Cape Peninsula
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A LOCAL DOSE MANAGEMENT SYSTEM FOR BRAIN COMPUTED TOMOGRAPHY IN NIGERIA

By

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DECLARATION

I, IDRIS GARBA, declare that the contents of this thesis represent my unaided work and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my opinions and findings of my research work, not necessarily those of the Cape Peninsula University of Technology (CPUT). In addition, the study had ethics approvals from CPUT and the research centre in Nigeria with reference numbers NHREC: REC-230408-014 and NHREC/28/01/2020/AKTH/EC/3186 respectively.

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Signed Date

ABSTRACT

"A Local Dose Management System for Brain Computed Tomography in Nigeria"

Background: Computed Tomography (CT) constitutes 6.3% of medical X-ray procedures, however, this essential imaging tool represents the highest contribution (43.2%) of artificial human exposure to ionising radiation. Modern CT technology has made radiological equipment more efficient, with the ability to produce high-quality diagnostic images with lower radiation doses. However, accumulated exposure to ionising radiation has the potential to result in radiation side effects and injuries; even cancer induction. Therefore, there is a need to ensure that justification and optimisation principles are successfully applied in clinical practice to prevent the likelihood of radiation injury.

AIM: The study developed and implemented the first prospective manual Radiation Dose Management System (RDMS) for brain CT procedures in a busy CT centre in Nigeria. This is to promote the concept of dose justification and optimisation in medical imaging.

Methods: The study was conducted in a CT centre located at a tertiary hospital in Nigeria. The research was carried out in phases starting with a systematic literature review on RDMSs to determine the most appropriate RDMS for this site. Articles on RDMS were sourced from PubMed, EBSCOhost, Web of Science, SCOPUS and Cochrane Library databases. The articles were screened for review using the preferred reporting items for systematic review and meta-analysis flow chart. Thereafter, a questionnaire-based study using a convenience sampling method investigated the knowledge of CT dose optimisation and justification among 50% (17 out of 34) radiographers, 35% (16 out of 46) radiologists and 84% (92 out of 110) referring physicians. Findings from these two studies were used in developing and implementing a manual RDMS. This instrument was used to prospectively track and monitor the radiation dose and scan parameters of patients having brain CT. The data extracted from the screened articles in the systematic review was synthesised narratively.

Meanwhile, data from the questionnaire and RDMS phases were analysed using the Statistical Package for Social Sciences (SPSS) version 20. The tracked doses were analysed in mean, median and 3rd quartile. These values were checked to determine compliance with the established national and international Diagnostic Reference Levels (DRLs).

Results: A total of 38 articles were selected and synthesised narratively. The results revealed that there are electronic and manual RDMS and provided an indication of their strengths and weaknesses for given environments. The questionnaire-based study showed that more radiographers (47.1%) than radiologists (18.8%) had good knowledge of CT doses and image quality. However, the difference in knowledge was not found to be significant ($p = 0.167$) which could be ascribed to the small sample size of the participants. In addition, knowledge of diagnostic reference levels (DRLs) was significantly ($p = 0.033$) higher amongst radiographers (52.9%) as compared to radiologists (12.5%). Meanwhile, physicians understood the principles of dose justification. However, their knowledge of referral guidelines was limited. The developed and implemented RDMS tracked and monitored radiation doses of 596 patients for brain CT scans grouped as <1 year: 36 (6%); 1-<5 years: 38 (7%); 5-<10 years: 25 (4%); 10-<15 years: 31 (5%) and adult (>15 years): 466 (78%). Patients identified with high doses above the Volume Computed Tomography Dose Index (CTDIvol) notification were as follows: <1 year: 1 (2.8%), 1-<5: 1 (2.6%), 5-<10: 0 (0%), 10-<15: 0 (0%) and adult (>15 years): 11 (2.4%). Furthermore, examinations with doses above the Dose Length Product (DLP) notification value were as follows:<1 year: 1 (2.8%); 1-<5:1 (2.6%); 5-<10:1 (4%); 10-<15: 1 (3.2%) and adults (>15 years): 18 (3.9%). The established typical paediatric DLP values were two-three times higher than the international paediatric DLP DRLs.

Conclusion: This thesis has for the first time, developed and implemented a manual RDMS specifically for brain CT examinations in a busy centre in Nigeria. Findings from the systematic literature review and questionnaire studies culminated in the development and implementation of this RDMS. The developed RDMS provided prospective assessment and records of

patient scan parameters and dosimetric information which indicates patient procedures where the dose value is above the locally established notification values in CTDIvol and DLP. Furthermore, the dose record shows that the paediatric DLP DRLs were two to three times higher than the international paediatric DLP DRLs. This calls for total protocol review and optimisation, considering the local CT centre's needs and practices for paediatric imaging.

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DEDICATION

I dedicate this work to my family who supported me throughout this journey

For

My beloved wife Maryam and children Murad and Adeelah

PREFACE

This thesis reports on the use of a manual radiation dose management system (RDMS) in a busy CT centre in Nigeria. The RDMS template was developed and implemented to prospectively track, monitor and manage the radiation dose of patients who were referred for routine brain computed tomography (CT). The use of ionising radiation offers a lot of clinical benefits ranging from diagnosis of diseases and treatment. However, radiation exposure from CT is considered high compared to other imaging modalities such as general radiography. The magnitude of this exposure from CT has the potential to cause radiation injuries including cancer induction in the exposed individuals. Brain CT is the most common CT procedure performed in Nigeria and in the course of the examination, patients receive relatively high doses in terms of CTDIvol and DLP. Structures including the lenses of the eyes are potentially exposed to radiation which could lead to radiation-induced cataracts and thus the need for dose monitoring for optimisation of CT procedures.

The thesis contains seven (7) chapters structured to include three academic publications as presented below:

Chapter One: introduces the thesis and provides the concept of why the study was initiated to develop a radiation dose management system, starting with brain CT procedures, to contribute to radiation dose optimisation and justification.

Chapter Two: includes relevant literature on principles of radiation protection which covers the concept of radiation dose optimisation and justification. A review of the current literature on radiation dose management systems (RDMS) including manual and electronic with their essential features is also covered. A specific focus is made on the manual dose management system, as this was the method developed and applied in this thesis.

Chapter Three: is the methodology chapter for the three publications addressing the study objectives. .

Chapters four, five and six are the results chapters and are presented according to the specific journal format. Each chapter presents results from a specific phase of the study. The chapters are as follows:

Chapter Four: Radiation Dose Management System in Computed Tomography Procedures: A Systematic Review which is published as part of this study. This work is part of the literature review presented in Chapter Two and addresses objectives i and ii.

Published article:

Garba, I., Engel-Hills, P., Davidson, F. and Ismail, A. (2023). Radiation Dose Management System in Computed Tomography Procedures: A Systematic Review. *Radiation Protection Dosimetry*, Volume 199, Issue 10, Pages 1063–1074, https://doi.org/10.1093/rpd/ncad124.

Chapter Five: Knowledge of Computed Tomography Dose Optimisation and Justification among CT Users and Referring Physicians: A Single Hospital Study published as part of this study. This is a separate phase of the study and addresses objectives iii and iv.

.Published article:

Garba, I., Engel-Hills, P., Davidson, F. and Ismail, A. 2023. Knowledge of Computed Tomography Dose Optimisation and Justification among CT Users and Referring Physicians: A Single Hospital Study. *Journal of Medical Imaging and Radiation Sciences*. Vol. 54, Issue 4; p 644–652. Available at: https://www.sciencedirect.com/science/article/pii/S1939865423018143 [Accessed: 21 August 2023].

Chapter Six: Prospective Dose Monitoring using a Manual Dose Management System: Experience in Brain Computed Tomography from a Tertiary Hospital in Nigeria. This is also a separate phase of the study and addresses objectives v, vi and vii.

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Chapter Seven: The summary of the discussion, conclusions and recommendations of the study and represents an integration of these aspects drawn from the three publications.

CONTENTS

GLOSSARY

Terms/Abbreviations	Definition/Explanation
A	
ALARA	As Low As Reasonably Achievable
AFROSAFE	Africa Safety
C	
CT	Computed Tomography
CTDIvol	Volume Computed Tomography Dose Index
D	
DLP	Dose Length Product
DRLs	Diagnostic Reference Levels
E	
EC	European Commission
EU	European Union
ESR	European Society of Radiology
I	
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ISRRT	International Society of Radiographers and Radiologic Technologists
N	
NNRA	Nigeria Nuclear Regulatory Authority
M	
MPPS	Modality Performed Procedure Steps
O	
OCR	Optical Character Recognition
P	
PACS	Picture Archival and Communication System
R	
RDMS	Radiation Dose Management System

RIS	Radiology Information System
S	
SPSS	Statistical Package for Social Sciences
U	
USA	United States of America

CHAPTER ONE: INTRODUCTION

1.1 Background and Context

The use of X-rays in medical diagnostic imaging has expanded worldwide with numerous benefits for millions of people each year (Perez 2013; Sherer et al. 2021). With the high demand comes the outcome that medical imaging represents one of the highest contributions of artificial radiation in medicine (Perez 2013; Jain 2021). Modern technology has made radiological equipment more efficient by producing optimal diagnostic images with lower radiation doses. However, it is known that radiation exposure at even small doses can result in radiation effects and injuries; even cancer induction (Perez 2013; IAEA 2016). Therefore, the application of radiation in clinical practice has to be balanced between the clinical benefits and radiation risks (Perez 2013; Sherer et al. 2021). This calls for a strong partnership with stakeholders such as the government, national radiation protection organisations, international agencies, radiation workers, and educators. This will ensure radiation protection measures become a part of everyday practice to allow for the highest levels of safety in the application of ionising radiation in medicine.

The core principles of radiation protection are the justification of the procedure, radiation dose optimisation and dose limits for personnel and members of the public (ICRP 2006; Sherer et al. 2021). These principles have been successfully applied to protect personnel, members of the public and patients (medical exposure) from the harmful effects of radiation (ICRP 2006; Frane & Bitterman 2023). Medical exposure differs from personnel and public exposure since patients are deliberately, directly, and knowingly being exposed in the course of their diagnoses of disease. This is considered beneficial though the exposure should be justified (IAEA 2016). In medical imaging exposure, patients do not have a limit in terms of radiation exposure provided that the benefits of performing the procedure are found to outweigh the risks. Therefore, the two principles: justification and optimisation are applied to medical exposure (IAEA 2016).

The use of the justification principle in medical practice remains the primary criterion to determine whether the procedure requested has benefits and should be conducted (IAEA 2016; Sherer et al. 2021). This is because in medical exposure, the radiation is directly applied to patients and the possibility of having radiation-induced injuries is relatively high (IAEA 2016). To apply the justification principle, there must be a consultation between the referring physicians and the radiology department where the procedure is to be conducted. This pre-exposure communication ensures unnecessary exposure of patients to radiation is avoided (IAEA 2016). In addition, justification involves the use of referral guidelines, such as those developed by professional organisations, with the support of the IAEA (IAEA 2016). Referral guidelines define the most appropriate medical imaging procedure based on the patient's clinical condition (ESR 2017). Such guidelines were developed in the United Kingdom (UK) in the late 1980s and were intended to guide physicians in deciding the most appropriate procedure (European Commission 2014). Referral guidelines have been proven as an effective tool in reducing the number of unnecessary radiology referrals and ultimately improving the quality of healthcare service (European Commission 2014). These guidelines have facilitated and improved the implementation of the justification principle at national and international levels (IAEA 2016).

On the other hand, optimisation of protection and radiation safety ensures that the amount of radiation exposure used for diagnosis, and the number of patients exposed, is carefully considered based on the guiding principle of; As Low As Reasonably Achievable (ALARA). Also, it is in accordance with the clinical requirements for each patient (IAEA 2016; Tsapaki 2020; Sherer et al. 2021). To enhance the justification and optimisation principles in radiation protection, the IAEA coordinated a scientific conference. The gathering brought together stakeholders from countries around the globe including the United Kingdom (UK), the United States of America (USA), Europe and Africa. The participants at the conference included policy makers, scientists and experts from different sectors and organisations globally. The IAEA coordinated meetings targeted to address current and future challenges

associated with radiation protection practice in medicine at the international level (IAEA 2012).

A few of the important action plans highlighted at the end of this 2012 conference included an effort to reignite the implementation of the principle of justification. This is to raise dose awareness, encourage dose audits and the use of the referral guidelines for medical imaging. Furthermore, the implementation of the diagnostic reference levels (DRLs) as a tool for optimisation was stressed as critical (IAEA 2012). In Nigeria, like in many European countries, several DRL studies, especially in computed tomography (CT) have been conducted to promote dose optimisation (Garba et al. 2015; Zira et al. 2017; Ekpo et al. 2018; Ekpo et al. 2019). Implementation of these DRLs into clinical practice has occurred widely across European countries. This is because the European Directives require automated dose tracking and monitoring, using available vendor software, especially for commonly performed CT procedures (Loose et al. 2021). However, prior to this study, in Nigeria, the implementation of DRLs through dose monitoring is yet to be implemented into routine practice. The reasons for the non-implementation of DRLs are complex but could include a lack of awareness and understanding of the role of DRLs in dose optimisation. In addition, DRLs are yet to be enforced in clinical practice by the regulating agency; the Nigerian Nuclear Regulatory Authority (NNRA).

The World Health Organisation report (WHO 2016) shows that CT, though representing only 6.3% of medical procedures involving ionising radiation, remains the modality responsible for the highest contribution of radiation dose (43.2%) in diagnostic imaging. In Nigeria, brain CT remains the most commonly performed CT procedure in CT imaging units (Ekpo et al. 2018). This is the same in the study site which has the highest CT patients throughput in the entire northwest region with an average of 25 patients daily. Brain CT has been reported to have the highest radiation dose in terms of the volume computed tomography dose index (CTDIvol) and dose length product (DLP). This is in comparison to other CT procedures such as the abdomen and chest (AAPM 2008; Garba et al. 2020). In addition, during a brain CT scan, the radiosensitive lenses of the eyes are frequently and directly

exposed to radiation which leads to the possibility of radiation-induced injuries such as cataracts (Image Wisely 2017; Poon & Badawy 2019). The procedure, therefore requires the highest level of dose justification and optimisation when compared to other imaging modalities such as conventional X-ray imaging using a Radiation Dose Management System (RDMS) (Rehani 2012; Parakh et al. 2016; Seeram 2022; Garba et al. 2023b). A radiation Dose Management System is a platform that tracks and organises patient radiation doses that could be used to establish DRLs for dose optimisation (Parakh et al. 2016; Fitousi 2017; IAEA 2023).

Studies conducted have shown that the use of a RDMS promotes the implementation of DRLs for dose justification and optimisation (Chatzoglou and Kottou 2016a; Nicol et al. 2016a; Loose et al. 2021; Garba et al. 2023b). Also, Diagnostic Reference Levels (DRLs) are a tool used by medical personnel including radiographers and radiologists for dose justification and optimisation purposes (ICRP 2017; Damilakis et al. 2023).

Due to the lack of RDMS in radiology centres in Nigeria, patients' reports, following CT procedures, are transmitted to the referring physicians without dose information. Providing dose information as part of radiologists' reports is a format that has been implemented and put into law in places around the globe; such as California, USA (Zucker et al. 2015). Having access to dose information could provide dose records and could be used in justifying and/or optimising a procedure (Rehani 2017). This motivated the present study to develop and implement a prospective manual RDMS that could be used to track brain CT doses in clinical practice. The integration of CT doses on the radiologist's report promotes the use and checking compliance with DRLs based on the translational research model. The translational research model facilitated the research findings, as in this study the established DRLs, were taken into consideration and implemented in the clinics to improve practice (Rubio et al. 2010). To enable proper implementation of the RDMS platform, personnel such as radiographers, radiologists, and referring physicians were assessed in terms of their knowledge of CT doses, DRLs, dose justification, and the use of the referral guidelines. No medical physicists were involved in this study, though their critical role in radiation dose management is

acknowledged as essential (McCollough 2016; Inoue 2023). This is because, in Nigeria, most medical physicists are confined to Radiotherapy due to their limited number.

Therefore, the cohort of this study only had radiographers, radiologists and referring physicians. In the course of the study, publications were made and contributions to knowledge from the publications were as follows:

a. A systematic literature review explored different RDMS with their strengths and weaknesses. The use of manual systems was noted to be still relevant in resource-constrained environments like the research site where no dose monitoring exists. Also, it was noted that RDMS promotes the use of DRLs as a tool for dose optimisation.
b. Knowledge of CT dose optimisation and justification among radiographers and radiologists including the referring physicians was established. This has helped in the development and successful implementation of manual RDMS to monitor radiation dose and scan parameters for brain CT for dose optimisation in the study locality.
c. Worthy of note from the use of RDMS, local paediatric DLP DRLs were noted to be two-three times higher than the international DRLs. This was a source of concern for children and therefore calls for a total review of protocol and CT practice in the study environment.

1.2 Statement of the research problem

Computed tomography remains the imaging modality responsible for the highest contribution of radiation dose (43.2%) in diagnostic imaging (WHO 2016). High radiation dose from CT requires careful dose justification and optimisation following the ALARA principle. In Nigeria, several CT radiation dose studies have been carried out, establishing local and national DRLs for dose optimisation (Garba et al. 2015; Ekpo et al. 2018). However, the implementation of DRLs through dose monitoring is yet to be implemented into routine clinical practice. The reasons for the non-implementation of DRLs are complex but could include a lack of awareness and understanding of the role of DRLs in dose optimisation. Also, DRLs are yet to be enforced in clinical practice by the regulating agency; the Nigerian Nuclear Regulatory Authority

(NNRA). The focus of the current study seeks to explore the translation of DRLs into clinical practice. This could be achieved through the development of a local radiation dose management system that will track and manage the radiation dose for brain CT. The brain CT doses could be checked to determine compliance with the established Nigerian DRLs for dose optimisation.

