RADIATION DOSE REFERENCE LEVELS OF ADULT PATIENT COMPUTER TOMOGRAPHY ABDOMINAL STUDIES IN ELDORET.

BY

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RESEARCH THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF MEDICINE IN RADIOLOGY AND IMAGING OF MOI UNIVERSITY.

2023

DECLARATION

I declare that this research project has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the project contains no material previously published or written by another person except where due reference is made in the thesis itself.

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DEDICATION

I dedicate this work to my beloved family for their invaluable support and encouragement in seeing that this journey becomes a success.

ACKNOWLEGEMENTS

I express my acknowledgement to my supervisor's Prof Elias Onditi and Dr. Kittony Rose both consultant radiologists at Moi Teaching and Referral Hospital, for their much needed critic, input and refinement of thesis. I give my gratitude to Prof Ann Mwangi for her much warranted statistical support in this study. Much appreciation also goes to Moi University School of medicine for offering this crucial platform to enable me sharpen my research skills and thus endeavor the scientific discourse.

DEFINITION OF TERMS

Adult: Any persons 18-year-old and above who underwent abdominal CT scan

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LIST OF ABBREVIATIONS

ACR	American college of radiology
ARPANSA	Australian radiation protection and nuclear safety agency
ALARA	As Low as Reasonably Achievable
CT	Computed tomography
CTDI(w)	Weighted computed tomography dose index
DLP	Dose-length product
DRL	A Dose reference level
EC	European commissioned
E	Effective dose
FRL	Facility reference level
IGIP	Image guided interventional procedures
ICRP	The International Commission on Radiological Protection
IAEA	International Atomic Energy Agency.
MES	Managed Equipment Scheme
MTRH	Moi Teaching and referral hospital
MRI	Magnetic resonance imaging
PET	Positron emission tomography
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
US	Ultrasound sonography
SPECT	Single photon emission computed tomography

ABSTRACT

Background: Computed Tomography (CT) is a medical imaging technique that uses X-rays to produce detailed images of the body. CT procedures contribute to 67% of the collective effective radiation due to medical procedures in the United Kingdom and United States of America. CT abdomen is one of the commonest examinations done and its international approximate effective dose is 8mSv. Radiation dose of 10mSv and above carry higher risks of radiation induced injuries. The International Commission on Radiological Protection (ICRP) in concert with International Atomic Energy Agency (IAEA) introduced a concept called Diagnostic Reference levels (DRL) with the objective of providing a reference level for the radiation dose for standard radiographic and CT examinations without compromising quality of the images and ensuring radiation safety. Diagnostic reference levels are established locally, regionally and nationally. It is primarily useful as a quality assurance tool to compare doses from different protocols and to compare scanner outputs from different manufacturers. The international DRL for adult abdominal scans as per European commission, Ireland, Japan, India, shows the Computed Tomography Dose Index (CTDIvol)(mGy), and (Dose Length Product) DLP (mGy.m) values at (35, 780), (13,1120), (30.8, 1180.5), (13.71,2336.4) respectively. In recent regional and local studies in Africa, Egypt, Nigeria, South Africa, and Tanzania estimated the adult abdominal DRLs (CTDIvol(mGy) & DLP (mGy.m)) to be (11.9–22.7,341-1314), (31,1325), (15. 716) (22.7,704) respectively. The international diagnostic reference levels (DRLs) are used as point of reference and so far, no regional protocols for abdominal CT scan have been adopted.

Objective: To assess radiation dose reference levels of adult abdominal CT at MTRH, St. Luke's Hospital, Eldoret Hospital and Mediheal Hospital.

Methods: A multi-center retrospective study conducted in institutions from Eldoret with a functional radiology department doing an average of 15 abdominal CT scans per day as basis of selection namely; MTRH, Eldoret Hospital, Mediheal Hospital and St. Luke's Hospital in a period of 6 months in the year 2021. The adult patients' radiation dose data that were 18 years and above and referred for abdominal CT-scan during the period of study were recruited. Incomplete radiation dose summary for any patient was excluded. Consecutive sampling was applied to the 3 private facilities while systematic sampling using the interval K ~2 was used in MTRH which is a public facility. The $CTDI_{vol}$ and DLP from CT abdominal scans for the adults were simply obtained from the various CT machines as displayed on the console and recorded into an adapted IAEA survey form. The data was analyzed statistically via calculation of the median, interquartile ranges and construction of confidence intervals. The results were presented in tables and figures.

Results: A total of 700 patient abdominal dose scans were reviewed. The age ranged from 18-101 years with a mean of 52 years with the majority being females at 53 % of patients who underwent CT abdominal scans. It was observed that 66.4% of the reviewed scans were from the public facility and Siemens was the most common scan model at 70%. The mean $CTDI_{vol}$ was 8.1mGy (SD=22.2) and the mean DLP values was 1699.1mGy.cm (SD=1053.1). Comparison by the type of scan model indicated that the median for the Total DLP and $CTDI_{vol}$ significantly differed by the model with the median for the Neusoft model being highest at 2538 mGy.cm and 10.3mGy respectively while those for the Siemens were the lowest for the two markers at 1318.5 mGy.cm for the DLP and 5.39mGy respectively. Comparison by the type of facility showed that the median DLP and $CTDI_{vol}$ values were significantly higher in the public facility at 1668.8mGy.cm and 6.3mGy respectively when compared to private facilities at 1282.4mGy.cm and 5.9mGy with a p value of <0.001. The average volume $CTDI_{vol}$ for the current study was lower than the reference countries by less than 3%. The DLP values in this study were approximately lower than the regional and comparable with most reference countries by over 50%. The Local Dose reference level (LDRL) was set as the median value for $CTDI_{VOL}$ and DLP at 6.1mGy and 1465 mGy.cm respectively.

Conclusions: The LDRLs values were markedly lower than the regional and the international values.

Recommendations: The current LDRLs can be adopted and maintained by both the private and public facilities.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

1.1 Background

The development of medical imaging technologies such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and Computed Tomography (CT) has significantly influenced the field of healthcare. These technologies enable image-guided interventions, which offer alternatives to traditional, more invasive procedures (Fingerle & Noël, 2018). Radiation encompasses the propagation of energy in the form of electromagnetic waves or particles. In medical imaging, ionizing radiation is frequently utilized. This form of radiation has enough energy to remove electrons from atoms, creating ions in the process. This ionization capability is fundamental for producing high-contrast images that can be useful for diagnostic and therapeutic purposes (Abba et al., 2018).

The reliance on medical imaging procedures has escalated in recent times, making radiation an integral part of healthcare. Radiation is vital for diagnosing a multitude of conditions and diseases, from broken bones to cancer. However, exposure to ionizing radiation has its own risks. The growing dependence on these imaging procedures raises concerns about the cumulative radiation dose absorbed by patients (Korir et al., 2013).

To address these concerns, it is critical to understand how radiation exposure is quantified. The unit millisievert (mSv) is commonly used to measure the effective dose of radiation a patient receives. This unit accounts for the varying sensitivity of different tissues to radiation, allowing for a more comprehensive assessment of

potential health risks like cancer (Nagarajappa, Dwivedi & Tiwari., 2015). Other units include Rad, Rem, Roentgen, Sievert, and Gray (Cunningham & Judy, 2014).

Computed Tomography (CT) is a specific type of medical imaging that employs X-rays to produce cross-sectional images of the body. It is widely used for a variety of diagnostic and therapeutic procedures, including the identification of tumors, blood clots, and various forms of internal bleeding. The abdomen is a commonly scanned area, with CT offering detailed images that are crucial for diagnosis and treatment planning (Simon et al., 2015).

Current surveys have shown growing dependency rate on imaging procedures for diagnostic and medical therapies since they have remarkably shown improvement on quality of health care services. Due to choice and frequency of imaging modality, there has been an increase in radiation burden to the patient's body during examinations and medical procedures, in regards to absorbed radiations.(Korir, Wambani, Korir, Tries, & Kidali, 2013).

The number of X-rays that gets absorbed when radiation is passed through the body contributes to the patient's effective dose. Millisievert(mSv) is the scientific unit of measurement for the whole-body radiation dose, (effective dose). Other radiation dose measurement units include Rad(rad), Rem(rem), Roentgen, Sievert and Gray (ICRP, 2007). In order to evaluate the risk of radiation to the entire body, effective dose takes into account how sensitive different tissues are to radiation(Muhogora et al., 2008). Hence, it allows the radiologist to compare the risks or possible side effects such as the chance of developing cancer later in life to common, daily sources of exposure such as natural background radiation (Muhogora et al., 2008).

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report (2010) have indicated that medical exposures constitute more than 99% of the total radiation dose burden to the global population from the anthropogenic activities (Korir et al., 2013). Advanced imaging modalities like computed tomography and interventional therapeutic procedures have the potential for deterministic effects (epilation and erythema) or could lead to non-threshold stochastic effects (leukemia and hereditary disease) due to their high dose radiation (Korir et al., 2013).

In the developed countries International Commission on Radiological Protection (ICRP) introduced a concept called Diagnostic Reference levels (DRL) with the objective of providing a reference level for the radiation dose for standard radiographic and CT examinations without compromising quality. This has resulted to significant decline in human radiation exposure. Radiation doses used to perform similar CT studies of diagnostic quality should remain within a relatively narrow range. However, multinational and national surveys indicate that this is not the case; large variability in dose levels exists (Korir et al., 2013).

In the United Kingdom and US, CT procedures contribute to 67 % of the collective effective radiation due medical procedures. In Kenya as computed tomography (CT) technology evolves, many new applications have emerged, leading to high numbers of CT scans performed. Today CT is a major contributor (80%) to patient radiation exposure (Korir et al., 2013). CT abdomen is one of the commonest examinations done and its international approximate effective dose is 8mSv. Related studies have been done in Kenya and it has collectively looked at the effective dose burden of the entire body organs (Korir et al., 2013). This study aimed to establish the examination

frequency and associated radiation dosages to patients specifically undergoing examination of CT abdomen at Moi Teaching and Referral Hospital, Eldoret Hospital and Mediheal Hospital in Eldoret. As a result, provided a basis for setting regional DRLs.

1.2 Problem Statement

In the sphere of medical imaging, advancements in technology have played a pivotal role, particularly in developed countries where these technologies are widely adopted. However, the increased use of imaging procedures, including CT scans, poses a challenge: elevated levels of radiation exposure to patients. International guidelines, such as those set forth by the International Commission on Radiological Protection (ICRP), promote the ALARA (As Low As Reasonably Achievable) principle to ensure safety in radiation dosage (ICRP, 2007). The goal is to minimize the risk while maximizing diagnostic utility.

Despite these international guidelines, a significant gap exists in the local healthcare setting. Specifically, there are no established national diagnostic radiation reference protocols for abdominal CT scanning in Kenya (Korir et al., 2013). This lack of standardized guidelines increases the likelihood of excessive radiation doses during radiological procedures and therapies, which elevates the risk of long-term health impacts like cancer (Pantos et al., 2011).

The current study aims to fill this gap by collecting and analyzing data on adult CT doses for abdominal studies conducted at Moi Teaching and Referral Hospital, Eldoret Hospital, St. Luke's Hospital, and Mediheal Hospital in Eldoret. The intention is to establish regional Diagnostic Reference Levels (DRLs), serving as a foundational

reference for radiation safety in Uasin Gishu county and potentially influencing national policy.

1.3 Justification

The CT scan is proving to play a critical role in the management of patients with various disease presentation requiring imaging. To an extent it has replaced some of the invasive procedures to a minimally invasive procedure. Owing to the advent of multi detector CT scanners the risk of high radiation dose to the patients is increased(Mayo, Aldrich, & Müller, 2003). Thus, this necessitates actions geared towards dose reduction mechanisms that ensures patients safety and still maintain quality images(Little et al., 2008). There are limited studies so far showing the dose burden of the multi-detector abdominal CT scan. The purpose of this study was to assess local doses for adult abdominal CT scan examination at MTRH and the 3 private hospitals under the survey. Excessive radiation exposure can lead to stochastic side effects to the patients furthering the cancer burden. The survey has provided a basis for comparisons of dose references levels among Moi Teaching and Referral Hospital, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital with international DRLs. Hence formed a basis for setting regional DRLs.

1.4 Research question

What is the radiation dose level of adult undergoing abdominal CT examination at Moi Teaching and Referral Hospital, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital?

1.5 Research Objectives

1.5.1 Broad Objective

To assess radiation dose reference levels of adult abdominal CT at Moi Teaching and Referral Hospital, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital in Eldoret.

1.5.2 Specific objectives:

1. To determine the mean $CTDI_{vol}$ and DLP values for adult abdominal CT examination at the MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital.
2. To compare the mean $CTDI_{vol}$ and DLP values for adult abdominal CT examination for MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital.
3. To compare dose reference levels for the adult abdominal CT scan modality at MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital in reference to the international DRLs.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

2.1 Computer Tomography

Computer Tomography has become a pivotal clinical tool in improving the quality of health care by reliably providing high quality imaging data in a faster and more accurate diagnosis. Over the past decade there has been advances in technology surrounding computer tomography both in its hardware and software capability(Fingerle & Noël, 2018). From single channel scanners to multi-channel scanners with better ability to acquire simultaneous helical datasets. In addition, with increase in gantry rotation speed coupled with the reduction in the size of the individual detectors has resulted in the ability to acquire detailed images in a very short scan time(Fingerle & Noël, 2018). Major manufactures currently have scanners with top notch specification scanners, up to 320 channels are available each with a detector size of as small as 0.5mm (Simon P.G et al,2015). The introduction of high-resolution and helical(spiral) CT techniques has contributed to further precision to the clinical investigation of suspected abdominal disease, though the use of such sophisticated tests should not be indiscriminate(Fingerle & Noël, 2018). Regardless of its benefits to diagnosis and medical management of patients, it is associated with relatively high radiation dose which poses an increased risk of carcinogenesis(Mayo et al., 2003). Thus, there should be strict adherence to the standards of radiation protection towards cautionary use of the modality to safeguard the risk to patients does not outweigh the benefit from the technique.

