in Kenya increased by 45% from 37,000 per year in 2012 to an estimated 47,887 new cases reported in the year 2019. Globally, the cancer burden is growing, with 19 million additional cases recorded in 2020 [9]. The number of cancer prevalence per population in countries are shown in figure 1.1. China was the leading worldwide with about 9.2 million cancer cases, followed by USA (8.04 million) and India (2.7 million cancer cases). In Africa, Egypt was leading with about 278,165 cancer cases, followed by South Africa (262,455 cancer cases) and Nigeria (233,911 cancer cases) [10].

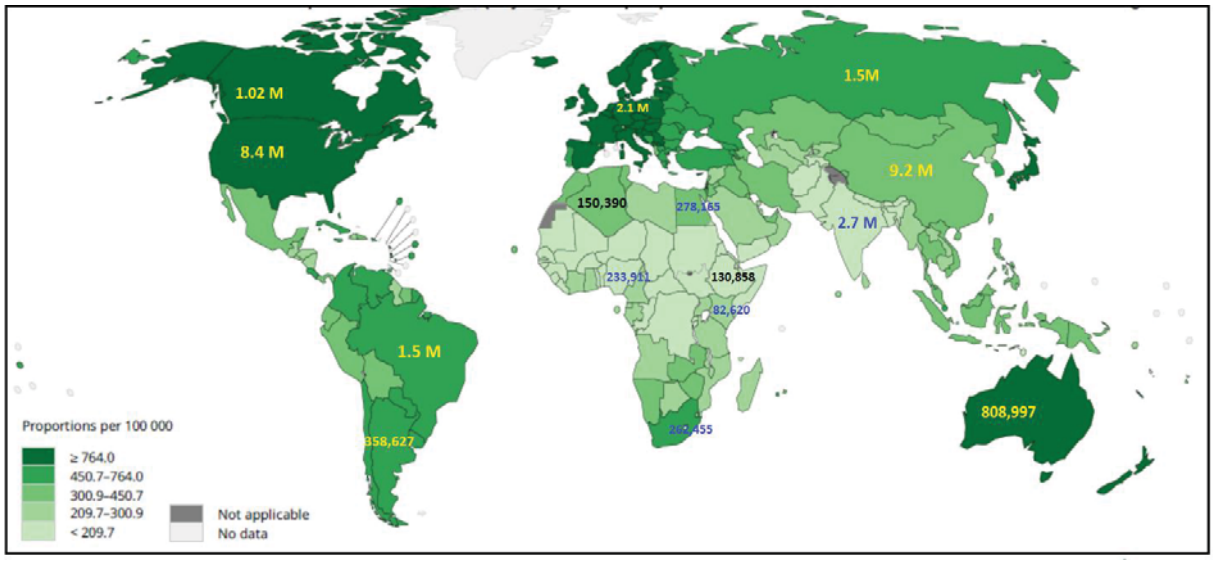


Figure 1.1: Estimated number of prevalent cases (5-year) as a proportion in 2020, all cancers, both sexes, all ages (Retrieved from www.iarc.fr)

Only 17% of radiological tests are CT scans, but they account for 49% of the total effective dose of all radiological tests [11]. According to Table 1.1, the amount of radiation resulting from CT procedures are much higher than conventional chest x-rays. In general, the various CT scanner clinical applications include; oncology, cardiology and neurology. Globally, CT use accounts for the largest contribution to medical radiation exposure, with research suggesting values of up to 62% [12].According to the UNSCEAR survey, the yearly collective dose from diagnostic imaging modalities in nuclear medicine has increased [12]. In most developed countries, CT utilization trends and patterns for patient-specific procedures are widely documented, although less is known in developing countries [13].

The use of MDCT scans as a diagnostic modality at the Nairobi Hospital started in the year 2012. The Nairobi Hospital offers various scanning techniques such as fluoroscopy, MRI, ultrasound, mammography, conventional X-rays, and CT scans. The Radiology Department at the Nairobi Hospital has two Philips; Brilliance®64-slice and Brilliance®16-slice CT equipment. Brilliance® 16 is used for oncoradiology purposes while Brilliance® 64 is mainly used in radiology. Brilliance® 64 scans at least 10 patients in a single day equivalent to more than 3000 patients per annum. In general, CT scanners are used for various examinations of anatomic parts (abdomen, CT angiography, lumbar spine, pelvis, chest, neck, etc.) for diagnosis. The different anatomic regions exhibit different radiation doses due to the varied radio-sensivity of organs [14].

The information regarding patients' exposure levels for CT scan procedures available locally is limited. Hence, there is a need to identify radiation protection dosimetry for the optimization of patient-specific CT examination protocols. The data will enable radiation workers to make informed decisions regarding radiological examinations. Additionally, the research will provide data that will prompt proper regulatory oversight, an adequate dosimetry system, and radiation protection management so as to educate both the public and private parties on the need for radiation safety.

Table 1.1: Radiation Doses from various CT examinations [15]

Examination	Effective Dose (mSv)	Chest X-ray Equivalents
3-view ankle radiography	0.0015	0.07
2-view chest radiography	0.02	1
Radionuclide cystogram	0.18	9
Flouroscopic cystogram	~0.33	~16
Radionuclide bone scan	~5	~250
Brain CT	2	100
Chest CT	up to 3	up to 150
Abdominal CT	up to 5	up to 250

1.2 Statement of the Problem

There is concern about patients' exposure levels to CT scans globally, due to limited studies on patients' exposure levels. Furthermore, attention to radiation exposure monitoring is mainly given to personnel. Not only the photons produced by CT scans are used for diagnosis and treatment planning, but also are a source of radiation hazards to patients, radiological officers, and the public.

There is an inadequate dosimetry system in developing countries as most healthcare facilities lack established local Diagnostic Reference levels (DRL) for various CT procedures which could result in unnecessary high patient exposure levels. Most hospitals use pre-installed generic protocols from the manufacturer, which may expose patients to unnecessary radiation [16].

The rising usage of CT scans in children has generated a serious public health issue [17]. Children who receive CT procedures have a longer-term increased risk of developing

cancer because their tissues and organs are inherently more vulnerable to cellular damage than adults' tissues and organs. The use of adult protocols on children would result in higher-than-necessary radiation exposure.

Frequent repetition and multiple CT scans provide accurate diagnostics but on the other hand, increase radiation exposure and medical costs on the patient life. In general, a CT scan examination results in more exposure than other radiographic examinations, and for similar imaging procedure, the effective dose for CT is 2 to 50 times than a conventional radiography, as shown in table 1.1. Long-time effects of unnecessary exposure to ionising radiation have detrimental health effects.

The use of multi-slice CT scanners delivers greater radiation to patients by irradiating a number of detector rows with a broader beam to create multiple slices. Consequently, the contribution of medical radiological exposure to the entire population has increased globally. It is therefore important to periodically carry out an assessment for CT scan examinations for exposure level and for compliance with the international standard requirements. Computerized tomographic scans are the imaging modality that exposes patients to the most radiation, so the doctor needs to be aware of the radiation doses given to be effective.

This research addresses the problem of patient's exposures level following various radiological CT examinations locally.

1.3 Research Questions

The research was informed of two questions, namely;

(1) Is it possible to assess patient's exposure levels of various CT scan examinations for radiation exposure compliance?
(2) Is it possible to accurately develop institutional DRLs for all CT examinations using dose metrics ($CTDI_{vol}$ & DLP) obtained from all examinations?

1.4 Objectives

1.4.1 General objective

To assess a patient's exposure level of various CT scan examinations for compliance at Nairobi Hospital.

1.4.2 Specific objectives

(i) To examine the DLP and CTDI dose values for common CT examinations (head and abdomen) with anthropomorphic phantoms;

(ii) To evaluate the patient Effective Dose for common CT examinations (angiography, spine, head, abdomen, pelvis and chest) from $CTDI_{vol}$ and DLP dose indices;

(iii) To establish the CT diagnostic reference levels (DRLs) by collecting Dosimetric quantities (CTDI and DLP) for the most commonly performed CT examinations as a function of patient's age in accordance with international DRL values;

(iv) To perform a quality assurance of the CT facility at the Nairobi Hospital for; radiation dose acceptance test and radiological compliance with the standard (60601-2-44) by International Electro-Technical Commission (IEC).

1.5 Justification of Research

CT scans are the major source for patients to be exposed to ionizing radiation (IR) and with continuing rapid technological advancement in the field, there is need for periodical evaluations of population doses and trends are necessary.

In order to evaluate the level of ionizing radiation exposure for patients in diagnostic radiology, the annual frequency of CT scans and the measurement of radiation doses for each sort of treatment are crucial.

The use of multislice scanners in diagnostic radiology units is still new in Kenya, first introduced in the year 2009, and its radiation exposure is a global concern. There is also concern about patient exposure levels since most attention is given to personnel. Therefore, there is a need to determine the exposure level to overcome long time effects of unnecessary exposure to excessive radiation and to comply with international standards. The availability of such data will also prompt revision and review of existing radiation protection management procedures locally, for medical professionals, patients, and the public.

The benefits of the treatment and diagnosis will also be fully realized and the risks will be significantly decreased if the proper procedures are followed.

1.6 Scope of Work

The effective dose for typical CT scan procedures (Angiography with contrast, Neck without contrast, cervical spine without contrast, Head without contrast, Abdomen with and without contrast, Paranasal sinuses, and Chest without contrast) was determined using Dosimetric quantities ($CTDI_{vol}$ and DLP) in this research investigation.

The research investigation was done retrospectively on records available for 215 patients who had undergone CT examinations and data collected over a 3-month period between January 2020 and March 2020. The patient age distribution averaged between 13 and 87 years and comprised 113 female and 102 male patients. Seventy-two adult patients had undergone two or more CT examinations. The Radiation effective dose for 215 CT scan examinations of patients was determined using $CTDI_{vol}$ and DLP dose indices.

The research investigation was limited to only anatomy investigation notwithstanding the weight of the patient, clinical indications, and operating conditions.

1.7 Organisation of the Thesis

The rest of this thesis is organized as follows: In chapter 2, a review of related works is presented and some knowledge gaps are identified as a lack of institutional patient-specific protocols, insufficient adherence to quality assurance, no gender-specific analysis, the exposure parameters not including gender and scanning time, doses for multidetector CT procedures having only been reported in a small number of research investigations, and a small number of research investigations have evaluated exposure levels based on the CT scanner's age or performance state.

Chapter 3 contain details in relation to the research methodology employed in this research investigation, Chapter 4 gives a comprehensive analysis of the results and the corresponding discussions, and Chapter 5 is a section that has information in relation to the conclusions and recommendations obtained from this research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Computed Tomography is a medical imaging technique that uses high-fluence x-rays to generate cross-sectional images of a patient's organ of interest. Since its discovery by Hounsfield in 1972, the use of CT scanners has grown and become an important medical imaging modality in the radiology units of major hospitals. In 1972, the scanner at Atkinson Morley Hospital in London generated the first CT images of a patient having a head scan examination. The images were able to detect a cystic frontal lobe tumour in the patient and produced convincing proof for many radiologists, and since then, it has been embraced by the medical community.

The technology of CT scanners has evolved from second-generation to third-generation to the fourth-generation system, respectively, to date. The fourth-generation system comprises of "*ultrafast*" CT scanners with increased speed of scanning and acquisition of images.
According to UNSCEAR's survey (Table 2.1), the yearly collective dose from all diagnostic imaging modalities in nuclear medicine has increased globally in general [12].

Table 2.1: Trends in the global use of radiation for diagnosis [18]

Evaluation	Annual number of examinations (millions)	Annual frequency of examinations per 1000 population	Annual collective effective dose (1 000-man Sv)	Annual effective dose per person (mSv)
UNSCEAR 1988 Report	1740	355	1890	0.37
UNSCEAR 1993 Report	1620	305	1780	0.33
UNSCEAR 2000 Report	2460	426	2460	0.43
UNSCEAR 2008 Report	3660	561	4210	0.65
UNSCEAR 2021 Report	4190	574	4150	0.57

The number of diagnostic examinations has increased annually between the years 2009 to 2018 in the Global Survey by UNSCEAR 2021 report [12]. According to table 2.2, there is a rise in procedures done globally and also an overall contribution to a collective effective dose in all the diagnostic modalities. Computed tomography examinations contribute the greatest collective effective dose, at around 62%, but comprise only about 10% of all diagnostic procedures [12]. The use of CT in medical imaging has increased significantly in many countries [19] [20]. According to table 2.2, there are approximately 403 million CT scans conducted annually in the world. In addition, the UNSCEAR 2021 report presents data for nationwide increase in the usage of CT modality for diagnosis. It was estimated that for a population of around 300 million people in the United States in the year 2016, 3.4 million CT scans were performed [21]. Elsewhere, in China 10 million CT procedures were recorded from a population of 1.4 billion [22]. The majority of procedures recorded in the global survey was chest screening at around 32%. The cumulative dose estimates shown in tables 2.1 and 2.2 are derived from the effective dose utilizing tissue weighting factors in ICRP Publication 60 and the Monte Carlo approach. [12].

Table 2.2: Global estimate of number of Diagnostic Procedures per annum and the corresponding Collective Effective Dose [18]

Modality category	Examinations/ procedures (millions)	Examinations Contribution (%)	Collective effective dose (1 000 man Sv)	Collective effective dose Contribution (%)
Conventional radiology (excluding dental)	2 626	62.6	955	23.0
Dental radiology	1 101	26.3	10	0.2
Computed tomography	403	9.6	2 556	61.6
Interventional radiology	24	0..6	334	8.0
Diagnostic nuclear medicine	40	0.9	297	7.2
Total	**4194**	**100**	**4152**	**100**

The reason behind the rapid rise use of CT in diagnosis is its technological development that offers views of the organ in three dimensions, and also an area of the body of interest that allows for clear analysis in the diagnosis of various diseases [21]. Due to the rapid acquisition of images from multiphase procedures, such as cardiac and vascular, patient radiation exposure from CT scans has also increased [20]. It is clear that CT has more radiation than conventional radiographic techniques, and physicians should avoid requesting unnecessary tests because they may raise the risk of developing cancer [23]. A higher fraction of the population is exposed to ionizing radiation as the frequency of CT scans rises [21]. Ionizing radiation's extensive usage in medical applications has resulted in the world's greatest man-made source of radiation exposure (61.6% of the annual collective dose) as shown in 2.2 [24].

The findings from many follow-up research investigations show that children who receive frequent low doses of ionizing radiation from CT multiple imaging diagnosis are at risk of developing cancer throughout their lifetime [25]. This is consistent with the BEIR (VII) 2006 report by the US National Research Council (NRC), which was based on an epidemiological investigation of 30,000 atomic bomb survivors in Hiroshima and Nagasaki and found that even those exposed to low doses of radiation between 5 to 100 mSv developed cancer [26]. In practice, there are many clinical benefits to the growing use of CT imaging, but there are also significant health risks associated with exposure to ionizing radiation. It is essential to adopt optimization scanning methods to reduce radiation exposure from CT scans [27].

The UNSCEAR 2021 report's global survey used data from a large number of developed and a small number of developing countries. This is due to the fact that most developed countries have access to sufficient data on each radiological procedure performed during a particular year. Additionally, the CT utilization trends and patterns for patient-specific procedures are widely documented in most developed countries, while less is known in most of the developing countries [13]. A research investigation to evaluate the CT scan usage in Brazil, a developing country was assessed from various outpatients undergoing CT examinations in Brazilian public healthcare system, for the period between the year 2008 to 2011. There was rapid growth in CT usage and had tripled during the research period by 17.5% due improved patient care with use of advanced CT facilities [13]. Increased CT usage is significantly linked to improved CT

patient care, but high frequency of unwarranted CT scans needs to be investigated for associated cancer risks. Examinations of the head, abdomen, and chest were the three most common CT procedures in Brazil [13]. The findings are in line with the UNSCEAR 2021 report that recorded majority of procedures in the global survey as chest screening at around 32% [12].

2.2 Review of Diagnostic Reference Levels, Effective Dose, Cumulative Effective Dose

Diagnostic Reference Level is a concept utilized in diagnostic radiology, notably CT scans, to optimize patient dose reduction [6]. When evaluating CT imaging procedures as surrogate dose quantities for patient dose optimization, $CTDI_w$, $CTDI_{vol}$, and DLPs are key metrics to take into account [28]. Since its establishment in 1996, the Diagnostic Reference Level (DRL) has been a crucial tool for optimizing patient safety during medical operations like interventional and diagnostic procedures [29]. DRLs are only intended for radiology and not in radiation therapy. Frequent surveys are carried out to re-evaluate and update DRLs both locally and globally in order to reduce patient radiation exposure to a level that is reasonably possible [29].

The research to systematically analyse existing literature on DRLs for the chest, head, and abdominal exams revealed variance in radiation exposure amongst different CT facilities [30]. Using the Effective Public Health Practice Project tool (quantitative method), CT dose indices ($CTDI_w$ and DLP) characteristics were examined in databases made up of selected top journals in radiology, medical physics, and radiography [30]. Eight researches used phantom data, 45 used human data, and one used combined phantom and human data. In phantom investigations, there were variances of up to a factor of 2, while in patients having the same procedure, there were variations of up to a factor of 3. The age of the scanner, the kind of scanner, changes in research design, variances in protocols, use of alternative dose indices, and variations in patient information were all cited as sources of variation [30]. The $CTDI_w$ and DLP (9%), DLP just (11%), $CTDI_{vol}$ (7%), $CTDI_{vol}$, DLP and ED (6%), $CTDI_{vol}$ and DLP and SSDE (1%), $CTDI_w$ only (4%), and $CTDI_w$, $CTDI_{vol}$, and DLP (1%), $CTDI_{vol}$ and DLP (59%) were also recorded.

Furthermore, the use of multiple dose indices ($CTDI_w$, $CTDI_{vol}$, SSDE, and DLP) made it difficult to compare doses between investigations [30]. The DRLs must be standardised in accordance with ICRP guidelines in order to decrease dose variation [30].

The adult patient dose in CT procedures in Kenya were assessed and compared with the international DRLs with an aim to establish the national DRLs [31]. A questionnaire was used to record the exposure factors on body and head dosimetry phantoms ($CTDl_w$ and DLP) for chest, head, pelvis, and abdomen adult examinations at 21 facilities; different clinics and hospitals in Kenya. The data retrieved from medical records was utilized to create graphs using a log normal graphical approach, and the first national DRLs for the two dose quantities were calculated using the graphs. According to the findings, patient radiation exposure through CT exams was 90 % and 62 % lower than the $CTDl_w$ and DLP reference values, respectively [31]. For some adult patients' examinations, the mean DLP values showed a significant difference of up to a factor of 11, and above worldwide DRLs. On the other hand, the mean $CTDl_w$ values were below DRLs. The research therefore, recommended the need to adopt local optimized scanning protocols, developed specifically to reduce doses from patients without affecting diagnostic image quality [31]. However, the scanning parameters ($CTDI_w$ and DLP) employed in the investigation did not include the gender type of patients and scanning time of CT procedures. The radiology departments are required to continue collecting patient data for effective establishment of DRL's [31].

2.2.1 Effective Dose

The quantity of radiation energy that is deposited in the patient's body as a result of exposure is known as the effective dose (ED), and the SI unit of measurement is sievert (Sv) or millisievert (mSv) [32]. The ED was developed to provide a dose quantity that was related to the likelihood of health damage resulting from stochastic effects from exposure to low doses of ionizing radiation. In addition, the ED can only be calculated from the weighted sum of doses to tissues known to be radiation-sensitive [33]. The effective dose, defined by the ICRP

in 1990, is calculated by Monte Carlo simulations of photon interactions using a simplified mathematical model of the human body [34].

Research to determine and to compare the ED values for DLP derived from CT scanning protocols and from Monte Carlo calculations was conducted at Oak Ridge National Laboratory in Tennessee, USA [35]. Using Monte Carlo techniques for a 64-slice MDCT scanner, effective dose levels for five anatomic areas (neck, head, chest, abdomen, and pelvis) were investigated. The Phantom series was utilized for both children and the adults. The Spiral scanning methods with various tube voltages were simulated using Monte Carlo simulations. The effective dose was computed using information from ICRP Publications 103 and 60 and compared to the ED determined from the DLP using previously published conversion factors [35]. The ED Values between ICRP publications 103 and 60 varied, with the differences being up to 32% and 33% lower than previously published values, respectively [35]. Based on previously published conversion factors, the ED for paediatrics derived from Monte Carlo calculations was greater than DLP [35]. There was no dependence on tube voltage for adult patients, and 15% variations on tube voltage for children observed. The effective dose of DLP Conversion factors in both genders must be provided individually and ought to follow the current ICRP guidelines. Additionally, new conversion factors unique to paediatrics should be created [35].

2.2.2 Cumulative Effective Dose (CED)

The cumulative effective dose occurs from multiple and repeated CT scans on patients. Frequent repetition of Abdominal CT scan to evaluate trauma from one hospital to another provides an accurate diagnosis but increases radiation exposure and medical costs on the patient life [36].

In research done retrospectively, the cumulative organ dose that adult patients undergoing CT head exams received from multiple exposures was evaluated [37]. The dose survey was carried

out in Medical and Dental Institute in Penang and the Hospital Universiti Sains Malaysia in Kelantan. A total of 203 adult patients with multiple (3 times or more) CT scans were chosen from the Emergency and Neurosciences Departments. Following the multiple CT exposures, the effective dose and cumulative organ doses were calculated using the CT ImPACT program [37]. According to the survey, the majority of patients had repeated (three or more) head CT scans, with the greatest incidence of repeated CT being 14 times [37]. For the 14 CT exposures, the eye lens got the highest equivalent dose of 8.02 mSv, and bone marrow with dose levels of 7.06 mSv. The maximum mean dose received by the eye lens was 8.02 mSv, which is 0.1 to 8.0% less than the ICRP's advised limit of 20 mSv, and was rated low risk by the organization. The chance of developing a radiation-induced cataract was also thought to be low with respect to the absorbed dose to the eye lens [37]. The increased frequency of repeated CT exposures, on the other hand, resulted in a dose increase (p-value = 0.01). Furthermore, after four exposures, the lens's absorbed dose surpassed the 2 Gy cataract risk range (M = 244.81, p = 0.01). Additionally, a p value of 0.01 revealed a significant difference between the maximum cumulative effective dose calculated using ImPACT (43.8 mSv) and the basic method (32.1 mSv) [37]. The repeated CT exposures should be properly monitored for organ exposure and effective dose, and they should be justified so that the patient receives the lowest dose that is reasonably achievable [37]. The CT scanning has higher radiation doses than other diagnostic modalities hence the need to develop standardized protocols across institutions [30].

In Kenya, a national survey was done on the frequency of radiological operations and the radiation dose given to the public at 300 x-ray facilities [38]. In order to determine patient radiation exposure, frequency, and total effective dose, for computed tomography, general radiography, interventional procedures (IPs), fluoroscopy, and mammography were evaluated [38]. Both the collective and individual radiation loads for 62 different adult and paediatric radiological exam types were measured using effective and collective doses. The average effective dose for each radiological examination was calculated using patient data from more than 30 common radiological institutions and results from X-ray efficiency performance evaluations. An estimated 3 million x-ray procedures were performed in the year 2011, resulting in a 0.05 mSv annual effective dose per person and a 2,157 Sievert annual effective dose [38]. The most frequently examined procedure was Conventional radiography (94%), computed

tomography (3.3%), and Fluoroscopy (2.5%). Despite being relatively seldom carried out, CT exams made up 36% of the total effective dose per person. The majority of examinations used general radiography, which accounted for 55% of the effective dose per person [38]. The CT scanning has higher radiation doses than other diagnostic modalities hence the need to develop standardized protocols across institutions [38].

2.2.3 Radiation Dose Measurements in Computed Tomography

The absorbed radiation dose is the quantity of radiation energy that a patient's body absorbs as a result of radiation exposure [39]. The CTDI and DLP are used in dose description for complex conditions of CT scanners and the two parameters estimates patient's absorbed radiation dose [40]. However, the amount of ionization events in air caused by photons (x-rays) that constitute radiation exposure can be determined using TLDs, GM counters, Scintillation counter or ionization chambers, based survey meters [39]. In dosimetry, Ionization chambers due to high sensitivity are the most preferred instruments to measure low to high-exposure rates typically over a wide energy range from 9.3×10^{-4} mSv/hr to 0.93×10^{-2} Sv/hr, and suitable for detecting alpha, beta, x-rays and gamma particles [39]. The CTDI and DLP dose indexes dictate the dose absorbed as it quantifies the patient's radiation dose from radiations. There are slight variations in measurements for the same type of examination, possibly occurs owing to patient size [41].

The Monte Carlo simulations are used in all current techniques. Although they are unrefined and patient-specific, effective dose estimates have been created; organ dose estimates are less prevalent [42]. The Fast MC simulations, which are independent of CTDI phantom data, can offer accurate dose estimates for specific patients and organs [42]. Such information is crucial and helpful in optimization efforts, particularly when it comes to 3D dose distributions. Recent years have seen significant progress in dose optimization, leading to applications with effective dose levels of under 1 mSv. In general, it is necessary to acknowledge a tendency toward decreasing dose levels brought on by technical developments. The effective dose levels are

typically far lower than 10 mSv, and a number of procedures, including cardiac and CT paediatrics, are regularly carried out on modern equipment with doses of less than 1 mSv [42].

In Germany, USA, and the UK, a patient dose survey based on computed tomography procedures was conducted between the year 1999 and 2001 [43]. The $CTDI_{vol}$ and DLP means values were computed. All the countries showed comparable mean values for head CT examinations, with a mean DLP of 760 ± 90 mGy cm and a $CTDI_{vol}$ of 59 ± 6 mGy [43]. The $CTDI_{vol}$ levels for body exams in the USA (21 ± 5 mGy) were more than twice those in Europe (12 ± 2 mGy) [43]. The average head $CTDI_{vol}$ values were similar to the diagnostics reference levels (DRLs) established by the UK Health Protection Agency and the European Commission, although they are lower than the current USA standard of 75 mGy. For abdominal imaging, the DRLs in the UK are nearly a factor of 2 lower (14 mGy) in relation to USA and other European Countries (25 mGy) [43]. The Effective dose, DLP, and $CTDI_{vol}$ are good metrics of CT radiation exposure that enhance patient safety by recognizing unexpected higher doses and standardizing CT scans [34, 36].

2.3 Effects of Ionizing Radiation on Human Health

Excessive radiation exposure causes detrimental health effects [44]. This is due to exposure to radiations in the range (0.25 - 20 Sv) for the various tissues, which is above the dose limits recommended by ICRP 41. Delayed radiation damage may lead to induced cancer. The excess radiation exposure also leads to alteration of DNA leading to genetic mutation for the offspring generation [44]. Deterministic effects are non-probabilistic and have a direct proportion with the amount of dose received by a person. The higher the dose received the greater the severity and vice versa. These effects have a limit for each organ according to ICRP 41, and when exceeded can trigger deterministic injuries, hair loss and other radiation diseases [45]. Stochastic effects are probabilistic and there is no threshold [45]. These effects can trigger negative impacts on the reproduction system and abnormalities in foetus [45].

However, there are reported cases of accidental exposures, for example, a case where there were 400 overdoses at eight hospitals in the United States of America, following CT brain perfusion scans [46]. Most of the radiation overdoses were attributed to user operator's error. The consequences of radiation overdoses triggers hair loss, possible eye damage, brain damage and other radiation long term risks of cancer [47]. In order to implement effective interventions, attention must be paid to developing quality, an integrated framework for safety, and risk management that can accommodate data and enable global information and tool sharing [46].

CT scans expose patients to considerably higher doses of radiation than conventional diagnostic x-rays, sparking concerns about the risk of radiation-related cancers [48]. In the United States future cancer risks from CT scans were estimated using risk models based on organ-specific radiation exposures and the BEIR report from National Research Council, according to sex, age, and scan type [48]. The risk uncertainty levels were calculated using analytical software, which conducted Monte Carlo simulations to anticipate the average number of radiation-related incident cancers with 95% confidence levels [48]. The projected risk per 10,000 CT scans in 2007 was connected to about 29 000 (95% UL, 15 000-45 000) future cancers from a total of 56.9 million CT scans in the USA, when sex and age-specific annual rates were combined. The most substantial contributions came from chest CT angiography (n = 2700; 95% UL, 1300-5000), head CT angiography (n = 4000; 95% UL, 1100-8700), pelvic and abdominal CT scans (n = 14 000; 95% UL, 6900-25 000), and chest CT scans (n = 4100; 95% UL, 1900-8100). One-third of the anticipated cancers were caused by scans performed between the ages of 35 and 54, and 66% of the anticipated cancers were in females. Scans performed at the age of 18 and under produced 15% of the anticipated cancers [48]. The most common projected radiation-related cancer was lung cancer (n = 6200; 95% UL, 2300–13 000), followed by colon cancer (n = 3500; 95% UL, 1000–6800) from CT of the abdomen & pelvis, and leukaemia (n = 2800; 95% UL, 800-4800) from CT of the chest. The sites of cancer with the highest risks have higher radio sensitivity (red bone marrow and leukaemia) [48]. Many aspects of CT scan utilization, such as age groups and scan types with a high frequency of scans requiring relatively high doses, were highlighted as areas where risk-reduction strategies may be needed, according to the study [48].