1.3 Aim of the study

The main aim of this study was to develop and implement the use of a prospective manual RDMS for brain CT. This aim was premised on the understanding that the use of RDMS will facilitate the implementation of DRLs based on the translational research mode approach for dose optimisation in clinical practice. The following objectives were constructed to answer the aim of the study.

1.4 Objectives of the study

i. To determine the available RDMSs in the literature and their usage.
   Question 1: What types of RDMSs exist globally?

ii. To develop a prospective manual RDMS for the brain CT examination.
   Question 2: What is the feasibility of developing a dose management system in a busy imaging department in Nigeria?

iii. To determine the knowledge and awareness of CT doses and DRLs among the radiographers and radiologists in a busy CT centre in Nigeria.
   Question 3: What is the radiographers' and radiologists' awareness and knowledge of CT doses and DRLs?

iv. To determine dose awareness, dose justification, and use of the referral guidelines among referring physicians in a tertiary hospital in Nigeria.
   Question 4: What is the referring physicians' awareness and knowledge of dose justification and use of the referral guidelines?

v. To implement a prospective manual RDMS for the brain CT examination.

Question 5: What is the feasibility of implementing a dose management system in a busy imaging department in Nigeria?

vi. To determine compliance of brain CT doses with the established DRLs amongst the radiographers and the radiologists.

Question 6: What is the impact of RDMS in managing brain CT doses to ensure compliance with the established DRLs among radiographers and radiologists in Nigeria?

vii. To evaluate the impact of a local dose management system for the brain CT examination in clinical practice.

Question 7: How can the use of the RDMS improve understanding of brain CT doses and the use of DRLs among radiographers, radiologists, and referring physicians in clinical imaging?

1.5 Significance of study

The RDMS template developed through this study was shown to be effective and efficient platform for tracking, monitoring, and management of radiation doses in CTDIvol and DLP as well as recording the scan parameters such as tube current and tube voltage for dose optimisation. It is anticipated that the developed dose management platform, when successfully implemented, will promote a culture of dose awareness, justification, and optimisation among radiographers, radiologists, and referring physicians. In addition, the RDMS can be used by the relevant stakeholders in Nigeria, such as the Nigerian Nuclear Regulatory Authority (NNRA) to monitor the use of the established DRLs in Nigeria for dose optimisation. The dose management system will also provide a platform for efficient decision-making for real-time CT protocol modification and optimisation based on the assessment of dose in CTDIvol and DLP and the scan parameters by tracking to identify the unintended errors that may occur during protocol selection. The developed manual RDMS is potentially a stepping stone to the later implementation of electronic monitoring of radiation doses in resource-constrained settings. In the future, the template, and lessons from the implementation of the manual system can be incorporated into an electronic platform such as the picture archival and

communication system (PACS) to provide a more effective and efficient RDMS.

Chapter One presents the background, objectives, and significance of the study. Chapter Two focuses on the literature related to the concept of dose optimisation and justification, and radiation dose in DRLs that was reviewed. Also, literature related to radiation dose management systems in computed tomography was reviewed.

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CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Chapter Two contains a literature review related to radiation dose justification and optimisation, as highlighted at the Bonn conference. In addition, DRLs for different CT studies, as established in Nigeria, are discussed. The systems for radiation dose management and its features are also discussed. These key aspects are additional to the content of the published systematic literature review presented in Chapter Four of this thesis.

2.2 The Bonn Call for Action Conference

Radiation dose from medical exposure remains an issue of concern due to the rise in cancer cases in the populace (Brenner et al. 2001; Mathews et al. 2013; Parikh et al. 2017; Ghetti et al. 2020). To ensure radiation exposure in clinical practice is properly managed and optimised, discussions on radiation protection were organised by the IAEA to assess the current practice and identify challenges (IAEA 2012). The first discussion which centred on the application of radiation measures in medicine took place in Bonn, Germany in 2012, and it was tagged as the Bonn Call for Action (IAEA 2012). The conference aimed to achieve the following: a) assess the current practice in radiation protection and identify weaknesses, b) provide ways for improving the current radiation protection measures in use, c) consider radiation measures in terms of advances, challenges, and opportunities, d) evaluate the implemented international programme on radiation protection, and e) make new recommendations for radiation protection taking into consideration newer equipment, procedures, protocols, and techniques (IAEA 2012). At the end of the 2012 conference, the following action plans were proposed:

i. Improve the implementation of the justification principle in radiation protection in the clinical setting.
ii. Improve the implementation of the radiation dose optimisation tools in the clinical setting.
iii. Improve and strengthen the safety features in the design and manufacturing of radiological equipment in terms of radiation protection.

iv. Ensure personnel education and training in radiation protection is improved and applied in the clinical setting.
v. Develop and promote research in radiation protection.
vi. Improve information dissemination about radiation exposure for both patients and personnel.
vii. Improve the radiation protection measures to avoid radiation incidents and accidents in the clinical setting.
viii. Improve the culture/practice of radiation safety amongst health care practitioners.
ix. Encourage discussion on radiation benefits and risks amongst personnel.
x. Ensure proper implementation of the radiation safety requirements globally.

Several relevant organisations such as the World Health Organisation (WHO), European Society of Radiology (ESR), International Society for Radiographers and Radiologic Technologists (ISRRT), and Pan African Congress of Radiology and Imaging (PACORI) made remarkable contributions to radiation protection in medicine to support the 10 proposed action plans (IAEA 2012). Some of these organisations such as PACORI launched a coordinated campaign among radiation workers to adhere to the principles of radiation protection and radiation safety in Africa (IAEA 2012). The Africa Safe (AFROSAFE) campaign launched by PACORI called on radiation workers in African countries to unite and address issues related to radiation protection in medicine (Parakh et al. 2016). The main focus of all organisations including the IAEA is to ensure the justification and optimisation processes are well rooted in clinical practice (IAEA 2012). In addition, the organisations ensure the training and retraining of staff to be conversant with their specific role regarding dose management and optimisation principles (Parakh et al. 2016). The referring doctors and radiologists ensure dose justification before the CT procedure commences. Whilst, dose optimisation and management are coordinated by the radiographers, radiologists and medical physicists during and after the procedure (Parakh et al. 2016).

2.3 Implementing the Bonn Call for Action Plans

In 2017, five years after the Bonn conference, the IAEA held another International conference in Vienna to review the action plans discussed at the Bonn conference (IAEA 2017). It is considered that a lot of work has been conducted in radiation protection in medicine across the globe including Nigeria. Additionally, the effort was found to be in response to the Bonn Call for Action and in particular was related to the justification and optimisation of patient radiation exposure. Specifically in Nigeria, a number of DRL studies, as presented in Table 2.1, have been carried out which led to improved DRL awareness as a tool for patient radiation dose optimisation in medical imaging (Abdulkadir et al. 2021b; Garba et al. 2023a). However, the established DRLs were yet to be implemented in clinical practice to monitor patient doses and to make a comparison to ensure the established DRLs were not exceeded. Only with this next step can the direct application of DRLs in CT dose optimisation be ensured. The majority of the CT DRL studies were conducted for the brain region which is the most commonly performed procedure. Also, during brain CT, the lens of the eyes is exposed to radiation which makes it susceptible to radiation-induced injuries such as cataracts. This provided a basis for RDMS platform that was used to monitor and manage radiation dose and guide dose justification and optimisation for CT brain imaging.

Table 2.1 presents DRLs for different CT procedures including brain CT as the most common examination. The diagnostic reference levels were established across the different regions in Nigeria indicating a geographical spread.

Table 2.1: Patient radiation dose studies conducted in Nigeria

Examination	Studies	Regions of country
Brain CT	Abdulkadir et al. (2021) Paediatrics	North-west
	Joseph Zira et al. (2021) Paediatrics	North-west
	Ekpo et al. (2019) Paediatrics	Nigeria
	Adejoh et al. (2018)	South-east
	Obed & Ekpo, (2018)	South-south
	Adejoh (2016)	South-east
	Okeji et al. (2016)	North-east
	Garba et al. (2015)	North
	Jibiri & Adewale (2014)	South-west
Chest CT	Rilwan, Onuchukwu, Umar, et al. (2020)	North-central
Brain and abdominal CT	Tobi (2021)	South-south
Brain, chest, and abdomen CT	Ukoha et al. (2023)	South-east
	Rilwan, Onuchukwu, Sabiu, et al. (2020)	North-west
	Abba & Ibrahim (2018)	North-west
	Abdulkadir & Schandorf (2016)	North-central
	Ekpo et al. (2018)	North-central
	Ngarama & Mohammed (2019)	North-east
	Akpochafor (2017)	South-west
	Hassan et al. (2020)	North-west
Urography CT	Garba et al. (2019)	North-west
Multiple body regions CT	OLaniyan et al. (2019)	South-west

2.4 Radiation Dose Management System

As defined in the previous section, a radiation dose management system (RDMS) is an organised and coordinated platform that allows patient radiation dose and scan parameters to be tracked, monitored and managed for dose justification and optimisation (Parakh et al. 2016; Fitousi 2017; NICE 2017; IAEA 2023). The primary roles of any RDMS include radiation dose optimisation, through checking the scan and dosimetric data, to ensure compliance with the local and national notification values, quality assurance, identification of wide exposure variations and provision of dosimetric records for radiation dose audit as well as for the establishment of local and nation DRLs (Loose et al. 2021). As part of the Bonn Call for Action proposed plans,

the IAEA, European Commission (EC), and American College of Radiology (ACR) embarked on raising awareness by developing a platform for a dose management system in Radiology (Fitousi 2017; Loose et al. 2021; IAEA 2023). As in many environments, dose management remains an important radiation safety tool in the European Union (EU) (Loose et al. 2021). The European Union stresses and ensures that the monitoring and control of patient radiation exposure, through the use of DRLs, must be adhered to in addition to the application of the justification principle (Loose et al. 2021). The European directives further state that the new Radiology equipment should be efficient enough to produce images of diagnostic quality while being based on the ALARA principle, and also should allow easy transfer of the dose information to the RDMS for dose audit and recording purposes (Fitousi 2017). This further supports the choice of CT in this study as it provides an instant dose report for each CT procedure performed and allows for easy transfer of dose information through a mini PACS system (from the scan console to the reporting console).

In 2019, a working group was launched by EuroSafe Imaging for the implementation of a dose management system in clinical practice (Loose et al. 2021; Vano et al. 2022b). Similarly, in 2023, the IAEA produced a document that guides and promotes patient radiation monitoring in medical imaging (IAEA 2023). The IAEA guidelines recommend the use of a manual system for centres without electronic RDMS or as a starting point for centres commencing radiation dose management (IAEA 2023).

In Garba et al. (2023b) systematic review that was conducted as part of this study, most studies reported the use of electronic RDMS, and only a few had manual RDMS. Additional electronic RDMS that were reviewed and published in the NICE (2017) study, are presented in Table 2.2. The systematic review evaluated the different RDMS methods, and their use and made a recommendation on those that could be implemented to promote dose optimisation in CT (Garba et al. 2023b). As stated earlier, most studies had electronic RDMSs which were believed to be more efficient in dose monitoring (Garba et al. 2023b; IAEA 2023).

Table 2.2: Vendor-specific RDMS in addition to what was reviewed in Garba et al., (2023b) as presented in NICE, (2017).

Technology name	Data acquisition	Installation	User access	Mode of data transmission
DoseM (Infinitt)	RDSR, MPPS, OCR, header	Local	Web	Electronic
DoseTrack (Sectra)	RDSR, MPPS, OCR	Cloud	Web	Electronic
DoseWise (Philips)	RDSR, MPPS, OCR, header	Local	App	Electronic
teamplay (Siemens Healthcare)	RDSR, OCR, header	Local and cloud	Web	Electronic

In low-resource settings such as Nigeria, there is a lack of infrastructure to support the electronic implementation of RDMS (IAEA 2023). Therefore, a manual dose management system remains the only means for dose monitoring in the effort to promote dose justification and optimisation in medical imaging (IAEA 2023). Although the manual system is considered cumbersome and time-consuming, with the validity of the results depending on the accuracy of the data transfer, it was found that with due diligence these limitations can be addressed (Greffier et al. 2015; Parakh et al. 2016; NICE 2017; Osman et al. 2020; IAEA 2023). Therefore, manual systems still have a place in countries with scarce resources and could be used as a starting point for dose monitoring and protocol optimisation. Over time a manual system could be automated for effective and efficient dose monitoring. The IAEA document provides a systematic approach to dose monitoring using both manual and electronic methods as presented in Figure 2.1 (IAEA 2023).

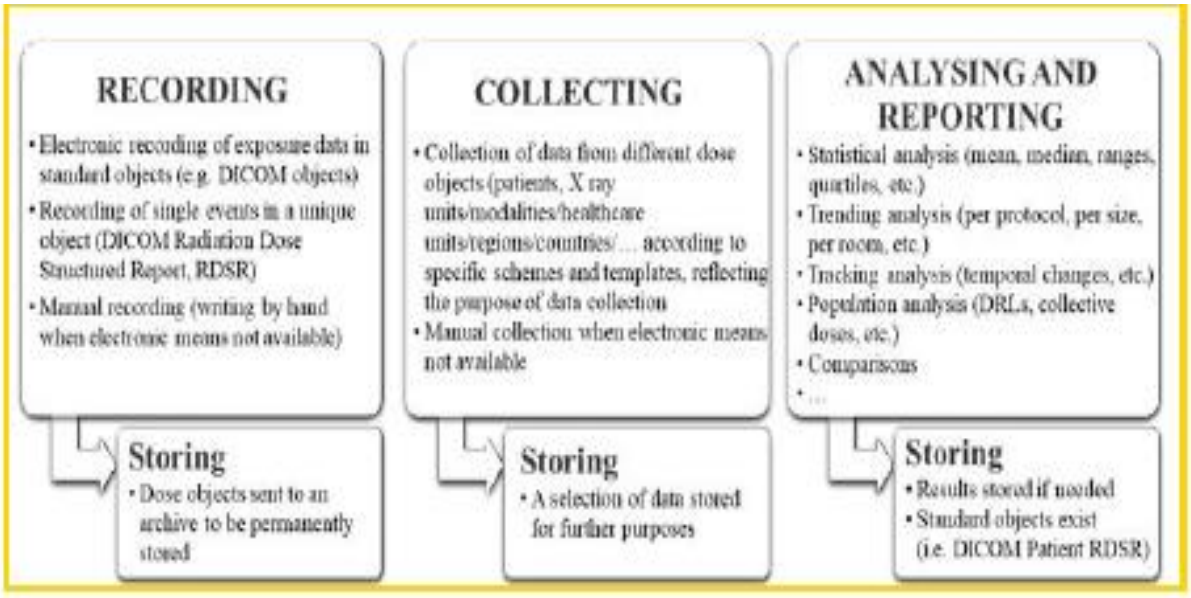

Figure 2.1: Patient dose monitoring using both manual and electronic systems. The figure is printed with permission from the International Atomic Energy Agency, Patient Radiation Exposure Monitoring in Medical Imaging, Safety Reports Series No. 112, IAEA, Vienna (2023).

2.5 Features of RDMS

To classify the exposure parameters and allow dose comparison, the RDMS template was designed to possess sections as recommended in the literature (Osman et al. 2020; Loose et al. 2021; IAEA 2023). The features include demography; examination information; scan parameters; scan and image reconstruction details; examination dose information; notification values; cumulative dose in DLP for the previous CT procedure; justification if above the notification value, a referring physicians section and space for the radiologist report (Figure 2.2). The alert value was not included as part of the features of the developed RDMS in this study. This is because, in the local protocol for brain CT, the cumulative dose may unlikely reach the suggested 1000 CTDIvol alert value (Vano et al. 2022a). However, for other CT examinations such as the abdomen where multiple series are performed, the alert value is required. Provision of the cumulative dose has been made, which accounts for the dose a patient could receive from a repeated examination over time (AAPM 2011; Vano et al. 2022a).

DEVELOPED CT RADIATION DOSE MANAGEMENT SYSTEM

Patient & Dose Information

Name: (1)			Age:			Clinic:		ADULT
Gender:			Weight (Kg):			Hosp. No.:		
Examination information (2)		**Scan parameters** (3)		**Indicate scan mode and image reconstruction used.** (4)	**Examination Dose information** (5)	**Notification values specific to this CT scanner** (6)	**Cumulative dose in DLP for the previous CT** (7)	**(Justify if above the notification values)** (8)
Procedure:	Routine Brain CT	kV		Wide volume	CTDIvol (mGy)	CTDIvol: 46		
Indication:		mAs		Helical:	Total DLP (mGy*cm)			
		Slice thickness		IR	Scan length (mm):	Total DLP: 1562		
		No. of slices		FBI	No. of series:			
Note: This exposure is equivalent to 100 chest X-rays and 10 months of exposure to natural background radiation (9) For further clarification, kindly contact the following number: +2348034532750								

_____ _____

Name of Radiographer **Sign & date**

Radiologist report

(10)

_____ _____

Name of Radiologist **Sign & date**

Figure 2.2: RDMS template

1 Demographic section:

The demographic section contains the name of the patient, gender, age, weight, clinic, and hospital number. In addition, the demographic section contains the patient ages grouped as <1 year, 1-<5 years, 5-<10 years, 10-<15 years and adults (>15 years) categories. The age grouping is recommended for all head examinations as weight does not well reflect head size (ICRP 2017; European Commission 2018; Inoue et al. 2022a). Although the European age classification for DRLs is different from what was adopted in this study (European Commission 2018), the adopted age classification is the most commonly used for establishing diagnostic reference levels (DRLs) as reported by the International Commission on Radiological Protection (ICRP) (ICRP 2017). This allowed the data obtained to be compared with the established DRLs from relevant studies.

2 Examination section:

The examination information section has the type of procedure and indication as reported in RDMS studies (Loose et al. 2021; Inoue 2023).