2.1.1 History of Computed Tomography

Literature on medical imaging highlights the issue of the generations of the CT scanner. The generations used for the assessments of CT scan are discussed in this section and are based on the detector array and the X-ray beam geometry. These include the pencil beam/first generation, small fun beam/second generation, fan beam with a revolving/third generation detector array, and fan beam with a static or motionless 360^0 detector array/fourth. The third-generation design has been highly successful and is currently the preferred scanner design. This design has a slip ring technology that enables the X-ray tube to revolve constantly and a detector array around the patient. The succeeding generations of scanners differ in the number of detectors and are also distinct in their ability to reduce the overall scan time.

2.1.2 First and second-generation CT scanners

The CT scanners of the first generation relied on a solitary X-ray beam that was pencil shaped and on at most two points. The beam's width determined the slice thickness of the image being produced. This CT imaging generation imaged the patient into a series of axial slices (Mohan, Singh& Gundappa., 2011). The Ct scanners in the 1^{st} generation had just one detector; this was strictly connected to the tube of the X-ray and the images were obtained through a translate-rotate motion (Goldman, 2007). This motion is the detectors and X-ray tube's linear transverse path across the patient. During the joint translation-rotation motion, the X-ray transmission is measured by the detector through the subject at numerous locations. One level of incremental rotation of the tube-detector assembly ensues after each translation. This movement sequence recurs until the detector and the tube are 180^0 from the starting position. However, the main weakness of these scanners was the protracted scanning

time, which took up to five minutes and was mainly reserved for head scanning (Cunningham & Judy, 2014).

The introduction of the 2nd generation CT scanners, which had a small fan beam design, occurred in 1975. Such systems relied on several detectors and radiation beams (up to thirty detectors) and like scanners in the first generation scanners, they also relied on the translate-rotate movement. This CT scanner generation significantly reduced the scanning time by increasing the rotation level from one to thirty degrees (Cunningham & Judy, 2014). Nonetheless, the image's low quality was often associated with patient motion, which was triggered by the substantial amount of time needed to obtain the CT images (Goldman. 2007).

2.1.3 Third and fourth generation CT scanners

The introduction of the 3rd generation CT scans occurred in 1976. The systems of the 3rd generation scanners have rotating detector assemblies and x-ray tubes. The X-ray tube generates a wide fan beam while several detectors are fitted in a curvy array. Based on the detector's location in the array, they each measure the rays passing only at a given distance from the centre of rotation (Kalender, 2011). The broad fan beam is adequately broad to cover the entire patient in a single exposure. This reduces the scanning time to almost 1 second per image; without affecting the quality of the image for diagnosis (Mohan et al., 2011).

The main setback of the CT scanners in the 3rd generation is the existence of ring artefacts; these arise from detector calibration errors in relation to other detectors. The detector consistently contributes to a false reading at each angular position, thus developing circular artefacts (Nagarajappa, Dwivedi & Tiwari., 2015). These artefacts cannot be eliminated even when the calibration has minimal inaccuracies (up to

0.1%). Regardless, these artefacts can be reduced through daily calibrations, choosing the right view of the scan field and having a high-quality detector design (Kalender, 2011). Image processing algorithms can also remove circular artefacts from CT images (Goldman, 2007). The design of the CT scanner in the 3rd generation CT is extensively used in the contemporary world and is presently being used in Toshiba Aquillion scanner. CT scanners in the 3rd generation have a wide array of detectors (300-700 detectors) and normally sub-second tube rotation times which makes body scanning quick and easy for patients to tolerate. The reduction in scan time within the 3rd generation systems also led to reductions in the radiation dose for patients and enhancement in technology of acquiring data and detector which has simultaneously enhanced the quality of the image; the reconstruction of the image reconstruction is significantly faster than 1st or 2nd generation units (Nagarajappa, Dwivedi & Tiwari., 2015).

Like the 3rd generation CT scanners, the 4th generation ones were developed in 1976. The design of these scanners was made in such a way to integrate a large ring of detectors (360^o array), with only the x-ray tube rotating around the patient. This scanner design utilized around 2,000 detectors, which is relatively higher than the five-hundred detectors in the 3rd generation systems. In the CT scanners in the 4th generation, Images can be obtained within two to ten seconds (Cunningham & Judy, 2014). Unlike detectors in the 3rd generation, the detectors can be calibrated dynamically.

Consequently, ring artefacts are eliminated. Nonetheless, 4th generation scanners have a major issue regarding the presence of scatter. The scatter-absorbing septa utilized in 3rd scanners were not usable in 4th generation technology. Septa would preferentially transmit scatter rather than primary x-rays as the tube rotated inside the detector ring

(Goldman, 2007). Despite the technical advantages of the fourth-generation CT scanners, they are very expensive (limiting their clinical utility). Consequently, most of the commercially available CT scanners today are third generation.

2.1.4 Abdominal CT Scan Modality

An abdominal CT scan can detect signs of inflammation, infection, injury or disease of the liver, spleen, kidneys, bladder, stomach, intestines, pancreas, and adrenal glands. It is also used to look at blood vessels and lymph nodes in the abdomen. In staging and following progress of cancer Ct scan has frequently proven useful.

Routine abdominal CT scan is the second most frequently done CT modality in the imaging department going by the daily registers of these facilities under the study. This modality was suitable in providing data on adult abdominal CT research so as to provide a basis to standardize patient doses for adult abdominal scan to a safe level at the hospitals under the current survey. A similar study was done by Abba et al in Nigeria and focused on the abdominal modality as its area of research (Abba et al., 2018).

2.2 Diagnostic Reference Levels

A diagnostic reference level (DRL) is an indicative dose that is not expected to be exceeded under normal imaging conditions for a given diagnostic procedure(www.arpansa.gov.au, 12/03/2021). A DRL is not a regulatory limit, it is a benchmark that when exceeded triggers a review(Bush, Ct, Mcnitt-gray, Cody, & Zeman, 2011)(Kalpana et al.,2017). Performing a local dose audit and comparing the results to a DRL provides an imaging facility with a simple method of identifying situations where they are delivering an unusually high patient dose(Pyfferoen et al., 2017).

The Australian radiation protection and nuclear safety agency (ARPANSA 2019) have been able to come up with DRLs for various modalities with focus on the procedures with the highest dose burden on the Australian population (www.arpansa.gov.au, 12/03/2021). Hence, ARPANSA has published so far DRLs for multi-detector computed tomography for adult and pediatric patients, general nuclear medicine and PET for adult patients only and CT conducted as part of SPECT/CT and PET/CT procedures for adult patients only. Kenya is yet to have its national DRLs and thus rely on the International DRLs as a point of reference for its major hospitals (Nyabanda et al., 2022).

2.2.1 Significance of DRLs

The objective of a DRL is to help avoid excess radiation dose to patients for a specified imaging task.(Sutton et al., 2014)(kalpana et al.,2017). Thus a diagnostic reference level can be used as a tool to; promote an optimum range of doses for specified medical imaging protocols; provide a common dose metric for the comparison of doses between facilities, protocols and modalities; as a trigger to perform local dose audits(Pyfferoen et al., 2017). DRLs can only be effective if appropriate local review and action is undertaken when the doses observed are consistently outside the relevant diagnostic reference level.(Sutton et al., 2014). The American college of radiology ACR (2008), did a review on the CT reference levels and were changed to a CTDIvol of 75 mGy (adult head), 25 mGy (adult abdomen) and 20 mGy (pediatric abdomen) (Bush et al., 2011) and committed to reassess these values periodically(www.arpansa.gov.au, 12/03/2021). The research has provided a tool to enable evaluation of abdominal CT dose applications within MTRH, Eldoret Hospital, St. Luke’s Hospital and Mediheal Hospital.

2.2.2 Determining and Setting DRLs

The International Commission on Radiological Protection (ICRP) recommends that DRLs should reflect common practice within a given geographical region. This can be achieved by determining DRLs based on the results of wide-scale surveys of imaging facilities, within a given nationality region or locality. (www.arpansa.gov.au, 12/03/2021). In validating the patient dose CT levels for abdominal scans at MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital comparisons with the international DRLs was done.

Survey participants submitted their protocol, patient, and dose information via the relevant accreditation and regulatory radiation protection bodies for a variety of procedures. The information was then used to calculate the facility reference levels (FRLs) for those surveys. The DRLs were based on the 75th percentile (third quartile) of the resulting FRL distributions(Pyfferoen et al., 2017).

A facility reference level (FRL) indicates the typical patient dose and is the quantity you compare against the national or regional DRL(www.arpansa.gov.au, 12/03/2021). It is the median dose delivered to a sample of patients undergoing a particular routine diagnostic imaging protocol at a given facility. In cases where the dose is dependent on the equipment used to perform the imaging (for example CT), the FRL is also equipment specific (i.e., a facility may have more than one FRL for a single procedure (Pyfferoen et al., 2017)

FRLs can be used to monitor local facility doses for common procedures, compare doses between similar protocols, assess the dose impact of the introduction of new protocols, compare doses between facilities with regional or nationals DRLs as shown in table 2.1(www.arpansa.gov.au, 12/03/2021).

MTRH being a regional public facility and the second largest teaching and referral hospital in the country serving the north rift valley and western part of Kenya. North rift has a rapidly expanding medical eco-system made up of not only the public but largely private mainly St. Luke's, Eldoret and Mediheal hospitals and others not involved in the survey. Eldoret town is an emerging healthcare destination for the surrounding localities and regions especially in seeking tertiary care, diagnostics and imaging being one of the services. In carrying out this study in the radiology departments of MTRH, Eldoret hospital, St. Luke's and Mediheal hospital provided a better platform to achieve a facility survey that could be used as benchmark for the regional DRLs and even further in developing the national DRLs.

2.2.3 Factors Influencing Dose Radiation in CT scans

2.2.3.1 CT scanner design factors (equipment-related factors)

These factors include the design of the collimator, the tube filtration and beam shaping filters of the X-ray and the focus on the axis distance, which are described in detail in the literature section.

2.2.3.2 Beam Filtration

In traditional projection radiography, Beam filtration is a popular method for minimizing radiation spectrum portions with minimal or zero impact on image formation. Beam filtration was relatively large in the formative years of CT, thus compensating hardening of beam artifacts. Filters developed using 0.5 mm of copper

and with a filtering quality similar to around 18mm of aluminium were common then. The current generation's x-ray tube scanners usually rely on a beam filtration made of 1 to 3 mm of aluminum and an extra filtration (the flat filter) of 0.1 mm copper, providing an aggregate beam filtration ranging from 5 to 6 mm aluminium. Besides this, other types of scanners (old and new ones) rely on an extra filtration of around 0.2 mm copper, resulting in an aggregate filtration ranging from 8 and 9 mm aluminium and, at times, even more (around 12 mm aluminium filtration) also exist (Diop et al., 2022).

Scanners that rely on lesser filtration also exist. Resultantly, the scanners' normalized doze values show a significant variation. In most situations, the lower or higher values are mistaken to be the indicators of the efficiency of scanners. However, this is not always the case. Besides the doses, other studies have considered the impact on the image's quality emanating from the beam's hardening and its attenuating filtration qualities (Khalis & Karim, 2016; Nagel, 2008). Using extra filtration damages the primary contrast and upturns noise because the beam's intensity is reduced per mm based on the detectors. Failure to compensate for the negative impacts (for instance, by raising the present-time product), the ratio of contrast to the noise, which influences the detectability of low or small-contrast details, is minimized (Nowik et al., 2015).

2.2.3.3 Beam Shaper

Most scanners have a special device for filtering, known as the bow-tie filter or the beam shaper, that modifies the spatial dispersal of the emitted radiation in the fan beam. This type of filter seeks (which is thicker towards the outer boundaries) adjusts the intensity of the beam intensity and thus aligns it with the lessened attenuation of the objects located in the fan beam's outer section. Therefore, it is possible to reduce

the detector’s dynamic range requirements. Concurrently, the impact of beam hardening is equally less likely. To provide the reducing qualities nearly equivalent to the tissue, the shapers of the beam must be made using materials containing elements with a low atomic number (Diogo et al., 2017).

Nonetheless, in practice, this is not always followed. Preferentially, the dose in the external parts of an object is affected by beam shapers, thus lowering peripheral CTDIp values. However, with the dose at the centre being created by the radiations scattered from the object's periphery, the value of the central CTDIp is reduced to some extent. The ratio of the periphery to the central dose is thus decreased, making the dose distribution in an object more standardized, which in turn enhances the noise uniformity in the image (Goodarzi et al., 2022). The impact of a beam shaper on the properties of the scanner's dose is greater than that of a flat filter (Omar et al., 2019).

2.2.3.4 Beam Collimation

The beam collimation determines the sliced image's thickness and is initially made close to the X-ray source (primary collimation). The dose profile’s shape is determined by the collimator’s aperture, length from the central spot, and shape and size (that is, the intensity distribution). For scanners with multi-slice with at least two detector rows, it is necessary to widen the primary collimator N times more than the chosen collimator's slice to avoid (or minimize) the penumbral effects in the detector’s array of the outer parts. In both situations, the profile of the dose is much wider than the nominal beam or slice profile width. It thus increases the level of exposure of the patient, as becomes obvious from normalized values of CTDI that increase with reduced width of the beam (Ahmad & Ewaidat, 2013).

2.2.3.5 Detector Array

Multiple-slice scanners have more than a single-row detector array that distinguishes them from a single-slice scanner. Fourth-generation stationary or single gas detectors are no more compatible with the requirements of the multi-slice. Resultantly, only the arcs of the third-generation detectors are still in existence. Generally, detectors with a solid shape are more efficient in terms of dose than gas detectors; however, they require extra means to subdue scattered radiations, which in turn cause a particular primary radiation loss, as well. The single detectors placed in a multi-row, state detector with a solid array is divided by narrow strips (septa), which are insensitive to radiation and thus fail to contribute to the detector's signal. Because of the high quantity of extra strips, inactive zones result in major or minor losses based on the detector array's design (Dougeni et al., 2012).