2.4 CT Examinations in Paediatric Patients

CT examinations may lead to radiation induced cancer in children when not used properly [49]. Figure 2.1, data from BEIR VII (2005), shows that children have a higher lifetime risk of cancer due to CT use because their tissues and developing organs are fundamentally more prone to cellular harm than those of adults [17].

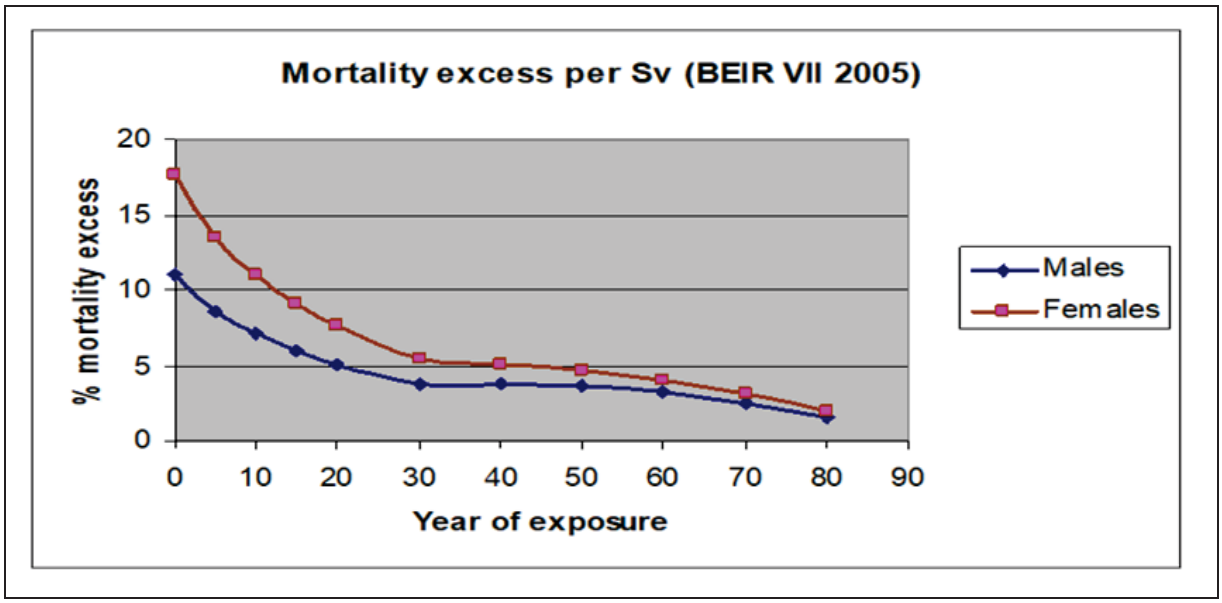


Figure 2.1: Mortality excess per Sv against Age and Gender (Retrieved from BEIR VII report 2005 [17])

Due to its versatility, speed, and accuracy, CT imaging exposes patients to much more radiation than other imaging techniques, especially because of children's smaller bodies [17] Although there is little possible risk, the rising frequency of CT scans in children has raised serious public health concerns. Several organizations have advised taking steps to reduce excessive radiation exposure from CT scans. Multiple or medically unnecessary scans should be avoided, patient-specific dose recommendations should be developed, and alternate radiography techniques should be used wherever possible [17]

The patient's exposure can be reduced by developing clinical pathways that encourage use of non-radiation imaging modalities [49]. Safe use of CT scanning is essential to ensure safest

possible care of children [49]. Paediatric healthcare provider also encouraged to reduce radiation exposure based on ALARA principles [49]. Paediatricians can design methods to lessen radiation exposure in children and new-borns by understanding the hazards and benefits of radiation exposure from CT scans [50].

The research to evaluate the magnitude of CT doses and the frequency of paediatric (≤ age 15 y of age) CT examinations in 28 countries was conducted in 128 CT facilities in Eastern Europe, Asia and developing countries of Africa [51]. A total of 101 out of 128 CT facilities in 19 countries had records of patient radiation dose. Questionnaire method was employed to evaluate the $CTDI_w$, $CTDI_{vol}$ and DLP for lumbar spine, chest (high resolution), chest, and pelvis and abdomen CT examinations. From the research investigation, the average frequency of children CT examinations was 5, 16 and 20% in Eastern Europe, Asia and Africa, respectively [51]. There were variations in $CTDI_w$ up to a factor of 6.6 (Eastern Europe), 16.3 (Asia) and 55 (Africa). The corresponding DLPs differed by a factor of 8, 10, and 20 in each case. For children's patients, eleven CT facilities in six countries utilized adult CT exposure settings, indicating a need for optimization and a lack of awareness. In general, Japan's $CTDI_w$ and DLP were lower than those of countries in the other three regions. In most developing countries, there is a pressing need to optimize and justify CT scans in children. This could be achieved through training, awareness and monitoring of radiation doses [51].

One non-paediatric and three paediatric institutions in Belgium participated in the research to assess paediatric examination protocols for common CT procedures from 5 single slice scanners and 2 MDCT scanners [52]. The goal was to compare patient radiation exposures to proposed reference values and analyse children's scanning parameters in comparison to adults [52]. Using Monte Carlo simulations, the DLP, $CTDI_w$, and ED for three typical procedures: the abdomen, the brain, and the thorax; were examined for patient ages (1 year, 5 years, and 10 years. DLP and $CTDI_w$ values were greater than the reference level for all types of examinations. The ED's range for abdomen, thorax, and brain exams was 0.4 mSv to 2.3 mSv, 1.1 mSv to 6.6 mSv, and 2.3 mSv to 19.9 mSv, respectively [52]. Only one hospital adopted patient specific protocols as function of patient size while the other centres used similar examination protocols for both adult and paediatric. Some centres used age group to divide the patients into only two/three groups,

while other hospital used weight to categorize the patients into 6 groups. Some centres utilized the same mAs for both examinations (adult and children), but with a lower pitch factor for children, resulting in greater radiation exposure. The technical scan settings must be carefully chosen based on the size/age group. To minimize excessively high radiation dose during CT examinations, paediatric patients must utilize adjusted CT parameters based on the examination [52].

2.5 Quality Assurance and Quality Control in Diagnostic Radiology: Facility Optimization

The planned and systematic efforts to verify the system's proper functioning is known as quality assurance. Quality control refers to the procedures used to test the radiological system's components and guarantee that the machinery is operating as intended [53]. In diagnostic radiology, both QA and QC tests provides timely detection of any quality degradation of the image produced by the scanner [54]. Additionally, MDCT scanners use standard cylindrical phantoms to provide dosimetric quantities such as CTDI that are also helpful for quality assurance objectives [54]. According to ICRP Publication 135, the CT acceptable DRL quantities are $CTDI_{vol}$ and DLP, utilized in assessing QA/QC testing. By performing QA/QC tests on a regular basis, patients' safety is ensured by delivering high-quality radiological services [54].

All clinical trials in radiation oncology need to improve their quality processes on a regular basis [55]. The ability to examine all procedures in real time will make clinical trials better and easier in the future, and will be in line with international cooperation [55]. In addition, the processes developed will permit expansion of informatics tools required and validate patient's clinical practice [55].

In CT facilities in Kenyan hospitals, research was undertaken to examine the level of compliance with image quality requirements and quality assurance [56]. A QA inspection and assessment of physical image quality in 18 CT facilities were part of the procedure [56]. The

data was gathered using a quantitative methodology, and the physical image quality was assessed using the water phantom developed by AAPM. The facilities were also evaluated for conformity with globally recognized standards such as the International B.S.S. and European guidelines for ionizing radiation quality criteria for CT, among others [56]. According to the findings, creating a CT quality management baseline is critical and may be accomplished by implementing the quality improvement process on a continuous basis [56].

The Radiology Department of KNH conducted prospective research to assess the quality of radiographic images, performance testing for x-ray machines, examination frequencies, and ESD using TLD for patient's dose having general radiographic evaluation [57]. The image quality and patient dose were evaluated on a total of 229 paediatric patients and 837 adult exams. The characteristics of device film reject rate, device performance, patient dose, and image quality were examined utilizing conventional and quick-speed (200 and 400) film screen combination techniques [57]. The output measurements and x-ray exposure parameters of the x-ray tube were developed, and the findings were compared to worldwide diagnostic radiography dose optimization criteria [57]. The three x-ray machines (Philips: installed in the year 1990) under investigation using Radiation QC equipment had variations in the kVp accuracy, radiation output, HVL and focal spot. The radiographs and image quality were evaluated using a quantitative QC approach. There were 7 to 10% film rejects due to poor grade, 67% of adult dose complied with guidance level while none of paediatrics dose complied. In addition, 80% adults and 20% paediatric frequency of examination were obtained. The findings led to the conclusion that the idea of "plan-do-check-act" needed to be introduced in order to optimize patient protection and reduce patient dose [57].

2.6 Optimization of Operating conditions: Effects on Protocol, Dose, Image Quality

The CT scans for five patients with cerebral palsy were done at 80 and 120 kVp, respectively [58]. The research was done both before and after the injection of iodinated contrast material, with a focus on radiation dose, noise, and contrast [58]. The mean noise at 80 kVp and 120 kVp

does not differ significantly (P =.042). While keeping mAs constant, the CBF at 80 kVp lowers the radiation dose by a factor of 2.8, on the other hand at 80 kVp there is enhanced contrast enhancement and less patient irradiation [58]. Increased contrast enhancement and improved CBF analysis should come from CT investigations of CBF, with a lower radiation dose [58].

The research on CT brain scanning was performed at 140 and 100 kVp to differentiate, in vivo, between blood and contrast materials (Iodine or Calcium solutions) [59]. The larger atomic numbers of calcium (Z=20) or iodine (Z=53) contrast-enhanced examinations causes the CT values to decrease greatly since they absorb some radiations imparted on the patient [59]. There was no significant change in blood flow in both cases of Ca and iodine contrast. In addition, eight individuals with calcified lesions, haemorrhages, or iodine-contrast enhanced lesions were tested on the concept. There was no difference in CT values for Haemorrhages in both 100 and 140kVp while significant change in CT values was observed in, iodine-contrast lesions containing calcified lesions [59].

The investigation was done at high and low kVp to see how tube potential affected CT images [60]. High contrast materials are required at low kVp settings for CT visibility but also produce high image noise, typically in larger patients. The research recommended that further technique refinement and clinical research as required as the use of CT scanners technology spreads [60]. A total of 100 patients underwent evaluations for the ED, CT attenuation, CNR of the ascending aorta, and image noise [61]. A tube voltage of 100 kVp was used for 50 patients' scans, while a tube voltage of 120 kVp was used for the other 50 patients [61]. For both 120 kVp and 100 kVp protocols, no significant change in the ED was observed (21.8 mSv ± 1.1, 21.7 mSv ± 1.6 vs., P = 0.65) [61]. The CNR of the ascending aorta did not differ significantly between the 120 kVp and 100 kVp procedures (18.8 mSv ± 3.5 vs. 18.7 mSv ± 3.8, P = 0.98). When using 120 kVp procedures instead of 100 kVp protocols, coronary arteries' CT attenuation was higher (P 0.05). At 100 and 120 kVp, the coronary artery image quality did not substantially differ between the two methods (3.7 ± 0.4 vs. 3.7 ± 0.5, P = 0.65) [61].

2.7 Review of CT Examinations and other Clinical Challenges

In a CT scan, a patient's exposure to radiation is impacted by a variety of variables. The scanner's design, the anatomic volume scanned, the patient's size, the x-ray beam's quality, the scanning procedure, and the method utilized are all factors to consider [62]. Radiation-induced cancer risk is mostly influenced by age and gender. Because of their more tissue-specific bodies, females face a higher overall risk than males. Furthermore, when one continues to age, the risks fall significantly [62].

In Indonesia, research was done to create a national DRL for head CT exams based on gender [63]. The data from a survey of 20,211 patients were evaluated, and were separated into non-contrast and contrast parameters, and outliers were eliminated using the z-score method. The maximum, minimum, the first (25%), median (50%) and third quartile (75%) values were determined using MATLAB R2017b software. The 75% percentile of data was used to develop the DRL. For the non-contrast parameter, $CTDI_{vol}$, DLP, and ED were 61 mGy, 1,350 mGy-cm, and 2.8 mSv; for the contrast parameter, they were 60 mGy, 1,811 mGy-cm, and 3.8 mSv [63]. The $CTDI_{vol}$ were the same for both males and females. However, the national DRL value in terms of DLP and ED were greater for males than that for females. The differences in head size, which are often larger in males than in females, are consistent with the variances in findings [63].

Using multi– and single–detector row helical CT systems, research was undertaken to evaluate colonic distention, respiratory artefacts, and polyp identification during CT colonography [64]. A total of 237 individuals received subcutaneous glucagon before having colonoscopies, with single-detector row CT colonography (n = 77), and multi-detector row CT colonography (n = 160) [64]. Intestinal distention, respiratory artefacts, and polyp representation were all evaluated individually by two radiologists. It was discovered that single-detector row CT was much more common than multi-detector row CT, with at least one segment present in 52% (40 of 77 patients) of tests compared to just 19% (30 of 160 patients) of multi-detector row CT exams (P.001) [64]. Only 16% of multi-detector row CT tests (26 of 160 patients) showed mild respiratory artifacts, compared to 61% of single-detector row CT exams (47 of 77 patients)

(P.001). When compared to multi-detector row CT, which identified 80% (eight of ten polyps), single-detector row CT revealed 89% (eight of nine polyps) of polyps larger than 10 mm (P >.05) [64]. When compared to single-detector row CT, multi-detector row CT greatly enhanced the depiction of colonic distention and showed less respiratory artifacts. For a small number of polyps, there were no appreciable variations in the representation of polyps larger than 10 mm between single- and multi-detector rows CT. Research with a greater prevalence of clinically important polyps is necessary for a more detailed analysis of variability in polyp diagnosis [64]

During routine CT scans, research of 111 people in Turkey examined at structural differences and critical regions of the paranasal sinuses to assess the carrying risks for catastrophic consequences [65]. Eighty individuals had coronal CT scans, while the remaining had coronal and axial CT scans. Three measurements were made: the depth of the lamina cribrosa, the separation between the orbital roof and the inferior turbinate of the anterior ethmoidal artery (AEA), and the separation between the orbital roof and the inferior turbinate of the inferior ethmoidal artery. In 23% of the instances, there were variations in the top attachment of the uncinate process [65]. In 43 percent of ethmoidal cells, AEA flowed easily. In 14% of the patients, the optic canal bulged into the sphenoid sinus, in 13%, and in 12% of the patients, the carotid canal had an extreme medial course [65]. Lamina cribrosa had an average depth of 5.9 mm and an average distance to the inferior turbinate of 25.7 mm. Average distances between AEA and the orbital roof and the inferior turbinate were 13.7 mm and 30.05 mm, respectively [65]. According to the investigation, lamina papyracea damage or a laceration of the AEA can cause serious issues including orbital contents herniation or bleeding. In addition, there is a risk of anterior clinoid sinus, Onodi cell, and other potentially harmful disorders, as well as direct or indirect injury to the optic nerves and veins throughout the optic and carotid canal [65]. Finally, while assessing CT before functional endoscopic sinus surgery, the course of AEA, optic and carotid canal, hazardous sphenoid septum, bone dehiscence, and alterations of the upper tip of PU should all be taken into account [65].

In Turkey, 400 patients enrolled in a further trial to examine anatomical differences using CT joint space measures, which included patients without sacroiliac joint complaints who underwent CT pelvic examinations [52]. From the findings, anatomical variants were observed. The variations observed were brought about by difference in patient's joint width, with a mean

joint value 1.72 ± 0.57mm (from 0.77mm to 4.39mm). The measured joint width was 2.49 ± 0.66mm, and 1.47 ± 0.2mm, in adults below the age of 40 years and older patients respectively. In conclusion, the anatomical variations and joint space are independently related to gender, age, body mass index and childbirth in patients [66].

2.8 Radiation Protection for Patient Medical Exposure Examinations

The framework of radiological protection for medical exposure is composed of justification and optimization [67]. In the case of patients' radiation protection, dose constraints and DRLs are recommended. According to the International B.S.S for medical exposure, dose constraints are only applicable in optimizing the protection to patients and not for workers or persons who assist in the support, care or comfort the exposed patients [67].

Radiation protection provides safety standards that protect people from unlikely exposure, by preventing the occurrence of radiation effects arising from probabilistic or non-probabilistic ways [68]. Radiations surveys are normally carried to assess the radiation to allowable limits [68]. The safety of patients and the enhancement of radiological services necessitate quality patient radiation dose monitoring management [68].

At Kenya, research was conducted in 54 typical x-ray medical facilities to examine the degree of quality management systems [69]. The questionnaire method was used to examine the x-ray facilities' quality control performance testing, quality management inspection, and patient radiation exposure. In addition, 140 hospitals across the country were surveyed on the frequency of examinations. The results showed that the nation's overall x-ray imaging quality management systems received a score of 61 ± 3 % out of a possible 100 % [69]. The lowest quality assurance performance indicators were general radiography x-ray equipment quality control tests, which were at 88 ± 4%, and adult interventional cardiology exams, which were 25 ± 1% below DRLs. Technical x-ray procedures, patient characteristics and image quality criteria are key in quality management programme [69].

The degree of radiation protection offered to patients and staff during interventional procedures was investigated in 20 Asian, European, and African countries [70]. Peak skin dose, details about radiation safety equipment, and kerma-area product data were gathered from 55 hospitals in 20 countries (6 in Asia, 9 in Eastern Europe, and 5 in Africa). The yearly burden in the interventional rooms was up to 40% of ≥ 2,000 patients annually [70]. The workload associated with paediatric interventional treatments has grown; in just three years, over 30% of participating nations have reported a 100% rise. Most of the institutions had access to KAP and lead aprons, but nobody had ever used them. One hundred of the 505 patient examined for PSD (20%) had deterministic effects that exceeded the 2-Gy threshold. In developing countries, all interventional procedures (adult and paediatric) are on the rise, and staff safety is acceptable [70]. Because numerous patients surpassed the dose threshold for common clinical indications including erythema and percutaneous trans luminal coronary angioplasty (62 %) above the established dose reference level, the justification for patient protection was not explored. According to the findings, it is critical to improve patient safety by adopting the idea of patient dose management [70].

2.9 ALARA Principle for Minimization of Patients Exposures

It is essential for diagnostic practices to keep radiation exposures to patients and staff As Low As Reasonably Achievable (ALARA) [71]. The Society for Paediatric Radiology firmly believes in this concept, particularly when using techniques and modalities that subject kids to higher radiation doses, like CT scans and fluoroscopic examinations [71]. Patients under the age of 18 may be up to 10 times more radiosensitive than adults. Therefore, following the ALARA principle is necessary for practice that lowers ionizing radiation exposure while enhancing imaging results [72]. In Kenyan medical institutions, application of good radiographic technique and justification appears to be the main components of ALARA utilized to reduce patients' radiation doses, especially in conventional radiography. However,

establishment of Diagnostic Reference Levels (DRL) forms basis for optimisation of patient protection with the use of Multi-Slice Detector CT scanners [73].

According to ICRP publication 103, the occupational exposure of any worker who works for 48 weeks in a year must not go above an effective dose of 50 mSv in any given year. In a single day, this translates to a dose rate of 0.1 mSv/hour [74]. All the radiological staffs should spend minimal time in any radiation area to overcome excess exposure levels [75]. Distance is another way of overcoming excess exposure levels and is governed by inverse square law [75]. Shielding is the third way of protecting people from exposure to radiations. High density materials such as lead are commonly used materials to prevent unlikely radiation exposure to patients, radiological staffs and the public [75].

In order to evaluate the degree of patient dose, device performance, film rejects, and image quality in 4 hospitals, a screen/high-speed film combination approach was used in the research [73]. According to the investigation, the performance of the quality control tests on the x-ray equipment ranged from 63% to 90%, showing that the radiographs had a good diagnostic value [73]. The most typical chest, lumbar spine, and pelvic exams were used to achieve these utilizing ESD measurements. According to the results, the patients' primary sources of radiation exposure were pelvis and lumbar spine, and the chest ESD levels were over the international DRLs. According to the research findings, the ALARA principle should be followed and a quality assurance baseline for radiation protection of patients undergoing diagnostic radiography should be put into place [73]. The safety of patients in terms of ALARA principle and justification is inadequate without use of proper quality assurance measures [73].

2.10 Summary of the Key Related works

There are variations in CTDI values from a patient dose survey from CT examinations in various countries in America, Europe, Asia and Africa. However, there is insignificant variation in the values reported for head CT examinations and significant variations were observed for abdomen examinations. The slight variations for the same type of body examination, possibly occurs owing to patient size. The research therefore, recommended the need to adopt local optimized scanning protocols, developed specifically to reduce doses from patients without affecting diagnostic image quality.

DRL is a concept utilized in optimization in diagnostic radiology, particularly CT scans, to minimize patient doses. Frequent surveys are used to re-evaluate and update DRLs both locally and internationally in order to keep patient exposure to a reasonable level. The cancer risk from radiation exposure depends largely on age and gender. The overall risk is higher for female patients, than male due to their highly tissue-specific bodies. In addition, the risks decrease with increases in age.

Children who undergo CT scanning have a higher lifetime risk of developing cancer than adults do because of the inherent vulnerability of their developing tissues and organs to cellular harm. Only a few hospitals in most developing countries have implemented patient-specific protocols depending on patient size, whereas the majority uses the same examination methods for adult and pediatric patients. As a result, CT scans in children must be optimized and justified in the majority of developing countries. This might be accomplished by radiation dose exposure training, awareness, and monitoring, for example.

The Quality Assurance status between the various generations of CT scanners available on the market differs in terms of protocols used but is necessary to ensure proper operation. The majority of research recommends adhering to the ALARA principle and creating an adequate quality assurance baseline for radiation protection of patients undergoing diagnostic radiography. The frequent performance of QA/QC tests guarantees safety of patients by providing quality radiological services. CT scanner operating conditions, such as that tube potential voltage, age of the scanner can adversely affect patient dose exposures.

2.10 Knowledge gaps

Few imaging procedures were designed to adhere to patient-specific protocols, and it was found that the majority of institutions use gender protocols even when imaging paediatric patients [13] [42].

In diagnostic procedures, there was insufficient adherence to quality assurance especially in developing countries [56].

Some research investigations did not work toward gender-specific analysis and the exposure parameters did not include gender and scanning time [28].

Doses for multidetector CT procedures have only been reported in a small number of research investigations [76].

Only a small number of research investigations have evaluated exposure levels based on the CT scanner's age or performance state [77].

There is an establishment of DRls that are focused on general anatomical classifications rather than clinical indications [64] [78] [79].

Considering CT procedures to be low-dose radiation procedures, few investigations did not evaluate the risks related to them [7] [8] [48] [17].

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Description of the Nairobi Hospital

The Nairobi Hospital is a private institution located in the upperhill area, Nairobi, Kenya. It is recognized as an advanced diagnostic, treatment, and referral centre for medical expertise and services. The hospital has a network of specialist centres within Nairobi, among which includes the Radiation Treatment Unit.

The unit was established in 2012 and is equipped with state-of-the-art radiation therapy devices to provide high-quality radiation treatment in a safe manner. The radiology department offers a variety of services, including CT scans, fluoroscopy, interventional, mammography/breast imaging, MRI, ultrasound, x-rays, Orthopantomogram (OPG), cardiac catheterization/angiograms, echocardiography, and Endoscopic Retrograde Cholangio-Pancreatography (ERCP). A high-dose rate Brachytherapy unit, in addition to general radiotherapy services, allows radiation to be delivered by directly introducing a radiation source into the body for various illness diagnostics and treatment, as well as cancer surgery.

Other facilities in the unit include the Phillips 64-Slice CT Scanner used in medical imaging, and a Philips 16-slice CT scanner used for oncoradiology purposes, the subject of this research.

3.2 Sampling Design

3.2.1 Ethical Considerations

Prior to the commencement of the research investigation, the Nairobi Hospital Ethics Review Committee gave consent vide the Research permit TNH/DCS/DMSR/14/02/2020 to carry out the research at their institution. In addition, Research permits License No: NACOSTI/P/20/4425 was granted by NACOSTI upon meeting the Nairobi Hospital Bioethics Committee requirements.

This is a requirement by law and has provisions, amongst others, to protect patients' privacy and confidentiality of information, such that the real names of the patients were not used in this research. Kenya's 2017 Health Act No 21 part 5(2) requires every person to be treated with dignity, and respect and have their privacy respected in accordance with the Constitution.

3.2.2 Sampling of CT scans for various Examinations for Patient Exposures (DLP, CTDI, ED and DRL)

The research investigation was performed on records available of all patients; adult CT examinations and data collected over a 3-month period between January 2020 and March 2020. A total of two hundred and fifteen CT scans were examined, which were distributed as shown in table 4.8. The age distribution of patients was 13-87 years, 113 (52.56%) female and 102 (47.44%) male patients, one child, and the majority were considered adults. Seventy-two out of 215 patients underwent two or more CT examinations during the research investigation.

The 215 CT scan imaging were extracted from exposure to Philips Brilliance 64 slice Scanner for the respective examinations, and the exposure parameters extracted from the Picture Archiving and Communication System (PACS) were recorded in a data collection worksheet (Appendix III). The parameters of interest as included in the data collection worksheet included the following patient data; age, gender, scanning time, the type of examination procedures, the operating conditions, and the corresponding $CTDI_{vol}$ and DLP values for the respective procedures.

The following patient's serial numbers were recorded and designated as follows; HE01-64: head examination procedures (without contrast); HEW01 head with contrast; CHEWC01-02; chest with contrast; CHE01-28 chest non-contrast; A01-21 angiography with contrast; AW01 angiography without contrast; CERVSP01-14 cervical spine without contrast, CERVSPW01 cervical spine with contrast; LUMBSP01 Lumbar spine examination; NE02-10 Neck without contrast; ABDW01-13 Abdomen non-contrast; ABDC01-24 Abdomen contrast; and PAR01-36 Paranasal sinuses examination.

Using the data from the CTDI and DLP, values for ED were computed. Effective doses (ED) were calculated for all CT procedures utilizing the values for the "k" conversion coefficients as listed in ICRP Publication 103 [80].

Diagnostic Reference Levels (DRLs) were also established from CTDI and DLP values using 75% percentile values as recommended by ICRP 103 [80]. In principle, diagnostic reference levels are established by obtaining 75% percentile values for all $CTDI_{vol}$ and DLP in a survey of preferably a minimum of 20 patients for CT examinations performed in each procedure.

Quality assurance of the Philips Brilliance 64-slice CT scanner was assessed using two-part PMMA phantoms; 16 cm phantom for the head and 32 cm phantom for body procedures and, for acceptance test of the radiation dose.

3.3 Instrumentation of CT scanner and Measurements

3.3.1 Philips Brilliance-64 CT Scanner

The major components of a multidetector CT scanner are a gantry, an x-ray control console, a patient table, a power distribution unit, and a computer system that controls image reconstruction, manages data acquisition, stores image data, and displays images, among other crucial tasks.

The Brilliance 64-slice CT system utilized in this research is a third-generation scanner with Essence technology, which incorporates a detector, x-ray tube, and reconstruction innovations that results in high-quality patient images. The typical configuration of the 64-slice CT scanner is shown in Figures 3.1 and 3.2. The 64-slice CT scanners is advanced, and a standard for most referral hospitals and imaging centres in Kenya.

The gantry is a ring-shaped part of the CT scanner and hosts the x-ray filters, the x-ray collimators, the x-ray tube, and the detectors. The x-ray generators and tubes are located on the opposite side of the rotating scan frame within the gantry, together with the detector assembly. They are of the high-frequency type with typical operating power of 80 to 120 kilowatts (kW), tube potential (80–140 kVp), and tube current (100–400 mA).

The x-ray tubes are equipped with two focal spots; one large focal spot (requiring high x-ray photon flux) and a small focal spot (for high spatial resolution). In practice, high mA selection on scans leads to the engagement of the large focal spot that may be undesirable for high spatial resolution, and users should be aware.