3 Scan parameter section:

The scan parameters section contains the tube kilovoltage (kV); tube current in milliamperes (mAs); slice thickness (ST) and the number of slices (NS). These parameters were registered in the scanner and were recorded at the end of every procedure. Recording of these scan parameters was recommended in previous RDMS studies (Loose et al. 2021; IAEA 2023; Inoue 2023).

4 Scan and image reconstruction section:

The scan and image reconstruction details section contains the type of scan mode used for the brain CT which could be a wide-volume axial or helical scan mode. In addition, the section contains the programmed image reconstruction software which could be iterative reconstruction (IR) or filtered back projection (FBP) (Inoue 2023).

5 Dose information section:

The examination dose information section has the CT machine radiation dose output expressed in CTDIvol and DLP which are based on the selected protocol. In addition, the section has the scan length which determines the extent of the length of the area covered which was from the vertex to the base of the skull, and the number of scan series which indicates whether both the non-contrast and contrast series were acquired or only the non-contrast series (Osman et al. 2020; Inoue 2023).

6 Notification value section:

The notification value was developed by AAPM and it is set in CTDIvol or DLP (AAPM 2011; Vano et al. 2022a). It triggers a notification to identify the dose value that is higher than the prescribed value by the Radiographer (Vano et al. 2022a). The dose notification values apply to individual scan series and require the radiographer to verify that the scan parameter settings are correct or should be modified (AAPM 2011; Tsalafoutas et al. 2020; Vano et al. 2022a). The International Commission on Radiological Protection (ICRP) recommends that DRLs should not be used as a notification value as DRLs are used for the optimisation of the protocol of a group of patients, not individual patients (ICRP 2017). Also, DRLs may trigger frequently and make the radiographers ignore high dose indices. Therefore, it is recommended that the notification value be set at a value above the institutional diagnostic range values (ICRP 2017). Therefore, the notification values for this study were set as the highest 5% value of the dose distribution in each age group. Though, AAPM recommends the use of CTDIvol or DLP (AAPM 2011), in this study, both parameters were used as notification values for robust radiation dose monitoring.

7 Cumulative dose section:

The cumulative dose in DLP indicates whether the patient has had a previous CT, and therefore, it shows cumulatively the dose the patient has received over time. i (Nett 2021). Although cumulative dose is not a perfect representation of total radiation risks, they provide an idea of the total

radiation dose a patient has received over time (Nett 2021). Nett, (2021) advise that cumulative doses should not deter patients from having imaging procedures where there is strong justification for the exams to be carried out.

8 Dose justification section:

The justification was handled at two different stages. In the first stage, justification is determined by the referring physicians and the radiologists by comparing risks versus benefits before the procedure starts (Parakh et al. 2016). The second stage of justification is for the radiographer to check the dose in CTDIvol and DLP and ensure it is within the notification value or otherwise. If within the notification value, it is indicated as “comply” and if the dose exceeds the notification value, the radiographer optimises the protocol or provides a reason to justify the increase in dose and proceed with the examination (Parakh et al. 2016). A similar study by Crowley et al. (2021) reported the use of justification feedback when the prescribed dose was exceeded which triggered a red alert notifying the radiographer for action to be taken.

9 Referring physicians’ section:

The referring physician section provides simplified information for the referring physicians to understand the magnitude of the exposure the patient received during brain CT procedures. It guides the referring physicians in making an informed decision before a request form is filled out for subsequent patients (Parakh et al. 2016) or for additional brain scans for the particular patient.

10 Radiologists section:

The radiologist report section provides a space where the radiologist writes reports. The radiologist assesses image quality by taking into consideration the scan parameters, and the radiation dose based on CTDIvol and DLP (Zucker et al. 2015).

From this literature review, the following conclusions are drawn:

i. The Bonn conference provided a platform to discuss action plans related to patient radiation dose which involved strengthening dose justification and optimisation in clinical practice.
ii. Follow-up from the Bonn conference focused on the implementation of action plans including dose justification and optimisation with an emphasis on the use of DRLs as a tool for optimisation.
iii. Different RDMSs were highlighted including electronic and manual systems with their strengths and weaknesses.
iv. Essential features of RDMS that provide effective dose records were listed and discussed.
v. The use of RDMS provided a system of dose monitoring and also facilitated the implementation of DRLs.

The next Chapter Three is the methodology for the three papers that were produced as part of this study.

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CHAPTER THREE: METHODOLOGY

3.1 Introduction

The chapter provides methodologies that were followed in carrying out this study. The study was conducted in stages, the methodologies were also explained in stages. The first methodology is for the systematic review of radiation dose management systems (RDMS), and this produced the first publication. The second methodology is for radiographers, radiologists and referring physicians's knowledge of dose optimisation and justification, and this produced the second publication. The third methodology is on the development and implementation of RDMS, and this produced the third publication.

3.2 Methods I: A Systematic Review of RDMS

The systematic literature search and review was conducted using a preferred reporting item for systematic review and meta-analysis (PRISMA) flow chart. The protocol for this systematic review was registered in PROSPERO with the registration number 325372. The search was conducted on publications from January 2005 to April 2022 in the following databases: PubMed (accessed date: 23 March 2022), EBSCOhost (accessed date: 23 March 2022), Web of Science (accessed date: 25 March 2022), Scopus (accessed date: 23 March 2022) and Cochrane library (accessed date: 4 April 2022). These databases were selected as they host the leading journals of radiography, radiology, and medical physics. In addition, relevant organisations such as the International Atomic Energy Agency (IAEA), the Radiological Society of North America (RSNA), the European Society of Radiology (ESR), the International Association of Radiation Protection (IRPA), and the International Society of Radiographers, and Radiological Technologists (ISRRT) were searched. Free hand-searching which involves searching the articles in the Google search engine was also conducted to identify articles not indexed in the selected databases or published on the website of the relevant organisations. The following defined search terms connected with a Boolean operator "AND" were developed: medical radiation dose AND dose management AND computed tomography AND management

system. To follow the population intervention and comparison observation (PICO) approach, the term *Medical radiation dose* was considered as population; *dose management* as intervention; *computed tomography* as comparison and *management system* as observation. Each term was further explored using the medical subject heading (MeSH) and free-text terms to provide relevant additional terms which were connected using the “OR” Boolean operator. Truncation was applied to identify terms where either the singular or plural term was used, and also where United States (US) English or British English spelling was used.

Screening of articles

Articles were screened by the student along with the three supervisors involved in the study based on the title, abstract and where necessary the full article. Only original research articles with RDMS established in CT were included. Furthermore, only articles published in the English language were included.

Quality assessment

The quality of the included articles was assessed using the quality assessment tool for quantitative studies as presented in Table 3.1, published in an article by Kmet et al. (2004). Additional, criteria, presented in Table 3.2 developed by the review team which includes a student and three supervisors were used to further assess the articles. All the articles were assessed individually using the assessment options provided in Tables 3.1 and 3.2. In the end, each article was considered either “strong”, “moderate” or “weak”. Articles that were assessed as “strong” satisfied all the criteria. Meanwhile, articles that were assessed as “moderate” failed in only one of the criteria presented. An article was considered “weak” when it failed in more than one criterion as presented.

Table 3.1: Critical appraisal tool for a cohort study Kmet et al. (2004)

Assessment criteria	Options			
	Yes	Partial	No	NA
1. Question/objective sufficiently described?				
2. Is study design evident and appropriate?				
3. Method of subject/comparison group selection or source of information/input variables described and appropriate?				
4. Subject (and comparison group, if applicable) characteristics sufficiently described?				
5. If the interventional and random allocation was possible, was it described?				
6. If interventional and blinding of investigators was possible, was it reported?				
7. If interventional and blinding of subjects was possible, was it reported?				
8. Outcome and (if applicable) exposure measure(s) well defined and robust to measurement/misclassification bias? Means of assessment reported?				
9. Is sample size appropriate?				
10. Analytic methods described/justified and appropriate?				
11. Some estimate of variance is reported for the main results?				
12. Controlled for confounding?				
13. Results reported in sufficient detail?				
14. Conclusions supported by the results?				

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments including the reason for exclusion:

_____
_____
_____

Table 3.2: Appraisal criteria developed by the review team

Assessment criteria	Options		
	Yes	Can't Tell	No
1. Did the study establish a dose monitoring system?			
2. Did the study mention the dose tracking method?			
3. Was DRL used for dose optimisation?			
4. Did the study mention the dose monitoring system was established?			
5. Did the study mention the manufacturer of the dose monitoring system?			
6. Did the study mention the dose extraction method from the images?			

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments including the reason for exclusion:

_____
_____
_____

Data extraction

From each article, the following information was extracted: type of RDMS; manufacturer of RDMS; dose tracking methods, host country of the research article, dose parameters and whether dose comparison using the DRLs was considered. The DRL tool was used to provide benchmarking for monitoring patient dose for dose optimisation.

Data synthesis

Information extracted from the included articles was synthesised narratively.

3.3 Methods II: Knowledge of CT Dose Justification and Optimisation among Radiographers, Radiologists and Referring Physicians

This was a cross-sectional questionnaire-based study conducted at a tertiary institution located in the northwest region of Nigeria from January to December 2022. Ethics approvals were obtained from the institutional

research and ethics boards of Cape Peninsula University of Technology as stated in the declaration page. The two questionnaires had a preliminary page providing information on the study and the confidentiality of the participants. The participants were given options to agree or otherwise before being included in the study. Only consented participants were included.

The entire radiologists, radiographers, and referring physicians working at the tertiary institution were invited to participate in the study. The referring doctors were contacted through their departmental heads, whilst the CT users (radiographers and radiologists) were contacted via WhatsApp platforms. The questionnaires were adapted from previous studies (Rehani and Berris 2012; Foley et al. 2013). A few changes were made which include removing and rewording some of the questions for clarity. The changes made were validated by the panel of experts using the Delphi technique that involves sequential rounds of discussions to get unambiguous questions. The experts comprised the radiographers, a radiologist and a biostatistician. The questionnaires were administered in the English language as all the participants were proficient in English.

Two different questionnaires were used in the study, one for the CT users, and the other for referring physicians. The two questionnaires are attached as Annexures 3 and 4. Amongst radiographers and radiologists the web-based method, using a Google form was chosen as this was an available media platform that could be used to invite and remind the radiology professionals as participants. The web-based questionnaire had 28 questions that covered the following sections: demographic information; knowledge and awareness of CT doses and image quality as well as DRLs.

A self-administered questionnaire was used for the cohort of referring physicians as there was no existing platform for contacting and reminding this participant group. The self-administered questionnaire had 20 questions with the following sections: demographic information; justification on the use of ionising radiation; knowledge about radiation exposure; and appropriateness of the use of the referral guidelines for imaging.

Pilot study

The questionnaires were pilot-tested among the selected CT users and referring physicians to determine the reliability of the study tool. The pilot testing was performed by administering the questionnaires to the 15 participants using a convenience method. Five participants each were selected amongst radiographers, radiologists and referring physicians. The pilot sample was determined based on a report of a study by Hertzog, (2008) who recommended a pilot sample of 10-20 participants of the studied sample. From the pilot sample, overall internal consistencies of 0.762 and 0.721 were determined using the Cronbach Alpha coefficient for CT users and referring physicians' questionnaires respectively at a 95% confidence interval. Cronbach Alpha is considered one of the most common statistical tools used to test scales that have been constructed or adopted for a survey questionnaire (Taber 2018).

Both questionnaires have options of yes and no; true and false; and multiple options tick box formats as appropriate to the particular questions. Some of the questions had an open-ended follow-up question where the participants were asked to state their understanding of these questions. At the end of the data collection process, the questions were manually entered into an Excel spreadsheet. Correct answers to the questions were given a score of one (1), meanwhile; incorrect answers were given a score of zero (0). Correct answers for the open-ended questions were determined based on the literature findings. A correct response was given a score of 1, whilst incorrect and incomplete responses were given a score of 0. Binning statistics in the statistical package for social sciences (SPSS) version (20) was used to define the scale of knowledge in this study as the scale was not provided in the questionnaires adapted. To determine knowledge in each section of the questionnaire, the total score from the participants in each section was obtained which was categorised into three: lower (≤33.3%), middle (>33.3%-66.6%) and upper (>66.6-100%) classes. The classes were further defined as poor for the lower class, moderate for the middle class and high for the upper class. Data cleansing was conducted to remove erroneous, missing

and incomplete data. The accuracy of the information provided in all the variables was rechecked.

The collected data were analysed using the SPSS version (20), supported by IBM SPSS Statistics 20, modified in May 2021. All categorical variables were presented in frequencies and percentages. A Yates-corrected chi-square statistic was used to determine whether there was a significant difference between the responses. A P value of 0.05 was used as a level of significance at a 95% confidence level. Only P values with Yates continuity corrections were reported where the data set was small.

3.4 Methods III: Establishment and Implementation of RDMS

As described in methods-II for the questionnaire study, a cross-sectional and prospective study was conducted on patients who presented for brain CT procedures at a tertiary institution located in the northwest region of Nigeria from August to December 2022. Ethics approvals as stated in the declaration page were obtained. The participants were given options to agree or otherwise before being included in the study. Only consented participants were included. These participants allowed their information related to radiation dose and scan parameters to be recorded and managed using the developed RDMS.

Quality control on the CT scanner

The CT scanner radiation dose output in CTDIvol and DLP were validated using Impact CT patient dosimetric calculator version 1.0.4. The scan parameters were entered in the system and the resultant dose in CTDIvol and DLP were noted not to differ significantly from the displayed CTDIvol and DLP on the scanner monitor. Furthermore, tube warm-up is performed daily by the radiographer to ensure consistent optimal image quality. Image quality assessment is also performed daily using image quality phantom and the result was noted to be within the acceptable limit as recommended by the CT scanner manufacturer.

CT radiation dose management

The CT radiation dose was monitored and managed using a manual radiation dose management system (RDMS) template which was developed based on a review of different literature (Parakh et al. 2016; Osman et al. 2020; Loose et al. 2021). The RDMS template has the following sections: demography; examination information; scan parameters; scan and image reconstruction details; examination dose information; notification values; cumulative dose in DLP for the previous CT procedure; justification if above the notification value, referring physicians section and space for the radiologist report. Information in these sections of the RDMS template was explained in Chapter Two.

Pilot study

Before implementation of the developed RDMS template, it was first pilot-tested over a month period on adult patients who were referred for brain CT in our tertiary institution. Paediatrics were excluded due to their limited number. However, the RDMS template was the same for both adult and paediatrics, the only difference was the age classifications in paediatrics. At the end of piloting, a total of 50 consented adult patients for brain CT were scanned. The data were scrutinised and analysed using SSPS software. Based on the result obtained, a few changes were made to ensure that the information provided on RMDS was essential and appropriate in managing the patient radiation dose and also promoting radiation dose optimisation. One of the changes made was changing the protocol from the helical mode to Wide Volume (WV). The helical protocol was the standard protocol for adult brain CT at the study centre. However, the pilot result shows that both helical and WV protocols were routinely used, and the patient doses in CTDIvol and DLP were statistically significantly ($p = 0.001$) higher in helical.

Protocol for brain CT at the study site

The brain images were acquired with the patient lying supine on the scanner table and the head positioned in the head holder. The patient's chin was tucked in to bring the radiographic baseline perpendicular to the midline of the table. The position also minimises radiation dose to the lenses of the eyes. Using laser lights, the head is positioned in the isocentre of the gantry as follows: the axial light is centred at the glabella, the coronal light is aligned

with the auricular plane of the head and the sagittal light is aligned to the median sagittal plane. Two scanograms were acquired in the front-occipital (FO) and lateral (Lat) projections. The scan is planned on the scan monitor using the positioning box and the images were acquired from the vertex to the base of the skull as reported in AAPM guidelines for brain CT protocol (AAPM 2016). However, in some trauma cases due to the suspected cervical spine injury, the protocol was modified to include the cervical spine. This group of patients were excluded from the study as the scan length is expected to be long which affects DLP.

The adult patients were scanned using the WV protocol. The WV protocol allows the scanner table to move into the gantry incrementally (Roy et al. 2018). Meanwhile, the paediatric patients were scanned using the helical mode. The helical mode allows continuous movement of the scanner table into the gantry during image acquisition (Seeram 2022). The helical mode is faster compared to WV, thus eliminating the possibility of motion blur in children. However, the protocol is associated with higher radiation exposure compared to WV if the same scan parameters are used unless the helical protocol is optimised.

Radiation dose management using RDMS

The validated RDMS template was used to monitor and manage the patient radiation dose for brain CT. For each patient, once the protocol was selected, the radiographer checked and verified the displayed dose in CTDIvol and DLP on the scanner console and ensured it was not above the established notification values in CTDIvol and DLP. The brain CT notification values were established as the highest 5% value of the dose distribution in each age group as presented in Chapter Two. The notification values were added as part of the information presented on the RDMS template depending on the age group. The age groups used for brain CT in this study were also presented in Chapter Two. Where the dose value(s) were noted to be above the notification value(s), the scan parameters were optimised by the radiographer. Where the scan parameters could not be adjusted for instance due to clinical requirements, a justifiable reason was offered. Thereafter, the radiographer

filled and signed the RDMS. The filled RDMS template was passed on to the reporting radiologists who wrote the report on the same RDMS template having access to all the scan and dose information provided on RDMS. The same RDMS template was designed on the computer where the radiologist report is typed. The typed report which was based on the information provided by the radiographer and the radiologist was printed, signed and submitted to the referring physicians who apart from the radiological findings also had access to information about the radiation dose the patient had incurred in the course of the procedure. The same process was repeated for all consented patients who were referred for brain CT including paediatrics during the data collection period.

Data collection

For each patient scanned, the following information was collected. Patient demographic information (age, weight and gender); examination information (indication); scan parameter details (kV, mAs, ST and NS); scan and image reconstruction details (scan mode and type of reconstruction software). In addition, radiation dose in CTDIvol and DLP including scan length and the number of scan series were collected. Notification values in CTDIvol and DLP; cumulative dose in DLP; and reason for justification where the dose exceeds the notification value were also collected.