2.3 CT helical protocol related factors (spiral interpolation)

Nagel (2008) states two main technological advances: helical scanning and changes in the patient's Z-axis detector array. The acquisition in helical/spiral scanning mode needs an extra interpolation step to get axial slices, referred to as "over-ranging". These additional rotations are required for helical interpolation; resultantly, an extra exposed tissue is separate from the chosen imaging volume. Helical scanning requires additional image data at each edge of the image plane to interpolate the axial images slices that are required. Helical scans also emit other additional radiations, which are called over-beaming. Over-beaming is the penumbra's radiation, which is not used to reconstruct the image data. The over-beaming radiation goes into the patient and contributes to the patient's dose, but not to the creation of images (Rajab, 2018).

2.3.1 Over ranging

Over-ranging refers to the increase in the length of the dose product because of the extra rotations at the start and the end of the helical/spiral scan needed for the interpolation for the reconstruction of the first and the last slice of the body region that is imaged, because the algorithm reconstruction needs extra raw data on the two sides of the planned scan. The over-ranging impacts can be articulated both in the context of the extra number of rotations and the upsurge in scan length (Schilham, van der Molen et al., 2010). The additional rotations result in an exposure of the tissue below and above the intended scan length. This increases the patient's radiation dose and is thus significant for accurate dose calculations.

Over-ranging is becoming a contentious issue because the present developers of the CT scanner seek to minimize scanning time by raising the length of the scan that each rotation covers, which in turn contributes the radiation dose that patient receives, even though the portion of the dose is not used for imaging (Schilham et al., 2010).

The over-ranging contribution to the total dose of the CT is, thus, significantly higher for examination of CTs that have shorter scan rangers, including the cardiac and pediatric scan. Coincidentally, Goo (2012) states that the development of the adaptive section collimation technology has already occurred to eradicate over-ranging during spiral CT scanning.

2.3.2 Over-beaming

Over-beaming refers to the extra dose beyond the periphery of the MSCT slice detector rows per rotation that leads to the penumbra of the focal spot located outside the active detector section. Its purpose is not for imaging purposes. The extent of over-beaming is indirectly proportional to the quantity of detector rows. Thus, it

unnecessarily exposes patients to radiation increasing radiation dose to patient (Goo, 2012; Sorantin & Sabine, 2013).

2.3.3 Pitch

For MSCT, pitch refers to the distance/table feed (mm/s) of the table of the CT per 360^{o} rotation of the X-ray tube, divided by the collimator of the X-ray beam. This parameter directly affects the ratio of dose that patients receive. The radiation dose is inversely related to pitch when all other aspects are held constant. This is because as increasing the pitch reduces the time that individuals spend at any given time on the X-ray beam (Midgley, 2014). As outlined by most manufacturers, the pitch value is based on the nominal thickness of the slice rather than the active length of the collimation in the z-axis. In CT protocols that are helical, the parameter of the pitch directly influences the radiation dose of the patient. Essentially, this occurs because an increase in pitch decreases the time that a patient spends at any given time in the X-ray beam. Choosing a higher pitch minimizes the patient's DLP rather than the CTDI and thus lowers the amount of rotations over an identical plane (Seeram, 2015). The table speed and the beam collimation are the pitch determinants, with the two parameters being intrinsically associated with the radiation dose and quality of the image (Valentin, 2007; Rehani, 2010; Paterson and Frush, 2007). A beam-pitch of 1.0 facilitates an acquisition with no overlap or gap, a beam pitch of less than 1.0 facilitates an overlapping acquisition, and a beam-pitch of greater than 1.0 facilitates an interspersed acquisition. Generally, the impact of a pitch is minor on the image quality when the MSCT scanners are used compared to its effect when the SSCT scanners are used (Flohr et al., 2005). The Toshiba Aquillion 16 CT scanner uses three types of pitch factor (HF) or helical pitch (HP), which include standard PF 0.938 (HP 15.0/) detail PF 0.688 (HP 11.0), and fast PF 1.438 (HP 23.0) (Toshiba Medical

Systems). In general, the radiation dose is indirectly proportionate to pitch when all other components are held constant. Consequently, the radiation dose can be consistently reduced by increasing the pitch. Michael, (2002) demonstrates that the $CTDI_{vol}$ (which is the only descriptor of the CTDI that considers the pitch), while the dose of radiation obtained in the head phantom, is doubled compared to the one acquired in the body phantom. The effect of the dose associated with the acquisition parameters of the CT (factors related to application) (Szczykutowicz et al., 2015; Raman et al., 2013 and AAPM Practice Guideline 1.a., 2015).

2.3.4 Application-related Factors

The effect of the dose associated with the acquisition parameters of the CT (factors related to application). This section articulates the main relevant parameters of the CT scan that directly affect the dose of radiation like the beam energy of the X-ray, (kilovolt peak), current of the tube current (in milliamperes), exposure or rotation time, techniques of reducing the dose like the tube current modulation or variation and CT gantry angulation. The dose of patients in the examination of the CT relies on the selection of radiographic parameters used to conduct the scanning (Szczykutowicz et al., 2015; Raman et al., 2013 and AAPM Practice Guideline 1 et al., 2015):

The CT scanners are the main contributors to the radiation department's radiation dose. Regulation authorities do not set CT protocols, though the local hospitals regard their guidance. According to Colagrande et al. (2014), the Dose Reference Level (DRL) is responsible for auditing the protocols. The parameters of acquiring the CT scan, like the time of tube rotation, tube current, the peak voltage of the tube and collimation, are primary contributors to the dose or radiation received in a CT assessment. Usually, if a single parameter is decreased, it is necessary to increase another one and thus ensure the radiation dose remains at the acceptable level and

simultaneously generates an image that has adequate diagnostic information. Most of the CT scanners available in most emerging economies are multislice CT (MSCT); consequently, this chapter will primarily focus on the parameters of acquisition and their impact on radiation dose in the context of MSCT only (Naif, 2016). In particular, the chapter focuses on several variables in each assessment procedure that determine the radiation dose.

2.3.4.1 Tube current (mA)

Tube Current (mA): mA is directly proportional to radiation dose. As tube current increases, more X-rays are incident onto the patient leading to higher patient dose.

Effective mAs: The mAs effectiveness considers the pitch. As pointed out, the doses for patients are directly related to mAs because the influence of the photon, as determined by the tube current–time product (milliampere-seconds), directly influences the dose of radiation that patients receive. Some CT scanners require users to enter a parameter labelled mAs. However, that parameter is the effective mAs, wherein 26 is milliamperage multiplied by time/pitch. For these scanners, the presence of varied pitch ensures that the mAs vary equivalently to ensure that the mAs constant remains constant (Sohrabi et al., 2018).

2.3.4.2 Slice Collimation (mm)

Slice collimation describes the wideness of the imaged slice. A collimator that is thicker has a greater mass that is being irradiated in comparison to a thinner one. Therefore, the radiation dose of thin and thick collimations is almost equal (the variance is accredited to the higher distribution anticipated in the thicker section.

Beam Collimation (MSCT only): This emanates from the sum of active channels of the detector being used and the thickness of the effective detector row. The quantity

of detectors determines the thickness of the MSCT slice. In a solo slice CT (SSCT), the slice's thickness is determined by the width of the collimation. Initial reports of the MSCT versions showed the vital reliance on X-ray beam collimation. These impacts emerge from variations of X-ray beam collimation, even when the exact reconstructed portion thickness is used.

Feed: This refers to the table movement (travel) per rotation. Increasing the movement of the table can, in turn reduce the dose of the radiation that the patient receives when all other factors are held constant.

2.3.4.3 X-Ray Tube Potential (kVp)

The voltage of the X-ray tube refers to the electrical potential applied across the tube of the X-ray to fast-track electrons toward the material that is being targeted. The radiation dose increases almost proportionately to the tube's voltage percentage change. The tube voltage for routine brain scans through the CT for adult patients is usually between 110 kVp and 140 kVp (Szczykutowicz et al., 2015; Raman et al., 2013)

The potential of the tube determines the incident X-ray beam's energy. In the past, this factor had not been adjusted consistently for body CT scans, particularly in children and infants, with most of them being conventionally conducted at 120-140 kVp (Paterson & Frush, 2007). Increasing the potential of the tube enhances both the beam's penetrating ability and the output of the tube while decreasing the image contrast. Higher voltages in the tube have been associated with better image quality and tube loading because the beam's penetrating capability and output are being enhanced. In contrast, the contrast of the image is negatively affected. Unlike the mAs

case, the impact of the kV variations cannot be easily evaluated (Galanski et al., 2007).

Galanski et al. (2007) point out that the association between tube potential and radiation dose is non-linear. Studies have demonstrated the existence of an exponential association that varies based on the specific situation, like factors linked to the CT machine's design and the patient's size. The radiation dose can substantially drop once the peak kilovoltage is reduced; however, the saving of the dose is partly linked to the individual CT machine's design; hence, different manufacturers have different geometries. The extra CT acquisition parameters are highlighted by Tack and Gevenois, (2004) and include the physical distance from the patient to the X-ray tube and intrinsic tube filtration.

Increasing the filtration of the tube hardens the beam further, which in turn reduces the energy photons being released, and thus a larger percentage of kVp values are emitted. The intensity of the X-ray beam is lowered as filtration increases. Huda et al. (2002) developed a report that shows that the radiation dose reduces four-fold once the kilovoltage of the tube is reduced from 140 kVp to 80 kVp for both head and body CT protocols. The patient's photon penetration in diagnostic imaging is increased through higher kV photons. This increases the images' high contrast resolution (Matsumoto et al., 2011). While conducting brain imaging through CT, a high kV (probably 120 kV) is required because it generates less noise in the image and less noise is necessary to maximize the brain image resolution. It has been established that increasing the tube's potential decreases the image noise but increases the patient dose (Duzenli et al., 2005).

2.3.4.4 Tube Current Time Product

During the image acquisition, the time (s) and the tube current (mA) control the photon flux. Here, the current time of the tube (mAs) can be adjusted by the operator of the CT and thus reduce the dose (that is, lower the amount of incident photons) or lessen the noise (that is, raise the amount of incident photons). The number of photons that the X-ray filament produces increases linearly with the rising mAs, and the tube load also increases. Equally, increasing the photons count per object enables more photons to penetrate the image detector (supposing that the beam has sufficient penetrating power by selecting the appropriate kVp). Noise reduction is after statistical photon counting and is roughly $1/\sqrt{N}$, where N represents the incident photons number (Seeram, 2015). The radiation dose and current tube exhibit a linear association (Paterson & Frush, 2007). The typical values of the mAs for a typical CT scan of the brain for adult patients, as highlighted by Tsapaki et al. (2006), Smith et al. (2007) and Livingstone et al. (2006) are 100, 200 – 350 and 250 – 270, respectively. While the value of mAs for typical CT scans of pediatrics brain range from 180 – 230 and 90 – 320, as pointed out by Mazonakis et al., (2007) and Huda et al., (2007) respectively.

Huda et al., (2004; 2007) states that for CT scans of the head, the mAs can be substantially lowered when assessing infants and that the patient doses can be reduced by lowering the X-ray tube voltage. To manage the dose in a reasonable way in paediatric application, it is necessary to scan smaller volumes and reduce the parameters of the tube load. Reduced mAs can be consistently applied and it is appropriate to lower the value of the mAs of the CT head scan for newborns by a factor of around 2 to 2.5. Adjusting the tube current manually based on the patient's

dimensions or weight can help create a proper balance between radiation exposure and image noise.

2.3.4.5 Automatic Tube Current Modulation (ATCM)

This is an automated method used in CT to adjust tube current of the X-ray in real-time in response to variations in the X-ray intensity received at the detector array caused by different body densities/thicknesses. Galanski et al. (2007) state that the mA modulation is used for the head as well as body CT examinations. Rather than remain fixed, the tube's current is modulated to meet a particular image noise/quality level along the full scan length. Large variations in attenuation are likely to occur both with the projection angle and along the anatomical volume (z-axis). Resultantly, a strong rationale for shifting away from a fixed tube current (FTC). mA modulation can be attained in near real-time by incorporating pre-programming or a feedback mechanism and a feedback loop. It can also occur angularly about the patient or along the patient's long axis (z) (Spampinato et al., 2018). This basic notion is based on the need for modulating the tube current modulation and thus adapting the current to the body region’s attenuation by increasing the tube current for more attenuating areas and decreasing it for less attenuating areas. Exceptionally large variations in radiation absorption by patients occur with variations in the anatomic region and projection angle. Since the projection with the highest noise level is the main determinant of quantity of noise on the final image, the radiation dose for the projection can be reduced without increasing the noise on the final image (Papadakis & Damilakis, 2019). Scanning protocols that are currently in use, which require optimizing the tube current for the radiation dose and the image's quality, should be modified (Tian et al., 2015; Strauss et al., 2010). Extant literature demonstrates that the tube current can be modulated through three methods.

The first method involves the Angular (x, y) mA modulation where the tube's current varies as the X-ray tube rotates around the patient (for instance, in the lateral direction vs the AP). The operator ought to choose the initial value of the mA and then modulates downward or upward from the initial value within a period of one gantry rotation. The mA can be varied as the tube of the X-ray tube between the lateral and AP positions according to the attenuation information determined from the CT scout image or in near real-time according to the measured attenuation from the 180^{o} previous projection (Graser et al., 2006; Kalra et al., 2004 & 2005; Marco, 2013; McCollough et al., 2009; Raman et al., 2013).

2.3.4.6 Longitudinal (z) mA modulation

The longitudinal (z-axis) mA modulation involves the variation of the radiation dose along the anatomical regions according to its attenuation by varying the tube current along the z-axis of the patient (e.g, shoulders versus abdomen). This differs from angular tube modulation, in which the tube current is varied cyclically concerning the starting tube current value. The main function of the z-axis modulation is to produce uniform noise levels across the various regions of the anatomy. To achieve this, the operator must select the desired level of image quality by using scanner presets which are relatively manufacturer-specific (the reference noise index, reference image acquisition, reference tube current–time product value, or reference standard deviation or image quality level as recommended (Graser et al., 2006; Kalra et al., 2004 & 2005; Marco, 2013; McCollough et al., 2006 & 2009).