The x-ray detectors use scintillation crystals usually arranged in multiple rows, to convert x-rays to visible light pulses, which in turn can be detected and counted by electronic circuits. The system contains collimators; fixed post-patient collimators (to reduce scatter radiation) and multiple pre-patient collimators to reduce unnecessary patient dose and to define x-ray beam dimensions.

The filters are made of materials; a Copper/Aluminium alloy, and used to shape the beam geometry and remove low-energy x-ray photons, which may contribute to patient doses. In practice, it has a number of active acquisition channels (64 rows) and a nominal slice thickness of each acquisition channel or each detector row (T = 0.625mm); the Brilliance-64 scanner has 64 rows × 0.625mm (40mm coverage).

The main operator's interface with the other key components is the system console. A Dell computer with two monitors powers the console and runs Brilliance workspace (1,280 x 1,024 Flat Panel LCD each). Images from the main console may be seen at a different location, such as the radiology reading room, using an optional slave monitor. Additionally, the console is used to initiate or terminate procedures, select scanning parameters, input patient demographic information, display and review images and communicate, for the radiological information system and image archiving and communication systems (PACS). Before, during, and after scanning, the Brilliance 64-slice system employs an auto voice set of commands for patient communication. Furthermore, customized messages may be generated.

A polychromatic x-ray tube and third-generation detector technology make up the gantry. 700mm gantry aperture, 360° rotation, -30° to +30° gantry tilt with 0.5° increments, 1040mm focus detector distance, and 570mm focus-isocenter distance. The vertical range of the patient table is between 578 to1028 mm with a 1.0mm increment, and the table is 1900 mm long with a scannable range of 1750mm. It moves at a speed of 0.5-143mm/s longitudinally.

The tube currents of the range 20 to 500 mAs with 1 mA increments and tube voltages of (80,120,140 kVp) are used in a 60kW generator. The x-ray tube has an anode storage capacity of 8 MHU, a maximum cooling rate of 1680 kHU per min, an anode diameter of 200mm, a focus spot of 0.5mm *1.0mm for small, and 1.0mm *1.0mm for large, in accordance with IEC 60601-2-28. The UA Filter, 250mAs, 120kVp, 10 mm, 250 mm FOV, 0.75 sec, and 21.6 cm water equivalent phantom have a noise level of 0.27%. With a low-contrast resolution of 4.0 mm @ 4 % and 4.0 mm @ 0.3 percent [250mAs, 120kVp, 10 mm, 250 mm FOV, 0.75 sec, 27mGy at surface of CATPHAN phantom], the scanner has an absorption range of -1024 to +3072 Hounsfield units.

X-rays tube target maximum On-Time (120kV, large focal spot, maximum power) of 23 sec @ 500 mA with a target angle of 7°. Slip ring and optical ring (- 5.3 Gbps transfer rate), Data sampling rate of up to 4640 views/element/revolution There are collimations for slices (40 x 0.625 mm, 2 x 0.5 mm, 64 x 0.625 mm, 32 x 1.25 mm, 16 x 2.5 mm). Slice thickness can be adjusted in the spiral mode between 0.55 and 7.5 mm and in the axial mode between 0.5- and 12 mm. Scan angles (240, 360, and 420°) and field of view (250 mm, 500 mm).

The other physical characteristics and technical specifications of Brilliance 64-slice CT scanner include; Spiral scanning is one of the scanning modes used, in which multiple contiguous slices are collected concurrently with continuous table movement during scans. Acquisitions can also be made in the reverse direction. With a spiral pitch of 0.13 to 1.5, the maximum exposure duration for spirals is 100 seconds (user-selectable). The second mode is axis scanning. With incremental table movement between scans, a multiple-slice scan with up to 64 contiguous slices can be created simultaneously. From narrow slice data, thick slices can be recreated using fused modes.

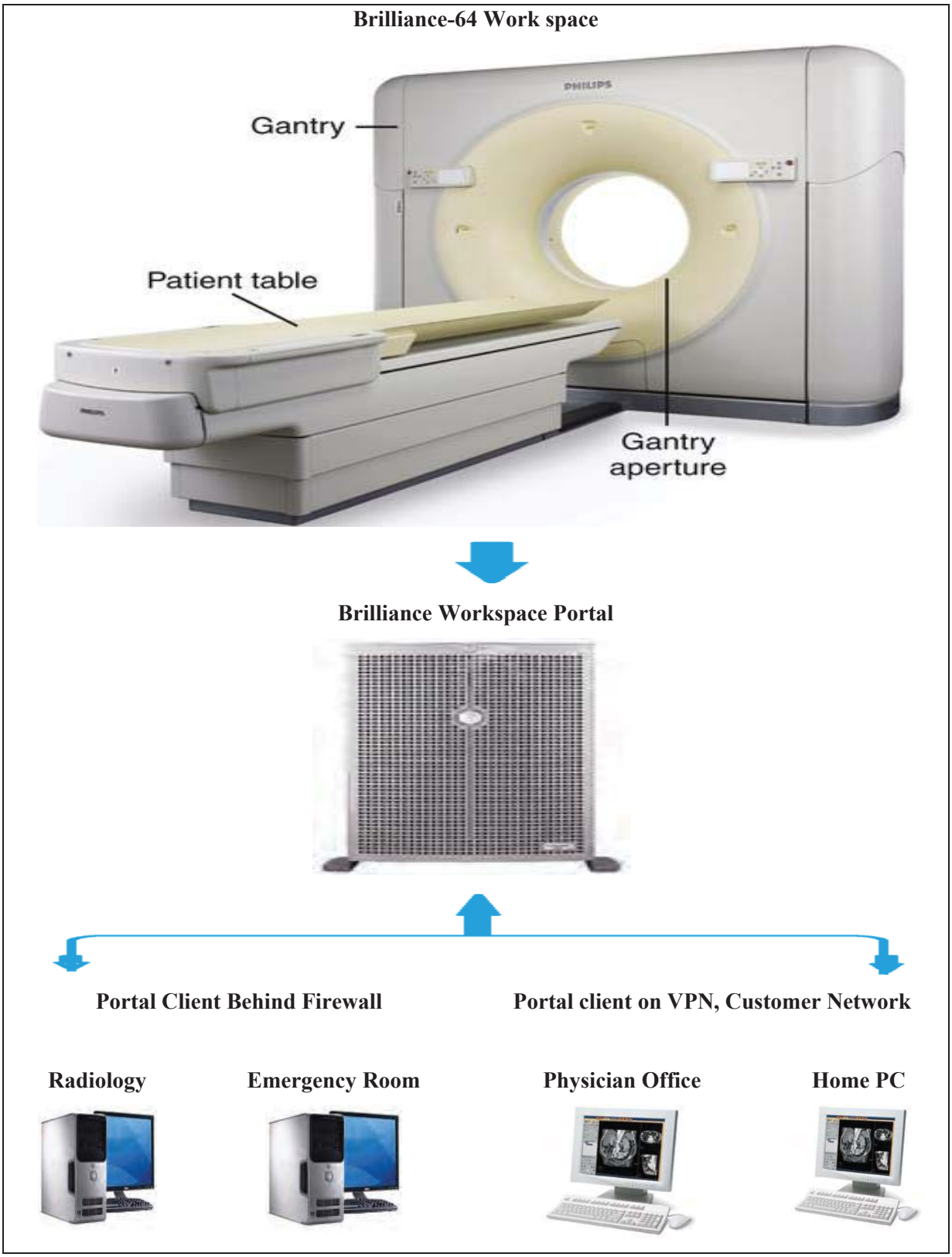


Figure 3.1: The major components of the modern MDCT system and Brilliance 64-slice CT works space (Retrieved from www.abufarhamedical.com)

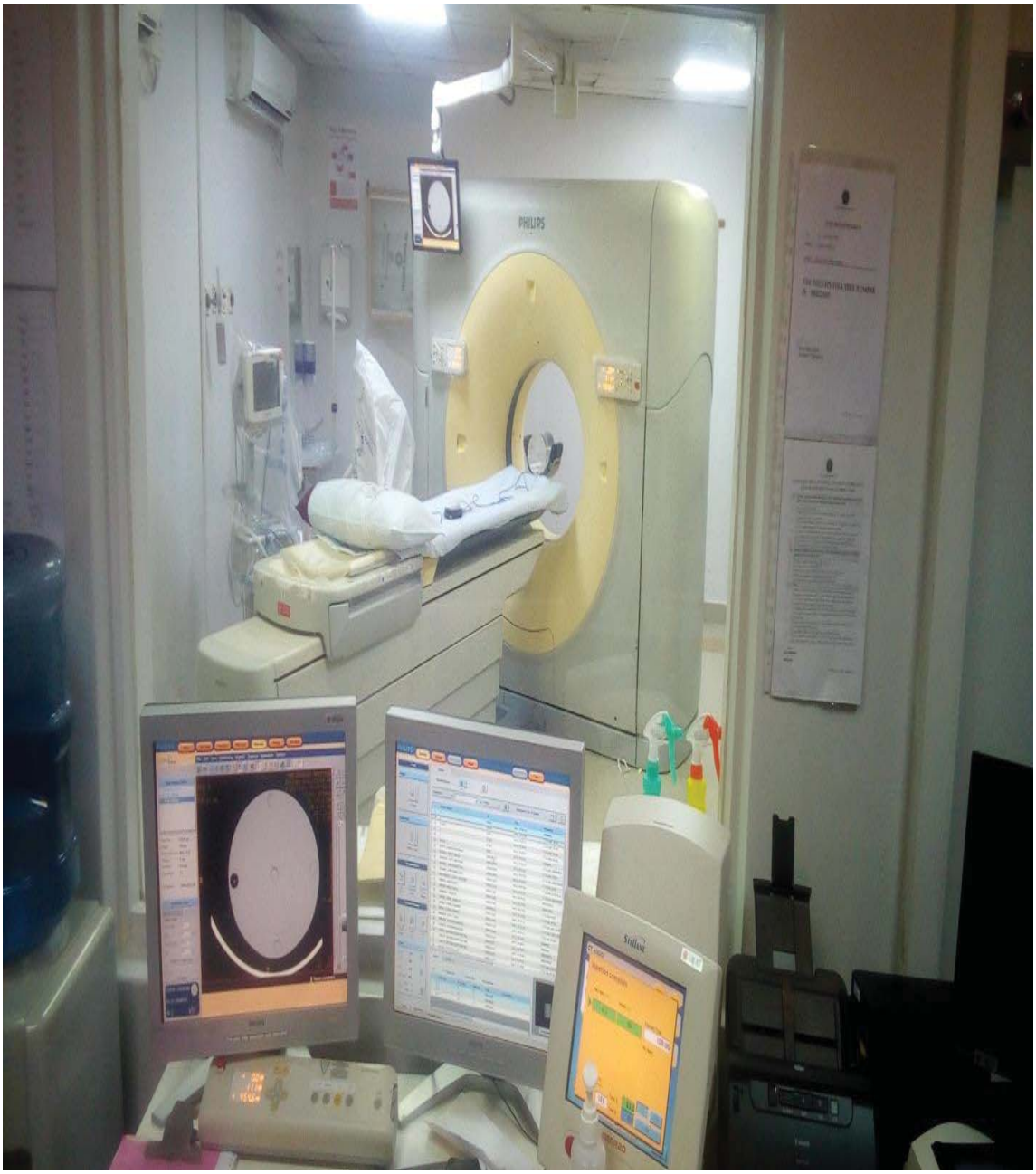


Figure 3.2: Console System and Philips Brilliance 64-slice CT scanner at the Nairobi Hospital

3.3.2 PTW-DIADOS E Dosimeter and Radiation Exposure measurements

The DIADOS E dosimeter, PTW, Freiburg, Germany is a diagnostic dosimeter for CT modalities quality control. The DIADOS E is used for routine quality control and acceptance tests of diagnostic x-ray modalities of all types. It records all dose values and the time of exposure. Semiconductor detectors are used in the PTW-DIADOS E dosimeter, which complies fully with IEC 61674. Stable cumulative dose According to IEC 61674, the detector must be exposed to an air KERMA of 40 Gy in an unattenuated x-ray beam of 70 kV before the response can change by more than 1%. In the 50–150 kV range for conventional diagnostic imaging and the 25–35 kV range for mammography in both attenuated and unattenuated beams, it has an energy response within 5%. It uses a separate high-voltage source and a 100 mm pencil ion chamber (Fig. 3.3).

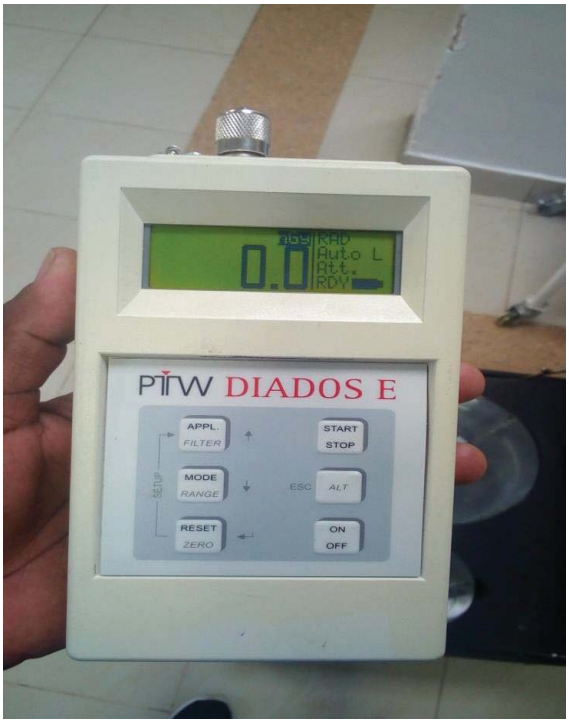


Figure 3.3: DIADOS E Dosimeter for Radiation Exposure measurements with Head Phantom

3.3.3 CT Chamber Type 30009- Pencil Ionisation chamber

The 100 mm pencil ionisation chamber (PTW, Freiburg, Germany) is developed for computed tomography $CTDI_{vol}$ and DLP measurements in accordance with the (IEC 60601-2-44) amendment. It is connected to the DIADOS E dosimeter, through a PTW CT adapter (Fig. 3.4 and Fig. 3.5) for radiation dose exposure measurements.

It's a vented pencil-shaped chamber used in computed tomography dosimetry to measure the Air KERMA as the exposure. It has a nominal sensitive volume of 3.14 cm^3, nominal response of 14 nC/ (Gy.cm), and reference Radiation Quality of 120 kV, HVL 8.4 mm Al, in line with IEC 61674 standards (RQT9) for diagnostic radiology.

The other salient features include the following:

- Offers a 10 cm sensitive measuring length.
- Displays a consistent response along the entire chamber's length.
- Can be used in a CT body phantom, head phantom, or free in air.

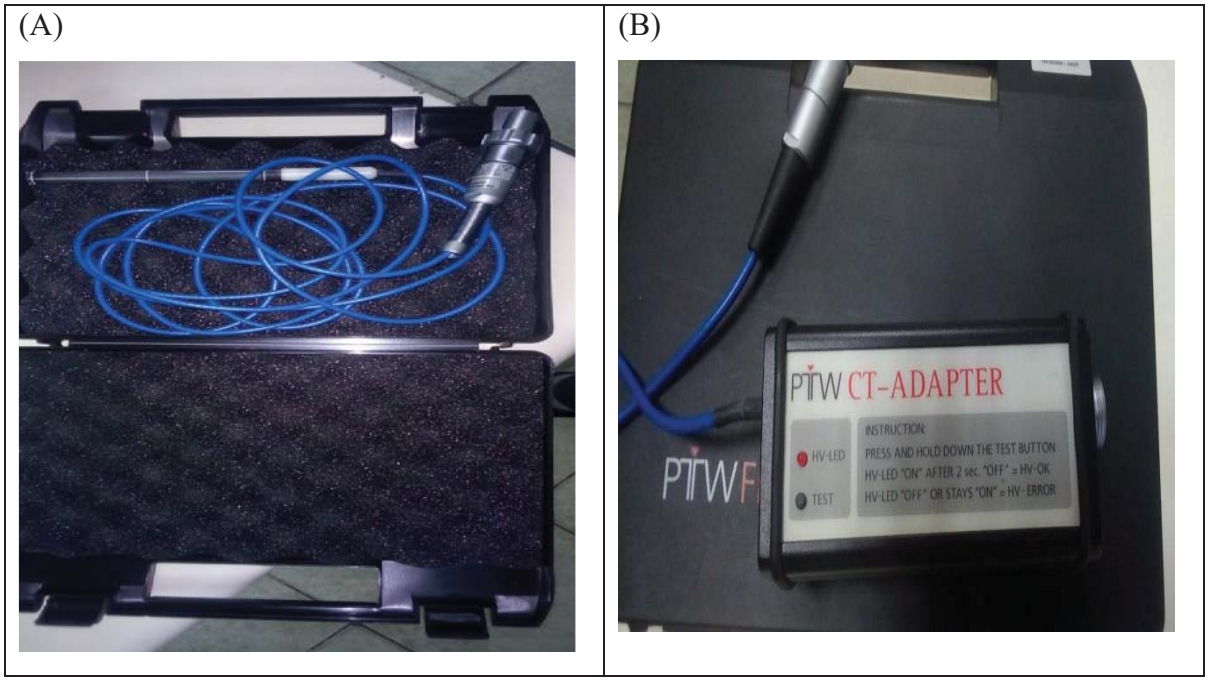


Figure 3.4: (A) 100mm Pencil Ionisation chamber (PTW, Freiburg, Germany), (B) PTW CT-adapter used in this Research

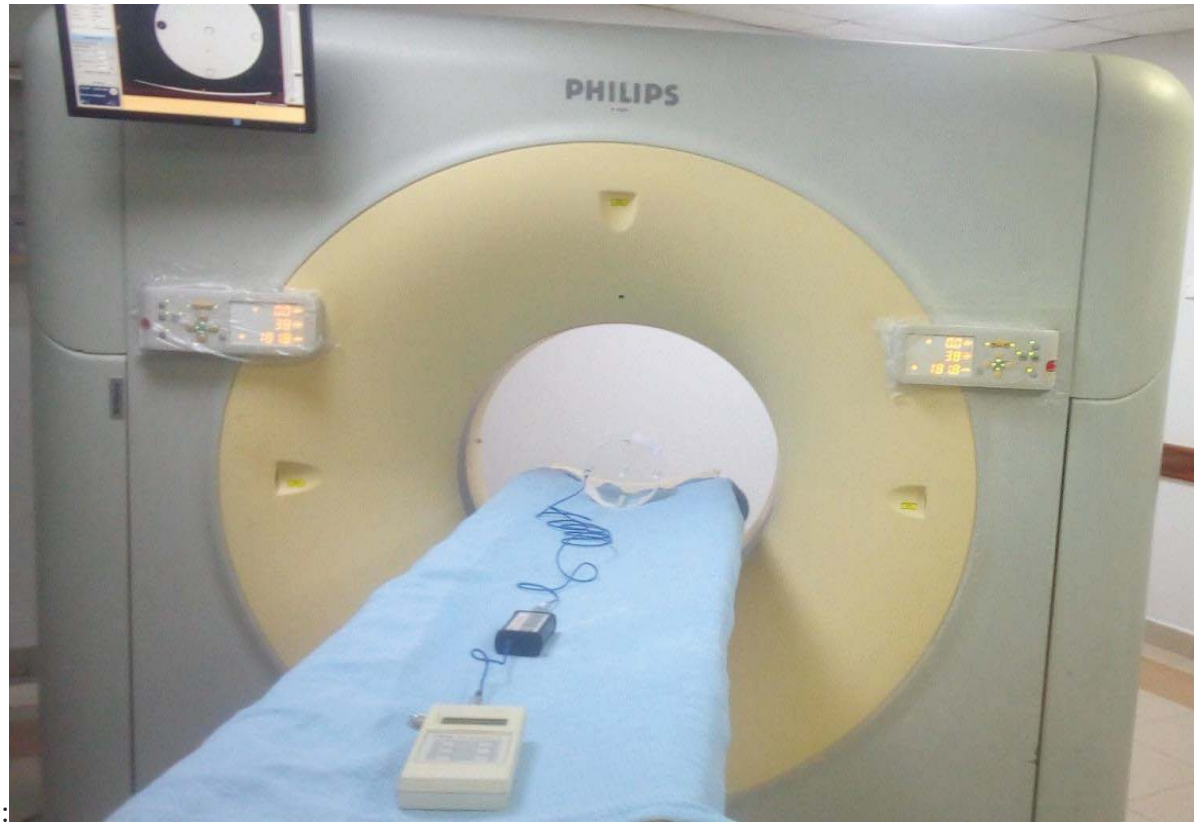


Figure 3.5: DIADOS E dosimeter (PTW, Freiburg, Germany) -to-PTW CT-adapter-to-100mm pencil ionisation chamber for body phantom measurements

3.3.4 RAD-60^{TM} Personal Dosimeter for Radiation Exposure Measurements

The RAD-60^{TM} dosimeter is a battery-operated, portable device that measures diagnostic x-ray equipment output radiation (Fig. 3.6). It is made up of a silicon diode and has a digital Liquid Crystal Display (LCD) that displays the exposure. Its measurement range is as follows;

- Dose rate: 0.5 mrem/h - 300 rem/h or 5 μSv/h - 3 Sv/h.
- Dose: 0.1 mrem - 999 rem or 1 μSv - 9.99 Sv.

Figure 3.6: RAD-60^{TM} Electronic Personal Dosimeter

An areal radiation survey of the PHILIPS Brilliance 64-slice CT facility room was performed using a RAD-60^{TM} dosimeter at various identified localities; Patient Waiting Area, Control Room, outside Entrance Door (E3 and E5), Public Waiting Area and Along the Corridor, when the CT scanner was in use, at distance (1m, 2m and 3m) away for compliance to the prescribed allowable limit 0.25 μSv/hr according to ICRP publication 73. The radiation dose exposure rate values measured at various localities varied between (0.12 to 0.20 μSv/hr), and were within the 0.25 μSv/hr ICRP limits (Fig. 3.7).

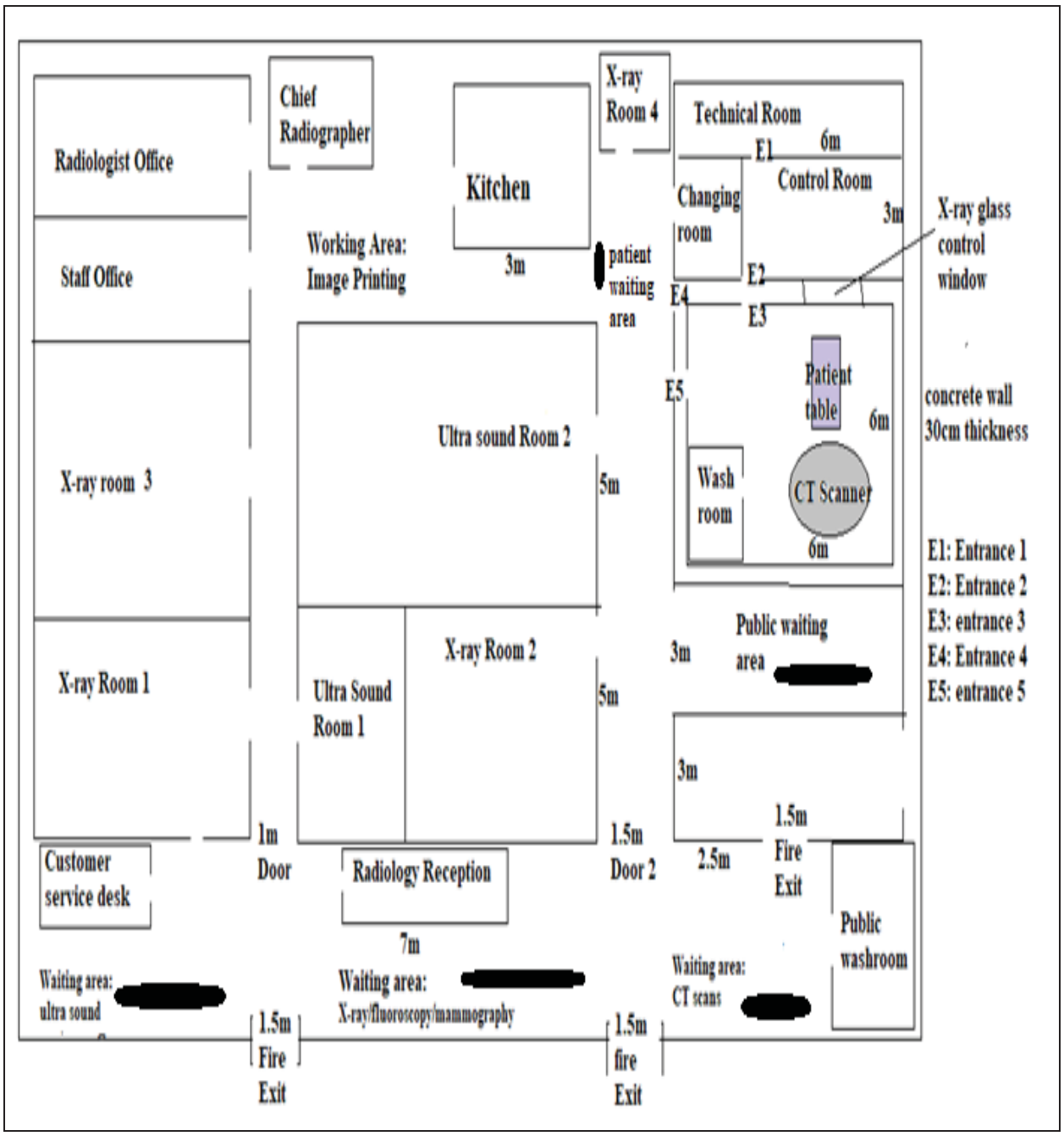


Figure 3.7: The Layout of the Radiology Unit (Brilliance 64-slice CT scanner) unit and various points

3.4 Quality Assurance: CTDIvol $_{and}$ DLP measurements using PMMA phantoms

The Quality assurance of the PHILIPS Brilliance 64 CT Scanner facility, used in this research investigation, was assessed for radiological compliance standard (IEC 60601-2-44) by the International Electro-technical Commission using 2-part PMMA CT-Phantom for CTDI measurements, which consists of; 1 adult head phantom (16 cm diameter, 5 holes); 1 adult body annulus (32 cm diameter, 5 holes); 10 acrylic rods for plugging all phantom holes (Fig. 3.8).

Figure 3.8: (A) PMMA (Body and Head) phantoms in the storage case, (B) PMMA Body Phantom connected with Pencil ionization chamber at the centre

3.5 CT Dosimetric Measurements

The European Commission states that to calculate Reference Dose Level (DRL) by guidelines on CT quality criteria, two descriptors Dose Length Product and weighted Computed Tomography Dose Index are utilized. The Monte Carlo calculation methodology is a developed and validated method for calculating radiation absorbed dose from images of anthropomorphic phantoms and patients in computed tomography examinations [80].

3.5.1 CTDI Measurements

The CTDI is described as being equal to the nominal slice thickness (d) divided by the integral across the dose profile for one x-ray tube revolution.

The average value of $CTDI_{100}$ in a volume of the phantom with thickness d is called the weighted $CTDI_w$, and it is calculated using equation 3.1.

$$\mathbf{CTDI_{100} = \left(\frac{1}{3}\, CTDI_C\right) + \left(\frac{2}{3}\, CTDI_P\right) \quad (mGy)} \qquad \mathbf{3.1}$$

The $CTDI_C$ and $CTDI_P$ are CT dose index measurements performed with an ionization chamber at the center and periphery of the phantom, respectively.

$CTDI_{100}$ is a practical expression for a chamber that provides air kerma (‘dose') (mGy), taking in into account the correction factors, is given by equation 3.2 [81]

$$\mathbf{CTDI_{100} = \frac{D \times Lc \times F \times CF}{N \times T} \qquad (mGy)} \qquad \mathbf{3.2}$$

Where;

D = measured dose at a point of the ionization chamber (mGy), Lc = length of the ionization chamber (100mm), F = Conversion factor of Acrylic/Perspex phantom (0.887), and CF = Pencil Ionization Correction Factor (0.946), N = Number of Slices for Single Scan and T = Slice Thickness.

As a single-number indicator of a patient's radiation dose, weighted CTDI is derived using equation 3.3 because, in practice, the CTDI recorded in the center and periphery of phantoms varied significantly [76].