Data cleansing

The collected data were cleaned for erroneous data entry or where most of the vital information such as radiation dose data was not provided.

Data analysis

The analysis was performed using the Statistical Package for Social Sciences (SPSS) version 20. The data were checked for normality and noted to be normally distributed based on the Shapiro-Wilk test results. The data was described using the mean and standard deviation. To establish local DRLs, CTDIvol and DLP were calculated in median values as recommended by the International Commission on Radiological Protection (ICRP) (ICRP 2017). The established local DRLs in median values were compared with the

relevant data from national and international studies. Although, most of the scans were acquired using multiple acquisitions whereby the patient had both non-contrast and contrast series, a single median DLP was calculated for comparison with the national DRL which reported the DLP based on a single series. Total median DLP as recommended by ICRP was equally recorded to allow comparison with the international DRLs. Inferential statistics based on one-way analysis of variance (ANOVA) were carried out to determine statistically significant differences in CTDIvol, DLP, kV and mAs between groups. A p-value of 0.05 at the 95% confidence interval (CL) was considered a level of significance.

The next chapters 4, 5 and 6 cover publications including manuscripts submitted for publication that were produced as a product of this study.

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CHAPTER FOUR: RADIATION DOSE MANAGEMENT SYSTEM IN COMPUTED TOMOGRAPHY PROCEDURES: A SYSTEMATIC REVIEW

Published article:

Garba, I., Engel-Hills, P., Davidson, F. and Ismail, A. (2023). Radiation Dose Management System in Computed Tomography Procedures: A Systematic Review. *Radiation Protection Dosimetry*, Volume 199, Issue 10, Pages 1063–1074, https://doi.org/10.1093/rpd/ncad124.

2023: vol.199, Issue 10; Pages 1063–1074.

Impact Factor in 2023: 1

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ABSTRACT

A systematic literature review was carried out to explore articles that reported the use of radiation dose management systems (RDMSs) in computed tomography (CT). The preferred reporting items for systematic review and meta-analysis flow chart were used to screen articles in PubMed, EBSCOhost, Web of Science, SCOPUS and Cochrane Library. A total of 1041 articles were retrieved and screened. After evaluation against criteria, 38 articles were selected and synthesised narratively. The results revealed that several RDMSs have been used in CT. The review also indicated that the use of RDMSs has promoted the implementation of diagnostic reference levels for dose optimisation. A RDMS, such as DoseWatch, is associated with compatibility challenges and failure in data transmission, while manual RDMSs are cumbersome and prone to data entry errors. Thus, a robust automated RDMS that is compatible with the different CT systems would provide efficient CT dose management.

Keywords: computed tomography; diagnostic reference levels; dose tracking method; dose optimisation, dose management systems.

INTRODUCTION

Computed tomography (CT) is an indispensable item of equipment in health care, which provides medical images for the diagnosis of injury and diseases [1]. While the contribution of CT to the clinical care of patients is acknowledged, radiation exposure from CT remains an issue of concern [2, 3]. This because radiation exposure from CT contributes in the region of 62% of the total exposure from diagnostic examinations involving the use of ionising radiation [3]. Efforts have and are continued to be made to reduce radiation dose, and recent advancements in CT scanner technology have contributed to reducing the patient radiation dose while maintaining images of diagnostic quality [4]. However, the cumulative doses remain high as the number of CT examinations continues to increase [4].

The consequence of long-term radiation exposure from medical procedures such as CT could be serious and may include cancer induction in the exposed individuals [3]. To ensure the radiation dose is well optimised while maintaining diagnostic image quality, the joint commission in the USA, which is a voluntary hospital accreditation body, recommends recording radiation doses for every CT examination performed and also investigating when the radiation dose exceeds the established diagnostic reference levels (DRLs) [3]. The ionising radiation medical exposure regulations (2000) further recommend a regular audit of patient radiation exposure to ensure that acceptable image quality is obtained at the lowest possible radiation dose [2]. As an additional action, a working group was formed by EuroSafe imaging in 2019 that was tasked with the development and implementation of a dose management system (DMS) in clinical practice [5]. One of the aims of implementing a DMS was to promote the establishment and use of local, national and European DRLs [5]. Radiation dose management in CT is defined as a method for coordinating personnel activities to ensure proper review and optimisation of CT protocols and doses [6]. Such DMSs have been reported to reduce patient radiation dose through standardisation and

optimisation of CT protocols [3]. A DMS should have the following elements: dose-tracking software, alert notification, protocol mapping and support for dose optimisation [2].

Several commercial and locally produced CT DMSs have been developed and are currently being used in clinical practice [3, 7, 8]. A systematic literature review was conducted to determine the RDMSs available and their use and furthermore to propose ways to promote dose optimisation for CT procedures.

METHOD

The systematic literature search and review was conducted using a preferred reporting item for systematic review and meta-analysis (PRISMA) flow chart (Figure 1). The protocol for this systematic review was registered in PROSPERO with the registration number 325372. The search was conducted on publications from January 2005 to April 2022 in the following databases: PubMed (accessed: 23 March 2022), EBSCOhost (accessed: 23 March 2022), Web of Science (accessed: 25 March 2022), Scopus (accessed: 23 March 2022) and Cochrane library (accessed: 4 April 2022). These databases were selected as they host the leading journals of radiography, radiology and medical physics. In addition, relevant organisations, such as the International Atomic Energy Agency, the Radiological Society of North America, the European Society of Radiology, the International Association of Radiation Protection and the International Society of Radiographers and Radiological Technologists, were searched. Free hand-searching, which involves searching the articles in the Google search engine, was also conducted to identify articles not indexed in the selected databases or published on the websites of the relevant organisations. The following defined search terms connected with a Boolean operator 'AND' were developed: medical radiation dose AND dose management AND computed tomography AND management system. To follow the population intervention and comparison observation (PICO) approach, the term *Medical radiation dose* was

considered as population; *dose management* was considered as intervention; *computed tomography* was considered as comparison and *management system* was considered as observation. Each term was further explored using the medical subject heading and free text terms to provide relevant additional terms, which were connected using the 'OR' Boolean operator, as presented in Table 1. Truncation was applied to identify terms where either the singular or the plural term was used and also where US English or British English spelling was used.

Screening of articles

Articles were screened by one of the four reviewers involved in the study (doctoral student, two radiographers and radiologist) based on the title, abstract and, where necessary, the full article. Only original research articles with RDMS established in CT were included. Furthermore, only articles published in the English language were included.

Quality assessment

The quality of the included articles was assessed using the quality assessment tool for quantitative studies, as presented in Table 2, published in an article by Kmet *et al*. [9]. Additional criteria, developed by the review team, were used to further assess the articles (Table 3). All the articles were assessed individually using the assessment options provided in Tables 2 and 3. A determination was made and each article was considered as 'strong', 'moderate' or 'weak'. Articles that were assessed as 'strong' satisfied all the criteria (Tables 2 and 3). Meanwhile, articles that were assessed as 'moderate' failed in only one of the criteria presented, while an article was considered as 'weak' when it failed in more than one criterion.

Data extraction

From each article, the following information was extracted: type of RDMS, manufacturer, dose-tracking methods, country, dose parameters and whether dose alert using the DRL was considered and if the DRL tool was

used to provide benchmarking for monitoring patient dose for dose optimisation.

Data synthesis

Information extracted from the selected articles was synthesised narratively, and the result is presented in a tabular form in Tables 4–6.

RESULTS

A total of 939 articles were obtained from the selected databases, while a total of 102 articles were obtained from the websites of the relevant organisations and free hand-searching, giving an overall total of 1041. Of the 1041 articles retrieved, 32 were removed as duplicates and the total number of articles was reduced to 1009. These articles were screened based on the title, abstract and, where necessary, the full article, and the 38 relevant articles were scrutinised as indicated in the PRISMA flow chart (Figure 1).

The screened articles were grouped based on the DMSs used and reported in the articles. Table 4 presents 10 out of 38 articles that reported the use of Radimetrics, a dose-monitoring software produced by Bayer Healthcare. In all the 10 articles, dose and patient information were electronically extracted, and in 7 of 10 articles, the following dose information was extracted: volume CT dose index (CTDIvol), dose length product (DLP), effective dose (ED) and size-specific dose estimate (SSDE). Of the 10 articles, 8 of them reported the use of DRLs to identify high-dose protocols.

Table 5 presents articles that reported the use of DoseWatch, which is also an available dose-monitoring software, and a product of GE Healthcare. Of the 38 articles, 12 reported the use of DoseWatch, and in all the 12 articles, the dose and patient information were electronically transferred from the dose report of the scanner to the dose-monitoring software. Of the 12 articles, 8 reported the dose information based on CTDIvol and DLP; 3 articles reported the dose based on CTDIvol, DLP and ED and 1 article reported the dose based on CTDIvol, DLP, ED and SSDE. In 9 of the 12 articles, the use of DRLs as a tool for tracking high doses was reported.

In Table 6, the remaining commercial and locally produced in-house dose-monitoring software are presented. There is a lack of uniformity in the dose information reporting format as articles reported the dose using different dose parameters. In these remaining 16 articles, 6 did not report the use of DRLs to identify high doses. In 2 of the 16 articles, dose information was extracted manually by the radiographers, while in 1 out of 16 articles, the dose information was extracted using both electronic and manual methods.

DISCUSSION

The study systematically reviewed the literature on RDMSs used in CT to evaluate the different RDMS methods, and their use and make a recommendation on those that could be implemented to promote dose optimisation in CT practice. Tables 4 and 5 present the most common dose-monitoring systems: Radimetrics and DoseWatch.

Radimetrics is a dose-monitoring software, produced by Bayer Healthcare, that provides comprehensive and real-time monitoring of patient doses [44]. It tracks and identifies the radiation doses for a patient from the dose report file of PACS [12]. The use of Radimetrics was reported in 10 studies (Table 4). The wide use of Radimetrics software could be connected to the fact that it is compatible with a variety of CT scanner models and types [44]. For example, Radimetrics is reported to have been connected to the Siemens, GE, Toshiba and Philips CT scanners (Table 4). In addition, the Radimetrics software calculates and provides dose information based on the ED and the SSDE. The ED parameter is calculated using the tissue weighting factors published by the International Commission on Radiological Protection 103 [11]. The ED parameter provides information on organ dose for the different examinations according to the body size [11]. Meanwhile, SSDE is a radiation dose estimate that takes into consideration corrections based on the patient size, which was measured using linear dimensions on the patient or patient images [11]. Mathematically, SSDE can be calculated by multiplying CTDIvol by the correction factor based on the

size of the patient [11]. The CTDIvol parameter is independent of patient size, thus SSDE provides information to account for the body size variation [45]. Three out of the 10 studies reported the CTDIvol and DLP parameters only [3, 7, 17]. The remaining seven studies reported CTDIvol and DLP alongside ED or SSDE or both for comprehensive analysis [10–16]. The combined use of the multiple-dose parameters provides robust radiation dose monitoring as the dose parameters provide different information. The dose information provided is complimentary, thus one dose parameter cannot replace the other and there is a need to have a more relevant dose parameter for complete dose assessment and monitoring.

In 8 out of the 10 studies that reported Radimetrics software, the reported and calculated doses were compared with DRLs to indicate when DRLs were exceeded. The DRL parameter is therefore one of the important features of RDMSs [5]. RDMS promotes the use and implementation of DRLs as a tool for dose optimisation in the clinical setting [44]. The Radimetrics allow DRLs to be set up to identify outliers that can be corrected through the process of dose optimisation [10]. One additional advantage of including DRLs is that it reduces variation in dose for the same protocol and CT scanner [44]. This ensures standardisation and consistency in the use of the scan protocol. Although Radimetrics allows dose thresholds to be set up to identify outliers, the continuous use of the established or defined reference values as dose thresholds is recommended to further promote the implementation of DRLs in the clinical environment and thereby ensure dose monitoring and optimisation.

Automated dose extraction was reported in the 10 studies that used Radimetrics (Table 4). The use of such automated dose-tracking helps to avoid manual dose-recording, which is time-consuming and prone to human typographical error. In addition to automated dose-tracking, the automated function in Radimetrics provides monitoring, simulation and calculation [44]. The automated function also has a dose alert capability to indicate to the CT users when the dose exceeds the programmed dose

threshold. In addition, the dose alert system enables CT users to adhere to the dose threshold and use it strictly for timely optimisation. However, it is noted that none of the 10 studies with Radimetrics reported the use of the alert function. DRLs were defined and used in eight studies with Radimetrics, however, not having an alert system that would notify the CT users when the dose threshold level is exceeded could be counter-productive as high doses could easily go unnoticed. Therefore, it is recommended that for the CT systems equipped with Radimetrics it is ensured that the alert system is activated in addition to having defined threshold values.

DoseWatch, a GE Healthcare software, designed to monitor the radiation doses of a patient undergoing a CT procedure [46] tracks and systematically extracts and analyses dose-related information such as CTDIvol and DLP [2]. One of the advantages of DoseWatch is that, similar to Radimetrics, it allows the dose-monitoring team to set a dose threshold for a procedure and, once this dose is exceeded, the software automatically sends an alert to the CT user for corrective action [2]. For example, in a study by Crowley *et al*. [18] that reported dose monitoring using DoseWatch, their findings indicated that the use of the alert system reduced the rate of unjustifiable increases to the patient dose, above the defined threshold, from seven to three because of the alert to the CT user. However, they explained that there is a low report in justification feedback due to the additional responsibility required of the CT users who operate in a busy working environment. Therefore, they suggest that to have an effective and efficient implementation of RDMS, the workflow process needs to be improved.

In 8 out of 12 articles that used DoseWatch, it was reported that the dose thresholds were set up to guide the CT user or the dose-monitoring team when the pre-scribed dose exceeded the recognised or defined DRLs (Table 4). This shows that DRLs are being implemented using RDMS in the clinical environment. However, as reported by Crowley *et al*. [18], there were some reported cases of failure in data transmission from the CT scanner to

DoseWatch. This could cause some high doses being missed unless the CT users are vigilant as DoseWatch does not alert when there is a failure in the data transmission. This limitation could impact on the full-scale dose optimisation process as some high doses that need to be corrected would not be accounted for [(18) .

In a study conducted by Katsari *et al*. (19), it was reported that DoseWatch provides the option for saving justification codes, which are a list of possible reasons that could allow for a protocol modification. These codes are used by the CT user to quickly explain the root cause for modifying the protocol when the dose exceeded the threshold (19). Even with an accessible list of justification codes, compliance in justification feedback remains a challenge because the CT users may not have the time to read through and select the justification code.

Higashigaito *et al*. (25) reported that embedded in the software are features for dose analysis for an individual protocol and dose comparison of the protocols of different studies. This is an important feature of the DoseWatch system, as it facilitates dose optimisation by ensuring that the dose for a procedure is well justified. These features are also programmed in Radimetrics, and this reduces dose variation and also promotes dose optimisation (44).

Like Radimetrics, DoseWatch is compatible with a variety of scanners as reported in Table 5. However, according to Chatzoglou and Kottou (23) and Osman *et al*.(2), one of the limitations of the DoseWatch software, a GE system, is that the dose information from other vendors such as Siemens and Philips may have to be transferred manually, and the dose information that is unsuccessfully transferred cannot be tracked and monitored by the software. This calls for improvement in the software technology to allow the automatic transfer of dose and patient information from the non-GE scanners to the DoseWatch software.

Similar to Radimetrics, DoseWatch provides automatic calculation of

other dose parameters, such as ED [21, 25, 27] and SSDE [24], in addition to the conventional CTDIvol and DLP that are extracted from the radiation dose structured report (RDSR) or Digital Imaging and Communication in Medicine (DICOM) header (Table 5). This feature has made DoseWatch very robust, versatile and comparable to Radimetrics. However, the two RDMS systems (Radimetrics and DoseWatch) require an established and developed facility, equipped with a PACS system, for proper installation. These facilities are not widely available in a resource-constrained environment, which perhaps explains why there are no RDMS studies from the African continent.

Several commercial and locally produced dose-monitoring systems have been established as presented in Table 6. In these examples, the software also extracts the dose information from RDSR which is later viewed and interpreted by the dose-monitoring team. In Table 6, two of the articles reported dose-tracking and monitoring using a manual approach [31, 32]. The manual process provides the CT user with an opportunity to be more conversant with dose-tracking, monitoring and possible causes of optimisation [35, 44]. Further, due to intermittent data transmission failure associated with DoseWatch, the manual process ensures adequate transfer of dose information by making sure the CT users are more vigilant in ensuring that all doses that exceed the threshold are tracked and recorded for corrective action[18, 23]. However, the manual process is cumbersome and characterised by typographical error; therefore, the process of dose monitoring cannot be performed routinely and systematically as in the case of automatic transmission. Thus, the automated method is recommended as it ensures the patient and dose information is seamlessly transferred from RDSR to the software system.

A study by Keegan *et al*. [37] that used both an automated and manual method, reported that the manual method took a long time, but there were no errors in reporting the dose information. Thus, they recommended that the manual process is feasible for a facility that wants to monitor patient doses but does not have access to a commercial automated system. This

indicates that the manual method can still be used where software is not available or to augment an existing automated system, as a form of quality control. However, there is a need for due diligence to minimise the possible errors that could be encountered using both automated and manual methods.

Table 6 presents a list of 16 articles that reported RDMSs apart from Radimetrics and DoseWatch. The list of RDMSs presented includes some of the following: Dose On-Line for Quality Assurance (DOLQA), eXposure, Doseintelligencea and RADIANCE. Similar to Radimetrics and DoseWatch, 7 articles out of 16 reported the implementation of DRLs. However, of all the 38 articles reviewed, not 1 is from an African country, which indicates that RDMS is yet to be established in Africa. As reported previously, some of the features of RDMS include collecting dosimetric information to establish local or national DRLs and also checking for compliance with the established DRLs. There are African countries where DRLs have been established, but having no country with RDMS indicates that the use of DRLs is yet to be implemented widely in the clinical setting. There is, therefore, a need for RDMS to promote the implementation of DRLs in Africa and to unravel the importance of having DRLs established.