2.3.4.7 Angular and longitudinal (x, y, z) modulation

This modulation technique combines the two methods mentioned above to vary the mA both during gantry rotation and along the z-axis of the patient (i.e from the anteroposterior direction to the lateral direction and from shoulder to abdomen. The

desired level of image quality must be selected by the operator using one of the following methods: the reference noise index (GE Healthcare Technologies, Waukesha, Wis), reference image acquisition (Philips Medical Systems, Best, the Netherlands), reference tube current–time product value (Siemens Medical Solutions, Forchheim, Germany), or reference standard deviation or image quality level (Toshiba Medical Systems, Tokyo, Japan) (Kalra et al., 2005; Marco, 2013; McCollough et al., 2009; Raman et al., 2013). The Toshiba CT machine uses this type of mA modulation.

Contemporary CT systems have ATCM systems that regulate the tube's current from three perspectives. Besides operating differently, the specifications of each of these systems are different. Nonetheless, the key principle is managing the radiation dose and the required quality of the image in a reproducible way by ensuring that the tube current is aligned with the patient's shape, size and attenuation. To avoid producing inferior images, radiographers usually choose safer scan parameters and thus increase the exposure as they seek to attain the necessary quality of the diagnostic image. ATCM systems have several benefits: better control of the dose of the radiation that patients absorb, enhanced consistency of the image quality among patients, reduced X-ray tube load and reduction of some image artefacts, thus prolonging its lifetime (Keat, 2005). Based on these benefits, users must determine how the systems can be used and applied appropriately. Radiographers depend on ATCM systems to lower the amount of dose that patients receive. The AEC depends on continuous noise levels (Paolicchi et al., 2019).

Consequently, users must be acquainted with the characteristics of their systems and the impacts of changing the reconstruction and scanning systems on radiation dose and image quality. However, in the usage of ATCM systems, it is essential to choose the proper standard deviation, noise index, reference image or reference

milliamperage. This process is not forthright. Nonetheless, as Lee et al. (2008) point out, the proper value of ATCM system usage can be determined in two different ways. The European Guidelines on Quality Criteria for CT are a good standard for optimizing scanning protocol with reasonable radiation dose. The values of these guidelines are offered in relation to the method for a standard-sized patient for each type of CT examination considered. The protocol can also be optimized through simulation software before scanning, although most CT practitioners do not have this technique. This software can simulate the effect of increasing image noise, and the resultant simulated data can be reconstructed. After that, users can evaluate image quality with radiation dose modulation (Lee et al., (2008). In general, the introduction of ATCM techniques in modern CT scanners represents an important step toward standardizing tube current protocols and eliminating arbitrary selection by radiologists and radiographers. McCollough et al. (2009) reported that using ATCM greatly enhances and simplifies efforts to decrease the patient dose. It has demonstrated reductions in the dose of about 20–40% when image quality is appropriately specified.

2.3.4.8 Rotation Time

The rotation time of the tube is the main determinant of the rotation speed of the tube around the patient. Together with the speed of the table, it describes the length at which the table moves in each X-ray tube rotation. The X-ray tube in CT exposes only a slender part of the body when it makes a complete rotation around the patient and several times around the patient. Overall, the number of times a tube rotates is supposed to remain as low as possible to minimize the movement artefacts, reduce the scan time (and thus lessen the breath-hold), and the scanning opportunity for a range that is as huge as possible (Honda et al., 2018). Rotation times that are relatively

longer may be necessary in case the required exposure is to be attained within the shortest scan time. In principle, the dose of the radiation is related to the time of the rotation when all other parameters of the CT scan are held constant. The clinical protocols of the standard paediatric CT head are typically attained with rotation times of 0.5 or 0.75second and with this time of tube rotation being increased with 1 second for adults.(Honda et al., 2018)

Nonetheless, for some clinical indications where exact details are required and where reducing the artefacts' motion like the corona radiate, centrum semi-ovale and skull base/middle cranial fossa, among others is necessary, it is important to reduce the rotation time, which in turn raises the quantity of radiation dose that is absorbed. The rotation times of the MSCT machines of currently available machines is in the sub-second gantry category. Since a linear relationship exists between the radiation dose and the current of the tube (mAs), when the rotation time is reduced from 1 to 0.5 seconds, the radiation dose will be reduced by 50% (Wang & Pelc, 2022). Both the current of the tube and rotation time are significant in CT. Lessening the examination time has been a significant factor in minimizing the general anesthesia or sedation for children subjected to this imaging type. Likewise, faster imaging times imply that images are less to display motion artefact, which previously required an assessment to be repeated, with an observable increase in the dose of radiation to the patient. Reducing the tube's current raises image noise, and it is necessary to consider this when choosing these parameters (Wang & Pelc, 2022).

2.4 Contrast and Non-Contrast Media

The majority of CT imaging applications use contrast medium administration to achieve better image quality. In CT imaging, the administration of iodine-based contrast media (CM) is essential for soft tissue differentiation. They are designed to

increase the absorption of x-ray photons and enhance image contrast of blood vessels and well perfused tissues. Although these contrast media are frequently used in medical practice, there is an ongoing discussion about their side effects and the dose dependent incidence of contrast-induced nephropathy. In addition, there is an ongoing debate on the impact of these iodinated CM on radiation-induced DNA damage with contradictory results (Buls et al., 2015).

Recent studies have noted the impact of iodinated contrast materials on DNA damage, particularly an x-ray–induced double strand break (DSB) effect, during CT examinations. A study applied a previously validated contrast medium perfusion human model in a population of virtual patients to estimate organ doses (radiation dose to tissue plus the dose to iodine molecules) in contrast-enhanced CT examinations. The results indicate a marked increase in the total radiation dose due to the presence of iodine (Eakins & Pearce, 2017).

The increase in radiation dose has been reported by scholars to be most likely caused by the photoelectric absorption and, particularly, the generation of secondary electrons when x-rays are absorbed by the contrast material (Taghavi et al., 2020). However, other studies have shown that radiation dose delivered to the tissue cannot be precisely known except through a complete biologic model, which was not the scope of most studies, even with the current study.

In a systematic review study, it was reported that for a contrast-enhanced abdominal CT examination, organ dose (dose to the organ plus the dose to iodinated contrast material) normalized by $CTDI_{vol}$ remarkably increased. The simulation results indicated up to a total 53%, 30%, 35%, 54%, 27%, 18%, 17%, and 24% dose increase in the iodinated contrast material enhanced heart, spleen, liver, kidneys, stomach,

colon, small intestine, and pancreas, respectively, with respect to the radiation dose in the absence of contrast material or at time of 0. The kidneys and heart showed the highest average dose increments (45%). High marked difference for the kidneys and heart is mostly attributed to the high renal enhancement resulting from their high vascularization and higher iodine concentration observed in the right side of the heart (Sahbaee et al., 2017).

A comparative study of phantom and patient confirmed that the presence of contrast administered increases the organ radiation dose in CT (Mazloumi et al., 2021). In the phantom study, a linear relation between the $CTDI_{vol}$ normalized radiation dose and clinical range of contrast administered concentrations was observed. In the patient study, data demonstrate that lower CA administrations result in lower doses. The maximum and minimum increase in the dose was observed in the kidneys and liver parenchyma respectively (Mazloumi et al., 2021).

2.5 CT Usage and Radiation Exposure

The healthcare outcomes have been enhanced through the introduction of CT into routine care. Nonetheless, the radiation dose emitted by the CT is relatively higher than traditional diagnostic X-ray examinations. De González et al. (2009) state that the radiation that reaches a patient through the CT, in some situations, can be almost 100 times higher than the ones received through routine radiographic examinations. In the past ten years, several studies have examined the risk of cancer linked with radiation exposure because of medical diagnostic imaging modalities. The focus of these studies is mainly on the CT being a relatively high dose modality, which is hypothetically over-utilized because of a lack of understanding of the risk linked with certain acquisition parameters (Brenner, 2002; Brenner et al., 2001a; Brenner & Hall, 2007; de González et al., 2009; Einstein, Henzlova, & Rajagopalan, 2007; Fazel et al.,

2009; Hall & Brenner, 2008; Hammer et al., 2011; Smith-Bindman, 2010; SmithBindman et al., 2009; Brenner, 2010). Even deterministic effects, as reported by the US Food and Drug Administration (FDA), such as hair loss, have been reported in incidents in the US from apparent erroneous overdoses due to CT brain perfusion scans (FDA, 2009, 2010).

CT imaging delivers approximately 70% of the overall radiation dose to the adult population. Crude estimations showed that the ED ranges between 6 and 100 mSv for pediatric patients. CT is a major source of medical radiation, and its availability and frequency of scanning are responsible for increasing the population dose. Due to the high ED of CT, an effort to minimize it is critically important. This is particularly significant in adult although the older the patient is at the time of exposure to radiation, the lower the risk. Because the cells of the adults are lowly radiosensitive, the lifetime risk of cancer linked to an individual CT examination is lower in adults than in children (ICRP, 2007). Moreover, because adult have a shorter lifetime to manifest cancer emanating from radiation, and the fact that the risk of cancer is cumulative over a lifetime, the risk of radiation from CT in adults is still one of the main present concerns in CT dosimetry (Akhlaghi, Hakimabad, & Motavalli, 2014).

CT technology has evolved over the years, with different impacts on the dose of radiation. After the traditional CT was introduced, helical CT became commercially available in 1991. Because of its emerging benefits, CT imaging usage increased in the pediatric population. Though helical technology offers extra prospects for CT in children, the dose of the radiation linked with helical CT is relatively higher than the dose of the radiation linked with sequential CT. Since its inception in the 1970s, the use of the CT scan has risen rapidly in all developed nations though the proportion of usage differs from nation to nation.

Miglioretti et al. (2013) conducted retrospective research on CT usage for adult up to 60 years old from 1996 to 2010, including 4,857,736 adult-years of observation. Radiation doses were calculated for 744 CT scans performed between 2001 and 2011. As stated in the study, the results showed that the use of CT increased between 1996 and 2005, remained stable between 2005 and 2007, and then began to decline. The solid lines show rates for adult younger than 50 years of age.

De Gonzalez et al., (2009) pointed out that the total number of CT scan examinations performed annually in the US has increased approximately sevenfold between 1981 to 1995 (from 2.8 million to 20 million). CT scan usage reported a massive increase as of 2007 where it had increased by around 70 million scans per year, including at least 1 million for adult. In the UK, almost 11% of diagnostic radiology procedures are CT examinations, nonetheless, their contribution to the collective dose was about 70% (Brenner & Hall, 2007; de González et al., 2009; Elliott, 2009; Dougeni et al, 2012). There is a considerable variation in the dose of radiation for similar CT examinations between sites, this information was recognized through several surveys and studies and potentially implies that using the average radiation dose as an indicator of CT dose levels may be misleading. Their results show a large variability in scanning technique and a resultant large range of ED obtained, reflecting the increasing complexity of CT scanning.

High radiation doses were observed in some centres that carry out limited pediatric studies (Moss and McLean, 2006). Effective dose was closely associated with mAs, with most centres using lower mAs for younger patients, but few centres reducing the kVp for pediatric patients. It is often difficult to achieve a balance between radiation dose and the attainment of diagnostic. The CT's indication often influences the chosen scanning and protocol parameters. The education and feedback for these

centres is required to avoid inappropriate doses of radiation in the hypothetically susceptible adult patient population. It is significant to ensure that the CT technique is designed for adult and that CT is specifically used in the presence of appropriate clinical indications. Based on surveys focusing on practice in the UK, a forty-fold variation of ED exists for a given evaluation between departments.

In contrast, a survey conducted in Australia shows a 36-fold variation in ED for comparable research between centres (Moss and McLean, 2006). The research was done to examine the frequency of CT assessments for adult patients above 40 years of age in 128 CT facilities in twenty-eight developing nations across eastern Europe, Africa and Asia and to examine the extent of CT doses (Muhogora et al., 2010). In the 11 CT facilities examined in six countries, adult CT exposure factors were found to be in use for the patients, demonstrating a lack of awareness and the necessity for optimization. The study's outcome indicates that it is necessary to have an ongoing protocol and education review, especially CT examinations for pediatrics, in a rapidly evolving and complex environment (Moss & McLean, 2006; Muhogora et al., 2010; Shrimpton et al., 2006; Smith-Bindman et al., 2009; Wallace et al., 2010). According to Brenner (2002), it is necessary to intensify the attention given to the radiation dose from multiple CT examinations.

Increasing attention is basically because of the rise in the speed of acquiring images that facilitates multiphase examinations, all linked with higher doses (Smith-Bindman et al., 2009). Evidence shows the association between exposure to low ionizing radiation levels at medical imaging doses and cancer development (Smith-Bindman et al., 2009). Individual risks are likely to be minimal; however, because of the high number of individuals exposed each year, even such minimal risks will become a significant number of cancer cases in the future. A comprehensive review by the

National Academy of Sciences' National Research Council has conducted a comprehensive review of the epidemiological and biological data associated with health risks emanating from exposure to the ionization of radiation. The review was published as the Biological Effects of Ionizing Radiation (BEIR) VII Phase 2 report (Smith-Bindman et al., 2009). The doses of radiation linked with a specific CT scan can vary significantly between different institutions and machines, as the US Food and Drug Administration (FDA) pointed out in their 2000-2001 survey. These included data on CT head scans from 203 facilities and found that the institution-to-institution multiple-scan average dose varied by as much as 10 (Hall & Brenner, 2008).