The pitch factor, $CTDI_{vol}$, and $CTDI_w$ are necessary to determine the average absorbed dose in the irradiated volume from a scan series. The pitch factor (p) is the ratio of the movement of the patient's table to two consecutive revolutions of the x-ray tube and the nominal slice thickness. Equation 3.3 is utilized to account for helical doses as well as conventional axial doses.

$$\mathbf{CTDIvol} = \frac{\mathbf{1}}{\boldsymbol{p}} \mathbf{.CTDI_w} \quad \mathbf{(mGy)} \qquad \mathbf{3.3}$$

3.5.2 DLP measurements

The term "Dose Length Product" in CT refers to the radiation dose incident on the patient. For the experimental measurements using the phantoms, DLP is calculated using equation 3.4.

$$\mathbf{DLP = (CTDI\ )(scan\ length)} \qquad \mathbf{3.4}$$

For helical scanning (continuous movement), the scanning length is the table travel distance between consecutive scans times the number of scans. For axial scanning (with stops in movement), the scanning length is the nominal width of the total collimation. For the same examinations, numbers of helical scans are dependent on the scan length.

The CT dose index displayed by the console uses a model that utilizes equation 3.5 and 3.6. The volume of the patient exposed to radiation throughout the entire examination is characterized as the DLP quantity displayed by the CT console, utilizing equation 3.5 as follows:

$$\mathbf{DLP} = \sum_i \mathbf{CTDIw.\ TiNi} \quad \mathbf{(mGy.cm)} \qquad \mathbf{3.5}$$

Where; i stand for each helical scan sequence, Ti stands for each different slice thickness used in the procedure, Ni stands for the number of Ti slices, and $CTDI_w$ stands for the $CTDI_w$ value for each individual Ti slice thickness.

For helical scanning, where the x-ray tube rotates around the patient table, equation 3.6 is utilized by the console.

$$\mathbf{DLP = \sum CTDIw.T \quad (mGy.cm)} \qquad \mathbf{3.6}$$

Where T is the nominal irradiation slice thickness in cm.

3.5.3 Normalized $CTDI_w$ measurements

The normalized weighted CT dose index, $CTDI_w$, is derived in accordance with EC's recommendations by dividing the absorbed dose integral along a parallel to the axis of rotation z of the dose profile D (z) of a single slice by the nominal slice thickness T.

The radiation dose from a single slice for a specific exposure setting is represented by the real $CTDI_w$ and is calculated using equation 3.7, and is derived by multiplying the C (mAs) value utilized at the hospital.

$$\mathbf{CTDIw = nCTDI.C \qquad (mGy)} \qquad \mathbf{3.7}$$

The relative performance of different scanners and procedures may be determined by comparing CTDIw and DLP measurements for a particular examination.

The quality criteria for region-specific normalized coefficients (see Tables 3.1 and 3.2) were adopted and utilized to estimate the risk of a specific testing process in order to compare our data with EU standards [82].

Table 3.1: Typical patient doses and diagnostic reference levels for Computed Tomography in European guidelines [83]

CT Examination Procedure	Effective dose E, (mSv)	Diagnostic Reference CTDIw (mGy)	Level DLP (mGy.cm)
Routine Head	2	60	1050
Routine Chest	8	30	650
Routine Abdomen	10	35	800
Routine Pelvis	10	35	600
CTA (coronary arteries/blood vessels)	12	15	1040

*CTA =Coronary Computed Tomography Angiography, DRL values obtained from UK national diagnostic reference levels (NDRLs) 2019 [78].

3.6 Determination of Effective Dose

The relative radiation risk of different CT scans or treatments is evaluated using a metric known as the effective dose with mSv units, which is directly related to radiation risk. To determine the Effective Dose (ED), detailed knowledge regarding the beam quality, irradiation geometry, and the patient's anatomy is needed. The use of Monte Carlo computations with known conversion factors was found to be completely satisfactory in this research investigation.

The ED for a certain scanning protocol is calculated using DLP values for an examination and properly normalized coefficients (see Table 3.2) and equation 3.8.

$$ED = E_{DLP}.DLP \quad (mSv) \quad 3.8$$

Where, DLP (mGy.cm) is the dose-length product and EDLP is the region-specific normalized effective dose ($mSv.mGy^{-1}\ cm^{-1}$).

Table 3.2: The "k" conversion coefficients ($mSv\ mGy^{-1}\ cm^{-1}$) over different anatomical patient body for various regions (EC, NRPB and ICRP 103) [84] [85]

DLP to E "k" Conversion Coefficients ($mSv\ mGy^{-1}\ cm^{-1}$)				
Anatomic Region	EC	NRPB-W67	ICRP 103	Phantom
Head	0.0023	0.0021	0.002	16 cm
Neck	0.0054	0.0059	0.005	32 cm
Chest	0.017	0.015	0.021	32 cm
Abdomen	0.015	0.015	0.022	32 cm
Pelvis	0.019	0.015	0.011	32 cm
CTA (coronary arteries)	0.012	-	0.031	32cm

* E = k × DLP, where DLP = dose-length product. The Phantom size is specified for the volume C T dose index measurements on which DLP is based. The "k" value from ICRP 103 as reported by [86]. The conversion Coefficients for CTA (coronary arteries) in NRPB-W67 is missing (-). Some authors employ organ-based dose data to compute effective doses for a mathematical anthropomorphic phantom using the Monte-Carlo method [87]. However, in accordance with European Guidelines on Quality Criteria for Computed Tomography, the effective dose in this research investigation is determined using DLP to E "k" conversion factors, derived from gender-invariant biokinetic and anatomical models.

3.7 Data Analysis

The data consists of two hundred and fifteen (215) patients' CT scans examinations, which were acquired using a Philips Brilliance 64-slice Scanner unit, available at the Nairobi Hospital, and have been assessed in this research investigation.

The scans were sampled over a 3-month period between the dates of 1st January 2020, to 30th March 2020, for the adult and paediatric CT examinations. A data collection worksheet was developed, which details the following information; specifications of the CT scan machine (The type of manufacturer and the detector rows number), operating conditions; (mAs, kVp, pitch, and the nominal slice thickness), and patient related data ($CTDI_{vol}$, DLP, age, sex, gender, scanned length and time) were recorded.

Thirteen types of common CT examinations including head, paranasal sinus, neck, chest contrast, chest non-contrast, angiography contrast, angiography non-contrast, abdomen non-contrast, abdomen contrast, lumbar spine, and cervical spine non-contrast and cervical spine with contrast were examined.

According to ICRP publication 135, diagnostic reference levels were established by obtaining 75 % percentile values for $CTDI_{vol}$ and DLP, using the Excel embedded ToolPak tool.

3.8 CT Dosimetry Measurements: Quality Assurance of Philips Brilliance 64-slice CT scanner was assessed using PMMA Body and Head Phantoms

The dose was measured using a pencil ionization chamber (PTW, Freiburg, Germany) connected through CT-adapter (T16018-00332, PTW, Freiburg, Germany) connected to a DIADOS dosimeter (PTW, Freiburg, Germany) as well as a CT dosimetry phantom. The chamber is designed for CT dosimetry and has a 100-mm active length. This was done in

accordance with the International Standardization in Dosimetry in Diagnostic Radiology, the IAEA International Code of Practice [88].

Quality Assurance of Brilliance 64-slice CT scanner was assessed using PMMA body and head phantoms for acceptance test, to check radiation dose at different points. The phantoms were positioned in iso-centre in the scan plane, with their axes parallel to the gantry rotation axis. Then, in the dosimetry hole (centre), a 100mm pencil ionisation chamber was inserted, and the other four peripheral holes (North, East, South, and West directions) were filled with PMMA plugs. Measurements were done 3 times for both 16cm head and 32 cm body PMMA phantoms. The procedures were carried out for each of the phantom holes and the measured CTDI were compared with the corresponding machine $CTDI_{vol}$ for radiological compliance with IEC quality criteria standards (<±20% between displayed and measured), and the percentage of deviation established for all the dosimetric measurements [82].

The scan parameters of the CT used were selected as follows: (a) PMMA Body phantom 120 kV, 309mAs, 162.0 mm Scan length (SL), 3.0 mm Slice thickness (ST), 109 numbers of images/slices, for the following examinations; (b) PMMA Head phantom: 120 kV, 250mAs, 166.0 mm Scan length (SL), 4.0 mm Slice thickness (ST), 82 numbers of images/slices.

Diagnostic reference levels were established using the 75th percentile values obtained from $CTDI_{vol}$ and DLP for each type of CT examination for comparison with existing International DRLs [89].

The measured CTDI were the normalized to weighted $CTDI_w$ and then CT dose quantities ($CTDI_{vol}$ and DLP) were calculated using Monte Carlo technique. The calculated CTDI and DLP values were used to determine ED.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results of the assessment of patients' exposure levels for Computed Tomography (CT) examinations at the Nairobi hospital. Section 4.2 presents the results of Quality Assurance of the Philip Brilliance-64 CT Scanner for exposure dose measurements using the 2-part PMMA CT-Phantom.

Sub-section 4.2.1 $CTDI_w$ measurements using 2-Part phantoms, subsection 4.2.2 describes Dose-Length Product measurements using 2-Part PMMA CT- Head and Body Phantom, and 4.2.3 Effective Dose measurements using 2-Part PMMA CT- Head and Body Phantom. Section 4.3 presents Background Radiation exposure measurements of the CT facility room and Section 4.4 shows the assessment of the CT Dose Data Protocols used in different examinations at the Nairobi hospital using the Philips Brilliance 64.

The percentile dosimetric values analysed using the ToolPak tool is presented in section 4.5 for assessment of CT scans of various examinations for patients' exposures (DLP, CTDI doses, effective dose and DRL). Additionally, the data for patients' exposures for the various CT Scan examinations are in section 4.5.1, results of the Patient Exposures: DLP and CTDI dose, Effective Dose, DRL for various examinations in 4.5.2 and section 4.5.3 show results of Patient Exposure for multiple CT examinations.

4.2 Quality Assurance and Quality Control (QA and QC) of Philips Brilliance-64 CT Scanner for Exposure Dose Measurements

Prior to dose measurements of the various anatomical regions, a complete QA and QC (mechanical, electrical, and radiation checks) were conducted for the Philips Brilliance 64-slice CT scanner used in this research investigation using the 2-part PMMA CT- head and body Phantom, for radiological compliance. For abdominal measurements, the scan parameters used were selected as follows; 120 kV, 309mAs, 162.0 mm Scan length (SL) and 5.0 mm slice thickness and 120 kV, 250mAs, 166.0 mm and 4.0 mm slice thickness (ST) for head examinations as shown in Fig. 4.1. The $CTDI_w$ values were measured using DIADOS E Dosimeter and were compared with the CTDI values on the CT console readings for compliance and are tabulated in Table 4.1 and Table 4.2, for both examinations (abdomen) and head (brain) examination, respectively.

Table 4.1: Mean $CTDI_{vol}$ Vs. Measured $CTDI_{vol}$ values using PMMA 32cm Body phantom (n=3)

Scanned Area	Machine $CTDI_{vol}$(mGy)	Measured $CTDI_{vol}$(mGy)	Deviation	Acceptable	Achievable
Centre(c)	17.80 ± 0.02	27.8 ± 0.6	-10.0	<±20%	-56.2%
P_N	17.90 ± 0.02	29.3 ± 0.2	-11.4	<±20%	-63.7%
P_E	17.20 ± 0.01	23.3 ± 0.2	-6.1	<±20%	-35.5%
P_S	17.20 ± 0.01	21.2 ± 0.2	-4.0	<±20%	-23.3%
P_W	17.20 ± 0.02	22.0 ± 0.7	-4.8	<±20%	-27.9%

Table 4.2: Mean $CTDI_{vol}$ Vs. Measured $CTDI_{vol}$ values using PMMA 16cm Head phantom (n=3)

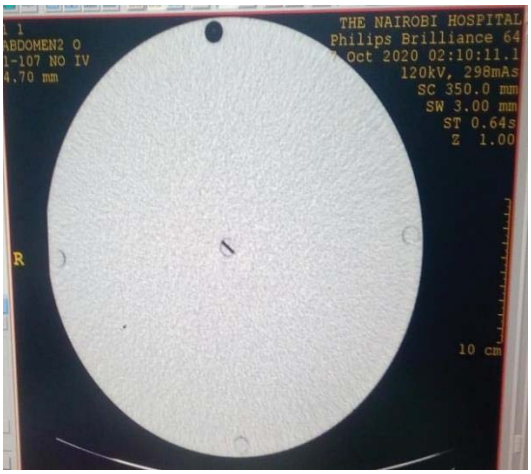
	Machine $CTDI_{vol}$(mGy)	Measured $CTDI_{vol}$(mGy)	Deviation	Acceptable	Achievable
Centre(c)	32.00 ± 0.01	43.7 ± 0.6	-11.7	<±20%	-36.6%
P_N	32.00 ± 0.01	45.2 ± 0.2	-13.2	<±20%	-41.3%
P_E	32.00 ± 0.01	43.10 ± 0.06	-11.1	<±20%	-34.7%
P_S	32.00 ± 0.01	43.6 ± 0.2	-11.6	<±20%	-36.3%
P_W	32.00 ± 0.01	43.9 ± 0.3	-11.9	<±20%	-37.2%

*Periphery (P) points: PN (North), PE (East), PS (South), PW (West)

For the QA and QC of the CT scanner, there was an observable significant difference (< ± 20 %) in all CT practices during both head and abdominal exams, between the measured and certified $CTDI_{vol}$. The negative percentage differences indicate that the console $CTDI_{vol}$ is lower than the measured values using the Diadose E dosimeter. According to the International Standardization in Dosimetry in Diagnostic Radiology and IEC quality criteria standards, the percentage of deviation between the measured CTDI values and machine should not exceed an acceptable level (<±20%) [90].

The percentage of deviation between the measured and machine dose data for both head (-34.7% to 41.3%) and abdomen (-23.3% to -63.7%) CT examinations, exceeded the acceptable level (<±20%). Therefore, this implies that the output from the scanner is high, and indicates that the patients are unnecessarily exposed to radiation. These variations may be explained by various factors such as the scanner's age, status of maintenance, scanner's state of operation, and the inherent changes in features such as; x-ray filtration, scattered x-rays, beam geometry, and a number of active detector rows, as discussed in section 3.3.1. It is important to carry out a maintenance schedule to assess and rectify any faulty feature so as to adjust the scanner's readings to account for actual exposure levels. Additionally, there is need to assess the lifetime attributable cancer incidence and mortality for all patients undergoing imaging with the MDCT 64-slice scanner in order to ascertain the level of radiation risks.

(A)CT PMMA HEAD PHANTOM



(B)CT PMMA ABDOMEN PHANTOM

(C)MACHINE CTDI FOR HEAD PHANTOM

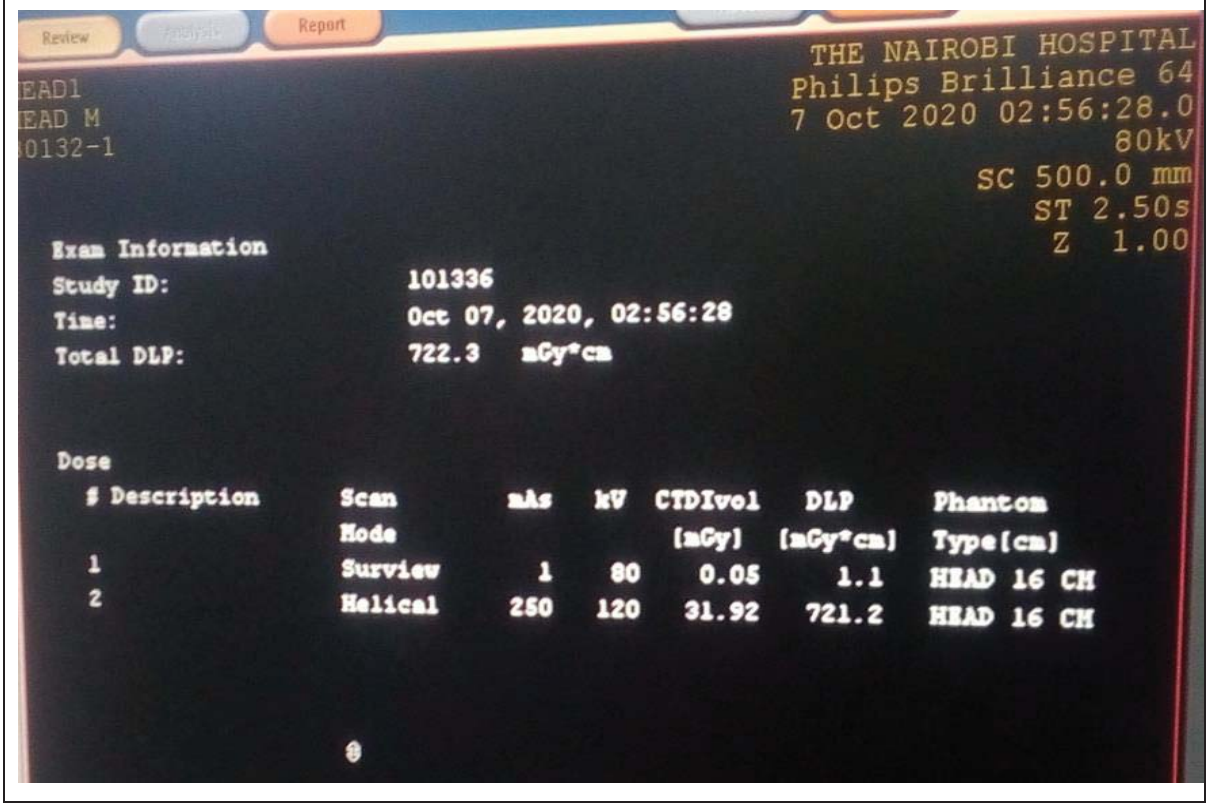


Figure 4.1: Quality Assurance on Brilliance 64 CT scanner at the Nairobi hospital. (A) CT PMMA head phantom measured at the periphery North (PN). (B) CT PMMA abdomen phantom measured at the centre. (C) Console CTDI value for PMMA head phantom

4.2.1 $CTDI_w$ Measurements Using 2-Part PMMA CT- Head and Body Phantom

Prior to dose measurements of the various anatomical regions, a complete QA and QC (mechanical, electrical and radiation checks) was conducted for Philips Brilliance® 64 slice CT scanner using the 2-part PMMA CT- head and body Phantom, for radiological compliance.

Table 4.3 and Fig. 4.2 shows the results of Dosimetric Exposure Quantities of interest; CTDIw measurements, which were assessed using 2-Part PMMA CT- Head and Body Phantom for routine adult head (Brain) and body (Abdomen), examinations.

Table 4.3: Mean $CTDI_w$ values Vs. EC guidelines Diagnostic Reference Levels and in other countries

Examination	Quantity	This Research (2020)	EC (2014) [77]	Brazil (2015) [91]	Egypt (2017) [92]	Singapore (2020) [79]
Head	CTDIw, mGy	92.04	60	50	30	51
Abdomen	CTDIw, mGy	52.89	35	12	31	12

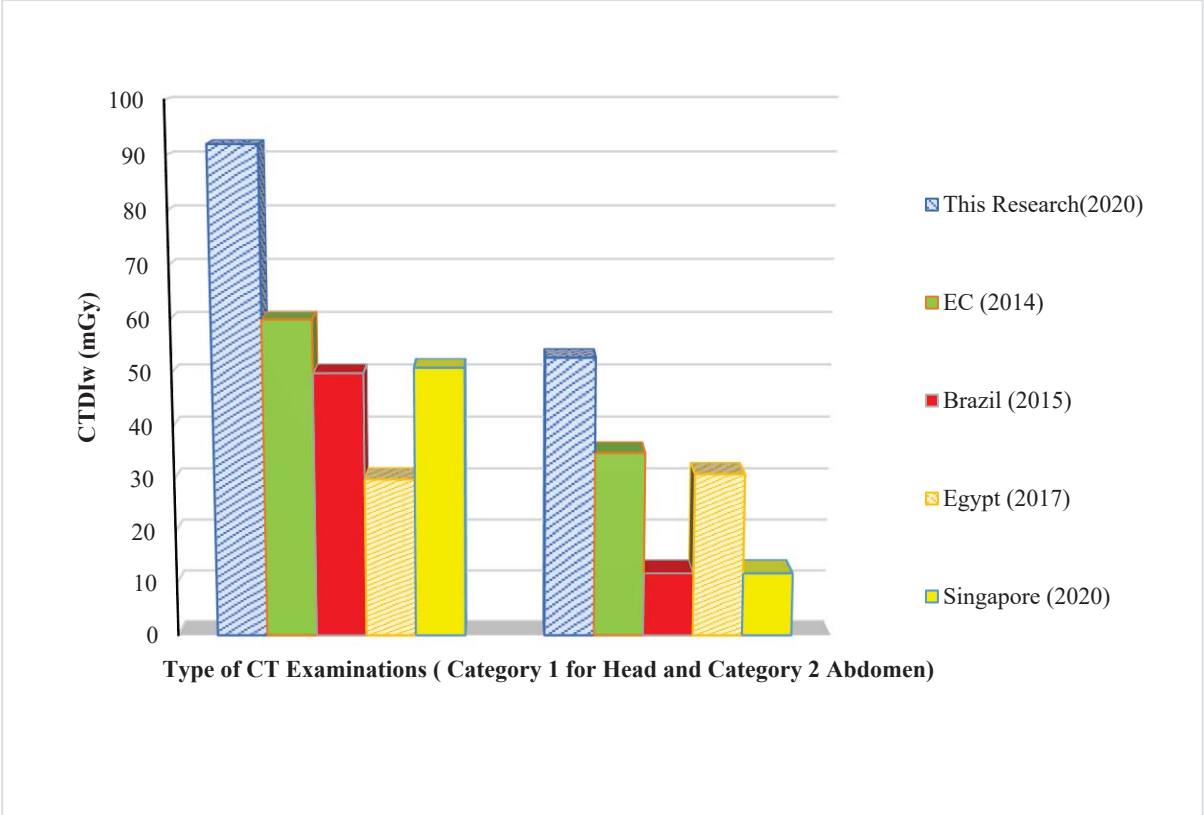


Figure 4.2: mean $CTDI_w$ values Vs. EC guidelines Diagnostic Reference levels and in other countries

$CTDI_w$ of both head and abdomen examination protocol (92.04 ± 0.08, 52.89 ± 0.7) mGy investigated were above EC RDL (60, 35) mGy, and other countries (Figure 4.2). In this research investigation, the head and the abdomen examinations were performed without contrast medium.

In practice, the radiation dose doubles if a patient undergoes both examinations with or without contrast. Correspondingly, the effective dose and DLP is expected to increase.

4.2.2 Dose-Length Product Measurements using 2-Part PMMA CT- Head and Body Phantom

Table 4.4 and Fig. 4.3 shows the results of dosimetric exposure quantities of interest; DLP measurements, which were assessed using 2-Part PMMA CT- Head and Body Phantom for routine adult head and abdomen, examinations.

Table 4.4: Mean-Dose Length Product (DLP) Vs. EC Guidelines and other countries (n=3)

Examination	Quantity	This Research (2020)	EC (2014) [77]	Brazil (2015) [91]	Egypt (2017) [92]	Singapore (2020) [79]
Head	DLP, mGy.cm	1527.86 ± 1.4	1050	950	1360	1060
Abdomen	DLP, mGy.cm	856.82 ± 11.7	800	380	1425	645

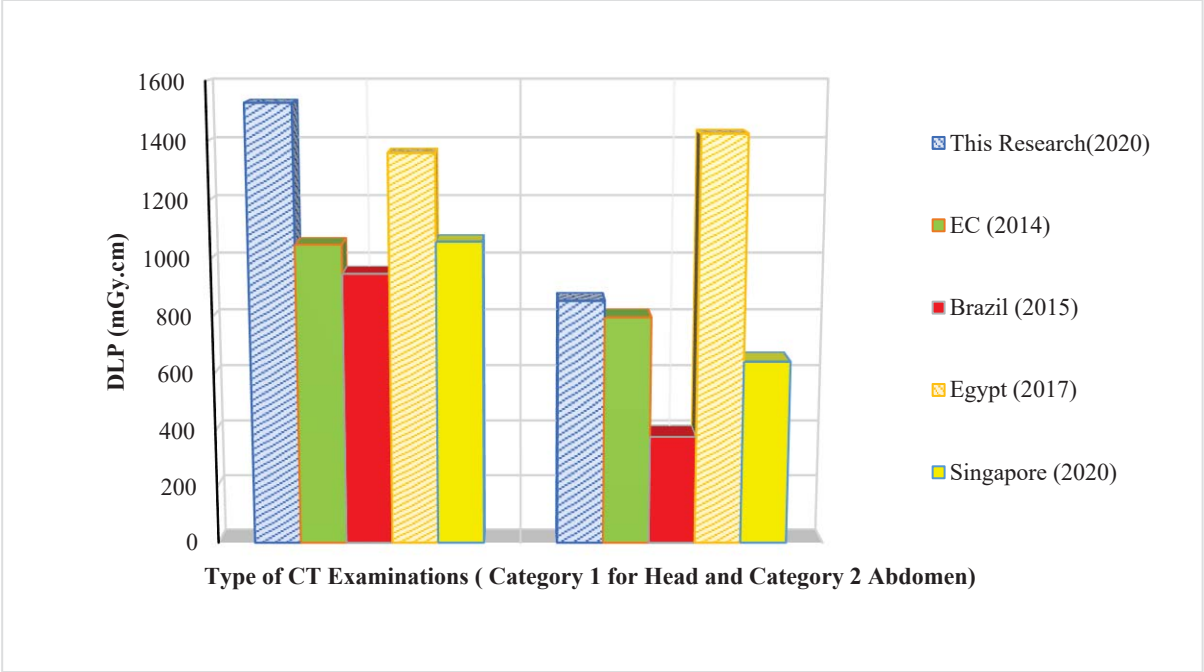


Figure 4.3: mean DLP values to EG Diagnostic Reference levels and DLP values stated in other countries

In general, the DLP values for head and abdomen examinations (1527.86 ± 1.4, 856.82 ± 11.7) mGy.cm were slightly higher than EC (1050, 800) mGy.cm and other countries guidelines (Table 4.4 and Figure 4.3). This could be as result of various factors such as the race (phenotype), social economic status, age of the Philip Brilliance 64 Scanner (year of manufacture; 2007) or use of generic pre-installed protocols by the manufacturer [16].

In this research investigation, scan lengths used for the head and for the abdomen were 16.6 cm and 16.2 cm, which were shorter than the scan lengths recommended by the European Commission (17.5cm head and 22.86 abdomen protocols) and those used in other countries for the same examination.

Diagnostic reference level (DRL) is a concept utilized in diagnostic radiology, particularly CT scans, to optimize patient lower doses [6, 22]. Frequent surveys are used to re-evaluate and update DRLs in order to minimize patient exposure to a level that is reasonably achievable without compromising image quality, especially after repairs.

4.2.3 Effective Dose Measurements using 2-Part PMMA CT- Head and Body Phantom

The relative radiation risk of various CT examination protocols is evaluated using a parameter known as the effective dose, which is directly related to radiation risk.

Other factors like as beam quality, irradiation geometry, and the patient's anatomy influence the ED. In this research investigation, it is determined that using Monte Carlo calculations with established conversion factors from the EC recommendations to estimate the effective dose is adequate. In previous validation efforts, the calculated doses with Monte Carlo technique due to small mean percent difference (−4.9%) between in-vivo dose measurements, demonstrates accurate values as compared to other calculation methods such as TLD measurements [80].

Theoretically, utilizing DLP readings from a specific examination and a suitable normalized coefficient, the effective dose for a particular scanning methodology could be determined.

By computing the dose-length product with the relevant “k” conversion factors (Table 3.2) as recommended by the European Commission, the mean ED for head and body (abdomen) examinations were calculated (Table 4.5 and Figure 4.4).