The review of literature on dose-monitoring systems has highlighted several applications of RDMS in dose-tracking, monitoring, notification and optimisation. However, apart from compatibility and failure in data transmission challenges, RDMS is also limited in not providing the referring physicians with the dose information that guides them in decision-making. As CT is associated with a high radiation dose, providing dose information that helps referring doctors in their decision-making about the use of CT could improve patient dose management. Currently, RDMSs are being managed by radiographers, radiologists and medical physicists, while referring physicians who are the first-line decision-makers are not being involved. Therefore, providing additional information on the CT dose that can be communicated to the referring physicians could improve the justification process for requesting a CT procedure.

The RADIANCE software reported by Cook *et al*. [39] provides CT users

with the opportunity to see how dose varies with factors, such as patient weight, and guides for appropriate dose optimisation. Other RDMS software, such as Radimetrics and DoseWatch, that extract their dose information from the RDSR and DICOM header do not have weight information, which is an important parameter for determining patient dose. The manual RDMS provides this information, although it is a cumbersome and time-consuming system. This calls for a holistic review of the current automated RDMSs to ensure that factors that affect dose are well captured for a complete review of patient doses.

CONCLUSION

The findings of the review have highlighted various RDMSs currently being used to manage CT doses. The findings have indicated that the use of RDMSs has promoted the implementation of DRLs that encourage dose optimisation. However, the review has shown that automated RDMSs such as DoseWatch are associated with equipment compatibility challenges and failure in data transmission, while manual RDMSs are cumbersome and prone to data entry errors. Therefore, providing a robust automated system compatible with the different CT systems will provide efficient CT dose management. The manual RDMS can be applied in environments where automated systems are not available but should mainly be used as a QC tool in monitoring the automated system.

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CONFLICT OF INTEREST

There was no conflict of interest in this study.

Table 1: Developed search terms using the PICO approach

Population	**Intervention**	**Comparison**	**Outcome**
CONCEPT 1	**CONCEPT 2**	**CONCEPT 3**	**CONCEPT 44**
Medical radiation dose OR medical radiation doses OR dose OR doses OR radiation OR radiation dose OR radiation doses OR patient dose OR patient doses OR radiation dosimetry OR patient dosimetry	Dose management OR radiation dose management OR radiation protection standard OR radiation protection standards OR patient safety OR radiation dose metrics OR dose metrics OR radiation monitoring OR radiation safety practice OR radiation safety practices	CT OR computed tomography OR CT scan OR CT scans OR tomography OR computed axial tomography	Management system OR management systems OR management software OR monitoring system OR monitoring systems OR monitoring software OR medical imaging system OR medical imaging systems OR dose management software OR dose management system OR dose management systems OR software OR software standards OR radiation dose management system OR radiation dose management systems

Table 2: Critical appraisal tool for a cohort study presented in Kmet et al. [9]

Assessment criteria	Options			
	Yes	Partial	No	NA
1. Question/objective sufficiently described?				
2. Is the study design evident and appropriate?				
3. Method of subject/comparison group selection or source of information/input variables described and appropriate?				
4. Subject (and comparison group, if applicable) characteristics sufficiently described?				
5. If the interventional and random allocation was possible, was it described?				
6. If interventional and blinding of investigators was possible, was it reported?				
7. If interventional and blinding of subjects was possible, was it reported?				
8. Outcome and (if applicable) exposure measure(s) well defined and robust to measurement/misclassification bias? Means of assessment reported?				
9. Is the sample size appropriate?				
10. Analytic methods described/justified and appropriate?				
11. Some estimate of variance is reported for the main results.				
12. Controlled for confounding?				
13. Results reported in sufficient detail?				
14. Conclusions supported by the results?				

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments including the reason for exclusion:

_____

_____

Table 3: Appraisal criteria developed by the review team

Assessment criteria	Options		
	Yes	Can't Tell	No
1. Did the study establish a dose monitoring system?			
2. Did the study mention the dose tracking method?			
3. Was DRL used for dose optimisation?			
4. Did the study mention the dose monitoring system was established?			
5. Did the study mention the manufacturer of the dose monitoring system?			
6. Did the study mention the dose extraction method from the images?			

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments including the reason for exclusion:

Table 4: Information extracted from the articles that reported the use of Radimetrics software

SN	Authors	Study design	Sample Size	Manufacturer	Data extraction method	Radiation Dose monitoring system	CT scanner	Dose tracking method	Country	Intervention	Dose parameters	Quality assessment score
1.	Fukunaga et al.[10]	Retrospective	642 patients	Bayer	RDSR and PACS	Radimetrics	Toshiba and Siemens scanners	Automated	Japan	Compared with DRLs	CTDIvol, DLP, SSDE	Strong
2.	Ghetti et al.[11]	Prospective	3224 patients	Bayer	RDSR, header	Radimetrics	3 Siemens scanners	Automated	Italy	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
3.	Li et al [12]	Retrospective	158 463 exams	Bayer	RDSR	Radimetrics	7 Siemens, 2 Philips and 1 GE scanners	Automated	China	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
4.	Rajiah et al. [3]	Prospective	222 CT protocols	Bayer	RDSR	Radimetrics	Four major vendors but names not specified	Automated	Dallas, TX USA	Not specified	CTDIvol, DLP	Moderate
5.	Guberina et al.[13]	Prospective	Phantom study	Bayer	RDSR and DICOM	Radimetrics	I Siemens scanner	Automated	Germany	Not specified	CTDIvol, DLP, ED, SSDE	Moderate
6.	Lee et al.[7]	Prospective	49863 scans	Bayer	RDSR	Radimetrics	6 Philips and 2 GE scanners	Automated	Philadelphia USA	Compared with DRLs	CTDIvol, DLP	Strong
7.	Guberina et al.[14]	Prospective	Not provided	Bayer	RDSR, header	Radimetrics	7 scanners, but names not provided	Automated	Germany	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
8.	Parakh et al.[15]	Retrospective	85187 exams	Bayer	RDSR, header	Radimetrics	7 Siemens and I Philips	Automated	Switzerland	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
9.	Smith-Bindman et al.[16]	Prospective	274124 exams	Bayer	RDSR	Radimetrics	14 Siemens, 13 GE, 2 Philips, Toshiba	Automated	California, USA	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
10.	MacGregor et al.[17]	Prospective	120836 exams	Bayer	RDSR, header	Radimetrics	2 GE scanners	Automated	Canada	Compared with DRLs	CTDIvol, DLP	Strong

Radiation dose structure report (RDSR); Digital Imaging and Communication in Medicine (DICOM); Diagnostic Reference Level (DRL)

Table 5: Information extracted from the articles that reported the use of GE DoseWatch software

SN	Authors	Study design	Sample Size	Manufacturer	Data extraction method	Radiation Dose monitoring system	Exams	Dose tracking method	Country	Intervention	Dose parameters	Quality assessment score
11.	Crowley et al.[18]	Retrospective	11298 exams	GE	PACS	DoseWatch	One GE scanner	Automated	Ireland	Compared with DRLs	CTDIvol, DLP	Strong
12.	Katsari et al.[19]	Prospective	Not provided	GE	RDSR	DoseWatch	CT scanners not specified	Automated	European countries	Compared with DRLs	CTDIvol, DLP	Strong
13.	Osman et al.[2]	Prospective	361 CT data set	GE	PACS	DoseWatch	Siemens and GE scanners	Automated	Malaysia	Compared with DRLs	CTDIvol, DLP	Strong
14.	Poehler et al.[20]	Retrospective	2026 Exams	GE	RDSR	DoseWatch	Two GE and one Siemens	Automated	Germany	Compared with DRLs	CTDIvol, DLP	Strong
15.	Rampado et al.[8]	Prospective	12000 exams	GE	RDSR, DICOM header	DoseWatch	Three GE CT scanner	Automated	Italy	Not specified	CTDIvol, DLP	Moderate
16.	Niiniviita et al.[21]	Retrospective	1526 exams	GE	RDSR, header	DoseWatch	Siemens and Toshiba CT scanner	Automated	Finland	Compared with DRLs	CTDIvol, DLP, ED	Strong
17.	De Bondt et al.[22]	Retrospective	296 exams	GE	RDSR, header	DoseWatch	Three GE and two Siemens CT scanners	Automated	Belgium	Compared with DRLs	CTDIvol, DLP	Strong
18.	Chatzoglou and Kottou, [23]	Prospective	2451 CT exams	GE	RDSR, header	DoseWatch	One Philips CT scanner	Automated	Greece	Compared with DRLs	CTDIvol, DLP	Strong
19.	Heilmaier et al.[24]	Prospective	6413 exams	GE	RDSR, header	DoseWatch	Two GE CT scanners	Automated	Switzerland	Compared with DRLs	CTDIvol, DLP, SSDE	Strong
20.	Higashigaito et al.[25]	Prospective	752 exams	GE	RDSR, header	DoseWatch	Three Siemens CT scanners	Automated	Switzerland	Not specified	CTDIvol, DLP, ED	Moderate
21.	Nicol et al. [26]	Prospective	7546 exams	GE	RDSR, header	DoseWatch	Three GE CT scanners	Automated	UK	Compared with NDRLs	DLP	Strong
22.	[27]Kirova et al. [27]	Prospective	9000 exams	GE	PACS	DoseWatch	one GE CT scanner	Automated	Bulgaria	Compared with DRLs	CTDIvol, DLP, ED	Strong

Radiation dose structure report (RDSR); Digital Imaging and Communication in Medicine (DICOM); Diagnostic Reference Level (DRL)

Table 6: information extracted from the articles that reported other software

SN	Authors	Study design	Sample Size	Manufacturer	Data extraction method	Radiation Dose monitoring system	CT scanner	Dose tracking method	Country	Intervention	Dose parameters	Quality assessment score
23.	Kirova et al. [28]	Prospective	21567 CT exams	Not provided	RDSR	Dose On-Line for Quality Assurance (DOLQA)	Not specified	Automated	Spain	Compared with DRLs	CTDIvol, DLP	strong
24.	Nakada et al.[29]	Retrospective	13 CT centres	Japan Dose Index Registry	RDSR	National Institute of Radiological Science tool (NIRS Tool and Dose Manager	Siemens, Toshiba, GE and Philips scanners	Automated	Japan	Compared with DRLs	CTDIvol, DLP	Strong
25.	Kim et al.[30]	Prospective	Not provided	Not provided	RDSR, DICOM	PACS	Not specified	Automated	Korea	Compared with DRLs	DLP	Weak
26.	AlSuwaidi et al.[31]	Prospective	9321 exams	Not provided	RDSR	RIS/PACS	GE scanner	Manual	Dubai	Compared with DRLs	DLP, ED	Strong
27.	AlSuwaidi et al.[32]	Prospective	3386 exams	Not provided	RDSR	RIS/PACS	3 unspecified scanners	Manual	Dubai	Compared with DRLs	DLP, ED	Strong
28.	Rehani et al.[33]	Retrospective	4283738 exams	Bryn Mawr, USA	RDSR	Imalogix	Not specified	Automated	USA	Not specified	DLP, ED	Moderate
29.	Riccardi et al.[34]	Prospective	Not provided	Commercially available product made by Medsquare France	RDSR,	Radiation dose monitor (RDIM) software	7 Siemens, 7 GE, 3 Philips, 2 Toshiba	Automated	Italy	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
30.	Tsapaki et al.[35]	Prospective	6010 exams	Software manufactured in Belgium	RDSR	Dose Qaelum software	1 Philips scanner	Automated	Greece	Compared with DRLs	CTDIvol, DLP, ED	Strong

Radiation dose structure report (RDSR); Digital Imaging and Communication in Medicine (DICOM); Diagnostic Reference Level (DRL)

Table 6: Information extracted from the articles that reported other software (cont)

SN	Authors	Study design	Sample Size	Manufacturer	Data extraction method	Radiation Dose monitoring system	CT scanner	Dose tracking method	Country	Intervention	Dose parameters	Quality assessment score
31.	Boos et al.[36]	Retrospective	36523 exams	DoseIntelligence, Pulmokard GmbH, Herdecke, Germany	RDSR	DoseIntelligence	3 Siemens	Automated	Germany	Compared with DRLs	CTDIvol, DLP	Strong
32.	Keegan et al. [37]	Prospective	5846 exams	Commercially available product	RDSR, header	eXposure	8 GE scanners	Manual and Automated	California USA	Compared with DRLs	CTDIvol, DLP, ED, SSDE	Strong
33.	Nitrosi et al.[38]	Prospective	Not provided	Web-based software developed using Pentaho suite	RDSR and MPPS	Gray Detector Software	4 Philips, 3 GE and I Siemens scanners	Automated	Italy	Compared with DRLs	DLP	Strong
34.	Cook et al.[39]	Prospective	Not provided	Open-source	RDSR, header	RADIANCE	Not provided	Automated	Philadelphia USA	Not specified	CTDIvol, DLP, ED	Moderate
35.	Christianson et al.[40]	Prospective	6351 exams	Not provided	Dose report screen shot	DICOM	3 GE scanners	Automated	North Carolina USA	Not specified	CTDIvol, DLP, ED	Moderate
36.	Sodickson et al.[41]	Retrospective	54549 exams	Locally made toolkit	RDSR	Generalised observation kit (GROK) DICOM	Siemens, Toshiba, GE and Philips	Automated	Boston, USA	Not specified	CTDIvol, DLP	Moderate
37.	Wang et al.[42]	Prospective	Not provided	Not provided	RDSR, header	DICOM Index Tracker (DIT) software	Not specified	Automated	Arizona, USA	Not specified	CTDIvol, DLP	Moderate
38.	Cook et al.[43]	Prospective	Not provided	Not provided	RDSR, header	Automated dose extraction pipeline	5 different model scanners	Automated	Philadelphia USA	Not specified	CTDIvol, DLP	Moderate

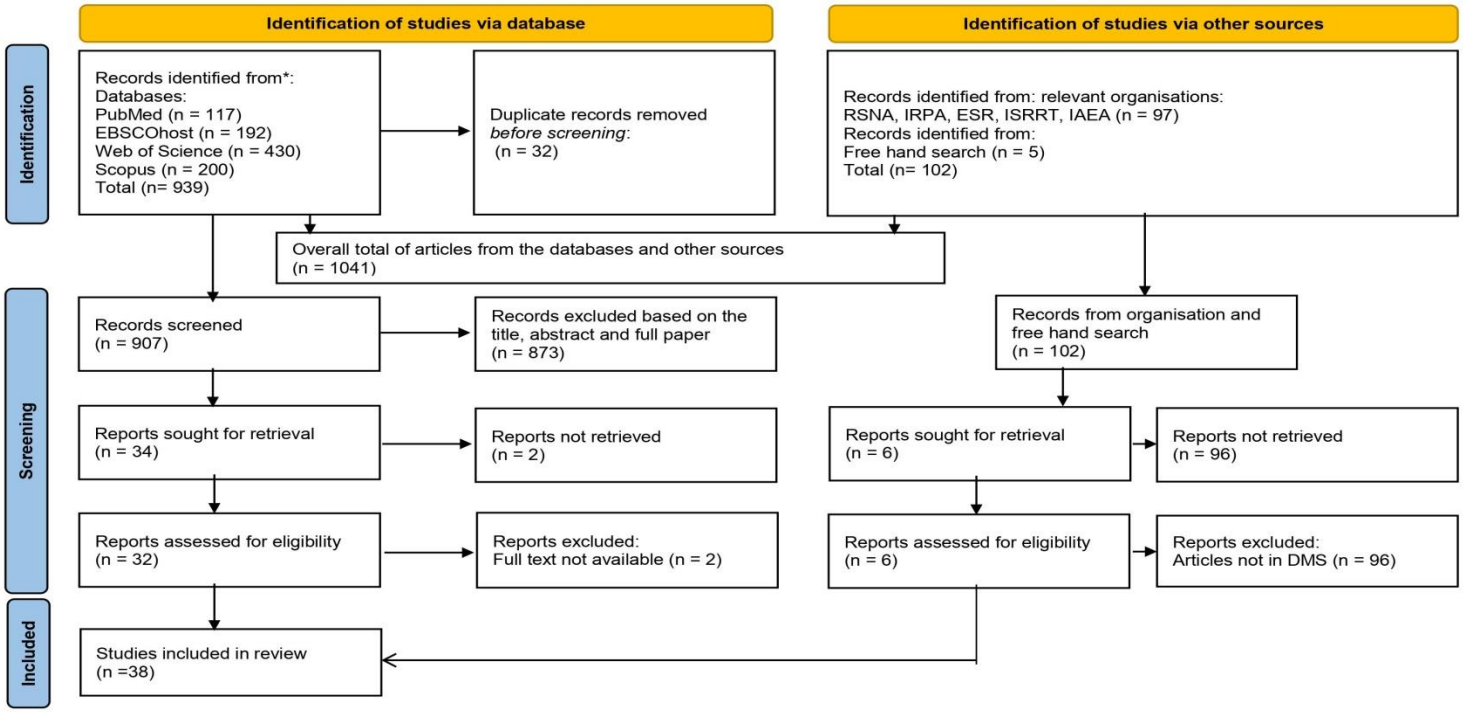

Figure 1: PRISMA flow chart indicating how the articles were screened

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CHAPTER FIVE: KNOWLEDGE OF COMPUTED TOMOGRAPHY DOSE OPTIMISATION AND JUSTIFICATION AMONG CT USERS AND REFERRING PHYSICIANS: A SINGLE HOSPITAL STUDY

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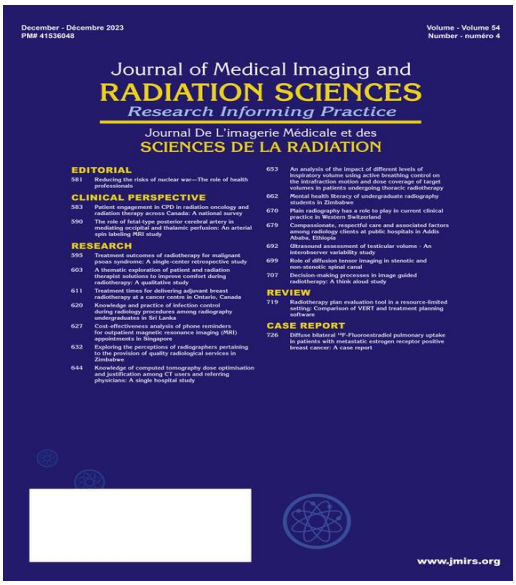

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Abstract

Introduction: Radiation dose associated with computed tomography (CT) remains a concern, and radiation risk does not receive the needed attention, especially in low and middle-income countries. This because the frequency of this high-dose examination is rapidly growing and systems for protocol optimisation and dose justification are yet to be provided in CT imaging.