Table 2.1: Relative radiation level designations along with common example

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range	Example Examinations
O	0 mSv	0 mSv	Ultrasound; MRI
☢	<0.3mSv	<0.03 mSv	Chest radiographs; Hand radiographs
☢☢	0.1-1 mSv	0.03-0.3 mSv	Pelvis radiographs; Mammography
☢☢☢	1-10 mSv	0.3-3 mSv	Abdomen CT with IV contrast, Nuclear medicine bone scan
☢☢☢☢	10-30 mSv	3-10 mSv	Abdomen CT without and with contrast; Whole body PET/CT
☢☢☢☢☢	30-100 mSv	10-30 mSv	CTA chest abdomen and pelvis with contrast; Transjugular intrahepatic portosystemic shunt placement

***The RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, the region of the body exposed to ionizing radiation, the imaging guidance that is used, etc.). The RRLs for these examinations are designated as "Varies."**

Source (ACR Appropriateness Criteria, 2020)

2.6 Radiation protection

In the past years most radiologists were not keen on radiation protection measures however over the recent years we have seen organizations and regions agitate on radiation protection issues and seen tremendous activity towards ensuring radiology workers are provided with the requisite tools. The International Atomic Energy Agency (IAEA) and the European Society of Radiology have played a leading role towards ensuring that Africa and Europe are building and strengthening their capacities, quality and safety awareness. This has seen the formation of AFROSAFE and EUROSAFE which are radiology bodies championing radiation protection in Africa and Europe respectively(G N M et al., 2016).

2.7 Global Literature on DRLs of CT scans

A study done in Canada demonstrated dose indicators such as the computed tomography dose index (CTDI) and dose-length product (DLP) were gathered for all routine abdomen-pelvis, chest and head examinations performed on all computed tomography (CT) scanners at a University Health Center (UHC) in Canada (Héliou, Normandeau, & Beaudoin, 2012). Analysis and comparison of the indicators with the range of diagnostic reference levels(DRLs) suggested by Health Canada and with DRLs in other countries was done. The results, however, showed some scanners exhibited mean DLP values below or above the upper limit of the range of DRLs suggested by health Canada(Héliou et al., 2012). This survey was a facility based and the international DRL was used as a point of reference since it is what is used nationally.

A review by the European commission (EC) was done of patient dose for the most common types of CT examinations reported during the past 19 years. Reported dosimetry quantities were compared with the European diagnostic reference levels (DRLs) (Pantos et al., 2011).

Effective doses were assessed with respect to the publication year and scanner technology (i.e., single-slice vs multislice). Considerable variation of reported values among studies was attributed to variations in both examination protocol and scanner design. Median weighted CT dose index (CTDI(w)) and dose length product (DLP) were found to be below the proposed DRLs; however, for individual studies the DRLs are exceeded(Pantos et al., 2011).

Median reported effective doses for the most frequent CT examinations were: head, 1.9 mSv (0.3-8.2 mSv); chest, 7.5 mSv (0.3-26.0 mSv); abdomen, 7.9 mSv (1.4-31.2 mSv); and pelvis, 7.6 mSv (2.5-36.5 mSv) (Pantos et al., 2011). Due to the limited number of studies reporting patient doses for multislice CT examinations the statistical power to detect differences with single-slice scanners is not yet adequate (Pantos et al., 2011).

According to a study done in Greece with the aim of applying European commission reference dose levels (EC RDLs) to routine CT examinations, the dosimetric quantities proposed in the European Guidelines (EG) for CT were weighted computed tomography dose index (CTDI(w) for a single slice and dose-length product (DLP) for a complete examination. Patient-related data as well as technical parameters for brain, chest, abdomen and pelvis examinations were collected for four CT scanners in the Euromedica Medical Center. Computed tomography dose index (CTDI) measurements were performed on each scanner and $CTDI_{vol}$, DLP and effective dose E were estimated for each type of examination for a random sample of 10 typical

patients. Mean values of $CTDI_{vol}$ had a range of 27.0-52.0 mGy for brain and 13.9-26.9 mGy for chest, abdomen and pelvis examinations.(Tsapaki, Kottou, & Papadimitriou, 2001). Mean values of DLP had a range of 430-758 mGy.cm for brain, 348-807 mGy.cm for chest, 278-582 mGy.cm for abdomen and 306-592 mGy.cm for pelvis examinations. Mean values of E were 1.4 mSv for brain, 10.9 mSv for chest, 7.1 mSv for abdomen and 9.3 mSv for pelvis examinations. Results confirm that the Euromedica Medical Center meets EC RDLs for brain, abdomen and pelvis examinations, in terms of radiation dose and examination technique(Tsapaki et al., 2001). The aim of this study was to focus on establishing the mean values of CTDI(w), DLP and estimated the effective dose of the adult abdominal CT examination.

Towards establishment of the national reference dose levels from computed tomography examination a study done in Tanzania assessed the radiation dose levels from CT examinations according to reference dose quantities proposed by the European Commission (EC) guidelines. The dosimetric quantities proposed in the EC for CT are weighted CT dose index (CTDI(w)) for a single slice and dose-length product (DLP) for a complete examination(Ngaile, Msaki, & Kazema, 2006).The RDLs from five common CT examinations were obtained from eight hospitals. The RDLs in terms of CTDI(w) and DLP were estimated from measurements of CTDI in standard phantoms using typical exposure parameters(Ngaile et al., 2006). Mean values of $CTDI_{vol}$, abdomen a range of about 11-25 mGy. Mean values of DLP for abdomen had a range of 717-1428 mGy cm. Wide variations of mean CTDI(w) and DLP values among hospitals observed for similar CT examinations were mainly attributed to the variations of CT scanning protocols and scanner types(Ngaile et al., 2006). The mean $CTDI_{vol}$ values per examination for almost all hospitals were below

proposed RDLs, while the mean DLP values per examination were almost all above the proposed RDLs for all except one hospital. These were mainly influenced by the large scan length used in Tanzanian hospitals. In order to achieve the required level of dose for establishment of the national RDLs, it was concluded that further investigation of optimization of scanning protocols is needed (Ngaile et al., 2006). Summarily the international DRL for adult abdominal scans as per European commission, Ireland, Japan, Nepal, India, shows the CTDIvol(mGy), and DLP (mGy.m) values at (35, 780), (13,1120), (15,1800) (30.8, 1180.5), (13.71,2336.4) respectively. In recent regional and local studies in Africa, Egypt, Nigeria, Cameroun, South Africa, Tanzania and Kenya estimated the adult abdominal DRLs (CTDIvol(mGy) & DLP (mGy.m)) to be (11.9–22.7,341-1314), (31,1325) (12, 2225.5), (15. 716) (22.7,704) (15, 737) respectively. The study sought to form a basis for the institutional DRL and hence provides a basis for further development of national DRL in the future.

2.7.1 Table on summary of knowledge gap

Find table 2.2, showing the summaries of studies on CT abdominal DRLs and the respective research gaps.

Table 2.2: summary of knowledge gap

Authors		Aim	Findings	Gaps
1.	(Héliou et al., 2012)	Comparison of the routine test dose indicators with the range of diagnostic reference levels (DRLs) suggested by Health Canada and with DRLs in other countries was done.	The results, however, showed some scanners exhibited mean DLP values below or above the upper limit of the range of DRLs suggested by health Canada.	Comparison on the facility DRLS with the regional/national DRLs
2.	(Pantos et al., 2011)	Dosimetric comparison of the most common CT examination	Median weighted CT dose index (CTDI(w)) and dose length product (DLP) were below the proposed DRLs; however, for individual studies the DRLs are exceeded.	Limited studies for multislice CT examinations
3.	(Tsapaki et al., 2001)	To apply European Commission reference dose levels (EC RDLs) to routine CT examinations for a single slice.	EC RDLs for brain, abdomen and pelvis examinations, in terms of radiation dose and examination technique meets the standards. The DLP for the chest examination is consistently exceeded for the proposed values, probably due to the large irradiation volume length L.	Studies for a multislice CT Multisysytem/multiple modalities
4.	(Ngaile et al., 2006)	Establishment of the national reference dose levels from computed tomography examination in Tanzania	Noted wide variations of mean CTDI(w) and DLP values among hospitals observed for similar CT examinations. The CTDI(w) being lower than proposed values and DLPs being exceeded than the proposed DRLs in all but one hospital.	Look into optimization of scanning protocols. Longer scan lengths-

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Design

The study involved a retrospective review of CT scans from adult patients who underwent abdominal scans, over a 6 months' period from 1st April 2021 to September 30th 2021. Retrospective analysis was utilized due to that this being a multi-facility study it was advantageous in mitigating time and resource constraints.

3.2 Study Area

Moi Teaching and Referral Hospital is the second largest National Teaching and Referral Hospital (level 6 Public Hospital) in the country. It is located in Eldoret town, Uasin Gishu County. It serves residents of Western Kenya Region, parts of Eastern Uganda and Southern Sudan.(http://www.mtrh.go.ke,24/02/2020). It has an imaging and radiology department equipped with 3 functional CT scanners. It performs an average of 40 general CT scan examinations per day.

Eldoret hospital is one the oldest private healthcare provider in Kenya since its inception in 1975 as a nursing home to a fully-fledged hospital with multi-disciplinary specialties' that include imaging department with a CT scan. It does around 8 CT scans a day. It is situated in Eldoret town Uasin Gishu county. Mediheal is a private hospital also located in Eldoret town, it has a modern imaging department with a functional CT scan. It carries out 10 CT scans in a day. St. Luke's as well is a private hospital with a fully-fledged imaging department with an operating CT scan doing averagely 12 CT scans per day. It is also serving the population of Eldoret and Western Kenya Region.

3.2 Study Population

The study population involved adult patients' radiation dose data that were 18 years and above and referred for abdominal CT-scan during the period of study.

3.3 Eligibility Criteria

3.3.1 Inclusion Criteria

The study included adult patients who have undergone standard abdominal CT examinations. Both contrast-enhanced and non-contrast-enhanced scans are eligible for inclusion. The criterion mandates that the CT scans must be complete in terms of dosimetry data, as this is essential for the comparative analysis of Volume Computed Tomography Dose Index (CTDIvol) and Dose-Length Product (DLP) values.

3.3.2 Exclusion Criteria

Patients were excluded from the study if their standard abdominal CT scans have incomplete dosimetry data. Incomplete dosimetry data could compromise the integrity of the comparative analysis of CTDIvol and DLP values across healthcare institutions.

3.4 Sampling Frame

The principal researcher obtained data from the registry at the CT department of the various facilities included in the survey entailing abdominal CT scans dosimetry for the adult population. In the year 2020, 2100 abdominal CT scans for the adults were done at MTRH. For the three private hospitals combined, 369 adult abdominal CT scans in the year 2020 were performed. Hence a total of 2469 CT scans for the 4 hospitals were done in the year 2020, with an average of 7 abdominal CT scans performed per day as basis of selection to the study. However, the number abdominal CT scans for the adults done at MTRH for the last 6 months were 1000 while for the three private hospitals combined, 150 adult abdominal CT scans were performed in

the year 2020. This 6 months' calculation was used as the basis for calculating sample size in table 3.1.

3.5 Sample Size

The study sample size was calculated based on the standard formula for estimating mean.

Formula:

$n = z^2 \sigma^2 / d^2$ where n is the sample size and σ^2 is the variance for the population.

Workings:

$1.96^2 * 74^2/5^2 = 842$, n=842

Based on the formula, the sample size of the study was 842 adult patients who underwent abdominal CT scans from the respective hospitals. And the distribution is as shown in table 3.1 below.

Table 3.1: Showing sampling frame of patient CT scans

Facility	**population**	**sample size**
MTRH (public)	1000	692
Private hospitals	150	150
Total	**1150**	**842**

3.6 Sampling Technique

Systematic and Consecutive sampling technique was used to obtain data in the various respective CT scans dose tracking software's from the hospitals. Consecutive sampling was applied to the 3 private facilities. While systematic sampling using the interval K was used in MTRH.

Workings:

K=1000/692~ 2 where K= interval, k ~2

The starting point for the sampling was determined by selecting a random point from the available list of adult patients who had undergone standard abdominal CT examinations and met the inclusion criteria. From this starting point, every 2nd patient dosimetry was then selected until the list was exhausted.

3.7 Equipment, protocols and Procedure

The CT equipment's available and functional in the respective hospitals under study are as shown in table 3.1

Table 3.2: Showing the various CT available in the Hospitals under Research

Facility	Brand	Model name	Slices
MTRH	Neusoft	Neusoft	128
	Siemens	Siemens Somatom. P	32
	Philips	Philips Ingenuity	64
Eldoret Hospital	Siemens	Siemens somatom .E	16
Mediheal	Siemens	Siemens Go-up	64
St. Luke's Hospital	Philips	Philips, MX	16

Table 3.3: Siemens scanner and Protocols

SIEMENS	**Emotion 16**	**Perspective 32**	**go-up 64**
Scan type	Spiral	Spiral	Spiral
Detector configuration	16 x 1.2 mm	32 x 1.2 mm 64 x 0.6 mm	64 × 0.6 mm (32 x 0.6 mm = 19.2 mm
Rotation Time (s)	0.5	0.5	0.5
Pitch	1.5	1.4	1.4
Tube voltage(Kv)	120	120	120
Quality ref. mAsCD	200	200	200
CARE kV	-	-	-
CARE Dose4D	ON	ON	ON
RECON 1			
Slice (mm)	5	5.0	5.0
Slice increment (mm)	5	5.0	5.0
RECON 2			
Slice (mm)	1.0	1.0	1.0
Slice increment (mm)	0.7	0.7	0.7

Table 3.4: Philips scanner and Protocols

PHILIPS	**MX 16**	**Ingenuity CT 64**
Scan type	Helical	Helical
Rotation Time (s)	0.75	0.75
Collimation	16 × 1.5 mm	64 × 0.625 mm
Tube voltage(Kv)	120	120
mAs (mAs/slice) @ water equivalent diameter	DoseRight (200 mAs @ 33 cm Reference), ZDOM	DoseRight (200 mAs @ 33 cm Reference), ZDOM
DoseRight ACS	ON	ON
Pitch	1	1
FOV (mm)	350-500	350-500
SP Filter	Yes	Yes
Adaptive Filter	Yes	Yes
Resolution Setting	Standard	Standard
RECON 1		
Type	Axial	Axial
Slice thickness (mm)	5	5
Slice increment (mm)	5	5
RECON 2		
Type	Axial	Axial
Slice thickness(mm)	2	0.9
Slice increment (mm)	1	0.45
RECON 3		
Type	Coronal	coronal
Slice thickness(mm)	3	3
Slice increment (mm)	3	3