Table 4.5: Calculated mean Effective Dose (ED) Vs European Commission (EC) and other Countries (n=3)

Examination	Quantity	This Research (2020)	EC (2014) [77]	Brazil (2015) [91]	Egypt (2017) [92]	Singapore (2020) [79]
Head	ED, mSv	3.5 ± 0.003	2	1.8	2.6	2.4
Abdomen	ED, mSv	12 ± 0.02	10	5	18	9.68

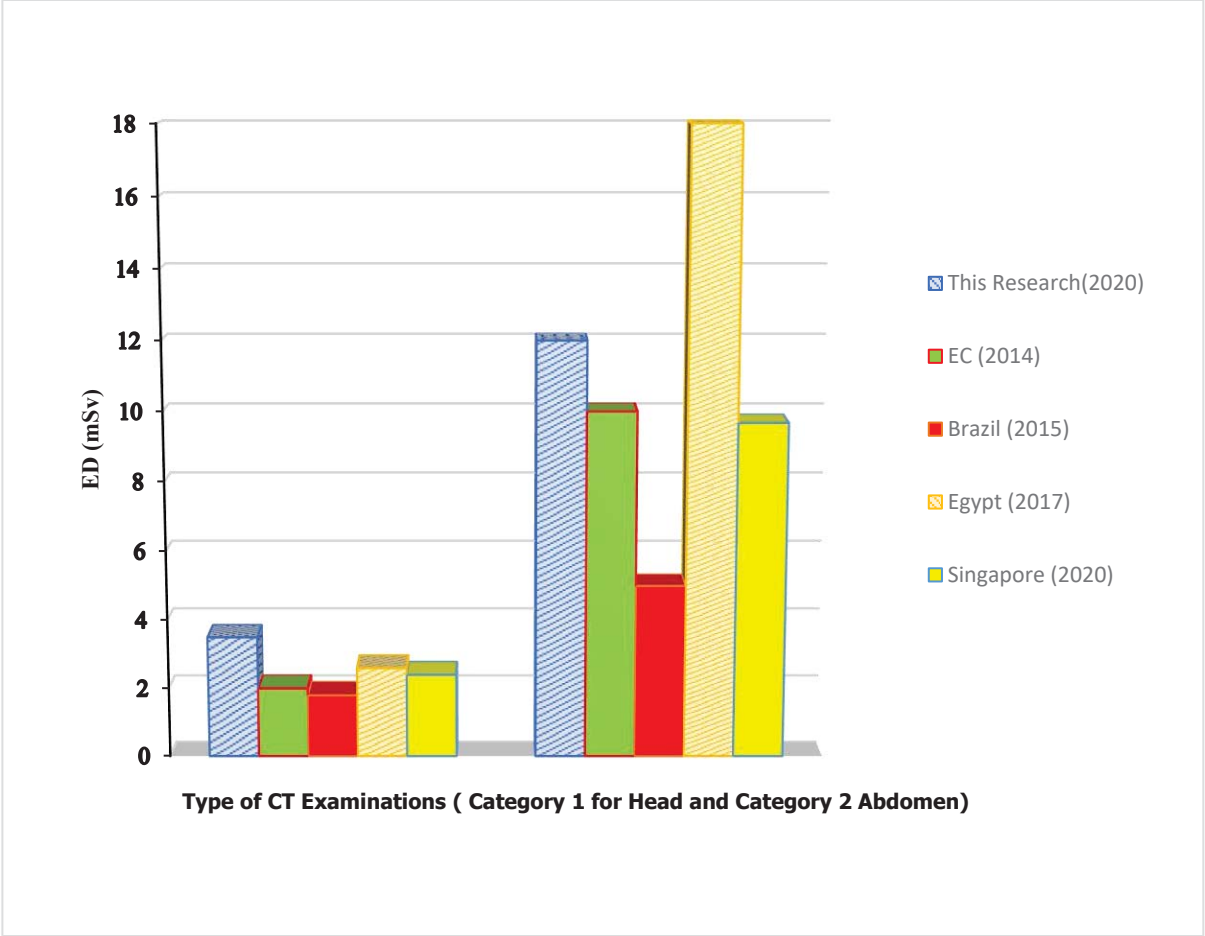


Figure 4.4: mean ED values Vs EC guidelines Effective Doses and other Countries

The results for the ED for head and abdomen examination (3.5 ± 0.003, 12 ± 0.02) mSv are slightly higher than the EC (2, 10) mSv, and other countries' guidelines. However, there are significant variations among the countries sampled for head and abdomen examinations but are within the EC's guidelines. The variation between these investigations in comparison to EC guidelines and other countries such as Egypt and Singapore could be a s result of large number of scanners of multi-slice capabilities between (2 to384) brands by Siemens 64 and 384-slice scanners, Philips 64 and 256-slice CT scanners included in the surveys for the same head and abdominal examinations [82, 83].

4.3 Background Radiation exposure measurements of CT facility room

The background dose rate was calculated according to annual exposure limit for the public (1mSv/yr.), see ICRP publication 73, which corresponds 0.25 μSv/hr.

The radiation dose exposure rate values measured at various localities varied between (0.01 to 0.20 μSv/hr), and were within the 0.25 μSv/hr ICRP limits.

The highest exposure level was found in washroom inside the CT room (0.20 μSv/hr), followed by entrance E3 (0.17 μSv/hr) and door E5 (0.16 μSv/hr). These localities had the highest level due to proximity to the CT scanner facility. However, all exposure values in the various localities were within the prescribed limits according to ICRP publication 73 (Table 4.6).

Table 4.6: Background Exposure values measurements with RAD-60^{TM} Dosimeter in μSv/hr at various Localities

Various Localities	Distance (1m)	Distance (2m)	Distance (3m)
Patient waiting Area	0.08	0.06	0.03
Control room	0.04	0.02	0.01
Entrance Door E3	0.17	0.15	0.12
Entrance Door E5	0.16	0.15	0.14
Public waiting Area	0.04	0.03	0.01
Washroom	0.20	0.18	0.14

The radiation exposure measurements levels at various localities; Patient waiting area, control room, patient waiting area, outside the entrance door E3, door E5, public waiting area and along the corridor when the CT scanner was in use, were all below the exposure limits specified for controlled and uncontrolled areas and varied between (0.01 to 0.20 μSv/hr), and is consistent with the background exposure rate (0.25 μSv/hr). Other investigations values for a newly commissioned facility indicated in the range 0.11 to 0.16 μSv/hr by GM counter and 0.14 to 0.23 μSv/hr by Ionization counter [93]. In dosimetry, Ionization chambers due to high sensitivity are the most preferred instruments to measure low to high-exposure rates typically

over a wide energy range from 9.3×10^{-4} mSv/hr to 0.93×10^{-2} Sv/hr, and suitable for detecting alpha, beta, x-rays and gamma particles [39].

4.4 Assessment of the CT Dose Data Protocols used in different examinations at the Nairobi Hospital using the Philips Brilliance 64

Table 4.7 shows the summary of the details of protocols used in different examinations for both paediatric patients and adults at the Nairobi hospital during the sampling period using the Philips Brilliance 64.

In general, there is the consistent use of the same tube voltage (120 kVp) for all examinations for both adult and paediatric patients, except for the 80 kVp value used for both CT abdomen and angiography for paediatric protocols. The tube current is the most variable parameter, for all examinations, for all patients and is dependent on patient sizes for; adult and paediatric examinations (250-400 mAs) with head examinations using the lowest value 250 mAs.

However, owing to Philips Brilliance 64's Automatic Exposure Control (AEC) technique, the scanner automatically applies reduced tube current mAs in actuality. Values for the slice thickness for each type of examination for both patient types vary between 1.0-5.0 mm.

In routine protocols, for all examinations, a constant pitch factor of 1, is used for both adult and paediatric patients. In this assessment, head examinations use lower 250mAs for both the paediatric and adult patients, variations in Slice Thickness (ST) have also been observed, ranging from 1 to 10 mm, consequently resulting in variations in doses for the same procedure for different patients.

Table 4.7: The details of Protocols used in different Examinations at the Nairobi Hospital

Machine Type: Philips Brilliance-64
Year of Manufacture: 2007

Age Group	Protocol Parameters	CT Abdomen	CT Head	CT Chest	CT Angiography	CT Neck	CT Paranasal Sinuses	CT Cervical Spine	CT Lumbar Spine
Paediatric	kVp	80	120	120	80	120	120	120	120
< 18 y	mAs	250-400	250	250-400	250-400	250-400	250	250-400	250-400
	ST (mm)	5.0	4.0	5.0	1-5	3.0	1.0	3.0	3.0
	Pitch	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Adult	kVp	120	120	120	120	120	120	120	120
>18 y	mAs	250-400	250	250-400	250-400	250-400	250	250-400	250-400
	ST(mm)	5.0	4.0	5.0	1-5	3.0	1.0	3.0	3.0
	Pitch	1.0	1.0	1.0	1.0	1.0		1.0	1.0

The Society of Paediatric Radiology and the American College of Radiology (ACR) assert that, while maintaining other parameters constant, increasing the tube voltage (from 120 to 140 kVp) results in an increase in both the x-ray penetration energy and patient radiation exposure of 30 to 40%. In order to reduce this, increase the x-ray tube voltage while decreasing the tube current (mAs) [94]. Slice Thickness (S.T) is an important factor influencing the image quality which is determined by the collimator setting and the type of clinical examination [94].

By dividing the increment of the patient table by the number of revolutions of the x-ray tube, the pitch is calculated. The pitch parameter is significant since it specifies the distance between CT slices. A pitch of 1:0 denotes no overlap of CT slices in helical CT or a single-slice axial. A high pitch factor (>1.0) implies that the slices are overlapping owing to gaps, resulting in a reduced patient dose but lower image quality. A pitch (<1.0) results in an overlap of the scanned tissue, and increased patient radiation dose, but results in better image quality [94].

In practice, utilizing a high number of thin slices to scan the same anatomy raises the patient's radiation exposure by 30 to 50 % compared to using fewer thicker slices. Radiation patient exposure in CT scanners extends beyond the slice collimators due to cone-beam geometry, x-ray beam profile greater than the detector width, focal spot penumbra, and scattered radiation.

Additionally, radiation exposure risks extend outside a large number of thin slices and result to overlapping and increased noise image [94]. In practice, in order to ensure that patient doses are kept as low as reasonably achievable and that any dose increase is justifiable in compliance with ICRP publications 60 and 87, protocols should be examined.

4.5 Assessment CT scans of various Examinations for Patient Exposures (DLP, CTDI, Effective Dose and DRL)

In this section, the summary of the results of patient exposure parameters, namely; DLP, CTDI, Effective Dose, and DRL, for the various CT scan examinations are presented.

4.5.1 Summary of the Results of Patient Exposures for the various CT Scan Examinations

In general, the evaluation considered 215 CT examinations and data collected from January 2020 to March 2020. These procedures were conducted using Philips Brilliance 64. The examinations were distributed as CT head non-contrast (n=64, 29.8%), CT head contrast (n=1, 0.5%), CT chest non-contrast (n=28, 13%), CT chest contrast (n=2,0.9%), CT neck non-contrast (n=10, 4.6%), CT abdomen non-contrast (n=13, 6%), CT abdomen contrast (n=24, 11.2%), CT cervical spine non-contrast (n=14, 6.5%), CT cervical spine contrast (n=1,0.5%), CT lumbar spine contrast (n=1,0.5%), CT angiography (n=20, 9.3%), CT angiography non-contrast(n=1, 0,5%) and CT paranasal sinuses (n=36, 16.7%).

Table 4.8: Summary of Patient examinations done on Philip Brilliance 64 scanner from January to March 2020

Examination	Head		Chest		Abdomen		Cerv spine		Neck	Lumb spine	Angio		Par. sinus	Total
	C	NC	C	NC	C	NC	C	NC	NC	C	C	NC		
No of examination	1	64	2	28	24	13	1	14	10	1	20	1	36	215
Percentage	**0.5 %**	**29.8 %**	**0.9%**	**13 %**	**11.2 %**	**6 %**	**0.5 %**	**6.5 %**	**4.6%**	**0.5%**	**9.3%**	**0.5%**	**16.7 %**	**100 %**

*Where C= contrast, NC= non-contrast, Lumb spine = lumbar spine, Angio =Angiography and Par sinus = Paranasal sinuses

4.5.2 Results of the Patient Exposures: DLP and CTDI values, Effective Dose, DRL for various Examinations

Appendix III shows the records in a data collection worksheet for exposure values. The parameters of interest included: age, gender, scanning time, the type of examination procedures, the operating conditions, and the corresponding $CTDI_{vol}$ and DLP values for the respective procedures.

Utilizing CTDI and DLP data, ED values were computed. Effective doses for all tests were calculated using the k conversion factors from ICRP Publication 103. Using the 75% percentile values recommended by ICRP 103, DRLs were also established from CTDI and DLP readings [80].

In principle, diagnostic reference levels are established by obtaining 75% percentile values for all $CTDI_{vol}$ and DLP in a survey of preferably a minimum ≥20 patients for CT examinations performed in each procedure. The median (50 % percentile) and 75% percentile of DLP (mGy.cm), $CTDI_{vol}$ (mGy) were determined using ToolpaK tool, an addin Excel Worksheet.

Table 4.9 and Figure 4.5, Figure 4.6, Figure 4.13, Figure 4.8, Figure 4.7 and Figure 4.12 shows the summary of the results of the radiation dosimetric exposure parameters; CT head non contrast, CT abdomen contrast, CT chest NC, CT angiography and CT paranasal sinuses reached the minimum required number.

Figure 4.9, Figure 4.10 and Figure 4.11 shows the DLP and $CTDI_{vol}$ values for Cervical Spine, Neck with contrast, and Abdomen non-contrast examinations, but the data did not reach the minimum required number of 20 to enable evaluation of DRLs, for these examinations.

Table 4.9: Summary of results of dosimetric parameters of various Examinations extracted from Philips Brilliance 64 CT scanner

Type of CT Examination	No. of Exams	$CTDI_{vol}$ (mGy)		DLP (mGy.cm)		Effective dose, ED (mSv)	
		Median (50^{th} percentile)	75^{th} Percentile	Median (50 percentile)	75^{th} Percentile	Median (50 percentile)	75^{th} Percentile
Head NC	64	50.98	50.98	1082.8	1134.72	2.49	2.61
Abd C	24	74	83.32	2518.6	2865.4	37.78	42.98
Angio	20	32.5	42.27	419.4	514.03	5.87	6.17
Par sinus	36	12.82	12.82	251.95	280.2	0.58	0.64
Chest NC	28	20.31	32.27	625.95	773.7	10.64	13.15

$CTDI_{vol}$ values for the 75th percentile, abdomen with contrast (83.32 mGy against 35 mGy), CT chest non-contrast (32.27 mGy against 30 mGy), and angiography (42.27 mGy against 15 mGy), were all higher by factor 2 to 3 than the EC recommended guidelines. This is due to the fact that more scan coverage range (13.3 cm to 34.8 cm) conducted on different patients in the three CT procedures as in table 4.10, which varied greatly than the scan lengths utilized by the European Commission (17.5cm to 22.86 cm) [77].

However, the $CTDI_{vol}$ for paranasal sinuses (12.82 mGy) and head non-contrast (50.98 mGy against 60 mGy) were below the value recommended by EC guidelines. This is due to compliance to good radiographic procedure, as the Nairobi hospital has only established Diagnostic Refence Level for head CT procedures that conform to the European Commission guidelines.

The DLP values for the 75th percentile for head non-contrast (1134.72 mGy.cm vs. 1050 mGy.cm), abdomen with contrast (2865.4 mGy.cm vs. 800 mGy.cm), and chest non-contrast (773.7 mGy.cm vs. 650 mGy.cm) were all higher than the EC guidelines. This is because various patients had a lengthier scan length (22.5 cm to 34.8 cm) conducted on different patients in the three CT examinations as in table 4.10, which were higher than the scan lengths utilized by the European Commission (17.5cm to 22.86 cm) [77]. The DLP for paranasal sinuses was 280.2 mGy.cm, and CT angiography was 514.03 mGy.cm, were below the value recommended by EC guidelines (Table 3.2). The mean scan length range (13.3 cm to 20.2 cm) conducted on different patients in the two CT examinations as in table 4.10, were lower than the scan lengths utilized by the European Commission (17.5cm to 22.86 cm) [77].

The ED for paranasal sinuses (0.64 mSv against 2 mSv) and CT angiography (6.17 mSv against 12 mSv) were below the value recommended by EC guidelines and therefore compliant. The corresponding ED values for head non-contrast (2.61 mSv against 2mSv), abdomen with contrast (42.98 mSv against 10 mSv by factor 4) and chest non-contrast (13.15 mSv against 8 mSv by factor 2) were higher than the ED values recommended by EC guidelines, as in table 3.2. Effective Dose (ED) is dependent on DLP (determined by scan length) values and calculated using equation 3.8 [80]. The varied scan lengths (22.5 cm to 34.8 cm) utilized in various CT examinations as in table 4.10, were higher than the scan lengths by the EC guidelines (17.5cm to 22.86 cm), thus resulted to higher ED values [77]. As a result, low-dose protocol optimization is needed in order to reduce patient's radiation risks.

Diagnostic Reference Level for other eight CT examinations as in table 4.8, were not established due to the insufficient dosimetric data (1 to 14 CT scans) recorded. In principle, a minimum ≥20 CT scans for each procedure are needed in a survey to establish DRLs by obtaining 75% percentile for all the $CTDI_{vol}$ and DLP values [80].

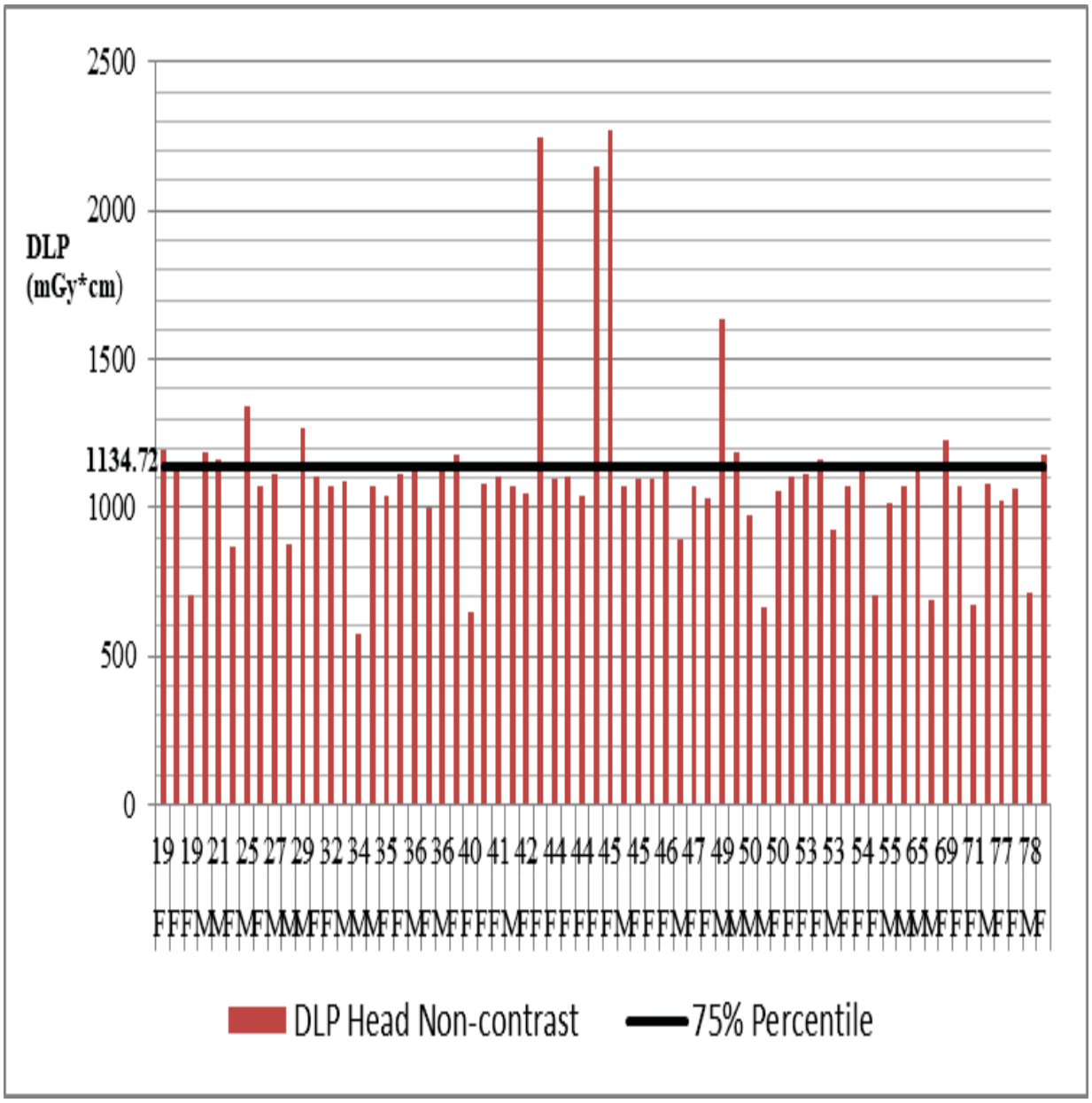


Figure 4.5: CT head DLP (mGy*cm) for various patients

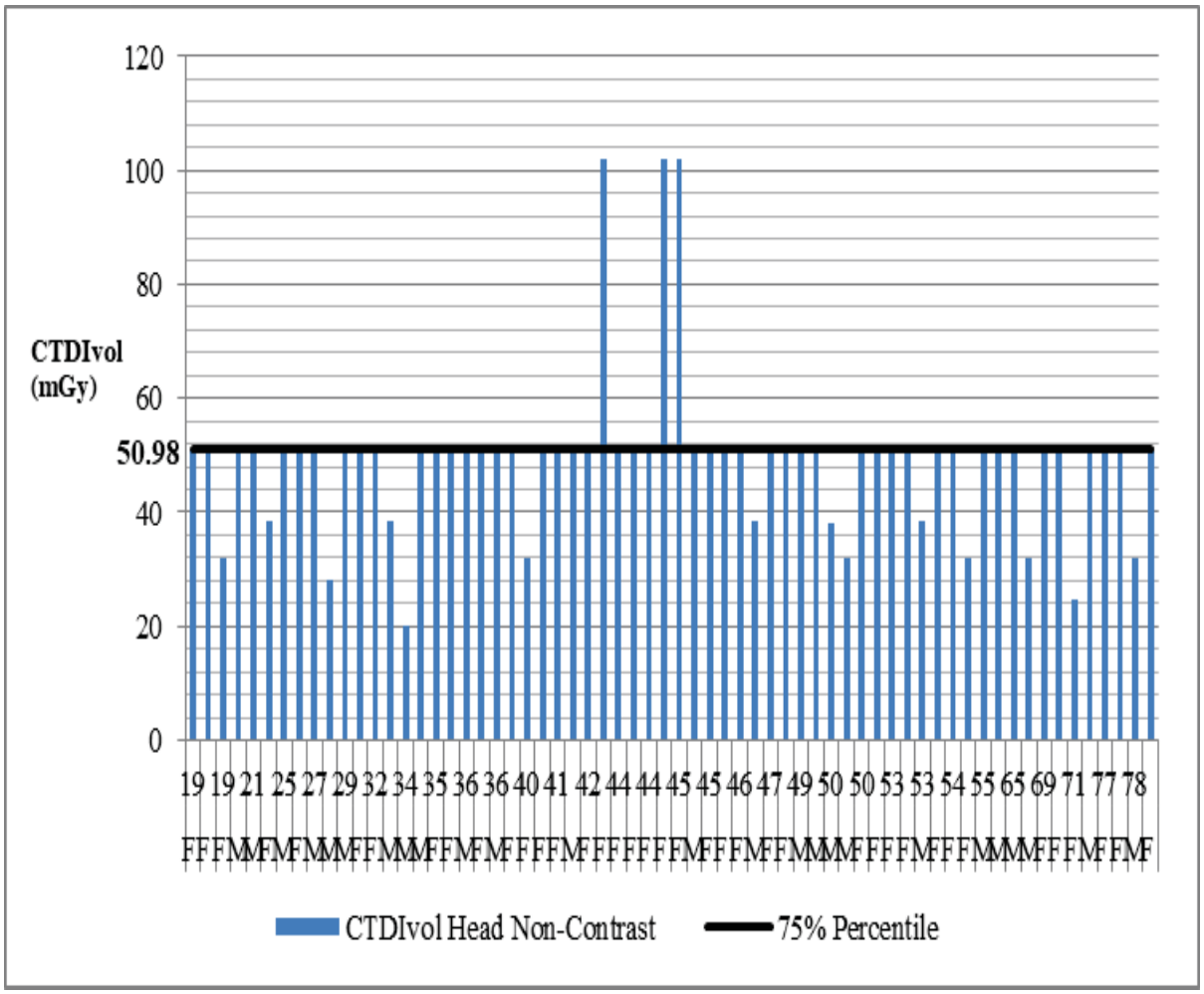


Figure 4.6: CT head $CTDI_{vol}$ (mGy) for various patients

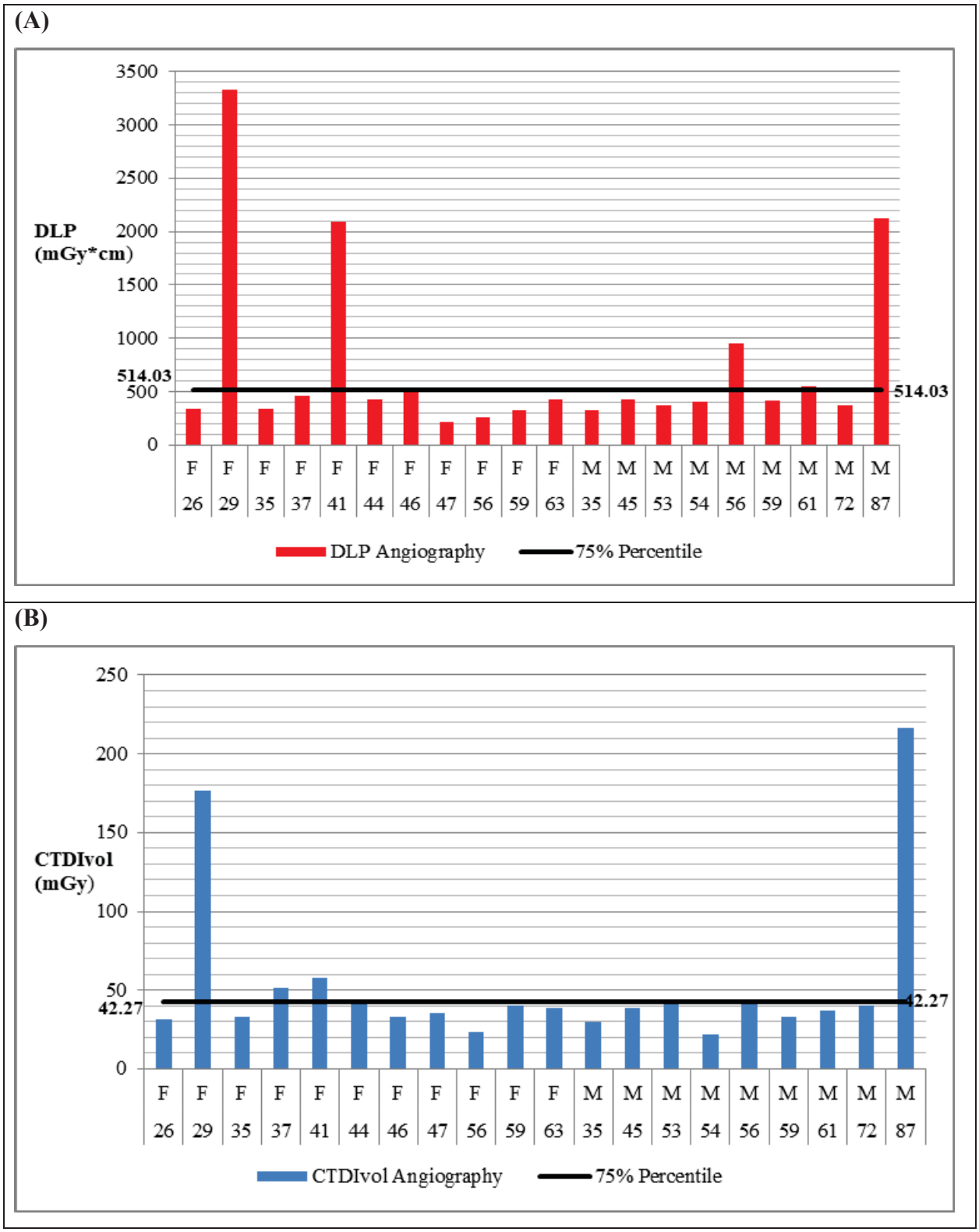


Figure 4.7: CT Angiography: (A) DLP (mGy*cm) and (B) CTDIvol (mGy) for various patients