Objective: To determine radiographers' and radiologists' awareness and knowledge of CT dose optimisation. We also determined knowledge of dose justification and use of the referral guidelines amongst the referring physicians.

Methods: Radiographers and radiologists were invited to complete a web-based questionnaire whilst the referring physicians completed a self-administered questionnaire. The returned questionnaires were analysed and a significant difference was determined using Yates corrected Chi-square, and a *p*-value of 0.05 was considered at the 95% confidence interval.

Results: The response rates were 50% (17 out 34) and 35% (16 out 46) for radiographers and radiologists respectively while referring physicians had a response rate of 84% (92 out of 110). Overall, more radiographers (47.1%) than radiologists (18.8%) had good knowledge of CT doses and image quality, however, the difference in knowledge was not found to be significant ($p = 0.167$). In addition, knowledge of diagnostic reference levels (DRLs) was significantly ($p = 0.033$) higher amongst radiographers (52.9%) as compared to radiologists (12.5%). Meanwhile, physicians understood the principles of dose justification. However, their knowledge of referral guidelines was limited.

Conclusion: The study revealed that radiographers were more knowledgeable on matters relating to radiation dose and image quality as well as DRLs when compared to radiologists. Meanwhile, the concept of dose justification was understood among physicians, however, they had limited awareness and knowledge of referral guidelines.

Keywords: Computed tomography; Optimisation; Radiation dose; Radiation protection

Introduction

Computed tomography (CT) is a diagnostic imaging tool that allows detailed visualisation of the internal structure of the human body [1]. Compared to conventional (plain) X-ray imaging, CT accounts for more than 50% of the total cumulative radiation dose from medical exposure [2,3]. Referring physicians value CT for diagnosis and intervention of patient medical conditions and professionals in medical imaging are competent in its use, radiation risk receives less attention. Therefore the frequency of use of this high-dose examination is rapidly growing and systems for protocol optimisation and dose justification are yet to catch up in CT imaging [4].

A strong justification principle determined by the referring physicians needs to be upheld to ensure that only prescribed procedures that have net benefits are requested [4]. The justification principle is therefore achieved by having knowledge and use of referral guidelines for imaging [5]. This translates to up to 20–40% of CT procedures being avoidable if referral guidelines are followed and a strong justification is provided [4]. However, request justification and use of the referral guidelines amongst the referring physicians have not previously been studied in this hospital.

Accordingly, all justified procedures must always adhere to the principle of optimisation, in accordance with the tenants of As low As Reasonable Achievable (ALARA) to obtain diagnostic image quality at the lowest radiation dose possible [5,6]. The success of optimisation is effectively achieved based on the strong knowledge of the scan parameters such as kilovoltage (kV), milliampere seconds (mAs) slice thickness and pitch, and their influence on CT image quality and dose [1,5]. The responsibility for protocol optimisation falls within the enclave of radiologists, radiographers and medical physicists in order that clinically acceptable images are produced within the defined diagnostic reference levels (DRLs) [4].

It is apparent that no study investigating radiographers' and radiologists' knowledge of CT dose optimisation and image quality has previously been conducted in Nigeria. Also, to our knowledge referral guidelines for imaging do not exist in Nigeria or the study centre. As a baseline study, radiologists'

and radiographers' knowledge of CT doses and image quality and DRLs was assessed. Furthermore, awareness, use and availability of the referral guidelines, including the application of the dose justification principle among referring physicians in our tertiary academic hospital were assessed.

Method

This was a cross-sectional questionnaire-based study conducted at a tertiary academic hospital located in the northwest region of Nigeria from January to December 2022. Ethics approvals were obtained from the research and ethics boards of Cape Peninsula University of Technology, South Africa and Aminu Kano Teaching Hospital, Nigeria with reference numbers CPUT/HW-REC 2022/H1 and NHREC/28/01/2020/AKTH/EC/3186 respectively. The two questionnaires had a preliminary page providing information on the study and ensuring the confidentiality of the individual participants. Only those who consented to participate were included.

For the purpose of this study, the term CT user refers to radiographers and radiologists as medical imaging professionals with experience in CT imaging. The radiographers all had board certification in CT by the Radiographers' Registration Board of Nigeria (RRBN) in addition to their bachelor's degree in radiography. Whilst the radiologists are medical doctors who had training and board certification in radiology and are responsible for image reporting including CT.

At the time of the study the total number of radiographers, including radiography interns, was 34, the number of radiologists, including radiology doctors in training, was 46 and the number of physicians working at the study site was 110. All CT users and referring physicians working at the tertiary academic hospital were invited to participate in the study. The referring doctors were contacted through their departmental heads, whilst the CT users were contacted via WhatsApp platforms. The questionnaires were adapted from previous studies [4,5]. A few changes were made which included removing and rewording some of the questions for clarity in the local

context. The changes made were validated by an expert panel comprised of radiographers, a radiologist and a biostatistician. The questionnaires were administered in the English language as all the participants were proficient in English.

Two different questionnaires were used in the study, one for the CT users, and the other for referring physicians. Amongst CT users a web-based method, using a Google form was chosen as this was an available media platform that could be used to invite and remind the radiology professionals as participants. The web-based questionnaire had 28 questions that covered the following sections: demographic information; knowledge and awareness of CT doses and image quality followed by DRLs.

At the same time, a self-administered questionnaire was used for the cohort of referring physicians as there was no existing platform that could be used for contacting and reminding this participant group. The self-administered questionnaire had 20 questions with the following sections: demographic information; justification on the use of ionising radiation; knowledge about radiation exposure; and appropriateness of the use of the referral guidelines for image requests as well as the availability of the referral guidelines to the referring physicians.

Both questionnaires had options of yes and no; true and false; and multiple options tick box formats as appropriate to the particular question. Some of the questions had an open-ended follow-up question where the participants were asked to state their understanding of the question. The responses to the questions were manually entered into an Excel spreadsheet where correct answers were given a score of one (1), and incorrect answers a score of zero (0). Answers to the open-ended questions were determined as correct based on the literature findings and a similar score of 1 for correct and 0 for incorrect or incomplete responses was given. Binning statistics in the statistical package for social sciences (SPSS) version [7]. was used to define the scale of knowledge in this study. Therefore, to determine knowledge levels, the total score from the participants in each section was obtained which was categorised into three: lower (≤33.3%), middle (>33.3–

66.6%) and upper (>66.6– 100%) categories. The categories were further defined as poor for the lower, moderate for the middle and high for the upper categories. Data cleansing was conducted to remove erroneous, missing and incomplete numerical responses.

Before the commencement of data collection, these questionnaires were pilot-tested among a group of 15 conveniently selected CT users and referring physicians to determine the reliability of the study tool. Five participants each were selected amongst radiographers, radiologists and referring physicians [8]. From the pilot sample, overall internal consistencies of 0.762 and 0.721 were determined for the CT user and referring physician groups respectively, using the Cronbach Alpha coefficient at a 95% confidence interval [9].

The collected data were analysed using the SPSS version [7], supported by IBM SPSS Statistics 20, modified in May 2021. All categorical variables were presented in frequencies and percentages. A Yates-corrected chi-square statistic was used to determine whether there was a significant difference between the responses. A *p*-value of 0.05 was used as a level of significance at a 95% confidence level. Only p values with Yates continuity corrections were reported where the data set is small.

Results

Section 1: CT users

Radiographers and radiologists had response rates of 50% (17 out 34) and 35% (16 out 46) respectively. The radiographers had a gender representation of 70.6% and 29.4%, males to females respectively. Meanwhile, in the radiologists' cohort, there were 87.50% and 12.5% male to female participants respectively. Amongst the radiographers, 52.9% had <5 years of post-qualification experience, whilst, in the radiologist cohort, those with 11–15 years of experience were more in number and represented 37.5% of the total respondents.

Knowledge of CT doses and image quality

Overall assessment of questions related to the impact of scan parameters on

dose and image quality showed that more radiographers (47.1%) than radiologists (18.8%) were knowledgeable of CT dose and image quality. In the same vein, more radiologists (50.0%) than radiographers (23.5%) lacked knowledge of CT dose and image quality. There was no statistically significant (p = 0.167) difference in knowledge noted between the two groups of CT users.

Radiographers and radiologists were asked whether they knew the radiation dose indices used in CT. The majority of both radiographers (88.2%) and radiologists (81.2%) knew the CT dose indices. There was no statistically significant (p = 0.576) difference in response noted between the two groups of professionals.

The CT users were asked to provide the name of the dose indices used in CT. More radiographers (76.9%) than radiologists (23.1%) responded correctly. A statistically significant difference (p = 0.019) was noted in response between the two groups (Fig. 1).

Automatic tube current modulation (ATCM) operation

The CT users were asked to state their agreement on a series of questions regarding the operation of ATCM. Both radiographers and radiologists showed understanding regarding the impact of ATCM on the dose, except for its effect on the anatomical location where less than half of both radiographers (47.1%) and radiologists (37.5%) answered correctly. There were no statistically significant (p = 0.579) differences in response noted between the two groups of professionals (Table 1).

Impact of kilovoltage (kV) on dose and image quality

The majority of radiographers (88.2%) and radiologists (75.0%) knew that kV impacts positively on the computed tomography dose index (CTDI) value, and only a few expressed otherwise. More radiographers than radiologists understood the impact of reducing the kilovoltage from 120 to 100 during an angiography procedure (p = 0.017). Similarly, a significant (p = 0.021) difference in response was noted between the CT users when asked whether reducing kV from 120 to 100, increases vessel enhancement. Relatively, few radiographers (41.2%) and radiologists

(25%) knew the impact of reducing kV on the image contrast (Table 2).

Impact of tube current (mA) on dose and image quality

The majority of radiographers (88.2%) and radiologists (81.2%) knew that mA has a linear relationship with dose, and there was no statistically significant (p = 0.576) difference in responses received. However, a smaller percentage of both radiographers (23.5%) and radiologists (37.5%) understood the relationship between mA and noise, and there was no statistically significant (p = 0.383) difference in response noted. More radiographers (88.2%) than radiologists (50.0%) understood the relationship between mA and radiation dose. Here the difference in response was statistically significant (p = 0.017).

Pitch

The CT users indicated considerable knowledge of the impact of the pitch on dose and image quality. Both radiographers and radiologists provided similar responses regarding their understanding of the impact of pitch on dose and image quality (Table 3). There were no significant differences in responses noted between the two groups of CT users. Less than half of the radiographers (47.1%) and 56.2% of radiologists understood the impact of the pitch in a single slice CT. However, there was no statistically significant (p = 0.598) difference in these responses.

Image noise

The CT users understood the impact of the scan parameters on noise, except for the window level, where fewer radiographers (23.5%) than radiologists (50%) showed an understanding. The difference in response was not statistically significant (p = 0.114) (Table 4).

Knowledge and awareness of CT diagnostic reference levels (DRLs)

Both Radiographers and Radiologists were asked whether they are aware of DRLs. More radiographers (61.5%) than radiologists (38.5%) indicated being aware of DRLs. The difference in response was statistically significant (p = 0.042).

Radiographers and radiologists were also asked to define DRLs. More radiographers (57.9%) than radiologists (42.1%) provided the correct definition of DRLs. However, there was no statistically significant difference ($p = 0.616$) noted between the two groups.

Radiographers and radiologists were asked whether they are aware of the established Nigerian DRLs for adult brain CT. A few radiographers (23.5%) and radiologists (12.5%) indicated being aware of the adult brain DRLs in Nigeria.

Radiographers and radiologists were asked to state the established Nigerian DRLs for adult brain CT. A few radiographers (11.8%) and radiologists (6.3%) provided the correct responses. Of the 17 radiographers, only 7 knew the function of DRLs. Similarly, only 7 out of the 16 radiologists knew the function of DRLs (Fig. 2).

Based on the entire set of questions related to DRLs, the radiologists (50%) lacked knowledge of DRLs compared to radiographers (17.6%). In contrast, slightly more than half of the radiographers (52.9%) were knowledgeable of DRLs compared to radiologists (12.5%). The difference in knowledge between the two CT users was statistically significant ($p = 0.033$).

CT protocol modification

Fig. 3 shows that the majority of the radiographers (11 out of 17) and radiologists (12 out of 16) indicated that developing a protocol in CT is a team approach. All radiographers (100%) and the majority of the radiologists (87.5%) indicated that they are allowed to modify the protocol. In addition, the majority of radiographers (94.1%) and radiologists (68.6%) indicated that they have the confidence to modify CT protocol to reduce patient dose.

Section 2: Referring physicians

The referring physicians had a response rate of 84% (92 out of 110). There was a gender representation of 65.2% and 34.8% males to females respectively. The referring physicians with 11–15 years of experience were more in number and represent 34.8%.

Dose justification

The referring physicians (64.1%) indicated that they always checked to ensure the CT procedure is justified before a request form is completed. More than half of the physicians (67.4%) responded that the number of CT scans the patient had in the past could affect their decision on requesting additional CT procedures, whilst 32.6% stated otherwise. Furthermore, 58.7% of physicians believed that it would be difficult to prescribe another CT procedure if a patient had an estimated dose of 100 mSv from the previous radiological examinations, whereas 41.3% stated otherwise. In addition, 92.4% of the physicians believed that having a system to provide quick dose information would be very helpful for dose justification, and the remaining 7.6% stated otherwise. More than half of the physicians (54.4%) indicated that a CT scan should be prescribed based on clinical indications and patient age, whilst 45.6% stated that CT should be prescribed based on the clinical indication only. In summary, the knowledge of radiation dose justification amongst the referring physicians is considered to be moderate (44.6%) as presented in Table 5.

Knowledge of CT dose

Responses from the physicians regarding the number of posterior-anterior (PA) chest X-rays that produced equivalent radiation doses to an adult brain CT indicated that the doctors have limited knowledge as only 29.9% had the correct answer, Likewise, knowledge of radiation dose associated with adult brain CT amongst the referring physicians is limited as only 25.8% knew the correct answer. However, 72.5% of the physicians knew that CT is the imaging modality that imparts the highest radiation exposure. Similarly, 90.1% of physicians knew that children are more susceptible to radiation injury than adults.

Appropriateness of the use of referral guidelines

The referring physicians were asked regarding awareness, availability and use of the referral guidelines in the hospital. Responses from the referring physicians indicated that 65.2% are not aware of the existence of the referral guidelines for imaging. Similarly, when asked whether they

have access to referral guidelines in their workplace, more than half of the proportion (55.4%) indicated that they do not have referral guidelines available. In addition, 72.8% of the physicians indicated that they never used the referral guidelines before requesting a CT procedure.

Discussion

Section 1: CT users Experience in clinical practice

The radiologists' year of experience was twofold higher than that of radiographers. More than half of the radiographers (52.9%) had <5 years of experience, whereas, in the radiologist cohort, 37.5% had 11–15 years experience. The reason for the wide difference in years of experience could be related to the fact that the department recently employed radiographers who needed to complete their one-year mandatory internship training and these were the majority in the radiographer cohort. This finding correlates with that of Foley et al [5] who reviewed the radiologists' and radiographers' knowledge of CT exposure parameters and also reported that radiologists had more years of experience than clinical radiographers.

Knowledge and awareness of CT radiation doses

Assessment of the impact of the scan parameters on dose and image quality shows that both radiographers and radiologists have knowledge of CT doses and image quality, albeit more so in the radiographers' cohort. The finding amongst the radiographers aligns with that of Rawashdeh et al. [10] who conducted a study on the knowledge and practice of CT exposure parameters among radiographers in Jordan. They reported that the radiographers have good knowledge of the exposure parameters and their influence on image quality and dose. The reason for a better understanding of CT doses amongst radiographers could be related to the fact that the radiographers' work entails manipulation of the scan parameters such as kV and mAs during image acquisition for dose optimisation, which enhances their understanding of CT doses and image quality. The fact that the radiographers were all fully qualified or in their year of internship while the radiologist group included radiology doctors in training could, in part, explain the lower level of knowledge of this group. In our study, more than

half of the radiographers (10 out of 17) provided the correct names of the CT dose indices (Fig. 1). This aligns with the findings of Abdulkadir et al. [11] who conducted a study in Nigeria on DRL awareness among radiographers. Their findings show that a sizeable number of radiographers knew the correct dose indices in CT. Furthermore, the number of radiographers that provided the correct CT dose indices in this study could be linked to the fact that the two parameters are available on the display monitor of the CT scanners, as recommended by the International Electrotechnical Commission (IEC) [1]. Thus, for every scan, the radiographers assess the displayed dose indices and decide whether they are within the acceptable range. In our centre, the radiologists do not see the dose report but only the images that are sent to them for reporting, This might explain why only a few (3 out of 16) provided the correct names of the dose indices. To improve understanding of CT dose and image quality amongst CT users, we recommend the use of a system such as the Radiation Dose Management System (RDMS) that contains the scan parameters and dose information to support the dose optimisation process. In addition, retraining the CT users on the CT scan parameters and their impact on dose and im- age quality is highly recommended to ensure CT doses are optimised in line with the ALARA principle. The RDMS template will also provide the radiologists with dose reports and the corresponding scan parameters in addition to images which will be more likely to promote dose optimisation.