Table 3.5 :Neusoft scanner and Protocols

NEUSOFT	**NeuViz 128**
Scan type	Helical
Rotation Time (s)	0.5
Collimation	128 x 0.625mm
kVp	120
Reference mAs	150
Pitch	1.4
DFOV (mm)	350-500
Resolution	Standard
Dose Modulation	O-Dose
RECON 1	
Type	Axial
Slice thickness (mm)	5
Slice increment (mm)	5
RECON 2	
Type	Thins for MPR
Slice thickness(mm)	1
Slice increment (mm)	0.5

Table 3.6: Showing Abdominal CT Protocols

INDICATION	-
ORAL PREP	-
SCAN	PV PHASE 60-70 SEC AFTER INJECTION STARTS
RECON	3.0mm/3.75mm AXIAL RECONS –STANDARD ALGORITHMS\ 0.6mm/0.625mm/1.25mm AXIAL ALGORITHMS
REFORMAT	3mm CORONAL AND SAGITTAL
3D POST PROCESSING	NONE

IV SIZE		
IV CONTRAST		IV injection of 1ml/kg of iohexol 350 at rate of 4mls/sec/WEIGHT BASED
INJECTION RATE		3-4mls/secs
PATEINT POSITION		SUPINE /FEET FIRST
LANDMARK	**SIEMENS**	ABOVE DIAPHRAGM
	PHILIPS	XYPHOID
	NEUSOFT	XYPHOID
BREATHING		EXPIRATION
SCOUTS		AP AND LATERAL

PARAMTER		**SCAN**
START		ABOVE DIAPHGRAM
END		BELOW SYMPHSIS PUBIS
DFOV		<TO PATIENT>
PREP GROUP	**SIEMENS**	70 SEC
	PHILIPS	70 SEC
	NEUSOFT	70 SEC

3.7.1 Study Procedure

Information from the respective CT registry was obtained by the Principal Investigator following authorization from the departmental heads. Using a IAEA survey guide that captured the facility name, demographics, scanner model, dosimetry's and relevant information pertaining to the study was retrieved, recorded and stored in password protected database. Data from the CT database systems from the Imaging and Radiology department in the respective hospitals were obtained retrospectively for a 6 months' period (2021) using the same type of dose management system. Data compilation, cleaning and analysis was performed.

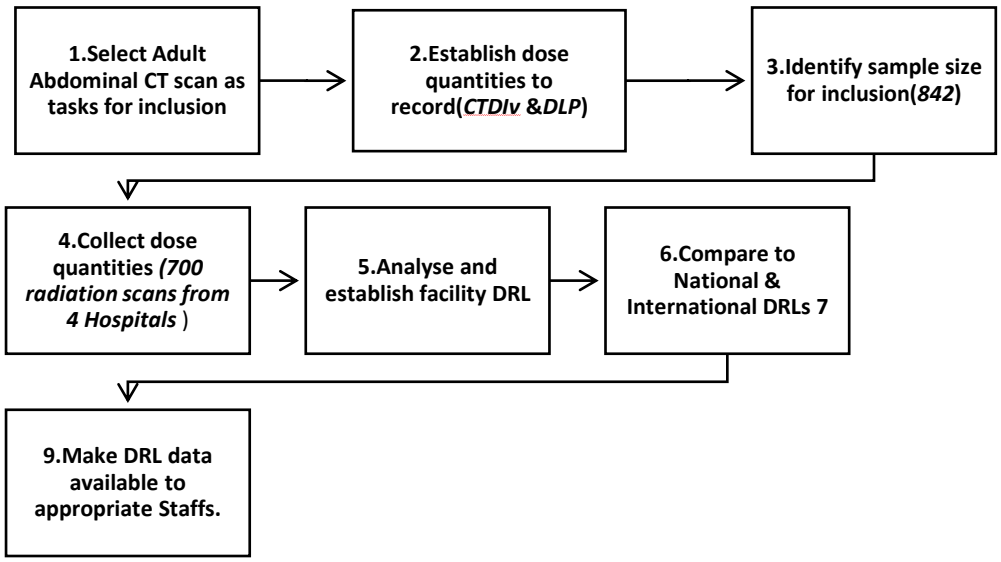

Figure 3. 1: Study flow chart

3.7.2 Data collection

Preliminary Steps

Before initiating the data collection process, approval was obtained from the respective ethical review boards of Moi Teaching and Referral Hospital (MTRH), Eldoret Hospital, St. Luke's Hospital, and Mediheal Hospital. Once approval was secured, coordinators at each facility were briefed on the study objectives and the type of data required.

Identification of Eligible Patients

At each participating healthcare facility, a list of adult patients who had undergone standard abdominal CT examinations was generated from the respective hospital records. This list was then filtered using the eligibility criteria specified in Section 3.3, with emphasis on complete dosimetry data for both contrast-enhanced and non-contrast-enhanced scans.

Data Retrieval Process

For the three private healthcare facilities, where consecutive sampling was employed, data was collected from the CT scans dose-tracking software for all eligible patients during the study period. At MTRH, where systematic sampling was utilized, the list of eligible patients was arranged in a sequential manner based on the time of their CT examination. A random starting point was chosen, and thereafter, every 2nd patient on the list was selected, consistent with the calculated interval $= K$.

Data Elements and Storage

The specific data elements collected included the Volume Computed Tomography Dose Index (CTDIvol) and Dose-Length Product (DLP) values for each CT scan. These metrics were extracted from the dose reports generated by the CT scans dose-

tracking software at each hospital. This data was then securely stored in encrypted files, with access restricted to authorized members of the research team.

Quality Assurance and Data Integrity

To ensure the accuracy of the collected data, a data quality audit was conducted. This involved cross-verifying a random sample of the collected data against the original CT scan reports from the dose-tracking software. Any discrepancies were resolved by revisiting the original data source and making the necessary corrections.

Data Anonymization

To maintain patient confidentiality, all collected data was anonymized. Identifiable information like names and patient IDs was replaced with unique study identifiers before analysis.

By following this rigorous data collection methodology, the study aimed to generate reliable and comprehensive data on CTDIvol and DLP values across the four healthcare facilities. The data served as a foundational reference for establishing Diagnostic Reference Levels (DRLs) for abdominal CT scans, thereby contributing to the advancement of radiation safety protocols.

3.7.3 CT dose measurements

CT dose is not measured directly on patients. It is measured using standard phantoms and then the measurements are used to estimate patient dosages. The standard phanthoms for the adult body is 32 cm and adult head is 16cm in diameter. Pediatrics phantom is 16 cm for the body EC (1999). CT dose is measured and reported through different methods, it can be classified into three broad categories: exposure, absorbed dose, and effective dose. In order to accurately determine a patient dose from a CT scan patient size and radiation output must be considered. Basically CTDI or CTDIvol

is thought of as a measure of how CT was performed as opposed to the amount dose a patient received. Exposure: is the amount of radiation at a set point in a known amount of air, measured by using an ionization chamber. The measurement of exposure via the ionization chamber is in coulomb per kilogram (Ckg^{-1}) which was previously measured in roentgen(R)[2.] Absorbed dose: it is also referred as the radiation dose; it is the measures of energy absorbed per mass. It is the appropriate parameter to refer to when quantifying how much dose a patient received in CT. It is measured in gray (Gy). Effective dose: the effective dose is the measure of radiation calculated with the radiosensitivity of specific organs taken into account. It also known as equivalent dose and it is measured in Sievert (Sv)

The commonly encountered dose metrics in CT scan are CT dose index (CTDI), CTDIvol, Dose length product (DLP) and Size Specific dose estimate (SDDE)[2] .CTDI is the standardized measure of dose output and it is best used to compare CT scanners. It is measured in mGy and it is not a measure of absorbed dose or effective dose. $CTDI_{vol}$ is a CT dose index that measures radiation per slice of tissue using a reference phantom only taking into account the scanner output and therefore not a measure of absorbed or effective dose. Dose length product (DLP)(mGy*cm) is the product of the $CTDI_{vol}$ and scan length. DLP factors in the length of the scan to show overall dose output and does not take into account the size of the patient and also is not a measure of absorbed dose or effective dose. It is measured in (mGy*cm). Size specific dose estimate (SDDE)[2] : it is the measure of absorbed dose but not effective dose. And it takes into account the patient's size, it is measured in mGy.

According to the EC the major dose indices used when measuring dosages are the namely; CTDI, $CTDI_W$, CTDIvol, DLP, Effective dose EC (1999). Theoretically CT

dose index (CTDI) is a measure of dose from single slice irradiation, is defined as the integral along a line parallel to the axis of rotation (z) of the dose profile, D(z), divided by the nominal slice thickness, t, given(Tsai, Tung, Huang, & Wan, 2003) by the formula;

$$\text{CTDI}_{\infty} = \frac{1}{t}\int_{-\infty}^{\infty} D1(z)dz.$$

When measuring the dose radiation, CTDI being the key parameter is obtained from measurement of dose, D(z), along the z-axis made in air using a special pencil-shaped ionization chamber 100mm in length and plastic anthropometrics dosimetry phantoms of standard size diameters (16 and 32). Measurements of CTDI in air (CTDI100, air) and in the cylindrical polymethyl methylacrylate (PMMA) phantoms (CTDI100, phantom) of diameter 32 cm (body) was appropriated for adult abdominal CT scan as recommended by EC guidelines based on the typical patient and exposure related parameters for this study (EC 1999).

In this study, CTDI among other parameters was to be obtained from the displayed CT parameters post exposure specific to the patient for CT Abdominal examination from the various CT scanners of the respective hospitals under the study. Currently Modern CT equipment have advanced dosimetry software and technical capacity to perform dose modulation according to patient size, height or weight which might provide homogenous and optimal effective dosages which are patient specific. Hence there are studies being done to compare whether Size Specific Dose Estimates can be more accurate in estimating patient dosages (AAPM 2014).

The CT scanners under the study have their valid licensure which is renewed annually by the Kenya Nuclear Regulatory Authority (KNRA). KNRA inspects and ensures the

CT machines are calibrated to the required legal safe dosimetry standards as required by law and in keeping with the ICRP, IAEA and UNSCEAR.

3.7.4 Determination of reference dosages

Advances in CT technology has made it possible to carry out digitally dose modulation specific to the patient through standardized software applications installed in the modern scanners and thus display average optimal effective dosage that are patient specific. The CT machines under the study were of current technology and hence the researcher collected the displayed average $CTDI_{vol}$, DLP of post exposure scan of each patient examined and for each specific CT machine for every hospital and estimated the dosages and come up with their mean distributions for comparisons with the international DRLs.

3.8 Data Analysis

The data analysis process involved cleaning, classification, coding, and tabulation of collected data hence amenable for analysis. The data collected from MTRH, Eldoret Hospital, Mediheal Hospital, St. Luke's Hospital was de-identified and recorded on an access database which was password protected so as to maintain confidentiality. Each hospital have different protocols and to prepare the data for use in analysis the following steps were used:

Stages of data preparation involved:

First, the raw data was sorted by hospital and CT brand to highlight any inherent patterns or biases linked to specific equipment or institutional protocols. This initial sort allowed for more nuanced analysis, as each CT brand and health facility might have unique settings that could affect radiation doses.

Second, a standardized abstraction template as per ICRP and IAEA was used to record key variables such as radiation dosage, patient age, weight, scanning parameters (e.g., tube current, tube voltage), and any other adjustable settings that could influence radiation exposure. This aimed to enable comparisons between different scans on an equal footing.

Third, the data was then cross-verified by medical physicists and radiologists to ascertain the validity of the collected information. Any outliers or anomalies were investigated to determine whether they were due to machine error, human error, or an actual extreme value. If it was the latter, notes were made to address these in the analysis.

Fourth, data normalization was performed. Given the larger sample from MTRH (692 scans) compared to the private hospitals (150 scans), weighted averages were used to ensure that the data from the smaller sample did not disproportionately skew the results. After the data preparation, data was analyzed in accordance to study objectives.

Descriptive statistics of the dose distribution findings across CT scanners surveyed was used to determine mean, minimum and maximum values. Mean values for each facility was calculated, and then rounded 75th percentiles of DLP and CTDIvol was used as a basis for DRLs. To compare doses between scanners of different numbers of detectors, Student's t-test and one-way ANOVA test was used to compare two and more than two groups of scanners, respectively.

The collected and analysed data included departmental CT protocols routinely applied to average-sized adult patients (weighing between 60 and 80 kg) for abdominal examination, included scanning parameters, such as detector collimation, slice

thickness, tube current, tube potential, tube rotation time, scan range and pitch. Radiation dose recordings included the displayed CT dose index volume (CTDIvol) and dose length product (DLP). Data was imported into STATA version 16 for analysis.

To answer objectives one and two, means and their corresponding deviations for Volumetric CT-dose index ($CTDI_{vol}$), dose length product (DLP) and scan length from the scans from each facility was calculated and presented in a table. Medians and their corresponding interquartile ranges were calculated for each facility.

To answer objective three, the averages calculated for Volumetric CT-dose index ($CTDI_{vol}$), dose length product (DLP) and scan length from each facility was compared with international DRLs through construction of confidence intervals. Also, comparison was made between different models of CT scanners for the respective facilities under survey. The results were presented in tables and figures and recommendations communicated back to each facility for comparisons and encouraged to take appropriate actions where necessary.

3.9 Ethical Consideration

Ethical review and approval were obtained from Moi University Institutional Research and Ethics Committee (MU-IREC) and NACOSTI for licensure before proceeding to the field. Permission to carry out the research at Moi Referral and Teaching Hospital, Eldoret Hospital, Mediheal and St. Luke's hospital was sought and duly provided. Since there is no direct involvement of patients there were no consent forms to be addressed. The respective facilities will receive a summary of the results and further disseminated to the relevant authorities via policy briefs, working paper, and journal articles.