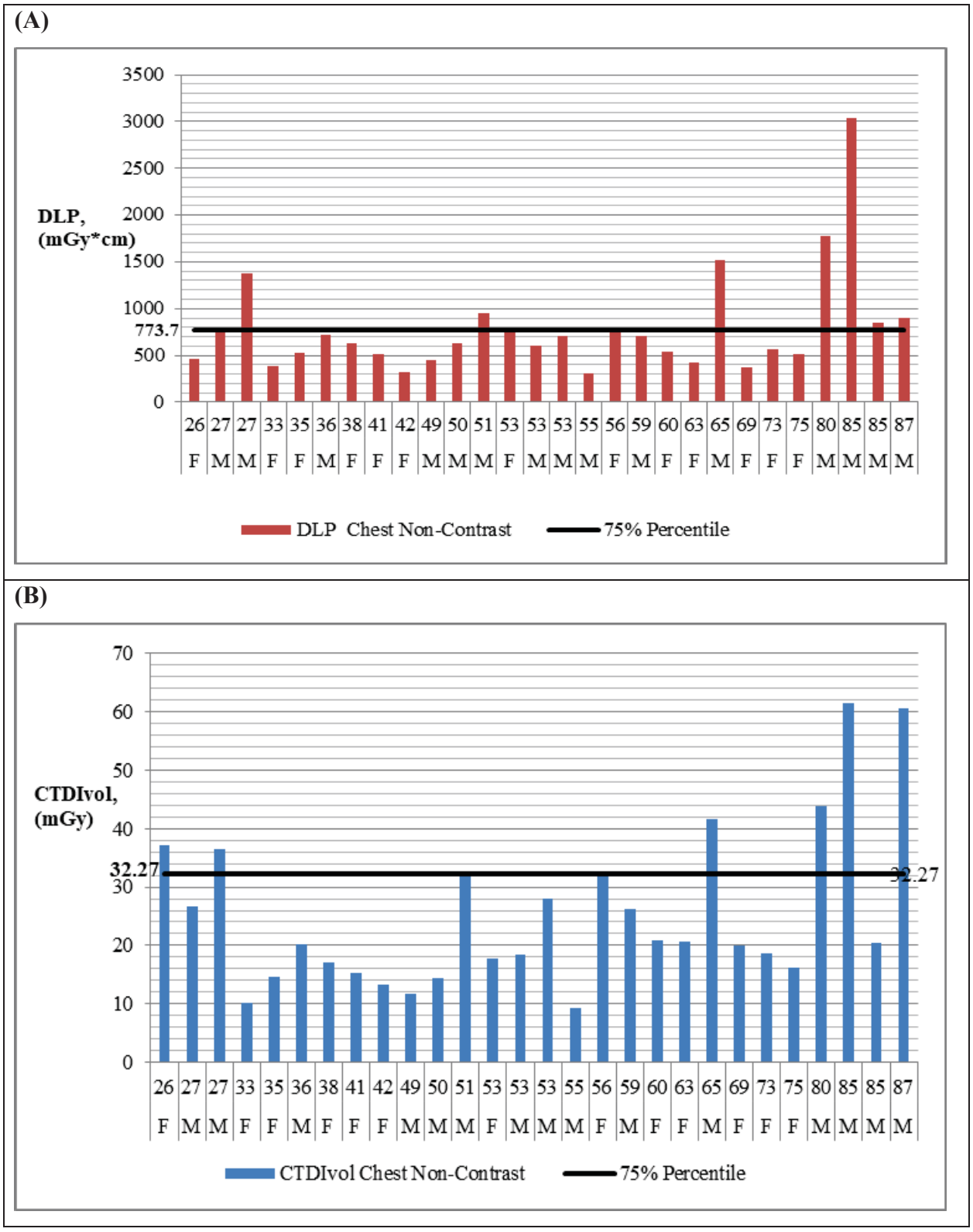


Figure 4.8: CT Chest without contrast: (A) DLP (mGy*cm) and (B) $CTDI_{vol}$ (mGy) for various patients

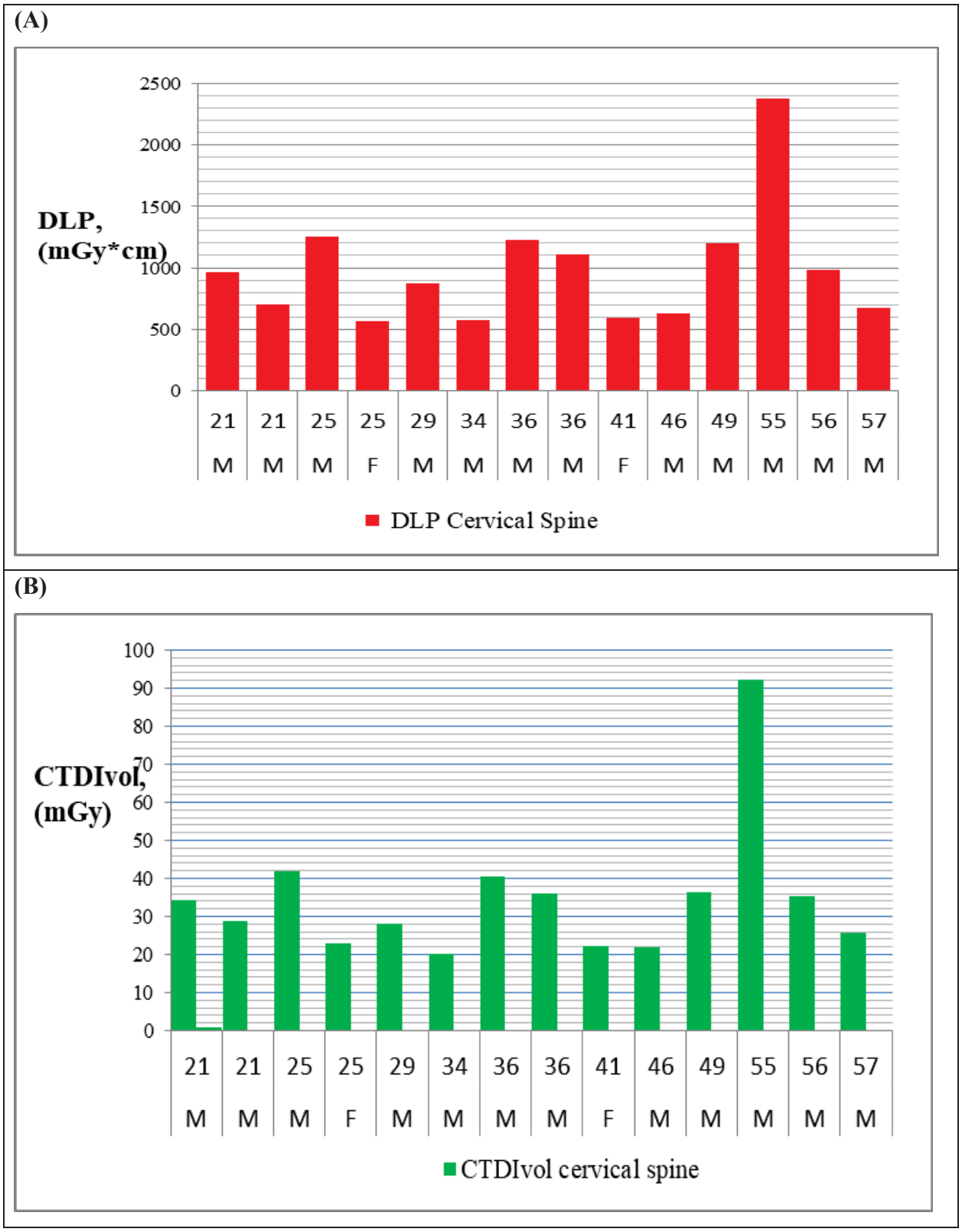


Figure 4.9: CT Cervical Spine: (A) DLP (mGy*cm) and (B) $CTDI_{vol}$ (mGy) for various patients

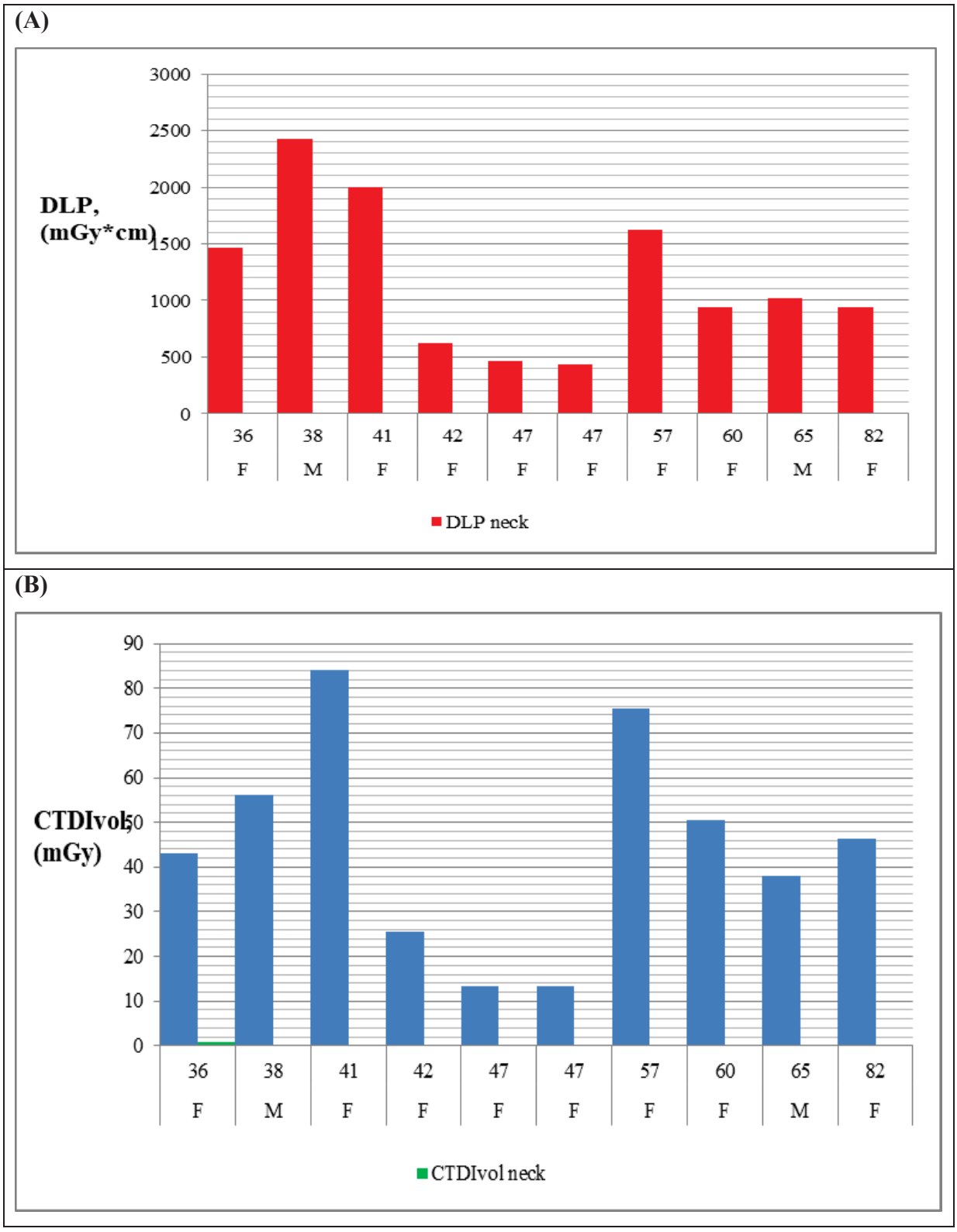


Figure 4.10: CT Neck: (A) DLP (mGy*cm) and (B) $CTDI_{vol}$ (mGy) for various patients

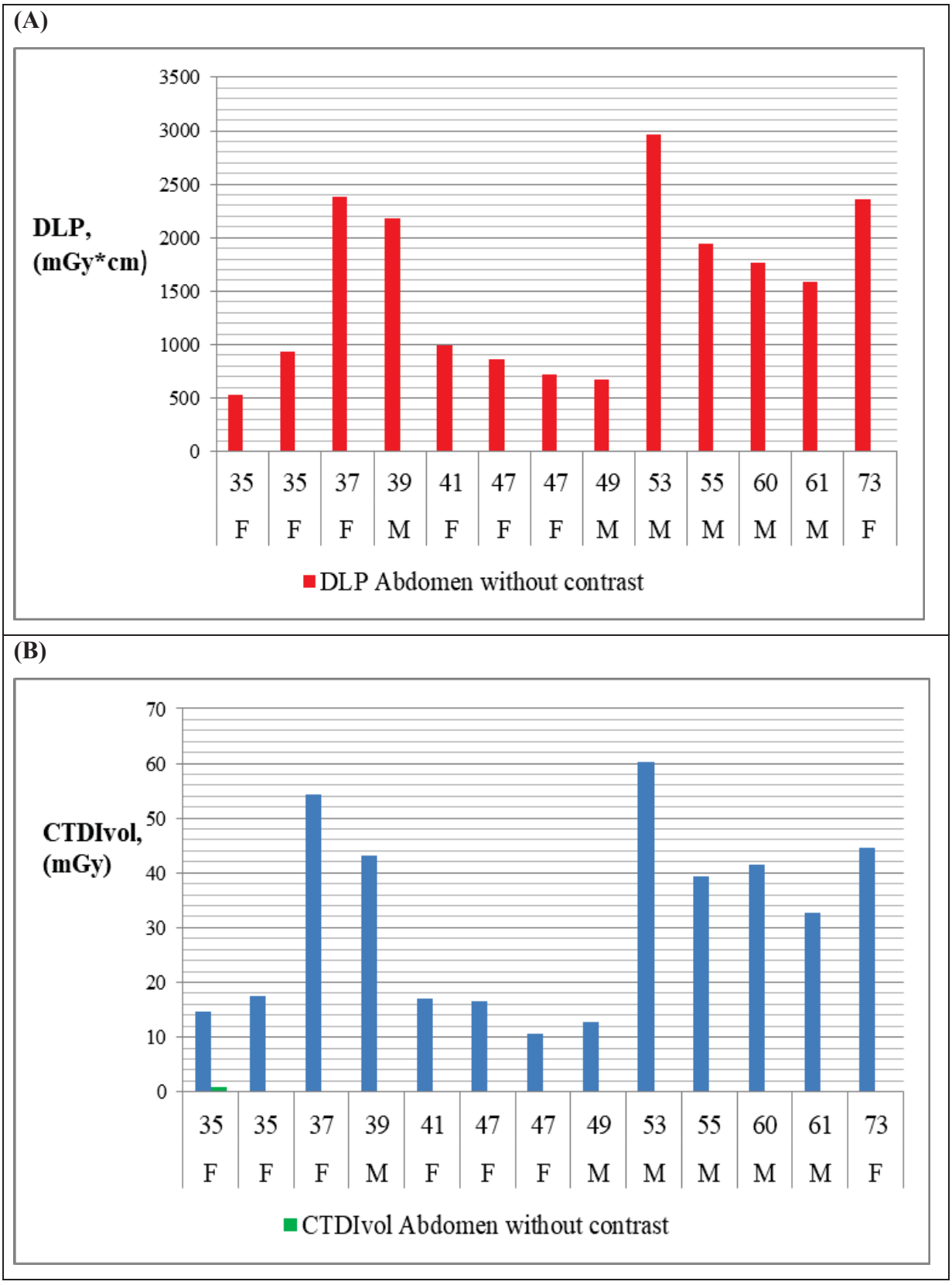


Figure 4.11: CT Abdomen non-contrast: (A) DLP (mGy*cm) and (B) $CTDI_{vol}$ (mGy) for various patients

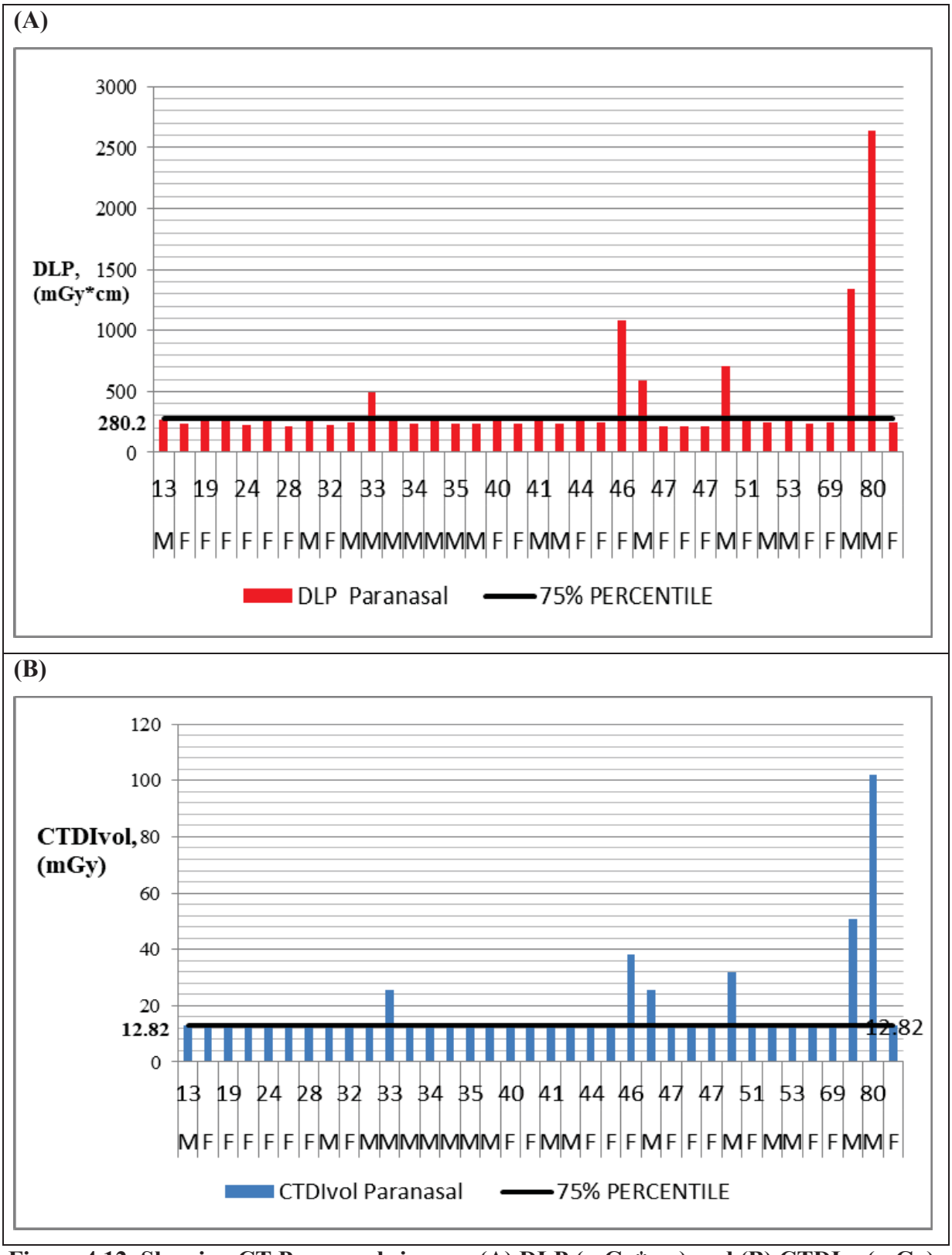


Figure 4.12: Showing CT Paranasal sinuses: (A) DLP (mGy*cm) and (B) $CTDI_{vol}$ (mGy) for various patients

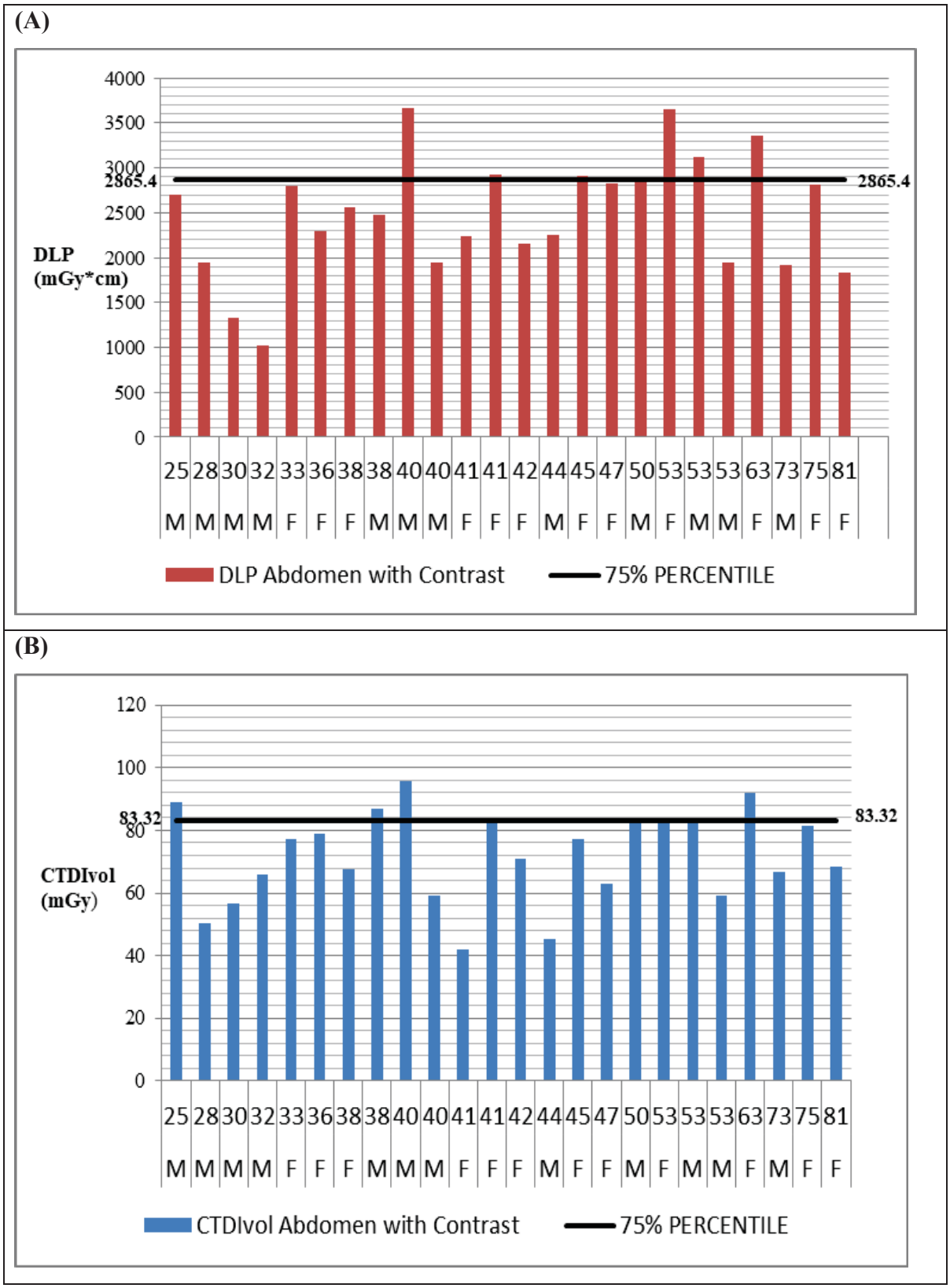


Figure 4.13: CT Abdomen with contrast: (A) DLP (mGy.cm) and (B) $CTDI_{vol}$ (mGy) for various patients

Table 4.10 shows the summary of the results of patients dosimetric quantities for various CT examinations done at the Nairobi Hospital using the Philips Brilliance 64.

Table 4.10: Summary of the Results of Patients Dosimetric Quantities for various CT Examinations

CT Examination type	Scan length(cm)	Scan time(s)	DLP (mGy.cm)	CTDIvol (mGy)	ED (mSv)
Head Non-contrast (n=64)	22.5 ± 2.4 (10%)	3.3 ± 0.8 (24%)	1099 ±304 (28%)	49.3±14.1 (29%)	2.6
Angiography with contrast (n=20)	13.3 ± 6.6 (50%)	4.4 ± 2.3 (52%)	733 ± 793 (108%)	53.2 ± 48.9 (92%)	7.4
Abdomen with Contrast (=24)	34.8 ± 8.0 (23%)	5.7 ± 1.2 (21%)	2479 ± 653 (26%)	72.0 ± 14.4 (20%)	43.2
Paranasal Sinus (=36)	20.2 ± 2.7 (13%)	2.9 ± 0.5 (17 %)	398 ± 447 (112%)	18.3 ± 16.4 (90%)	0.7
Chest Non-Contrast (=28)	31.6 ± 8.7 (28%)	4.8 ± 1.9 (40%)	785 ± 551 (70%)	25.2 ± 13.5 (54%)	13.5
Chest with contrast (n=2)	18.5 ± 0.001 (0%)	4.0 ± 0.5 (13%)	1023 ± 70 (7%)	55.3±3.8 (7%)	-
Cervical Spine non-contrast (n=14)	28.2 ± 2.4 (9%)	4.4 ± 1.2 (27%)	980 ± 459 (47%)	34.8 ± 17.4 (50%)	-
Cervical Spine with contrast (n=1)	17.72	4.5	1341.3	75.71	-
Abdomen non-Contrast (=13)	50.5 ± 7.3 (14%)	6.1 ± 1.2 (20%)	1530 ± 765 (50%)	31.1 ± 16.5 (53%)	-
Neck with contrast (n=10)	28.0 ± 7.5 (27%)	4.7 ± 1.4 (30%)	1196 ± 635 (53%)	44.6 ± 22.5 (50%)	-
Head with contrast (n=1)	21.6	2	690	32.0	-
Lumbar spine(n=1)	41.2	5	750.3	18.2	-
Angiography non-contrast (n=1)	3.1	8	205.21	65.37	-

In summary, are the following salient observations from the analysis of dosimetric data for the various examinations are:

(i) There are significant variations in scanned length in the range (3.1to 50.5 cm); scanning time (2 to 8 sec), DLP (205.21 to 2479.3 mGy.cm) and $CTDI_{vol}$ (18.2 to75.71 mGy) values in all examinations assessed for the 215 scanned images.

(ii) All examinations protocols and corresponding patient dosimetric quantities obtained, in this research investigation are neither gender nor age specific.

(iii) Patient effective exposures are dependent on scan time but independent of other dosimetric parameters.

(iv) The maximum DLP value was 2479.3 mGy.cm for Abdomen with contrast, whereas the minimum DLP value was 205.21 mGy.cm for angiography without contrast.

(v) The highest patient exposure level at 43.2 mSv was obtained for abdomen with contrast, whereas the lowest value at 0.65 mSv was obtained for paranasal sinus scans.

Table 4.11 shows the summary of the results of gender based patient exposures for various examinations.

Table 4.11: Summary of the results of gender based patient exposures for various CT examinations

CT Examination Type	Mean DLP (mGy.cm)		Mean $CTDI_{vol}$ (mGy)		Mean Scanning Time(sec)		Mean Scanning Length (cm)		Mean ED (mSv)	
	F	M	F	M	F	M	F	M	F	M
Angiography (n=20; F=11, M=9)	792 ± 946	661± 546	51 ± 40.8	55.8 ±57.1	4.0 ±1.4	4.9 ±3.0	13.4 ±8.0	13.2 ±4.5	9.5 ±11.3	7.9 ±6.6
Abdomen with contrast (n=24: F=12, M=12)	2697 ± 495. 4	2262 ± 716	73.8 ± 12.4	70.1 ± 16.01	5.8 ± 1.4	5.5 ±0.8	37.2 ±7.1	32.5 ± 8.2	40.5 ±7.4	34 ±10.7
Chest Non-contrast (n=28: F=13, M=15)	519 ± 126	1016 ±661	19.5 ±7.1	30.1 ± 15.6	5.1 ± 2.1	4.5 ± 1.6	28.7 ± 8.3	34.1 ± 8.2	8.8 ± 2.1	17.3 ± 11.2
Head Non-contrast (n=64: F=39, M=25)	1136 ± 342	1043 ±223	52.4 ±15.7	44.5 ±9.3	3.2 ±0.72	3.5 ±0.8	21.7 ± 1.3	23.7 ±3.2	2.6 ±0.8	2.4 ±0.5
Paranasal Sinuses (n=36, F=19, M=17)	288 ±188	520 ±596	14.1 ± 5.7	23 ± 22.2	2.8 ± 0.6	3.0 ± 0.4	19.5 ± 2.8	21 ± 2.3	0.7 ± 0.4	1.2 ±1.4

Table 4.12 shows the t test values of gender based patient exposures for various examinations.