Knowledge and awareness of DRLs

As noted in this study a substantial number of radiographers (16 out 17) were aware of DRLs and likewise the radiologists (10 out 16). This aligns with the findings of Abdulkadir et al. [11] and Bawazeer [12] who studied awareness and knowledge of DRLs among CT radiographers in Nigeria and Saudi Arabia respectively, and reported that the majority of the participants indicated being aware of DRLs. On the contrary, Foley et al [5] who assessed the radiologists' and radiographers' knowledge of CT exposure parameters in Ireland, reported that the majority of radiologists were unaware of DRLs. The reason for DRLs awareness amongst the CT

users in this study could be due to the continuous advocacy of DRLs as a tool for dose optimisation in the study site. In the same vein, more than 50% of both the radiologists and radiographers knew the correct definition of DRLs and also indicated that the use of DRLs is implemented in their facility. The findings of this study are slightly higher than that of Abdulkadir et al. [11] and Bawazeer [12] who reported 47.9% and 29% of the participants respectively that correctly defined DRLs. On the other hand, only a few radiographers and radiologists knew about adult brain DRLs in Nigeria despite brain CT being the most common procedure and the DRLs being available for 7 years. This meant that only a few could provide the correct values of the adult brain DRLs. The findings are different from that of Foley et al. [5] where the majority of the CT users were reported to have known the DRL values for the most common procedures. This shows that in this hospital there is a lack of DRLs usage in clinical practice even though brain CT procedure constitutes about 50% of the total CT procedures performed. It was noted in our study that less than 50% knew the function of DRLs which also aligns with the findings of Abdulkadir et al. [11] and Bawazeer [12] who reported that only 43% and 35% of radiographers respectively knew and were familiar with the function of DRLs. This further stresses the need for continuous awareness of DRLs amongst CT users through the use of RDMS and also by making the DRLs visible in strategic places where the CT users could have easy access to the information.

CT protocol modification

In the present study, the majority of the CT users believed that protocol modification is a team approach (Fig. 3). The finding does not align with that of Foley et al. [5] who reported that only 14% believed that the protocol modification should be a team approach. On the other extreme, Kazemi et al. [13] reported that 59.4% of the participants believed that protocol decisions are made by radiographers. The finding of the current study is encouraging as having a protocol based on ALARA requires a team approach which is also in line with the American College of Radiologists (ACR) recommendation [5]. The protocol team requires collaboration from

experts which include radiographers, radiologists and medical physicists that should work together to build a protocol that will produce acceptable image quality with the lowest radiation dose possible [14]. Further, it is interesting that all radiographers (100%) and the majority of radiologists (87.5%) indicated that they are allowed to modify protocols and also 94.1% and 68.6% of radiographers and radiologists respectively have confidence that they can modify the protocol. However, Almohiy et al. [15] who studied radiologists' attitudes and knowledge of CT radiation dose and exposure in Saudi Arabia, reported that the majority (60%) of the participants did not have the confidence to alter the scan protocol. We, therefore, in line with ACR recommendations, encourage a continuous team approach of protocol review and optimisation in all CT facilities to ensure protocols provide the required image quality following ALARA.

Section 2: Referring physicians Knowledge of dose justification

The findings of the current study indicated that the majority of referring physicians (64.1%) stated that they always checked to ensure the CT procedure is justified before a request form is completed. This does not align with that of Moifo et al. [16] who reported knowledge of dose justification as unsatisfactory amongst 79.5% of the referring physicians. The knowledge of dose justification amongst physicians is crucial and should be encouraged as they are the gatekeepers who determine whether the procedure is justified or otherwise. Furthermore, 92.4% of physicians have indicated that having a system for dose monitoring would be helpful for dose justification. Similarly, Rehani and Berris [4] reported 60.5% for the same question. Similar to the finding of Rehani and Berris [4] who reported that 65.7% of physicians have indicated that CT should be requested based on indications including the age of the patient, 54.4% of physicians in this study indicated the same opinion. These findings may indicate that the physicians have an interest in ensuring that the radiation dose to the patient is reduced. Providing a system like the Radiation Dose Management System (RDMS) or SMARTCARD recommended by the International Atomic Energy Agency (IAEA) would help greatly in managing patient doses and in clinical decision-making [17]. Patient age and clinical indication are two important parameters

that could influence decision-making. Using indication alone without patient age as a consideration might lead to unnecessary exposure to the paediatric age group which is prone to radiation injury due to the sensitivity of tissue to ionising radiation [6]. Overall, 44.6% of physicians knew about dose justification (Table 5). The level of knowledge of dose justification in this study is higher than the findings of a previous study where the authors reported that 79.5% of physicians had unsatisfactory knowledge of dose justification [16]. Of note, Rehani and Berris [4] reported that 65.1% of physicians indicated the importance of dose justification based on information about previous patient exposures.

Knowledge about radiation doses

This study showed the lack of knowledge of radiation dose associated with posterior-anterior (PA) chest x-ray relative to the adult brain CT with 29.9% of referring physicians providing the correct response. Likewise, knowledge of radiation dose for adult brain CT procedures was limited amongst physicians as only 25.8% stated the correct answer. Reports from similar studies have confirmed the mentioning of inaccurate CT doses across all medical specialities [4,18,19]. This implies that referring physicians are not always aware of radiation dose differences across various imaging modalities. Educating the referring physicians on radiation doses associated with different equipment that uses ionisation radiation is important to reduce the number of unnecessary exposures. Interestingly, a majority of the physicians (72.5%) knew that CT imparts the highest radiation and a large number (90.1%) believed that children are more sensitive to radiation than adults. Similarly, Dauda et al. [20] reported that more than 75% of physicians knew that children are more sensitive to radiation than adults. Although the physicians indicated knowledge that CT imparts the highest dose and that children are more susceptible to radiation injury, their knowledge of actual CT doses was noted to be limited. The findings align with previous studies where limited knowledge of CT doses was reported among physicians [7,20]. This calls for retraining of referring physicians in CT radiation dose associated with CT to achieve the maximum healthcare benefits of radiation.

Appropriateness of the referral guidelines for imaging

Responses from the referring physicians regarding the use of the referral guidelines for imaging are discouraging as only a small proportion (10%) indicated that they always consider the referral guidelines. Similarly, Borgen and Stranden [21] reported that the percentage of physicians who used referral guidelines was reported to be 37.5%. Referral guidelines for imaging help medical personnel to make an informed decision about imaging procedures based on established evidence-based criteria [22]. In European countries, the use of referral guidelines for imaging has become a legal requirement [23]. However, despite the introduction of the referral guidelines by the Royal College of Radiologists, awareness and utilisation of the referral guidelines remains poor among physicians. This stressed the importance of referral guidelines in medical imaging to be available and used in hospitals [4].

Limitations of the study

The study is limited to a single hospital and by the number of radiographers and radiologists that participated in the study. This is similar to the findings of the previous studies by Foley et al. [5] and Almohiy et al. [15] and also typical of a questionnaire study. The findings from this study can inform practice in Nigeria but cannot be generalised to the entire population of radiographers, radiologists and referring physicians in Nigeria.

Conclusion

The study revealed that radiographers had higher levels of knowledge on matters relating to radiation dose and image quality as well as DRLs when compared to radiologists, though in both cohorts there could be improvement. Meanwhile, the concept of dose justification was understood among referring physicians, however, they had limited awareness and knowledge of referral guidelines available at the study site. Therefore there is a need to make available resources accessible and for continued training and retraining to promote dose justification and optimisation, specifically on the use of DRLs amongst CT users and referral guidelines amongst physicians.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jmir.2023.07. 019.

Table 1: Percentage of correct responses on the impact of ATCM on patient dose

Options	Radiographers (n = 17)	Radiologists (n = 16)	P value
ATCM has been shown to decrease the patient dose on average	16 (94.1%)	16 (100%)	0.325
Z-axis ATCM reduces the dose along the z-axis of the patient	14 (82.4%)	9 (56.2%)	0.103
XY-axis ATCM reduces the dose along the XY-axis of the patient	12 (70.6%)	8 (50%)	0.226
ATCM increases the patient dose in the brain region compared to the neck region	8 (47.1%)	6 (37.5%)	0.579
ATCM is affected by centring the patient within the gantry	12 (70.6%)	10 (62.5%)	0.622
Is ATCM useful for dose saving?	15 (88.2%)	15 (93.8%)	0.582

Table 2: Percentage of correct responses on the impact of reducing kV from 120-100 in angiography procedure

Options	Radiographers (n = 17)	Radiologists (n = 16)	P value
Reduces the radiation dose	15 (88.2%)	8 (50%)	0.017
Reduces the image contrast	7 (41.2%)	4 (25%)	0.325
Increases the image noise	10 (58.8%)	11 (68.8%)	0.554
Increases the vessel enhancement	14 (82.4%)	7 (43.8%)	0.021

Table 3: Percentage of correct responses on the impact of pitch on image quality and dose

Options	Radiographers (n = 17)	Radiologists (n = 16)	P value
Pitch may impact the image quality	16 (94.1%)	16 (100%)	0.325
Pitch may impact the patient's dose	14 (82.4%)	13 (81.2%)	0.935
Spiral artefacts are reduced at a lower pitch value	13 (76.5%)	11 (68.8%)	0.619
For single-slice CT, the higher the dose the higher the pitch	8 (47.1%)	9 (56.2%)	0.598

Table 4: Percentage of correct responses on the impact of the scan parameters on image noise

Options	Radiographers (n = 17)	Radiologists (n = 16)	P value
Kv	16 (94.1%)	15 (93.8%)	0.965
Mas	17 (100%)	14 (87.5%)	0.133
Window width	12 (70.6%)	12 (75%)	0.776
Collimation	14 (82.4%)	11 (68.8%)	0.362
Slice thickness	16 (94.1%)	15 (93.8%)	0.965
Helical pitch	15 (88.2%)	12 (75%)	0.325
Exposure time	14 (82.4%)	13 (81.2%)	0.935
Window level	4 (23.5%)	8 (50%)	0.114
Reconstruction algorithms	15 (88.2%)	11 (68.8%)	0.171

Table 5: Overall knowledge of dose justification amongst referring physicians

Knowledge	Referring physicians (92)
Poor (≤33.3%)	27 (29.3%)
Moderate (>33.3-66.6%)	41 (44.6%)
High (>66.6-100%)	24 (26.1%)

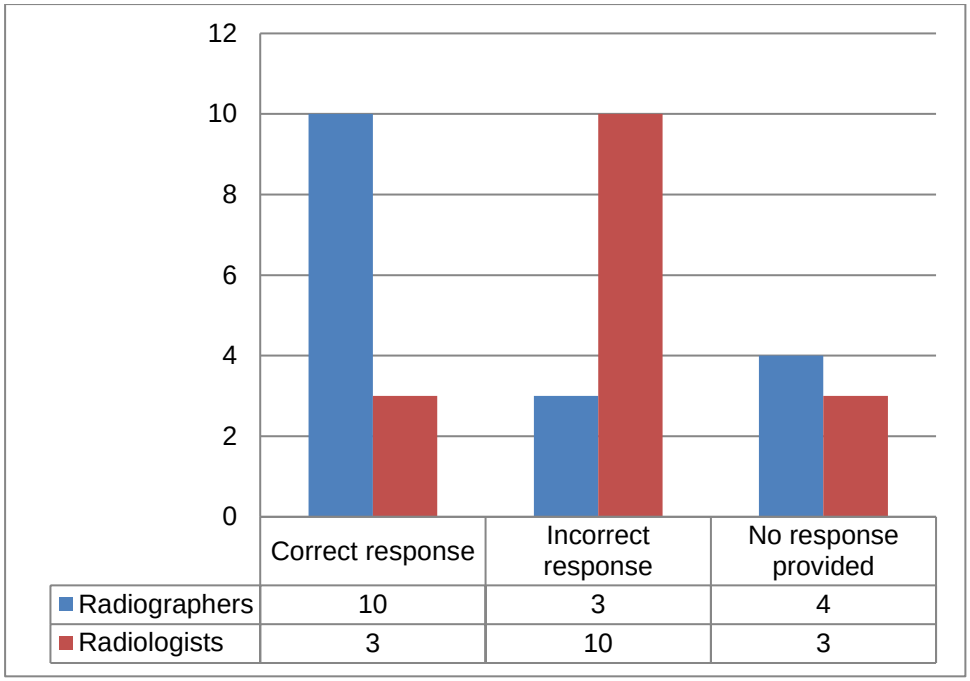

Figure 1: Radiographers and radiologists' response to naming the CT dose indices

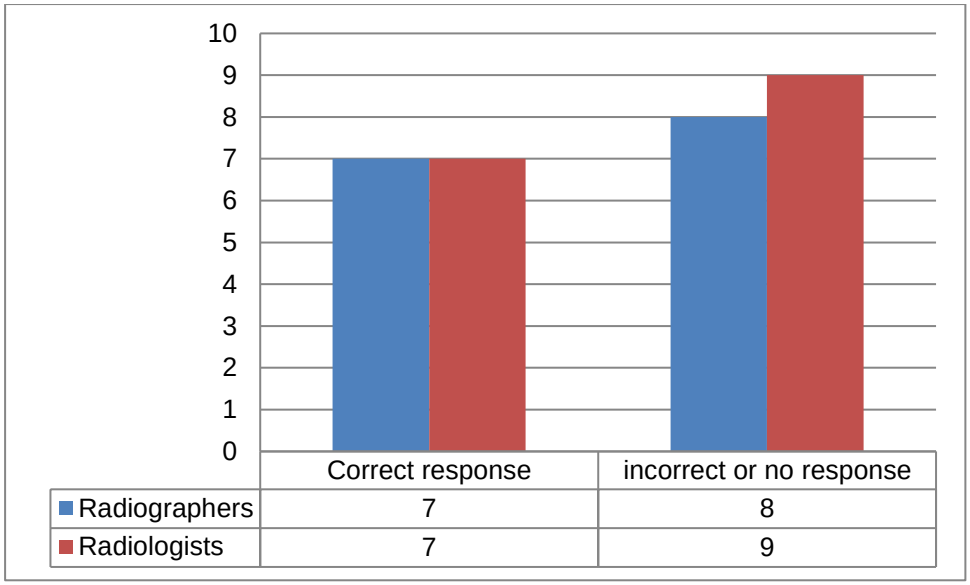

Figure 2: Responses from the participants about the function of DRLs

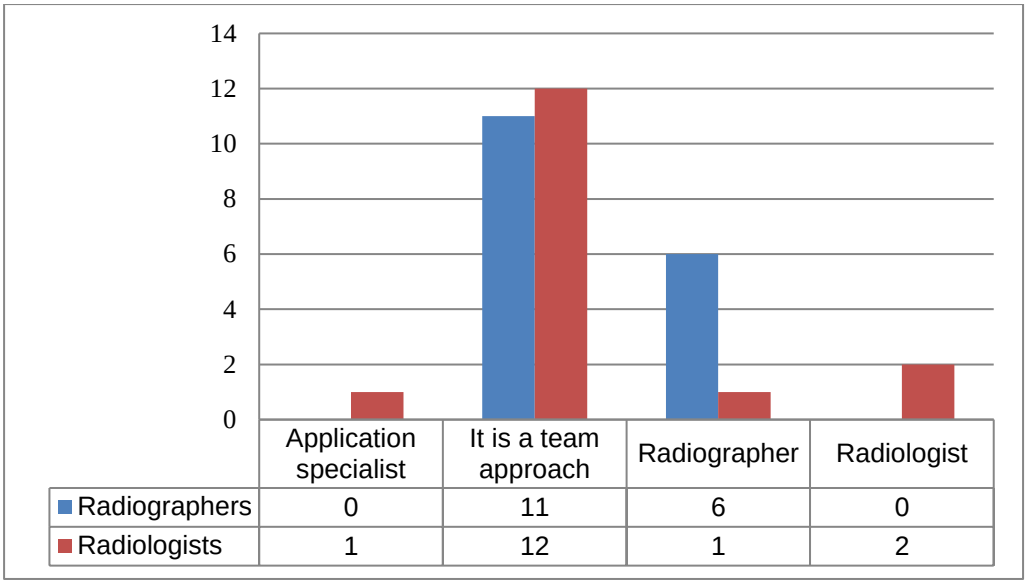

Figure 3: Responses from the participants on developing CT protocol

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CHAPTER SIX: PROSPECTIVE DOSE MONITORING USING A MANUAL DOSE MANAGEMENT SYSTEM: EXPERIENCE IN BRAIN COMPUTED TOMOGRAPHY FROM A TERTIARY HOSPITAL IN NIGERIA.

Published paper:

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2024: 200 (7):648-658

Impact Factor in 2023: 1

Journal Ranking in 2023: Q3

Conference presentation

A paper covering this content has been accepted for poster presentation at the International Radiation Protection Association (IRPA) 16th Congress to be held in Orlando, USA, between July 7-12, 2024.

Abstract

A manual radiation dose management system was developed to track the radiation dose and scan parameters of patients for brain computed tomography (CT). Radiation dose in volume computed tomography dose index (CTDIvol) and dose length product (DLP) were monitored to identify procedures that may require optimisation using notification values. The data were analysed and compared with national and international diagnostic reference levels (DRLs). A total of 596 brain CTs were monitored and grouped as <1: 36, 1–<5: 38, 5–<10: 25, 10–<15: 31 and adult: 466. The CTDIvol notification value identified the following number of examinations having high CTDIvol in <1 y: 1, 1–<5: 1, 5–<10: 0, 10–<15: 0 and adult (>15): 11. Furthermore, the DLP notification values identified the following examinations with high DLP in <1 y: 1, 1–<5:1, 5–<10:1, 10–<15: 1 and adults (>15): 18. The established local paediatric DLP DRLs were 2–3 times higher than the international paediatric DLP DRLs. This calls for a total protocol review and optimisation considering the local CT practices for paediatric imaging.