CHAPTER FOUR: RESULTS

4.0 RESULTS

There was a total of 700 Abdominal CT scan that were reviewed in this study and included in the analysis. This represented 83 % of the total sample size of 842 as had been calculated. A target of 100 % could not be achieved at the time of data collection due to routine CT maintenance at the respective study sites. In addition, the target sample size was not achieved due to non-cooperation from the health facilities in granting more time for data collection. Table 1 shows the characteristics of the reviewed scans as well as the characteristics for the participants whose CT scan were reviewed. We observed that 451 (66.4%) of the reviewed scans were from public facilities and Siemens was the most common scan model 490 (70%). Majority of the scan 560(82.3%) were from CT scan that were manufactured as from 2016. Almost all the scan had a contrast administered 665 (96.8%). The mean CTDI was 8.1mGy. (SD=22.2) and the mean DLP values was 1699.1 mGy.cm (SD=1053.1)

The mean age of the participants was 52years (SD=17.7) and 376 (53.7%) were females. For almost all the patients 685(98.1%) whose CT scans were reviewed the positioning was H-SP.

Table 4.1: Descriptive

Variable	Freq (%)
Type of Facility	
Private	249 (35.6%)
Public	451 (64.4%)
Scanmodel	
Neusoft	72 (10.3%)
Philips	138 (19.7%)
Siemens	490 (70.0%)
Year of manufacture	
Missing	19
2007	19 (2.8%)
2013	75 (11.0%)
2014	27 (4.0%)
2016	316 (46.4%)
2017	189 (27.8%)
2018	55 (8.1%)
Contrast administered	
Missing	13
Contrast	665 (96.8%)
Non-contrast	22 (3.2%)
Patient Age	
Missing	3
Mean (SD)	52.227 (17.668)
Range	14.000 - 101.000
Patient Gender	
Female	376 (53.7%)
Male	324 (46.3%)
Patient positioning	
N-Miss	2
Feet First Supine	13 (1.9%)
H-SP	685 (98.1%)

Objective 1: To determine the mean CTDI (w) and DLP values for adult abdominal CT examination at the MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital.

The mean CTDI was 8.1mGy. (SD=22.2) and the mean DLP values was 1699.1 mGy.cm (SD=1053.1) as shown in Table 2 below

Table 4.2: CTDI and DLP values

	Median (IQR)	Mean (Std)	Range
Total DLP(mGy.cm)	1465.0 (1019.5, 2213.7)	1699.1 (1053.1)	0.0 - 7318.2
CTDI vol (mGy)	6.1 (4.6, 8.4)	8.1 (22.2)	0.0 - 549.3

Objective 2: To compare the CTDI(w) and DLP values for adult abdominal CT by type of facility, scan model and whether contrast was administered.

We observed that the CTDI and DLP values were highly dispersed hence in this analysis instead of comparing the mean we compared the median. Table 3 shows the comparison by scan model we observed the median for the Total DLP and for the CTDI significantly differed by the model with the median for the Neurosoft model being highest and those for the Siemens were the lowest for the two markers.

When the markers were compared by whether there was contrast or not we observed that there was a statistically significant difference in the DLP values with the median being higher where there was contrast. However, there was no significant difference in the CTDI values.

Table 5 shows the comparison by the type of facility we observed that the median DLP and CTDI values were significantly higher in the public facilities when compared to private facilities.

Table 4.3: DLP and CTDI by Scan model

	NEUSOFT (N=72)	PHILIPS (N=138)	SIEMENS (N=490)	p value
Total DLP(mGy.cm)				< 0.001
Median	2583.8	1785.8	1318.5	
Q1, Q3	2112.1, 3201.5	1155.1, 2799.6	961.5, 1851.0	
CTDI vol(mGy)				< 0.001
Median	10.320	8.470	5.390	
Q1, Q3	9.050, 11.817	6.083, 11.185	4.280, 6.860	

Table 4.4: DLP and CTDI by Contrast administration

	Contrast (N=665)	Non-contrast (N=22)	p value
Total DLP(mGy.cm)			0.020
Median	1488.0	680.8	
Q1, Q3	1077.0, 2234.0	251.5, 2124.9	
CTDI vol(mGy)			0.757
Median	6.2	6.5	
Q1, Q3	4.7, 8.4	3.0, 10.8	

Table 4.5: DLP and CTDI by Facility type

	PRIVATE (N=249)	PUBLIC (N=451)	p value
Total DLP(mGy.cm)			< 0.001
Median	1282.4	1668.8	
Q1, Q3	823.8, 1713.0	1140.5, 2459.5	
CTDI vol(mGy)			0.008
Median	5.9	6.2	
Q1, Q3	4.4, 7.730	4.7, 9.5	

Objective 3: To compare dose reference levels for the adult abdominal CT scan modality at MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital in reference to the international DRLs

Table 4.6(a)(b): To compare dose reference levels for the adult abdominal CT scan modality at MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital in reference to the international DRLs

Table 4.6(a)

NATIONAL DRLS FOR COMPUTED TOMOGRAPHY	Protocol	Scan region / technique	CTDI vol per sequence (mGy)	DLP per complete examination (mGy.cm)
UK(2019)	Abdomen	All sequences	14	910
	Abdomen and pelvis	All sequences	15	745
Japan DRLs 2020 for Adult CT	Abdomen and pelvis	All sequences	18	880
The Egyptian DRLs	Abdomen-pelvis	All sequences	31	1325
Ghana,Kenya,Namibia and Senegal	Abdomen	All sequences	15.7	737

We observed that results for the UK's 2019 DRLs recommend a CTDIvol of 14 mGy and a DLP of 910 mGy.cm while Japan's 2020 guidelines suggest slightly higher CTDIvol at 18 mGy but similar DLP at 880 mGy.cm. Egypt presents the highest values with a CTDIvol of 31 mGy and a DLP of 1325 mGy.cm. Conversely, the combined data from Ghana, Kenya, Namibia, and Senegal recommend a CTDIvol of 15.7 mGy and the lowest DLP of 737 mGy.cm. We observed the existence of significant variations in recommended dose reference levels for adult abdominal CT scans across different international benchmarks.

Table 4.6(b)

Country	CTDI(mGy)		DLP(mGy.cm)	
	reference value	**Proportion >Ref**	**reference value**	**Proportion >Ref**
UK	15	18 (2.6%)	910	568 (81.1%)
Japan	18	10 (1.5%)	880	580 (82.9%)
Egypt	31	5 (0.7%)	1325	401 (57.3%)
Ghana / Kenya / Namibia/ Senegal	15.7	14 (2.0%)	737	608 (86.9%)

Results show that 2.6% of cases exceeded the UK's CTDI reference value of 15 mGy, while a significant 81.1% surpassed the DLP reference of 910 mGy.cm. Results indicate that in Japan, only 1.5% of cases went beyond Japan's CTDI reference of 18 mGy, but 82.9% exceeded the DLP reference of 880 mGy.cm. Results in Egyptian DRLs reveal that a mere 0.7% of cases exceeded Egypt's relatively high CTDI reference of 31 mGy, but 57.3% surpassed the DLP reference of 1325 mGy.cm. Results from Ghana/Kenya/Namibia/Senegal indicate that 2.0% of cases surpassed the CTDI reference of 15.7 mGy, and a substantial 86.9% exceeded the DLP reference of 737 mGy.cm. These results indicate that while CTDI values at the Kenyan hospitals are largely within international guidelines, the DLP values frequently exceed those guidelines. Difference in CTDI and DLP values were not observed for their statistical differences as this was not part of the objective.

CHAPTER FIVE

5.0 DISCUSSION

A total of 700 adult patients who underwent abdominal CT scan from the respective hospitals were enrolled in the study. Participant mean age was 52.227 (17.668) years and ranged from 18 years to 101 years, with more than 53% of the reported examinations belonging to the female patients. The average age of the population gave the impression that currently CT abdominal examination in private and public hospitals in Eldoret is mostly performed on patients that are more advanced in age. Older individuals are more likely to experience health issues that necessitate CT abdominal examinations, thus inflating the mean age of the sample. The age data align with findings from previous research. A study by Korir et al., (2016) in Kenya reported a similar age distribution. Raksha Erem et al. (2022) also noted a comparable mean age of 52 years in their study, reinforcing the pattern observed in this research.

The majority of CT scans in this study were conducted using Siemens machines, a trend that aligns with findings by Nikièma et al. (2016), who reported Siemens as the prevalent models in Sub-Saharan Africa. The significance of discussing CT scan models lies in multiple factors: Technology Advancements: The years of manufacture for the CT scans ranged from 2007 to 2018, indicating that most installations have occurred in recent years. This is critical for understanding the state of technology available in healthcare facilities, which impacts the quality of scans and patient safety. Rate of Adoption: Uushona et al. (2022) reported an 80% increase in the use of CT scanners in Kenya between 2012 and 2019. Discussion of CT scan models is important in gauging the rate at which new technology is being adopted, which in turn could affect diagnosis and treatment. Policy Impact: The increase in CT scans between 2016 and 2018 is notably linked to the MES, a public-private partnership

project initiated in 2016. Discussing CT scan models helps to assess the impact of healthcare policies on technology adoption. Private Sector Role: The private sector has been instrumental in the increase of CT scans (Gathuru et al., 2021). Mentioning the CT scan models sheds light on private sector participation in healthcare. By discussing CT scan models, the study provides a lens through which to examine technological advances, policy impacts, and sectoral contributions to healthcare. This multi-faceted understanding is crucial for understanding the context of CT scans in MTRH, St Lukes hospital and Eldoret hospital.

5.1 Mean CTDI(w) and DLP values for adult abdominal CT examination

The findings of this study indicated an average CTDIvol and DLP for abdominal CT of 8.1 mGy and 1699.1 mGy.cm, respectively. These results were obtained using dose values measured with a dosimetry phantom, a method that is considered to provide accurate and reliable dose assessments. This approach also included the average number of slices typically performed on an adult patient at each facility to offer a comprehensive dose measurement.

When compared with the Wambani et al., (2010), which also employed dosimetry phantoms, our study showed higher CTDIvol values with the Wambani study reporting average $CTDI_{vol}$ and DLP values for abdominal CT of 6.9 mGy and 1403.1 mGy.cm. Several factors could account for this discrepancy. First, advances in CT technology and protocols over the years could lead to different dose distributions and consequently higher CTDIvol values in more recent studies. Second, differences in the patient populations, such as body mass index or medical conditions, could necessitate different scanning parameters, affecting the resulting CTDIvol. Third, variations in device protocols, standard examination techniques, equipment

performance, age of the equipment, and maintenance conditions (Smith-bindman et al., 2019) can also contribute to the divergence in measured values.

This findings of the study also contradict a much more recent study conducted by Korir et al. (2016) in Kenya that reported lower values. The results can be attributed to study methodology, more so the use of Philips CT model as opposed to our study that three model of Philips, siemens and neusoft. The use of Scanners manufactured by a single company (philips) in the former study, may have led to substantial homogeneity in the radiation outputs owing to the similar technology and protocol used. The high calculated measured values may also be attributed to the higher exposure factors used and to the possible presence of longer than necessary scan lengths (Adam, 2016). Our study findings were in support of the high average mean values reported for abdominal CT scan at KNH (Musila, 2009).

5.2 Comparison of the CTDI(w) and DLP values for adult abdominal CT by Type of facility, Scan Model and Contrast Administration

The study's results indicate that variations in CTDI (vol) and DLP values are mainly due to differences in machine factors, specifically the CT models used. This aligns with findings by Masjedi et al. (2019), who reported that CT dose levels are influenced by machine design. However, this contrasts with Tayal & Ali (2021), who found that dose levels are not determined by the machine model. In our study, (Neusoft and Philips) were found to have higher CTDI(vol) and DLP values. Comparisons were made across similar machine models in different facilities to ensure consistency. The variations in values are not solely due to machine differences but also to procedural factors. For instance, radiology technicians' expertise and protocols could vary between government and private hospitals, as our study encompassed both.

Nagpal et al. (2020) also reported that CT scanner output can vary between 10 and 15%, adding another layer of complexity to our findings. The divergence in findings between our study and that of Tayal & Ali (2021) could be attributed to institutional factors, including the level of training of radiology technicians. Notably, the study by Tayal & Ali (2021) was conducted in government referral hospitals, while our study included both referral and private hospitals.

The finding of a statistically significant variability in radiation dose for contrast-enhanced CT examinations was confirmed for DLP values. The findings suggest that for contrast-enhanced abdominal CT examination, organ dose volumetric DLP remarkably increased. Results of previous studies (Geso et al., 2020; Paolicchi et al., 2013) have attributed the increases in CT dose levels to photoelectric absorption and, more so, the generation of secondary electrons due to absorption of x-rays by contrast

agent. Significant relationship between $DLP_{contrast}$ and $DLP_{non\text{-}contrast}$, with higher media values for contrast has been reported in other studies (Cauteren et al., 2018; Mazloumi et al., 2021; Sahbaee et al., 2017).

The findings showed that relationship between $CTDI_{vol,contrast}$ and $CTDI_{vol,non\text{-}contrast}$ is not significant. Shofi et al., (2021) reported in their findings that minimal differences between media values of CTDI contrast and non-contrast is due to the use of same protocol scan for routine abdominal scans with and without the use of a contrast agent. Results of (Nitasari et al., 2021; Tobi et al., 2021) also confirmed non-significant differences between $CTDI_{vol}$ values contrast and non-contrast media.

Our findings reported that the median DLP and $CTDI_{vol}$ values were significantly higher in the public facilities when compared to private facilities. Generally, variation in the protocol can affect the radiation dose; therefore, the same scanner in public vs private hospitals might result in doses higher or lower DRLs and $CTDI_{vol}$. Variation in CT protocols is the largest source of dose variation across imaging facilities and is more important than patient factors or machine make and model in explaining this variation across public and private facilities (Whitebird et al., 2022). This study confirmed that variation in CT protocols within organizations is an important barrier to dose optimization. Yurt et al.(2020) suggests that technical capacity of radiologists in public and private hospitals also account for variations in mean $CTDI_{vol}$ and DLPs. Technical capacity determines how providers or clinical staff chose to set the machine technical parameters which affect dose levels (Smith-bindman et al., 2019).