Table 4.12: The t-test values of Gender based Patient Exposures for various CT Examinations

CT Examination Type	Mean DLP (mGy.cm)		Mean $CTDI_{vol}$ (mGy)		Mean Scanning Time(sec)		Mean Scanning Length (cm)		Mean ED (mSv)	
	Calculated t-value	Critical t-value	Calculated t-value	Critical t-value	Calculated t- value	Critical t-value	Calculated t- value	Critical t-value	Calculated t- value	Critical t-value
Angiography (n=20; F=11, M=9)	+10.6	±1.72	-1.5	±1.72	-1.3	±1.72	+0.18	±1.72	+1.2	±1.72
Abdomen with contrast (n=24: F=12, M=12)	+43.5	± 1.72	+2.39	± 1.72	+0.71	± 1.72	+4.2	± 1.72	+5.3	± 1.72
Chest Non-contrast (n=28: F=13, M=15)	-64.5	± 1.71	-8.2	± 1.71	+1.2	± 1.71	-5.0	± 1.71	-8.5	± 1.71
Head Non-contrast (n=64: F=39, M=25)	+21.1	± 1.67	+8.2	± 1.67	-1.4	± 1.67	-6.1	± 1.67	+0.95	± 1.67
Paranasal Sinuses (n=36, F=19, M=17)	-35.7	± 1.70	-7.3	± 1.70	-0.8	± 1.70	-2.7	± 1.70	-1.56	± 1.70

In general, there was significant difference for the following parameters; DLP values for all the examinations, $CTDI_{vol}$ values (except Angiography examinations), Scanning length values (except for angiography) and ED values (for only Abdomen with contrast and Chest without contrast) for female and male patients. This clearly shows that the protocols are not gender specific, since for similar gender-based CT examinations the exposure parameter values differ greatly, as shown in table 4.11. This therefore requires reevaluation for optimizations of chest and abdomen examinations.

4.5.3 Results of Patient Exposure for Multiple CT Examinations

Out of 215 patients, seventy-two underwent two or more CT examinations during the study. The age distribution of patients was 13 to 87 years, represented by 113 (52.56%) female and 102 (47.44%) male patients. Head examination had the highest, out of the total repeats. Cervical spine had the highest number of repeated examinations for any one examination in this research investigation (Table 4.13 and Table 4.14).

Table 4.13: Summary for repeated CT examinations in the survey

CT Examination	Number of CT examinations	Female	Male	Age distribution	Number of Repeated CT scans
Head-NC	64	39	25	19-80	22
Par sinus	36	19	17	13-80	8
Chest-NC	28	13	15	26-87	10
Abdo-C	24	12	12	25-81	6
Angio-C	20	11	9	26-87	3
Angio-NC	1	1	0	35	0
Cerv spine-NC	14	2	12	21-61	11
Abdo-NC	13	7	6	35-73	6
Neck-C	10	8	2	36-82	3
Chest-C	2	0	2	38-40	1
Cerv spine-C	1	0	1	61	0
Head-C	1	1	0	44	1
Lumb spine	1	0	1	49	1
Total	**215**	**113**	**102**	**19-87**	**72**

*Where C = contrast, NC = non-contrast, Head-C = head with contrast, Head-NC = head with contrast, chest-NC = chest without contrast, chest-C = chest with contrast, Cerv spine-NC = cervical spine without contrast, Lumb spine = lumbar spine, Angio-C =Angiography with contrast, Angio-NC = Angiography without contrast and Par sinus = Paranasal sinuses.

Table 4.14: Summary of Proportion for repeated CT Examinations in the Survey

CT Examination	Head		Chest		Abdomen		Cerv spine		Neck	Lumb spine	Angio		Par. sinus	Total
	C	NC	C	NC	C	NC	C	NC	NC	C	C	NC		
Total	1	64	2	28	24	13	1	14	10	1	20	1	36	**215**
No of multiple	1	22	1	10	6	6	0	11	3	1	3	0	8	**72**
Percentage/exam	100%	34.38%	50%	35.71%	25%	46.15%	0	78.57%	30%	100%	13.04	0	22.22%	**33.49%**

In a research investigation on CT exposure level during a 6-year period to assess patients with flank pains and chronic nephrolithiasis, 4% of patients underwent multiple (3 to 18) examinations, all of whom had chronic nephrolithiasis, with cumulative effective doses (20 to 154 mSv) [95].

The quantity of radiation doses given to patients is really reduced by the use of dose-lowering software or low-dose CT protocols [96].

The DLP values for repeated examinations were in the range of 2105 to 4596.8 mGy.cm. The highest DLP value for patient was observed in patient with four repeated CT examinations, corresponding to 2 Neck and 2 Abdomen examinations (Appendix IV).

The cumulative effective values for patients with repeated examinations were in the range 3.68 to 83.48 mSv, representing an increase by factor 2 to 3 (Appendix V). The highest cumulative ED of 83.43 mSv was observed from the oldest male patient aged 80 years old, who had

repeated paranasal sinuses examinations. In general, the risk levels for most of the repeated examinations were considered as low level (10 to 100 mSv) in accordance to NRPB 2001.

According to the NRPB 2001, the risk level is divided into four major categories: negligible (0.1 mSv), minimal (0.1-1 mSv), extremely low (1-10 mSv), and low (10-100 mSv) [97] .

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The research investigation evaluated the patient's exposure to the most frequent CT scan tests for radiological compliance. The purpose was to determine radiation protection dosimetry for optimizing patient-specific CT examination protocols. To accomplish this goal, DLP and CTDI values for typical CT scans (angiography, abdomen, spine, head, pelvis, and chest) were calculated using patient archived data.

The background radiation survey of the CT facility performed using a RAD 60^{TM} dosimeter at various localities recorded exposure rate values between (0.01 to 0.20 μSv/hr), which were below the allowable limit of 0.25 μSv/hr according to ICRP Publication 73. Elsewhere, values for a newly commissioned facility were reported in the range (0.11to 0.16 μSv/hr) by GM counter and (0.14 to 0.23 μSv/hr) by Ionization counter [93]. In dosimetry, Ionization chambers due to high sensitivity are the most preferred instruments to measure low to high-exposure rates typically over a wide energy range from 9.3×10^{-4} mSv/hr to 0.93×10^{-2} Sv/hr, and suitable for detecting alpha, beta, x-rays and gamma particles [39].

The International standardization in dosimetry in diagnostic radiology and IEC quality criteria standards for QA and QC of the scanner were applied, and found that there were significant discrepancies between the machine and measured $CTDI_{vol}$ for all CT practices. The percentage of deviation between the measured and machine dose data for both head (-34.7% to 41.3%) and abdomen (-23.3% to -63.7%) CT examinations, exceeded the acceptable level (<±20%). Therefore, this implies that the output from the scanner is high, and indicates that the patients are unnecessarily exposed to radiation. These variations may be explained by various factors such as the scanner's age, status of maintenance, scanner's state of operation, and the inherent changes in features such as; x-ray filtration, scattered x-rays, beam geometry, and a number of active detector rows. It is important to carry out a maintenance schedule to assess and rectify any faulty feature so as to adjust the scanner’s readings to account for actual exposure levels. Additionally, there is need to assess the lifetime attributable cancer incidence and mortality for

all patients undergoing imaging with the MDCT 64-slice scanner in order to ascertain the level of radiation risks.

There were variations in the CT Dose data protocol used at the hospital, specifically for the tube current, due to the variations in the sizes of patients, which resulted in dose variations for the same examination. However, owing to Philips Brilliance 64's AEC technique, the scanner automatically applies reduced tube current mAs in actuality.

The Society of Paediatric Radiology and the ACR state that while maintaining all other parameters unchanged, increasing the x-ray tube voltage (from 120 to 140 kVp) increases x-ray penetration energy and patient radiation exposure by 30 to 50%. In order to reduce this, increase the x-ray tube voltage while decreasing the tube current (mAs) [94].The patient data used in this research investigation was obtained using the Brilliance 64-slice CT scanner at the Nairobi hospital, which is mainly for diagnostic purposes, and was considered representative, for the purpose of establishing preliminary institutional diagnostic reference levels.

The $CTDI_w$ with anthropomorphic phantoms for both head and abdomen examination protocol (92.04 ± 0.08, 52.89 ± 0.7) mGy investigated were above EC reference levels (60, 35) mGy, and other countries (Figure 4.2). In this research investigation, the Head (Brain) and the abdomen examinations were performed without a contrast medium. In general, the DLP values with anthropomorphic phantoms for head and abdomen examinations (1527.86 ± 1.4, 856.82 ± 11.7) mGy.cm were slightly higher than EC (1050, 800) mGy.cm and other countries' guidelines. The corresponding ED for Head and abdomen examination (3.5 ± 0.003, 12 ± 0.02) mSv are slightly higher than the EC (2, 10) mSv, and other countries' guidelines. However, there are significant variations among the countries sampled for head and abdomen examinations but are within the EC's guidelines. This is due to the large number of scanners included in the surveys for the same head and abdominal examinations and the use of multi-slice capabilities (2 to 384-slice) brands by Siemens 64 and 384-slice, and Philips 64 and 256-slice CT scanners [82, 83]. That may be a result of the age of the Philip Brilliance 64 Scanner (year of manufacture; 2007) or the use of pre-installed generic protocols on the scanner by the manufacturer.

This research investigation has determined the DRLs for all the examinations, that reached a minimum number greater than 20 patients for the following dosimetric parameters: the $CTDI_{vol}$ values for the abdomen with contrast (83.32 mGy against 35 mGy), CT chest non-contrast (32.27 mGy against 30 mGy), and angiography (42.65 mGy against 15 mGy) were all higher by factor 2 to 3 than the EC-recommended guidelines. However, the $CTDI_{vol}$ for paranasal sinuses (12.82 mGy) and head non-contrast (50.98 mGy against 60 mGy) was below the value recommended by EC guidelines. This is due to the fact that more scan lengths were conducted on different patients.

The DLP values for the 75th percentile for head non-contrast (1134.72 mGy.cm vs. 1050 mGy.cm), abdomen with contrast (2865.4 mGy.cm vs. 800 mGy.cm), and chest non-contrast (773.7 mGy.cm vs. 650 mGy.cm) were all higher than the EC guidelines. This implied that a longer scan length was used by different patients. The DLP for paranasal sinuses was 280.2 mGy.cm, and CT angiography was 514.03 mGy.cm, which was below the value recommended by EC guidelines.

The corresponding ED values for head non-contrast (2.61 mSv against 2mSv), abdomen with contrast (42.98 mSv against 10 mSv by factor 4) and chest non-contrast (13.15 mSv against 8 mSv by factor 2) were higher than the ED values recommended by EC guidelines, as in table 3.2. Effective Dose (ED) is dependent on DLP (determined by scan length) values and calculated using equation 3.8 [80]. The varied scan lengths (22.5 cm to 34.8 cm) utilized in various CT examinations as in table 4.10, were higher than the scan lengths by the EC guidelines (17.5cm to 22.86 cm), thus resulted to higher ED values [77]. As a result, low-dose protocol optimization is needed in order to reduce patient's radiation risks.

Seventy-two out of 215 patients underwent two or more CT examinations during the study. Additionally, the age distribution of patients was 13 to 87 years, with 113 female and 102 male patients, see Table 4.12. The DLP values for repeated examinations were in the range of 2105 to 4596.8 mGy.cm. The highest DLP value was observed in patients with four repeated CT examinations, corresponding to 2 neck and 2 abdomen examinations.

The cumulative effective values for patients with repeated examinations were in the range of 3.68 to 83.48 mSv, representing an increase by factors 2 to 3 (Appendix V). The highest

cumulative ED of 83.43 mSv was observed from the oldest male patient aged 80 years, who had repeated paranasal sinuses examinations. In general, the risk levels for most of the repeated examinations were considered as low level (10 to 100 mSv) in accordance with NRPB 2001.

In general, there was a significant difference for the following parameters; DLP values for all the examinations, $CTDI_{vol}$ values (except for Angiography examinations), Scanning length values (except for angiography), and ED values (for only Abdomen with contrast and Chest without contrast) for female and male patients. This clearly shows that the protocols are not gender specific, since for similar gender-based CT examinations the exposure parameter values differ greatly, as shown in table 4.11.

The research investigation had limitations as it was based only on anatomy investigation notwithstanding the weight of the patient, clinical indications, and operating conditions.

5.2 Recommendations

From the results and conclusion, the following are recommended:

(i) The results on Quality Assurance and Quality Control of the CT scanner, recommends the need for periodical QA and QC using PMMA phantoms so as to reduce radiation output from the scanner.

(ii) The findings may be important in the re-evaluation for optimizations of all CT procedures to obtain gender-specific protocols.

(iii) The research suggests the adoption of ALARA principles and use of the tenets of Radiation Protection (Optimisation and Justification) in order to reduce unnecessary radiation exposure levels in patients for all the CT procedures.

(iv) The results of the research on unnecessary patient's exposure level, recommends the adoption of low-dose CT procedures or dose-lowering software so as to reduce the radiation doses given to patients.

(v) The investigation suggests the possibility for future research in discovering the challenges causing significant variations in chest and abdomen CT examinations.

(vi) The findings suggest the establishment DRLs for all CT practices, since it is an important tool for spotting poor procedures or generally substandard protocols linked to high radiation dose in patients.

(vii) Examining a wider context of the scanner for all CT practices could lead to low patient exposure without significantly degrading the image quality, particularly after repairs.

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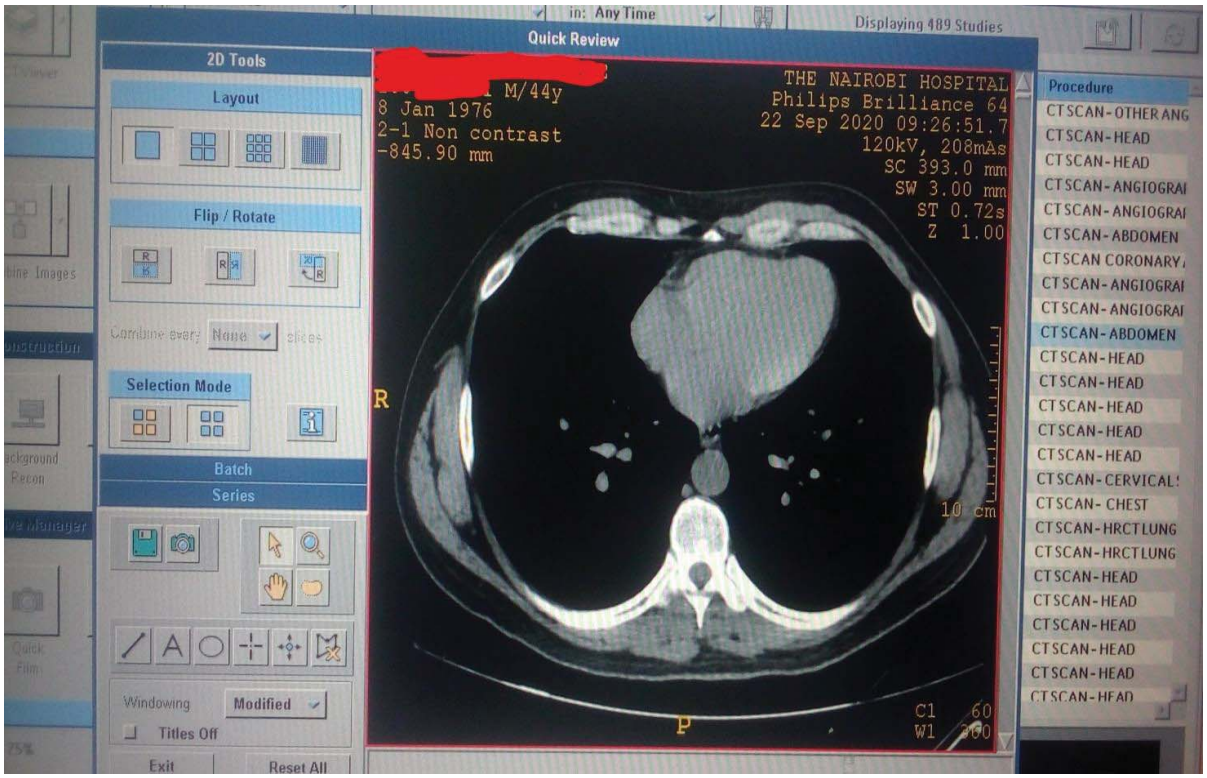
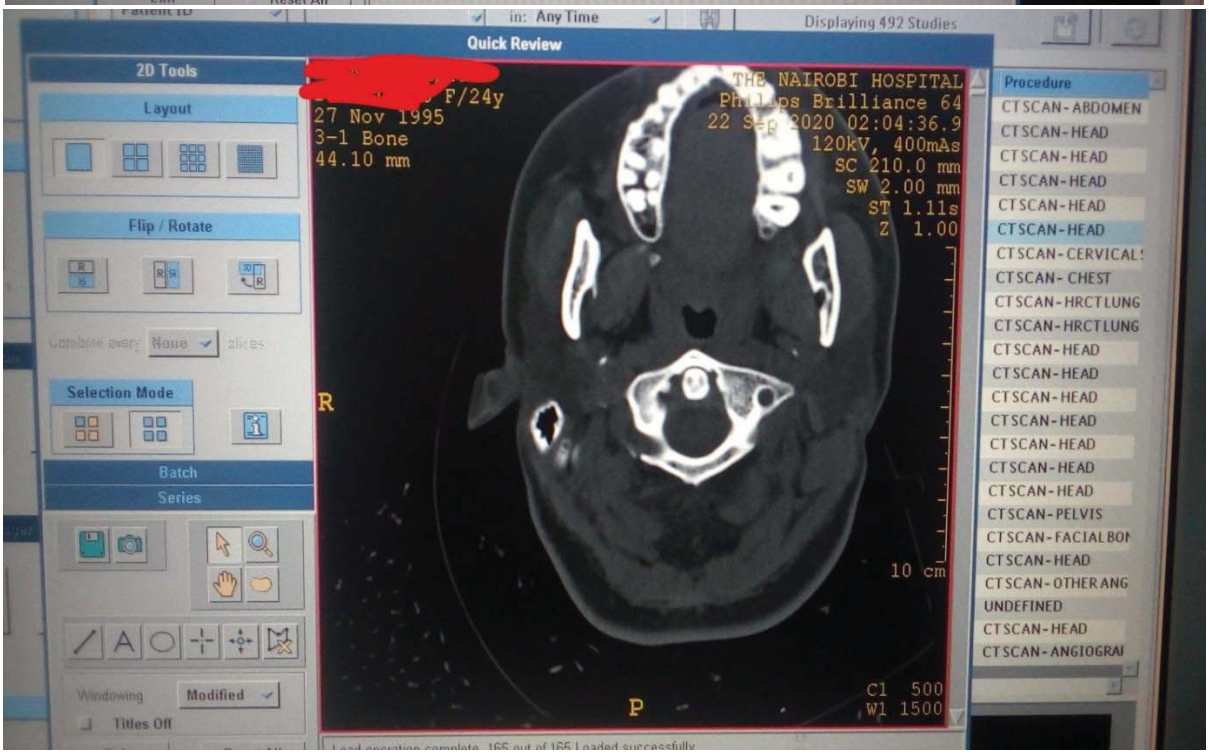
APPENDIX I

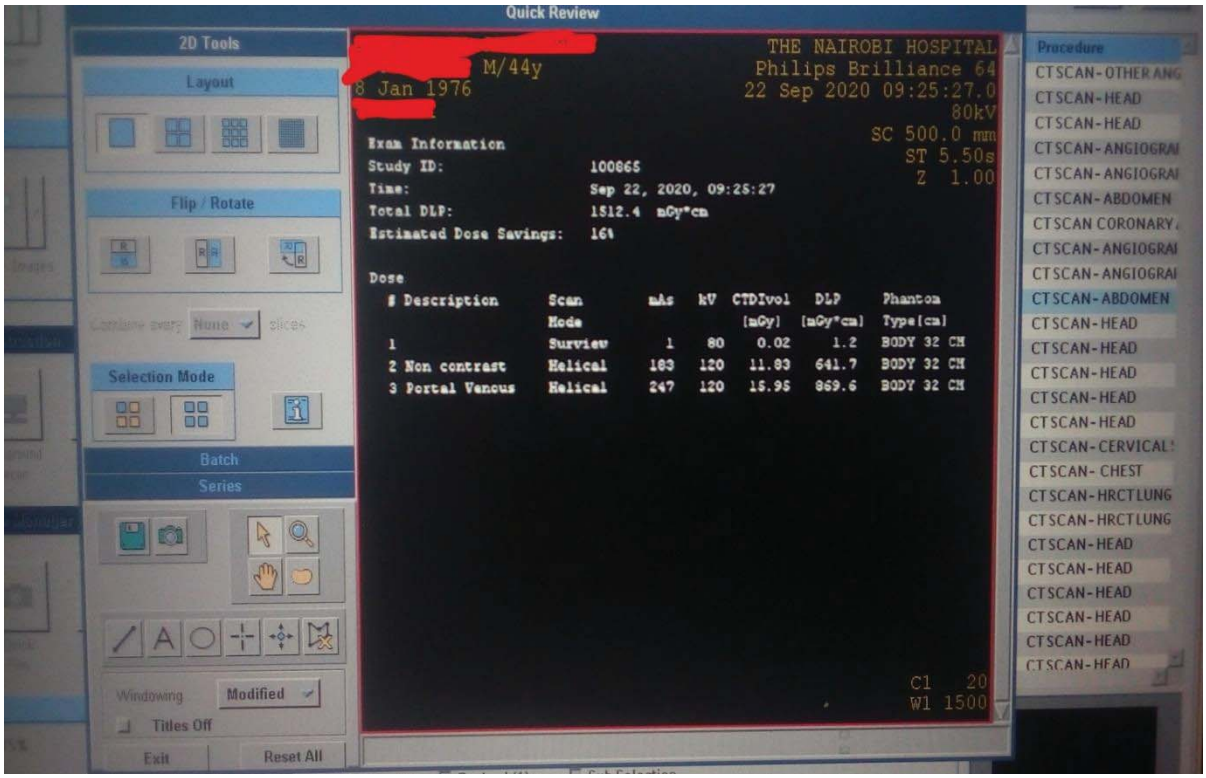
TYPICAL CT SCAN IMAGING FOR A DIAGNOSTIC EXAMINATION AND CORRESPONDING DOSEMETRIC QUANTIES SCAN OUTPUT DISPLAY FILE

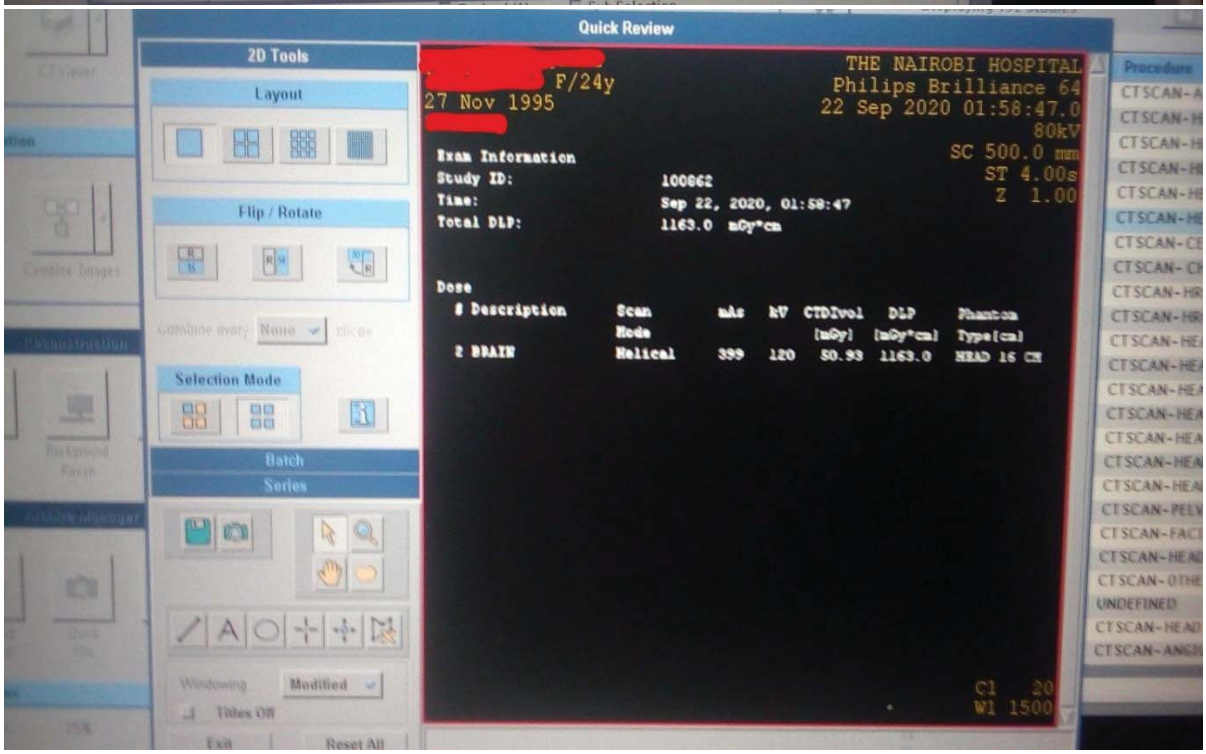




APPENDIX II

TYPICAL CT SCAN IMAGING FOR A DIAGNOSTIC EXAMINATION AND CORRESPONDING DOSEMETRIC QUANTIES SCAN OUTPUT DISPLAY FILE





APPENDIX III

DATA COLLECTION WORKSHEET OF CT EXAMINATIONS

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Head Without Contrast

CT Examination Period ..... January — March 2020

Operating Conditions..... 120 KVp, 250 MAs, Slice Thickness=4.0mm, pitch=1.0

DRL ..... $CTDI_{Vol}$ = 50.98 mGy, DLP = [illegible] 1134.72, ED (mSv) = 2.61

Effective Dose..... 2.61 mSV

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	HE01	48	F	50.98	1033	3.5	20.26
2	HE02	44	F	50.98	1093.5	2	21.45
3	HE03	19	F	31.97	709.5	2.5	22.19
4	HE04	54	F	50.98	1073.8	3.5	21.06
5	HE05	35	F	50.98	1043.2	3.5	20.46
6	HE06	53	F	50.98	1114.7	3.5	21.87
7	HE07	53	F	50.98	1165.7	3.5	21.87
8	HE08	80	F	50.98	1176	3.5	23.07
9	HE09	50	M	50.93	1184.6	3	23.26
10	HE10	50	M	38.25	978	3	25.57
11	HE11	40	F	31.97	652.1	2.5	20.40
12	HE12	50	M	31.97	668	2.5	20.89
13	HE13	36	F	50.98	1114.7	3.5	21.87
14	HE14	29	M	28.12	873.2	4	31.05
15	HE15	29	M	50.93	1266.3	4	24.86
16	HE16	67	M	31.97	692	2.5	21.65
17	HE17	53	M	38.35	928.3	3.5	24.21
18	HE18	36	M	50.93	1133.5	5	22.26
19	HE19	27	M	50.98	1114	2	21.85
20	HE20	44	F	50.93	1102.9	3	21.66
21	HE21	51	F	50.98	1104	2.5	21.66
22	HE22	34	M	38.3	1087.6	4.5	28.40
23	HE23	34	M	20.19	573.4	4.5	28.40
24	HE24	76	M	50.98	1083.2	3	21.25
25	HE25	34	M	50.98	1073.8	3.5	21.06
26	HE26	44	F	50.98	1043.2	3.5	20.46

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

1

Head without contrast

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
27	HE27	55	M	50.98	1012.5	3.5	19.85
28	HE28	77	F	50.98	1022.7	3.5	20.06
29	HE29	29	F	50.98	1104	2.5	21.66
30	HE30	41	F	51.03	1106.5	4	21.68
31	HE31	54	F	50.98	1134.6	2.5	22.26
32	HE32	69	F	50.98	1226.5	2.5	24.05
33	HE33	19	F	50.93	1194.8	4	23.46
34	HE34	44	F	101.91	2146	3.5	21.06
35	HE35	47	F	50.98	1073.8	3.5	21.06
36	HE36	46	F	50.98	1124.9	3.5	22.07
37	HE37	65	M	50.98	1135.1	3.5	22.27
38	HE38	41	M	50.98	1073.3	2.5	21.05
39	HE39	45	F	101.91	2267.9	2	22.25
40	HE40	45	M	50.98	1073.8	3.5	21.06
41	HE41	36	F	50.98	1002.3	3.5	19.66
42	HE42	77	F	50.98	1063.6	3.5	20.86
43	HE43	43	F	101.91	2247.5	2	22.054
44	HE44	50	F	50.98	1053.4	3.5	20.66
45	HE45	25	M	50.93	1337.8	4	26.27
46	HE46	45	F	50.98	1093.7	2.5	21.45
47	HE47	45	F	50.98	1082.4	2.5	21.45
48	HE48	40	F	50.93	1073	3	21.25
49	HE49	32	F	50.98	1124.7	1.8	21.05
50	HE50	36	M	50.98	1184.6	3	23.06
51	HE51	21	M	50.93	1135.1	5.5	23.26
52	HE52	19	F	50.98	1072.2	3.5	22.27
53	HE53	57	M	50.93	1072.2	3.5	21.05
54	HE54	24	F	38.35	867	3.5	22.61
55	HE55	37	F	50.98	1176	3.5	23.07
56	HE56	42	F	51.03	1046	4.8	20.50
57	HE57	25	F	50.98	1073.8	3.5	21.06
58	HE58	78	M	31.97	716.4	3.5	22.41
59	HE59	21	M	50.93	1164.1	4	22.86
60	HE60	49	M	50.98	1634.9	5	32.07
61	HE61	54	F	31.97	703	2	21.99
62	HE62	71	F	51.03	1076.6	4.8	21.10
63	HE63	71	F	24.67	674.1	4	27.32
64	HE64	46	M	38.35	890	3.5	23.21