Abba and Ibrahim (2018) reported higher values of $CTDI_{vol}$ and DLPs in public health facilities as opposed to private health facilities. Similarly, Erem et al., (2022) found out that public health facilities had higher mean values for $CTDI_{vol}$ and DLPs

when compared to private health facilities. The authors explained that in public health facilities there is the likelihood of having an aging machine or poorly maintained scanner that may yield values outside the accepted standards for effective radiation dose optimization. DLP is also proportional to scan length hence the higher DLP could be explained by scanning longer region than required. This could be due to fast scanning technique of CTs especially those with higher slices. Lack of support from radiology leaders for dose optimization activities is also likely a contributing factor higher values for CT examinations in sub-saharan Africa (Whitebird et al., 2022).

5.3 Comparison of dose reference levels for the adult abdominal CT scan modality at MTRH, Eldoret Hospital, St. Luke's Hospital and Mediheal Hospital in reference to the international DRLs

CTDIvol and DLP are standard metrics generated by contemporary CT scanners. Their availability makes them valuable tools for quality assurance assessments across various scales in local, regional, national, and international. In this study, the average CTDIvol was found to be within a 3% range when compared to international reference values. Specifically, the CTDIvol was 2.6% greater than that of the UK.

Comparisons were also made with a recent survey covering four African countries: Kenya, Ghana, Senegal, and Namibia (Uushona et al., 2022). The regional DRLs in this African survey were 10% greater than the UK values, aligning with prior observations that developing countries often report higher CTDI than European nations (Tobi et al., 2021; Toori et al., 2015; Yurt et al., 2020). Various factors, such as CT equipment performance and departmental protocols, could be responsible for these differences.

Contrastingly, the study's $CTDI_{vol}$ was lower than that of several reference countries, including Japan, Egypt, and the aforementioned African countries, by a range of 0.7% to 2%. This discrepancy might be attributed to different fundamental CT scan parameters like tube voltage, tube current, and rotation time. While this study did not delve into these parameters, it's worth noting that other studies (Shirazu et al., 2017; Jafari et al., 2020) have found that DRLs can vary significantly based on local practices and equipment.

Concerning DLP values, the study reported levels considerably lower by more than 50% than international standards. This finding requires specific attention, as it seems to contradict other sections of the discussion that attribute dose variations to the absence of standardized protocols. In settings without standardized protocols, there is often no rigorous peer review or calibration process for CT parameters. As a result, some machines might be set to deliver higher or lower doses without a clear medical justification. An observation made during the study in the public facility (MTRH) was that they reduced their scan length for the abdominal examination hence probably could explain the lower DLP values.

Moreover, the CT scanners in this study originated from multiple manufacturers, introducing an additional layer of complexity due to technological and protocol differences. Studies such as those by Awad et al. (2020) and Garba et al. (2020) have similarly reported lower DLP values when compared against international benchmarks.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The mean $CTDI_{vol}$ was 8.1(mGy) (SD=22.2) and the mean DLP values was 1699.1(mGy.cm) (SD=1053.1) for adult abdominal CT examinations.

The median for the Total DLP and for the $CTDI_{vol}$ significantly higher in the public facility, Contrast CT and in Neusoft model CT machine.

The LDRLs values were markedly lower than the regional and the international values.

6.2 Recommendation

In general, DRLs for all adult patient CT abdominal examinations were lower than international values. It is recommended that this reference dose be temporarily considered as standard dose for optimization procedures in facilities under survey until further studies are conducted and information on all adult abdominal CT examinations collected.

Optimized scanning protocols and proper CT planning should be adopted by the three private facilities and MTRH facility so as to deliver safe dosages ($CTDI_{vol}$ and DLP) without sacrificing image quality.

Inter-facility optimization committee within Eldoret health system that includes various stakeholders should be set up hence establish LDRLs through, institutional dosimetry audits, quality assurance so as to come up with baselines that would optimize local imaging practice, and enhance patient safety.

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APPENDICES

APPENDIX I: Informed Consent

This informed consent form is for health care providers (facilities) in Eldoret town which are invited to participate in a research project, titled "Validation of Radiation dose Reference levels of Adult Computer Tomography Abdominal studies in Eldoret".

Name of Principle Investigator_____

Name of Organization_____

Name of Sponsor_____

Name of Project and Version_____

This Informed Consent Form has two parts:

- **Information Sheet (to share information about the study with you)**
- **Certificate of Consent (for signatures if you choose to participate)**

Part I: Information Sheet

Introduction

I am Ouma Edward, pursuing a MMed degree in Radiology and Imaging at Moi University, School of Medicine. I am doing research on validation of radiation dose reference levels of adult computer tomography abdominal studies in Eldoret.

I will need information from your facility and invite you to be part of this research.

Purpose of the research

Patient dosimetry studies have been shown to be of great importance in improving patient safety in providing quality and safe radiation doses in radiological examinations. The purpose of this study is to survey radiation dose for patients in Abdominal CT examinations and to perform comparisons with established diagnostic

reference levels. In the current setting the research has not been done so far, therefore we want to establish a local diagnostic reference levels by comparing our local common practices to the International standards. The study is designed to collect dose data representative of current CT abdomen practice in Eldoret, and to identify if the current diagnostic reference level (DRL) is still appropriate. As a result of the study, provide a guide for further reviews or improvement on appropriate CT abdominal dose radiations. We believe this facility can be of help by participating in the survey through providing us access to data for CT abdominal scans for analysis and comparisons with the rest of the established DRls.

Type of Research Intervention

This research will involve your participation by allowing us access to your departmental imaging CT database systems(PACS) so as to obtain data for Abdominal CT scan dosimetry.

Participant Selection

The facility is being invited to take part in this research because we feel that the imaging experience as a health provider can contribute much to our understanding and knowledge of Adult abdominal CT dosages.

Voluntary Participation

Participation in this research is entirely voluntary. The choice that you make as facility will have no bearing on your institution or on any facility-related evaluations or reports. The facility may drop from the survey in case there is change of mind later and stop participating even if there was an earlier agreement.

Duration

The research will take place for over 3 months. During that time, we will visit the facility 5 times for data collection at 2 weeks' interval and each session will last for

about one hour each.

Benefits

There will be no direct benefit to the facility, but your participation as a facility is likely to help us find out more about adult abdominal CT scan radiation dosages in relation to developing local Diagnostic reference levels(DRls).

Confidentiality

We will not be sharing information obtained from the facility to anyone outside of the research team. It will not be shared with or given to anyone except the research department of Moi university.

Sharing the Results

Information retrieved today from the facility will not be shared with anybody outside the research team, and nothing will be attributed to you by name. The facility will receive a summary of the results and further disseminated via policy briefs, working paper, and journal articles.

Right to Refuse or Withdraw

The facility does not have to take part in this research if it does not wish to do so, and choosing to participate will not affect the facility or facility-related evaluations in any way. You may stop participating in the survey at any time that it wishes so.

Who to Contact

In case of any questions, the facility can contact any of the following:

Name: _____

Address: _____

Mobile number _____

e-mail: _____

This proposal has been reviewed and approved by Moi university IREC, which is a

committee whose task it is to make sure that research participants are protected from harm. If you wish to find about more about the IREC,

Contact: _____

Name: _____

Address: _____

Mobile number: _____

It has also been reviewed by the Ethics Review Committee of the NACOSTI, which is supporting the study.

Part II: Certificate of Consent

(This section is mandatory)

The facility has been invited to participate in a survey about validation of radiation dose reference levels of adult computer tomography abdominal studies in Eldoret. I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. On behalf of the facility management, I consent voluntarily that the facility participates in this study

Print Name of Facility Administrator _____

Signature of Facility Administrator _____

Date _____

Day/month/year

APPENDIX II: Data abstraction tool

SECTION A: FACILITY INFORMATION LEVEL (check box where appropriate)

Facility Name: Date:

Facility type: Public ☐ Private ☐

Scanner: Model

Year of manufacture:

SECTION B: RADIOLOGY DATABASE RECORDS(PACS/CONSOLE)

Accession number:

Examination:

Patient name:

Patient ID no:

Patient Age:

Gender: Male ☐ Female ☐

Patient weight/size:

Scan parameters: KV MAS , ch range

SECTION C: DISPLAYED PATIENT DOSE INFORMATION

Slice thickness(mm):	
CTDIvol(mGy):	
DLP(mGy*cm):	
Dose Eff.%:	
Phantom:	

SECTION D: REMARKS

APPENDIX III: Research timelines

Name	Ouma Edward Ochieng				
Reg. no	SM/PGR/06/18				
Title	Radiation dose reference levels of adult patient computer tomography abdominal studies at Moi teaching and referral				
Project start date	01/03/2021				
Project lead	Self				
SCHEDULE	**START**	**END**	**DAYS**	**% DONE**	**WORK DAYS**
Research proposal	11/01/2021	15/03/2021	60	75	20
Proposal defense and submission	15/03/2021	22/03/2021	7		7
NACOSTI/IREC approval	22/03/2021	22/04/2021	30		30
Data collection	04/04/2021	04/09/2021	150		150
Writing of dissertation	10/09/2021	30/04/2022	10		10
Dissertation Defense	31/08/2023	29/09/2023	30		30
publication	1/03/2023	26/05/2023	60		60

APPENDIX IV: Field Work Plan

Period	**Activities**
Day 1.	Constitute team of interviewers and personnel
Day 2.	Train the field personnel on the research instruments and interview
Day 3.	Assign the teams their specific roles
Day 4.	Logistics arrangements; transport, Lunch allowance
Day 5.	Schedule of research work in the facility-
Day 6-150	Collection, collation, data cleaning, analysis, entry
Day 150-180	Generating reports and sharing with the relevant stakeholders
Day 180-200	Feedback to the participant's and institutions

APPENDIX V: Budget plan

Items	**Particulars**	**Quantity**	**Unit cost**	**Per day**	**Amount**
1. Co-ordinators	• Project coordinator • Statistician	1 1	20,000 20,000	- -	20,000/= 20,000/=
2. Equipment's					
	• Tablet	1	15,000	-	15,000/=
	• Flash USB drive	2	500	-	1000/=
3. Printing	• Printing ink (colored) • Printing paper(rim)	4 cartridges 2	1500 500	- 	6,000/= 1,000/=
4. Allowances for Research assistants/personnel	• Lunch	2 pax	1000	5	10,000/=
	• Transport	2 pax	500	5	5,000/=
	• Airtime	-	5000		5,000/=
5. Registration fee	• NACOSTI/IREC	-	2000	-	2,000/=
Grand Total					**85,000/=**

APPENDIX VI: IREC Approval

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471//2/3

MOI UNIVERSITY
COLLEGE OF HEALTH SCIENCES
P.O. BOX 4606
ELDORET
Tel: 33471/2/3

Reference: IREC/2021/75
Approval Number: 0003917
12th July, 2021

Dr. Ouma Edward Ochieng,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

Dear Dr. Ochieng,

VALIDATION OF RADIATION DOSE REFERENCE LEVELS OF ADULT COMPUTER TOMOGRAPHY ABDOMINAL STUDIES IN ELDORET

This is to inform you that ***MTRH/MU-IREC*** has reviewed and approved your above research proposal. Your application approval number is ***FAN: 0003917.*** The approval period is **1st July, *2021- 30th June, 2022.***
This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, Material Transfer Agreements (MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***MTRH/MU-IREC***.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***MTRH/MU-IREC*** within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***MTRH/MU-IREC*** within 72 hours.
v. Clearance for export of biological specimens must be obtained from ***MOH at the recommendation of NACOSTI*** for each batch of shipment.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***MTRH/MU-IREC.***

Prior to commencing your study; you will be required to obtain a research license from the National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and other relevant clearances from study sites including a written approval from the CEO-MTRH which is mandatory for studies to be undertaken within the jurisdiction of Moi Teaching & Referral Hospital (MTRH) and its satellites sites.

Sincerely,

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
12 JUL 2020
APPROVED
P. O. Box 4606-30100 ELDORET

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc	CEO	-	MTRH	Dean	-	SOP	Dean	-	SOM
	Principal	-	CHS	Dean	-	SON	Dean	-	SOD

APPENDIX VII: Hospital Approval (MTRH)

An ISO 9001:2015 Certified Hospital

MOI TEACHING AND REFERRAL HOSPITAL

Telephone :(+254)053-2033471/2/3/4
Mobile: 722-201277/0722-209795/0734-600461/0734-683361
Fax: 053-2061749
Email: ceo@mtrh.go.ke/directorsofficemtrh@gmail.com

Nandi Road
P.O. Box 3 – 30100
ELDORET, KENYA

Ref: ELD/MTRH/R&P/10/2/V.2/2010

13th July, 2021

Dr. Ouma Edward Ochieng
Moi University
School of Medicine
P.O. Box 4606-30100
ELDORET-KENYA

VALIDATION OF RADIATION DOSE REFERENCE LEVELS OF ADULT COMPUTER TOMOGRAPHY ABDOMINAL STUDIES IN ELDORET

You have been authorised to conduct research within the jurisdiction of Moi Teaching and Referral Hospital (MTRH) and its satellites sites. You are required to strictly adhere to the regulations stated below in order to safeguard the safety and well-being of staff, patients and study participants seen at MTRH.

1. The study shall be under Moi Teaching and Referral Hospital regulations.
2. A copy of MTRH/MU-IREC approval shall be a prerequisite to conducting the study.
3. Studies intending to export human bio-specimens must provide a permit from MOH at the recommendation of NACOSTI for each shipment.
4. No data collection will be allowed without an approved consent form(s) to participants unless waiver of written consent has been granted by MTRH/MU-IREC.
5. Take note that **data** collected must be treated with due confidentiality and anonymity.

The continued permission to conduct research shall only be sustained subject to fulfilling all the requirements stated above.

MOI TEACHING AND REFERRAL HOSPITAL
CEO
APPROVED
13 JUL 2021
SIGN.....
P. O. Box 3-30100, ELDORET

13/07/2021
DR. WILSON K. ARUASA, *EBS*
CHIEF EXECUTIVE OFFICER
MOI TEACHING AND REFERRAL HOSPITAL

cc - Senior Director, (CS)
- Director of Nursing Services (DNS)
- HOD, HRISM