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type: PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture: 2007

CT Examination Procedure: Paranasal Sinuses

CT Examination Period: January - March 2020

Operating Conditions: 120 kVp, 250 mAs, Slice Thickness (1.0mm), pitch=1.0

DRL: $CTDI_{vol}$ = 12.82 mGy, DLP = 280.2 mGy.cm

Effective Dose: 0.64 mSv

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	PAR01	40	F	12.82	283.5	3	22.11
2	PAR02	32	F	12.82	229	1.2	17.86
3	PAR03	50	M	31.84	710.3	2.5	22.31
4	PAR04	41	M	12.82	284.3	2	22.17
5	PAR05	51	F	12.82	303.5	2	23.67
6	PAR06	40	F	12.82	235.4	2.5	18.36
7	PAR07	33	M	25.59	492.8	3	19.26
8	PAR08	21	F	12.82	256.7	3	20.02
9	PAR09	28	F	12.82	213.3	3	16.63
10	PAR10	53	M	12.82	261.2	3	20.37
11	PAR11	39	M	12.82	235.5	3	18.37
12	PAR12	46	M	25.54	589.2	3.5	23.07
13	PAR13	34	M	12.82	279.1	3	21.77
14	PAR14	69	F	12.77	244.5	2.5	19.15
15	PAR15	19	F	12.82	273.1	4	21.30
16	PAR16	26	F	12.82	2724	2.5	21.25
17	PAR17	34	M	12.82	238.9	3	18.63
18	PAR18	24	F	12.82	227.4	3	17.74
19	PAR19	34	M	12.82	2727	3	21.27
20	PAR20	47	F	12.77	210.6	3.5	16.49
21	PAR21	46	F	38.2	1082	3.5	28.32
22	PAR22	47	F	12.77	210.6	3.5	16.49
23	PAR23	47	F	12.77	210.6	3.5	16.49
24	PAR24	80	M	50.98	1339.1	3.5	26.27
25	PAR25	80	M	101.91	2636.4	3.5	25.87
26	PAR26	46	F	12.82	250.3	2.5	19.52

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

3

PARANASAL SINUSES

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
27	PAR 27	82	F	12·82	244·3	2·5	19·06
28	PAR 28	31	M	12·82	253·9	2·5	19·80
29	PAR 29	18	F	12·82	240·5	2·5	18·76
30	PAR 30	42	M	12·82	239·5	3	18·68
31	PAR 31	35	M	12·82	240·1	3	18·72
32	PAR 32	53	M	12·82	245·4	2	19·14
33	PAR 33	55	F	12·82	236·6	2·5	18·46
34	PAR 34	13	M	12·82	272·7	3	21·27
35	PAR 35	32	M	12·82	251·6	3	19·63
36	PAR 36	44	F	12·82	252·3	3	19·68
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$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Chest Without Contrast

CT Examination Period ..... January - March 2020

Operating Conditions.... 120 KVp, 250-400 mAs, Slice Thickness = 5.0mm, pitch = 1.0

DRL ..... $CTDI_{vol}$ = 32.27 mGy , DLP = 773.7 mGy.cm

Effective Dose..... 13.15 mSV

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	CHE01	56	F	32.2	741.7	3	23.03
2	CHE02	27	M	26.58	750.7	3	28.24
3	CHE03	80	M	43.89	1771.6	3.15	40.36
4	CHE04	50	M	14.3	627.2	8	43.86
5	CHE05	41	F	15.3	512.2	4.1	32.48
6	CHE06	55	M	9.31	303.2	7	32.57
7	CHE07	27	M	36.45	1370.4	4	37.60
8	CHE08	33	F	10.06	380.7	8.2	37.84
9	CHE09	73	F	18.71	571.2	5	30.53
10	CHE10	49	M	11.82	450.3	6	38.07
11	CHE11	53	F	17.77	941.9	8.5	41.75
12	CHE12	53	M	18.45	600.5	3.5	32.55
13	CHE13	53	M	27.94	701.7	3.5	25.11
14	CHE14	85	M	61.55	3030.7	6.45	49.24
15	CHE15	42	F	13.28	318.2	4	23.96
16	CHE16	63	F	20.73	426	3	20.55
17	CHE17	65	M	41.64	1517.9	4	36.46
18	CHE18	51	M	32.47	950.5	5	29.27
19	CHE19	38	F	17.14	624.7	7	36.45
20	CHE20	35	F	14.72	529.1	8	35.94
21	CHE21	85	M	20.46	842.7	4	41.19
22	CHE22	26	F	37.08	468.1	3	12.62
23	CHE23	60	F	20.9	542.1	3.5	25.94
24	CHE24	75	F	16.19	519.4	6	32.08
25	CHE25	87	M	60.5	902.2	3	14.91
26	CHE26	69	F	19.94	367.3	3	18.42
27	CHE27	36	M	20.16	724.8	4	35.95
28	CHE28	59	M	26.29	702.7	2.8	26.73

DATA COLLECTION WORKSHEET

Machine Type: PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture: 2007

CT Examination Procedure: Abdomen with Contrast

CT Examination Period: January - March 2020

Operating Conditions: 120 kVp, 250 - 400 mAs, Slice Thickness = 5.0mm pitch = 1.0

DRL: $CTDI_{vol}$ = 83.32 mGy, DLP = 2865.4 mGy.cm

Effective Dose: 42.98 mSV

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	ABDC01	41	F	41.9	2236.5	4.1	53.38
2	ABDC02	30	M	56.64	1323.7	5.5	23.37
3	ABDC03	44	M	45.38	2246.7	4.1	49.50
4	ABDC04	33	F	77.27	2804.6	8.2	36.30
5	ABDC05	53	F	83.34	3656.6	8.5	43.86
6	ABDC06	53	M	82.73	3124.8	4.5	37.77
7	ABDC07	63	F	92.03	3358.5	5.5	36.49
8	ABDC08	38	F	67.46	2557.4	7	37.91
9	ABDC09	42	F	70.86	2153.9	5	30.40
10	ABDC10	81	F	68.59	1897.5	4.5	26.64
11	ABDC11	75	F	81.59	2812.2	6	34.47
12	ABDC12	40	M	95.62	3662.1	5.5	38.30
13	ABDC13	25	M	88.99	2695	5.5	30.28
14	ABDC14	53	M	59.31	1938.6	5.5	32.69
15	ABDC15	40	M	59.31	1938.6	5.5	32.69
16	ABDC16	47	F	63.15	2830.7	6.5	44.83
17	ABDC17	36	F	78.98	2291.6	4.5	29.01
18	ABDC18	41	F	83.7	2926.1	5.5	34.96
19	ABDC19	38	M	87.01	2499.8	5.5	28.50
20	ABDC20	45	F	77.13	2908.6	4.2	37.71
21	ABDC21	28	M	50.25	1947.4	5.5	38.75
22	ABDC22	73	M	66.77	1914.2	5.5	28.66
23	ABDC23	32	M	65.92	1018	5.5	15.44
24	ABDC24	50	M	83.31	2851	8	34.22
25							
26							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) = Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Angiography with Contrast

CT Examination Period ..... January - March 2020

Operating Conditions..... 120 kVp, 250-400 mAs, sliceThickness(1-5mm), pitch = 1.0

DRL ..... CTDIvol = 42.27 mGy, DLP = 514.03 mGy·cm

Effective Dose..... 6.17 mSV

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	A01	35	M	29.61	3269	2.5	11.04
2	A02	56	F	23.12	263.1	2	11.38
3	A03	54	M	22.09	406.4	4	18.40
4	A04	45	M	38.6	429.3	3	11.12
5	A05	37	F	51.02	465.9	3	9.13
6	A06	63	F	38.39	426.3	3	11.10
7	A07	72	M	40.21	375.1	3.5	9.33
8	A08	35	F	33.2	334.5	5	10.07
9	A09	53	M	43.39	368.5	3	8.49
10	A10	61	M	37.02	553.7	5	14.96
11	A11	44	F	41.02	426.5	3	10.40
12	A12	26	F	31.32	338.6	3.5	10.81
13	A13	46	F	33.1	500.8	5	15.13
14	A14	87	M	216.2	2119.2	12	9.80
15	A15	54	F	39.97	326.8	3.1	8.18
16	A16	41	F	57.71	2091	7.5	36.23
17	A17	24	F	176.94	3330	4.8	18.82
18	A18	47	F	35.56	211.3	2.8	5.94
19	A19	56	M	41.9	954.4	8	22.78
20	A20	59	M	32.84	412.5	3	12.56
21							
22							
23							
24							
25							
26							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER.....

Year of Manufacture..... 2007.....

CT Examination Procedure..... Cervical Spine without contrast.....

CT Examination Period ..... January - March 2020.....

Operating Conditions..... 120 KVP, 250-400 mAs, Slice Thickness 3.0mm, Pitch = 1.0.....

DRL ..... - .....

Effective Dose..... - .....

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	CERVSP01	25	M	42	1252.5	4.02	29.83
2	CERVSP02	36	M	40.58	1228.8	4	30.28
3	CERVSP03	36	M	35.89	1104.8	5	30.78
4	CERVSP04	55	M	92.38	2375.8	5.5	25.72
5	CERVSP05	21	M	34.16	961.4	5.5	28.14
6	CERVSP06	57	M	25.56	674.5	3.5	26.39
7	CERVSP07	25	M	23	565.8	3.5	24.6
8	CERVSP08	21	F	28.79	701.2	4	24.36
9	CERVSP09	49	M	36.56	1200.2	3	32.82
10	CERVSP10	46	M	21.95	625.8	3.5	28.51
11	CERVSP11	34	M	20.19	573.4	4.5	28.40
12	CERVSP12	41	F	22.33	591.5	4	26.49
13	CERVSP13	29	M	28.12	873.2	4	31.05
14	CERVSP14	56	M	35.22	984.2	8	27.94
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Abdomen Without Contrast

CT Examination Period ..... January – March 2020

Operating Conditions..... 120 kVp, 250–400 mAs, slice Thickness = 5.0mm, Pitch = 1.0

DRL..... –

Effective Dose.....

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	ABDW01	41	F	17.06	993.6	7.5	58.24
2	ABDW02	55	M	39.27	1944.8	7	49.52
3	ABDW03	37	F	54.31	2379.8	5	43.81
4	ABDW04	73	F	44.61	2360.6	5	52.91
5	ABDW05	61	M	32.7	1582.4	5.5	48.39
6	ABDW06	49	M	12.67	669.7	6	52.86
7	ABDW07	60	M	41.37	1766	4.1	42.69
8	ABDW08	35	F	14.72	529.1	8	35.94
9	ABDW09	47	F	16.61	866.7	6.5	52.18
10	ABDW10	47	F	10.69	716.8	6.5	67.50
11	ABDW11	39	M	43.24	2177.6	4.8	50.36
12	ABDW12	53	M	60.32	2963	5	49.12
13	ABDW13	35	F	17.41	989.4	8	53.38
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Neck Without Contrast

CT Examination Period ..... January - March 2020

Operating Conditions..... 120 kVp, 250-400 mAs, Slice Thickness=3.0mm, Pitch=1.0

DRL ..... -

Effective Dose..... -

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	NE01	57	F	75.59	1628.4	3	21.54
2	NE02	38	M	56.01	2429.2	6.5	43.37
3	NE03	42	F	25.4	625.8	4.8	24.64
4	NE04	82	F	46.37	938.9	4	20.25
5	NE05	60	F	50.57	939.6	4	18.58
6	NE06	36	F	43.15	1469.7	4	34.01
7	NE07	65	M	38.02	1093.5	2.5	26.93
8	NE08	47	F	13.43	436.8	6.5	34.53
9	NE09	47	F	13.31	435.6	6.5	32.73
10	NE10	41	F	83.97	2004.8	5	23.88
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type: PHILIPS BRILLIANCE - 64 CT SCANNER

Year of Manufacture: 2007

CT Examination Procedure: chest with contrast

CT Examination Period: January - March 2020

Operating Conditions: 120 kVp, 250-400 mAs, Slice Thickness = 5.0 mm, Pitch = 1.0

DRL: -

Effective Dose:

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	CHEWC01	M	38	59.02	1092.3	4.5	18.51
2	CHEWC02	M	40	51.51	953.4	3.5	18.51
3							
4							
5							

DATA COLLECTION WORKSHEET

Machine Type: PHILIPS BRILLIANCE - 64 CT SCANNER

Year of Manufacture: 2007

CT Examination Procedure: Cervical Spine with contrast

CT Examination Period: January - March 2020

Operating Conditions: 120 kVp, 250-400 mAs, Slice Thickness = 3.0 mm, Pitch = 1.0

DRL: -

Effective Dose:

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	CERVSPC01	61	M	75.71	1341.3	4.5	17.72
2							
3							
4							
5							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Head With contrast

CT Examination Period ..... January- March 2020

Operating Conditions..... 120 kVp, 250 mAs, Slice Thickness = 4.0mm, Pitch = 1.0

DRL ..... -

Effective Dose..... -

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	HEC01	44	F	31.97	690.2	2	21.59
2							
3							
4							
5							

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Lumbar spine

CT Examination Period ..... January- March 2020

Operating Conditions..... 120 kVp, 250-400 mAs, Slice Thickness = 3.0mm, Pitch = 1.

DRL ..... -

Effective Dose..... -

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	LUMBSP01	49	M	18.2	750.3	5.0	41.23
2							
3							
4							
5							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

DATA COLLECTION WORKSHEET

Machine Type..... PHILIPS BRILLIANCE-64 CT SCANNER

Year of Manufacture..... 2007

CT Examination Procedure..... Angiography without contrast

CT Examination Period ..... January–March 2020

Operating Conditions..... 120 kVp, 250-400 mAs, Slice Thickness (1-5mm), pitch=0

DRL .....

Effective Dose.....

NO.	PATIENT DETAILS	AGE	GENDER	DOSIMETRIC QUANTITIES			
				$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	ST(sec)	SL(cm)
1	AW01	35	F	65.37	205.21	8	3.14
2							
3							
4							
5							

$CTDI_{vol}$ (mGy) = Volume Computed Tomography Dose Index, DLP (mGy.cm) =Dose length Product, ST (sec) = scanning time (seconds) for patients, SL (cm) = Scanned length (centimeters) on patients.

APPENDIX IV

THE COMPUTED TOMOGRAPHY DLP DATA FOR PATIENTS WITH MULTIPLE CT EXAMINATIONS

Patient	No of Multiple CT Examinations	Type of Examinations								
		Head	Chest	Abdo	Cerv Spine	Neck	Lumb Spine	Angio	Par sinus	Total
M 80	2								3975.5	3975.5
M 46	3	890			625.8				589.2	2105
M 25	2	1337.8			1252.5					2590.3
F 45	2	2187.4								2187.4
M 21	2	1184.6			961.4					2146
F 69	2	1226.5							244.5	1471
F 40	2	1082.4							283.5	1365.9
F 32	2	1073							229	1302
F 47	4(2Ne,2Abd)			3697.4		899.4				4596.8
F 75	2		519.4	2812.2						3331.6
F 38	2		624.7	2557.4						3182.1
F 53	2		741.9	3656.6						4398.5
F 33	2		380.7	2804.6						3185.3
F 41	2		512.2	2236.5						2748.7
F 35	3		529.1	929.4				205.21		1663.71
F 73	2		571.2	2360.6						2931.8
M 55	2		303.2	1944.8						2248
F 41	2			993.6				2091		3084.6
M 38	2		1092.3			2429.2				3521.5
M 53	2 C		1302.2							
M 57	2	1072.2			674.5					1746.7
F 42	2	1046				625.8				1671.8
F 25	2	1073.8			565.8					1639.6
M 21	2	1164.1			701.2					1865.3
M 49	5	1634.9	450.3	669.7	1200.2		750.3			4705.4
F 71	2H	1761.7								1761.7
F 44	3(2H,1Ang)	1783.7						426.5		2210.2
M 34	2	1087.6			573.4					1661
F 41	2	1106.5			591.5					1698
F 53	2H	2280.4								2280.4
M 29	2	1266.3			873.2					2139.5
M 36	2	1133.5			1104.8					2238.3
M 29	2	1266.3			873.2					2139.5
M 36	2	1133.5			1104.8					2238.3
F 44	2	1102.9							252.3	1355.2
F 46	2	1124.9							1082	2206.9
F 19	2	1194.8							273.1	1467.9

APPENDIX V

THE CUMMULATIVE EFFECTIVE DOSE DATA FOR PATIENTS WITH MULTIPLE CT EXAMINATIONS

Patient	No of Multiple Examinations	Type of Examinations								
		Head	Chest	Abdo	Cerv Spine	Neck	Lumb Spine	Angio	Par sinus	Total, E (mSv)
M 80	2								83.48	83.48
M 46	3	1.87			3.69				12.37	17.93
M 25	2	2.81			7.39					10.2
F 45	2He	4.6								4.6
M 21	2	2.49			5.67					8.16
F 69	2	2.58							5.13	7.71
F 40	2	2.27							5.94	8.21
F 32	2	2.25							4.81	7.06
F 47	4(2Ne,2Abd)			55.46		5.31				60.77
F 75	2		7.27	42.18						49.45
F 38	2		8.75	38.36						47.11
F 53	2		10.39	54.85						65.24
F 33	2		5.33	42.07						47.4
F 41	2		7.17	33.55						40.72
F 35	3		7.41	13.94				1.5		22.85
F 73	2		8	35.41						43.41
M 55	2		4.24	29.17						33.41
F 41	2			14.91				15.26		30.17
M 38	2		15.29			14.33				29.62
M 53	2 C		18.23							18.23
M 57	2	2.25			3.98					6.23
F 42	2	2.2				3.69				5.89
F 25	2	2.25			3.34					5.59
M 21	2	2.44			4.14					6.58
M 49	5	3.43	6.3	10.05	7.08		11.25			38.11
F 71	2H	3.68								3.68
F 44	3(2H,1An)	3.75						3.11		6.86
M 34	2	2.28			3.38					5.66
F 41	2	2.32			3.49					5.81
F 53	2H	4.79								4.79
M 29	2	2.66			5.15					7.81
M 36	2	2.38			6.52					8.9
F 44	2	2.32							5.29	7.61
F 46	2	2.36							22.72	25.08
F 19	2	2.51							5.74	8.25

*2Ne= refers to two neck examinations repeated, 2 C = two chests repeated, 1Ang = one angiography repeated, 2H = two head examinations repeated and 2Abd = two abdomen examinations repeated.

APPENDIX VI

QUESTIONNAIRE

QUESTIONNAIRE

As part of my MSC research, at the Institute of Nuclear Science & Technology, University of Nairobi, I am conducting a research study that investigates **"ASSESSMENT OF RADIOLOGICAL PATIENT EXPOSURE LEVEL FOR COMPUTED TOMOGRAPHY SCANNING EXAMINATIONS".** I will appreciate if could complete the following questions. Any information obtained in connection with this study that can be identified with you will remain confidential.

Respondent details:

Name: [redacted] Age: 27 Gender: Male/Female

Mobile Number: [redacted] Department: Radiology Occupation: Radiographer.

Please tick the box provided to show your consent to part of the research ☑

1 What is your role in the radiology department?

Taking C.T. Scans of patients.

2 How long have you worked in the radiology department?

☐ Less than a year ☑ 1-5years ☐ 5-10 years ☐ 10+ years

3 How frequent do you perform QA/QC on the Philips Brilliance 64 CT Facility?

☑ Daily ☐ Weekly ☐ Monthly ☐ Annually

4 Which of the following tools are used in QA/QC checks?

☑ IQ phantoms ☐ PMMA phantoms ☐ Both IQ and PMMA phantoms ☐ Other

If other, Please specify

.....

5 How familiar are you with Radiation Protection Dosimetry?

☐ Personal & environmental monitoring for both Ionising radiation and non-ionising radiation.

☑ Personal & environmental monitoring for ionising radiations.

☐ Personal monitoring for ionising radiations.

6 Do Patients require radiation protection?

☐ Yes ☐ No ☑ Not Sure

Comments/Suggestions:

Sometimes the machine hangs during examination and so the exam is repeated. Does this account to much unnecessary exposure?

Gedion. K. Kibet, MSC Student, The Institute of Nuclear Science & Technology, University of Nairobi.

APPENDIX VII

SCIENTIFIC PAPER PUBLICATION

Evaluating the relationship between Quality Assurance and Exposure Level for Head and Abdomen Computed Tomography Procedures in a selected Kenyan Hospital

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***Abstract*— This research aimed at evaluating the relationship between a scanner's operating conditions and the exposure levels for head and abdomen procedures to a 64-slice Multi-Detector Computed Tomography, and for radiological compliance. The Quality Assurance of the scanner was assessed using two-part phantoms for acceptance tests by International Electro-Technical standards. Significant discrepancies between the machine and measured $CTDI_{vol}$ were detected. The percent Coefficient of Variation (%CV) for the exposure parameters ($CTDI_w$, DLP, and ED) varied between 7.1 to 75% as compared to EC guidelines. To reduce patient radiation exposure and achieve clinical accuracy, institutional DRLs should be established for radiological compliance.**

I. INTRODUCTION

The use of Computed Tomography (CT) for diagnosis and therapeutic planning, to assess the relationship between body composition and clinical outcomes has grown exponentially since the introduction of Multi-Detector Computed Tomography (MDCT) scanners [98]. These scanners are effective for diagnosing various anatomical regions, including patients with severe abdominal pain. The risks associated with exposure to Ionizing Radiation (IR) should not be discounted, especially in pediatric patients [99].

According to the ICRP publications 118 and the UNSCEAR 2007 report, threshold values above 1 Gray (Gy) cause tissue reaction effects for the majority of organs and systems, with radiation-induced eye cataracts currently below 0.5 Sieverts (Sv). The majority of research used Polymethyl methacrylate **(**PMMA) phantoms to examine the Quality Assurance (QA) of newly installed and repaired scanners [100]. There were deviations in the CT dose parameters that were not within allowable standard levels but were corrected. The correlation between quality assurance and the exposure parameters during diagnosis has not been examined [100].

Utilizing digital imaging effectively is challenging because MDCT scanners can produce high-quality images with any amount of radiation. In practice, a CT scan procedure has the potential to high exposure levels to patients from inappropriate use of radio-diagnostic protocols. One of the major factors affecting the patients' radiation dose is the energy of the CT beam. Previous research identified scanner settings, equipment characteristics, radiographer expertise, and patient size variations as dose contributors [101].

The International Atomic Energy Agency (IAEA) has established fundamental patient protection safety criteria. They recommend implementing Diagnostic Reference Levels (DRLs) to optimize the reduction in patient dose. The establishment of DRLs without taking into account the scanner's operational state could be deceptive due to many factors such as the age of the scanner, wear and tear, and mechanical factors [102]. The diagnostic tool with poor mechanical or electrical performance affects the accuracy of the reported outcomes, limits the expected clinical benefits, and increases the lifetime cancer risks to patients [102]. The purpose of this research was to assess the performance of an MDCT scanner (64-slice, third generation x-ray tube, year of manufacture 2007, essence technology, Philips's system).

II. MATERIALS AND METHODS

The use of Monte Carlo computations with known conversion factors, and for the purpose of contrasting the findings with European Commission (EC)-recommended values, the percent Coefficient of Variations (%CV) was established for all the dosimetric parameters [103].

A. Quality Assurance

The quality assurance of the Philips Brilliance 64-slice CT scanner was assessed using body and head PMMA phantoms for acceptance test in accordance with the IAEA International Code of Practice. The measured Computed Tomography Dose Index (CTDI) was compared to the corresponding machine $CTDI_{vol}$ for radiological compliance with IEC standards [104].

B. Weighted CT Dose Index-$CTDI_w$

The weighted radiation dose from a single slice for a specific exposure setting is represented by the $CTDI_w$ as given in equation (1).

$$CTDI_w = (\tfrac{1}{3} CTDI_C) + (\tfrac{2}{3} CTDI_P). \quad (1)$$

Where $CTDI_C$ and $CTDI_P$ are CT dose index measurements performed with an ionization chamber at the center and periphery of the phantom, respectively.

C. Volume CT Dose index-$CTDI_{vol}$

The $CTDI_{vol}$ accounts for overlapping and determines the average absorbed dose in the irradiated volume from a CT scan series. Thus, the pitch factor and $CTDI_w$ are necessary for determining the $CTDI_{vol}$ as in equation (2).

$$CTDI_{vol} = \frac{1}{p}(CTDI_w). \quad (2)$$

Where p is the pitch value utilized at the hospital.

D. Dose Length Product-DLP

The DLP is the radiation dose incident on the patient's body and the scanned length using equation (3).

$$DLP = CTDI \times L. \quad (3)$$

Where L is the scan length.

E. Effective Dose-ED

The ED, radiation risk is computed using DLP values and ICRP's normalized coefficients using equation (4).

$$ED = E_{DLP} \times DLP. \quad (4)$$

Where E_{DLP} is the region-specific normalized coefficients ($mSv.mGy^{-1}\ cm^{-1}$).

III. RESULTS

The CTDI values measured at all points of the phantoms were recorded and compared to machine values.

A. Quality Assurance and Quality Control (QA and QC)

There were significant discrepancies between the machine and measured $CTDI_{vol}$ that were above or below the acceptable level of at least ±20% as in Table Ia and Ib.

TABLE I. THE MACHINE $CTDI_{VOL}$ VS. MEASURED $CTDI_{VOL}$ VALUES

(a) USING PMMA 320MM BODY PHANTOM				
Scan Area	***Machine $CTDI_{vol}$***	***Measured $CTDI_{vol}$***	***Deviation***	***Achievable***
Centre (c)	17.84	27.75	-9.91	-35.71%
P_N	17.88	29.29	-11.41	-38.96%
P_E	17.23	23.26	-6.03	-25.92%
P_S	17.23	21.23	-4.00	-18.84%
P_W	17.23	21.96	-4.73	-21.54%
(b) USING PMMA 160MM HEAD PHANTOM				
Scan Area	***Machine $CTDI_{vol}$***	***Measured $CTDI_{vol}$***	***Deviation***	***Achievable***
Centre (c)	31.97	43.72	-11.75	-26.87%
P_N	31.97	45.19	-13.22	-29.25%
P_E	31.97	43.07	-11.10	-25.77%
P_S	31.97	43.64	-11.67	-26.74%
P_W	31.97	43.89	-11.92	-27.16%

B. The $CTDI_w$, DLP, and ED Measurements

The exposure parameters of the investigated head and abdomen examinations exceeded the EC diagnostic reference levels. The variation of the %CV was as low as 7.1% for the abdomen and as high as 75% for the head as in Table II.

TABLE II. THE MEASURED EXPOSURE PARAMETERS VALUES FOR ROUTINE HEAD AND ABDOMINAL EXAMINATION

Routine head	**Exposure Parameters**		
	$CTDI_{vol}$ (mGy)	***DLP (mGy*cm)***	***ED (mSv)***
This Survey (2020)	92.04	1527.86	3.5
EC (2014) [77]	60	1050	2
% CV	53.4%	45.4%	75%
Abdomen	**Exposure Parameters**		
	$CTDI_{vol}$ (mGy)	***DLP (mGy*cm)***	***ED (mSv)***
This Survey (2020)	52.89	856.82	12
EC (2014) [77]	35	800	10
% CV	51.11%	7.1%	20%

IV. CONCLUSION AND RECOMMENDATIONS

The research has determined significant discrepancies between the machine and measured $CTDI_{vol}$ for abdominal and head examinations, and above the acceptable level of at least ±20%. There were variations on the computed %CV between 7.1 to 75 % for patients' exposure parameters as compared to EC guidelines. The reliance on machine CTDI values in the establishment of institutional DRLs could be deceptive without taking into account the scanner`s operational state and as a result, patients could be unduly exposed to unnecessary radiation. The use of such invalidated scanners has future practical implications with the increased cancer incidence and mortality. The scanner's operating condition needs to be checked and adjusted to reflect the actual readings.

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