Keywords: Brain CT; DRLs; notification value; optimisation, radiation dose management system.

Introduction

Computed tomography (CT) is an invaluable imaging modality used to diagnose and manage disease[1]. However, the CT procedure is associated with radiation exposure that has the potential to cause serious radiation injuries that could potentially include cancer induction in the exposed individuals[2]. Brain CT is the most commonly performed procedure, especially in the emergency departments[3]. Compared with chest and abdominal examinations, brain CT has a lower effective dose; however, the cumulative exposure from brain CT is high because 39% of patients undergo repeated follow-up scans[3]. This calls for continuous dose justification and optimisation of brain CT exposure following the principle of as low as reasonably achievable (ALARA).

The radiation dose associated with CT has made the implementation of a dose management strategy more important. Thus, in 2019, a working group was launched by EuroSafe Imaging for the implementation of a dose management system in clinical practice[4]. The European Union Council Directive recommends that the radiation dose information forms part of the radiologist's report to facilitate dose justification and optimisation where possible [5].

A patient radiation dose management system (RDMS) is an organised and coordinated platform that allows patient radiation dose exposure to be tracked and managed for dose optimisation[6, 7]. The primary roles of a RDMS include radiation dose optimisation through the establishment and monitoring of local and national DRLs, quality assurance, identification of wide exposure variations and record-keeping of radiation doses[4].

Several electronic RDMS software, such as Radimetrics (Buyers), DoseWatch (GE Healthcare), DoseWise (Philips) and Teamplay (Siemens) have been developed and are currently being used to manage patient radiation doses[2, 8–11]. However, despite the large volume of CT scan examinations performed in the Nigerian study centre, there is a

lack of electronic platforms to support the management of the scan parameters and radiation dose data. This is similar for CT scan examinations in many of the low- and middle-income countries (LMICs)[12]. In place of electronic RDMS, the study therefore developed and tested a manual RDMS template that allows prospective monitoring and management of the scan parameters and dose information by radiographers, radiologists, medical physicists and referring physicians to enhance dose optimization.

Method

This was a cross-sectional, prospective study conducted on patients that presented for brain CT procedures at a tertiary institution, located in the northwest region of Nigeria, from 1 August to 31 December 2022. Ethics approvals were obtained from the relevant research ethics committees with reference numbers CPUT/HW-REC 2022/H1 and NHREC/28/01/2020/AKTH/EC/3186, respectively. The informed consent process allowed participants to agree or otherwise before being included in the study. Only those participants who consented were included. The consent was requested from the participants to allow age, weight and gender to be collected in addition to the dosimetric information from CT scans requested as part of their medical management.

Quality control on the CT scanner

The CT scanner radiation dose output in CTDIvol and DLP was validated using Impact CT patient dosimetric calculator version 1.0.4. The scan parameters were entered in the system, and the resultant doses in CTDIvol and DLP were noted not to differ significantly from the displayed CTDIvol and DLP on the scanner monitor. Furthermore, a tube warm-up is performed daily by the radiographer to ensure consistent optimal image quality. Image quality assessment is also performed daily using an image quality phantom, and the result was noted to be within the acceptable limit as recommended by the CT scanner manufacturer.

CT radiation dose management

The CT radiation dose of individual patients was monitored and managed using a prospective manual RDMS template. The RDMS template was developed based on the findings of the systematic literature review conducted prior to the study[13]. The RDMS template has the following sections: demographic information; examination information; scan parameters; scan and image reconstruction details; examination dose information; notification values; cumulative dose in DLP for the previous CT procedure; justification if above the notification value, referring physicians' section and space for the radiologist to report. The provision of age groups was made to allow age classifications in paediatrics. The age was classified as <1, 1–<5, 5–<10, 10–<15 and adult categories. The age classification is based on the recommendation of the International Commission on Radiological Protection (ICRP) for establishing diagnostic reference levels (DRLs). According to ICRP[14], the age classification is the most commonly used internationally, and it was adopted in this study to allow local DRLs to compare with the established DRLs from other relevant studies[15, 16]. The authors are aware of the European age classification for brain CT DRLs; however, it is at variance with the recommended ICRP age classification[17]. For this study, the developed RDMS template was designed for application to all patients undergoing brain CT who consented. In future studies, this template could be used for other body regions. A sample of the developed adult RDMS template is presented in Figure 1.

Validity and reliability of RDMS

The face and content validity of the RDMS were established by a group of experts, which included two diagnostic radiographers and a radiologist. These experts scrutinised the template to ensure that appropriate information for dose management was provided. Thereafter, the RDMS template was pilot-tested in a selected group of consented patients who presented for brain CT.Radiation dose management using RDMS

The validated RDMS template provides a system for managing the patient scan and dose information prospectively, which can be added to the radiology archive and patient hospital folder. During the study period, for each consented patient that presented for a brain CT, the demographic and clinical information of the patient, as provided on the patient request form, were transferred onto the RDMS template by the radiographer. In addition, once the patient was positioned and the protocol selected, the scan parameters, including the estimated dose in CTDIvol and DLP, were evaluated and recorded on the RDMS.

Use of notification value

The notification value was used to trigger when the displayed dose in CTDIvol and DLP exceeded the configured dose for a single scan[18]. Using RDMS, for every patient, the radiographer looked at the displayed CTDIvol and DLP to see whether they fell within the preset notification value or otherwise before a scan commenced. If the estimated dose was within the notification values in CTDIvol and DLP, the scan was authorised. Where the estimated dose was above the configured notification value, the scan parameters were optimised by the radiographer. If the scan parameters could not be optimised, for instance, due to clinical requirements, a justifiable reason was provided and documented on the same RDMS.

The ICRP recommends that DRLs should not be used as a notification value, as DRLs are used for the optimisation of the protocol of a group of patients and not for individual patients[14]. Furthermore, DRLs may trigger frequently and make the radiographers ignore high dose indices. Therefore, it is recommended that the notification value be set at a value above the institutional diagnostic range values[14]. Therefore, the notification values for this study were set as the highest 5% value of the dose distribution in each age group. The American Association of Physicists in Medicine (AAPM) recommends the use of CTDIvol or DLP[19], as

notification values, and therefore, in this study, both parameters were used for robust dose monitoring as presented in Table 1.

In Figure 1, the space for the cumulative dose in DLP, which was meant for patients who come for a repeated procedure, was never entered because, during the period of study, there was no case of a patient attending for a follow-up examination. In addition, the alert value was also not provided in the developed RDMS in this study, as the AAPM recommended the alert value for brain CT is 1000 mGy[19], and for a routine brain CT procedure in our centre, this value may not be attained; however, the alert value could be relevant for brain CT angiography or interventional procedures.

The filled RDMS template was passed from the radiographer's desk to the reporting radiologist, who wrote the report on the same RDMS template, having access to all the scan and dose information as provided by the radiographer. The same RDMS template was designed on the computer where the radiologist report is typed. The typed report, which was based on the information provided by the radiographer and the radiologist, was printed, signed and submitted to the referring physician who apart from the radiological findings also had access to information about the radiation dose the patient had incurred in the course of the procedure. The same process was repeated for all consenting patients who were referred for brain CT during the data collection period.

Protocol for brain CT at the study site

The scan was performed on a 160-slice Toshiba CT scanner, which was manufactured in 2013 and installed in 2015. Following the AAPM protocol for brain CT[20]. The patients were positioned supine on the scanner table, and two scanograms were acquired in the front-occipital (FO) and lateral (Lat) projections. Thereafter, the scan was planned on the scan monitor using the positioning box, and the images were acquired from the vertex to the base of the skull. However, in some trauma cases, due to the suspected cervical spine injury, the protocol was modified to

include the cervical spine. This group of patients was excluded from the study as the scan length is expected to be longer, which affects DLP for comparison purposes. All patients scanned had contrast and non-contrast series scans, except those with acute bleeds due to trauma or cerebrovascular disease (CVD) who were scanned using a single series acquisition.

The adult patients were scanned using the wide volume (WV) protocol. The WV protocol allows the scanner table to move into the gantry incrementally[21]. Meanwhile, the paediatric patients were scanned using the helical mode. The helical mode allows continuous movement of the scanner table into the gantry[1]. The helical mode is faster compared with WV, thus reducing the possibility of motion blur in children[1].

Data collection

For each patient scanned, the following information was collected: patient demographic information (age, weight and gender); examination information (indication); scan parameter details (kV, mAs, slice thickness (ST) and number of slices (NS)) and scan and image reconstruction details (scan mode and type of reconstruction software). In addition, radiation dose in CTDIvol and DLP, including scan length and number of scan series, were collected. The CTDIvol and DLP recorded were based on the 16 cm phantom size as per the recommendation for the brain procedure[22]. Notification values in CTDIvol and DLP and reason for justification where the dose exceeded the notification value were also collected.

Data cleansing

The collected data were cleaned for any erroneous data entry, such as providing adult information in place of paediatric, or where vital information, such as radiation dose data, was not provided.

Data analysis

The analysis was performed using the Statistical Package for Social Sciences (SPSS) version 20. The data were checked for normality and noted to be normally distributed based on the Shapiro–Wilk test results. The data were described using the mean and standard deviation.

Patients having high doses were identified using the established notification values presented in Table 1. To establish local DRLs, CTDIvol and DLP were calculated in median values as recommended by the ICRP[14]. Furthermore, the established median values were compared with the national and international DRLs. Although most of the scans were acquired using multiple acquisitions, whereby the patient had both non-contrast and contrast series, a single DLP was calculated for comparison with the national DRL, which reported the DLP based on a single series scan. Total DLP, as recommended by ICRP, was equally calculated to allow comparison with the international DRLs.

Results

A total of 596 patients referred for brain CT were included in the study. The paediatric group of 130 (22%) represents the <1: 36 (6%), 1–<5: 38 (7%), 5–<10: 25 (4%) and 10–<15: 31 (5%) age groups. Meanwhile, the adults (>15 y) represent 466 (78%).

The demographic data of the patients are presented in Table 2. The majority of the patients were adults. In all the groups, there were more male participants than females, except for age group 1–<5. Clinical indications based on age groups are also presented in Table 2. CVD was the most common indication (182) followed by trauma (100) in the adult group. Meanwhile, in 1–<5, 5–<10 and 10–<15, trauma was the common indication, and hydrocephalus was the common indication in <1.

Table 3 presents the scan parameters used for brain CT in the study area. Of the 466 adult patients, 457 were scanned using the WV protocol and the remaining nine (9) were scanned using the helical protocol. Meanwhile, most of the paediatric patients were scanned using the helical protocol. In all the groups, the scan was performed based on one (1) or two (2) series

acquisitions. All the adult patients were scanned using 120 kV and 225 mAs. Meanwhile, paediatric patients were scanned using a range of kV and mAs.

In terms of CTDIvol, the following number of examinations in each group adult: 11, <1 y: 1, 1–<5 y: 1, 5–<10 y: 0 and 10–<15 y: 0 were identified as having CTDIvol readings above the set notification values (Figure 2). Also, in terms of DLP, the following number of examinations in each group adult: 18, <1 y: 1, 1–<5: 1, 5–<10: 1 and 10–<15: 1 were identified as having DLPs above the notification values.

Table 4 shows descriptive statistics of patient doses in CTDIvol and DLP. Mean, standard deviation and range values were calculated for each group. Similarly, the median values (second quartile) of CTDIvol and DLP for each group were calculated to allow for establishing local DRLs and also for comparison with DRL values from other studies.

Figure 4 presents the established local DRLs in median CTDIvol and DLP. The median CTDIvol for 5-<10 and 10-<15 were the same, and higher than the adult DRLs. Similarly, the median CTDIvol for the <1 and 1-<5 were the same and lower than that of 5-<10, 10-<15 and adult values.

Figure 5 shows the established local brain DRLs in median DLP. The adult median DLP was statistically significantly ($p = 0.001$) lower than the DLP of 5-<10 who had the highest DLP followed by 10-<15. The <1 and 1-<5 had the lowest DLP but this was not a statistically significant ($p= 0.159$) difference.

Figure 6 shows the established median CTDIvol in comparison with the national and international values. Although there are no data available for the international adult brain DRLs, the established median adult CTDIvol was lower than the national DRLs. The established median CTDIvol for the paediatric brain was slightly lower than the national and international established DRLs except for <1 y, which was higher. The international DRLs presented as green bars were established based on the data collected across the globe[16].

Figure 7 shows a DLP comparison to the national DRLs. The national DRLs were established based on a single-series scan. To compare with the national DRLs, the present study calculated DLP DRLs for a single scan, and this resulted in a lower comparative value to the national DRLs across all the age groups.

The DLP DRLs of the present study were calculated and established based on a total DLP to allow comparison with the DLP DRLs of the international study (Figure 8). The values obtained were compared higher to the international DLP DRLs by 2- to 3-fold (Figure 8). There were no international adult DRLs available for comparison with the local DRLs.

Discussion

The focus of this study was on the use of a prospective RDMS template for monitoring patient radiation dose information during brain CT scans, which could be managed to promote dose optimisation from procedures with high radiation exposure. The use of the RMDS template has provided a source of patient scan parameters and dosimetric records added to the radiologist's report, as presented in Tables 3 and 4. This is the first known study that provides scan and dose information on the radiologist's report in Nigeria for CT practice. The provision of such information, along with the radiologists' report, proves useful in promoting radiation dose monitoring and optimisation[23]. In the same vein, one of the EU recommendations to member states in the management of patient doses in CT is the provision of dose information on the radiologist's report[5].

It was noted that the majority (78%) of the patients scanned were adults, and most were referred on account of trauma and CVD (Table 2). Similar clinical indications were reported in a clinical indication DRLs and post-optimisation image quality study by Ukoha *et al.*[24]. As in the Ukoha *et al.*[24] study, there was no protocol variation in this study due to differences in clinical indications, thus the adult patient had the same CTDIvol. However, the CTDIvol value of the present study was marginally lower than the value reported by Ukoha *et al.*[24], who reported 43 mGy for both CVD

and trauma compared with 42 mGy in the present study. Although 51% of the trauma patients had a single series scan, which reduced the radiation dose in DLP by 50%, there is a need to incorporate a strong justification principle to further reduce the rate of contrast series on account of trauma. In the study conducted by Mutch *et al.*[25] on imaging evaluation of acute traumatic brain injury, it was indicated that contrast series is not useful in head trauma unless vascular damage is suspected; otherwise, it only adds to the cumulative patient dose. The present study has shown that only 27% of CVD patients had a single series scan; thus, the majority could potentially receive high doses due to both non-contrast and contrast series acquisition. This is against the practice, as non-contrast CT is considered the first imaging method for all patients with suspected stroke[26]. Protocol review is therefore recommended for patients with suspected CVD to ensure dose justification and protocol optimisation.

In the present study, hydrocephalus was the common indication in <1 y (Table 2). Beyond <1 y age, the next most common indication was trauma. Similar indications were reported in a clinical indication-based DRLs for paediatric brain CT study by Joseph Zira *et al.*[27]. Most paediatrics 125 (96%) had both non-contrast and contrast series acquisition, while only a few with trauma 5 (4%) had only the non-contrast series (Table 2). A study conducted in Nigeria by Abdulkadir *et al.*[28] on the evaluation of age-based radiation dose in paediatric head CT also reported the acquisition of multiple scan series in paediatric CT. However, a study by Nievelstein *et al.*[29] on multidetector CT related to the current concept and dose reduction strategies in children reported that multiple-phase CT should be avoided. They reported that the non-contrast series adds insignificant additional diagnostic information and should be abandoned. It is therefore recommended that multiple series acquisitions in paediatric patients only be considered with strong justification, due to the vulnerability of children to radiation injury.

The notification values in CTDIvol identified 11 (2.4%) procedures in the adult category, 1 (2.8%) in <1 y, 1 (2.6%) in the 1–<5 y, 0 (0%) in the 5–

<10 y and 0 (0%) procedure in the 10–<15 y groups (Figure 2). Similarly, the notification values in DLP identified 18 (3.9%) procedures in the adult category, 1 (2.8%) in <1 y, 1 (2.6%) in 1–<5 y, 1 (4%) in 5–<10 y and 1 (3.2%) procedure in 10–<15 y (Figure 3). A similar study conducted by Osman *et al.*[2] on radiation dose management in CT imaging, though using GE software, identified procedures having high doses above the DLP notification value. In addition, a study by Cook *et al.*[30] using customisable interactive Radiance toolkits for CT dose management reported procedures that had higher and lower doses than the established limits. In addition, a study by Parakh *et al.*[6] on CT radiation dose management reported a gradual reduction, in many CT procedures identified as having high doses based on CTDIvol over the years, which shows the effectiveness of the dose optimisation strategy. The procedures identified in this study were those adult cases incidentally scanned with the mostly helical protocol. Also, the procedures had both non-contrast and contrast series and mostly had a long scan length in their respective groups. Long scan length has been reported as one of the reasons for having DLP above the notification value[8]. Other possible causes of high DLP include the scan mode and CTDIvol[1, 31]. This indicates the need for a critical review of every protocol selected to ensure that the dose is within the accepted levels to avoid unnecessary exposure to anatomical areas that could have been saved.

The notification values in CTDIvol and DLP for paediatrics were noted as being triggered frequently, which shows the protocols were incorrectly programmed and need review. A review of the protocol, considering the local CT practice in addition to the national DRLs protocol, is therefore recommended. The AAPM[19] and ICRP[14] have recommended that the notification values could be set in CTDIvol or DLP. In this study, the two-dose parameters were considered as notification values. The CTDIvol determines the tube output, but it does not consider the extent of anatomy (scan length) exposed to radiation during the scan. The DLP is the product of CTDIvol and scan length; thus, it provides additional information on the anatomy exposed[1]. The AAPM proposed notification values were in

CTDIvol, not in DLP. Thus, using the two parameters CTDIvol and DLP provided robust information that could not be achieved with a single parameter. In this study, using CTDIvol alone could have allowed higher exposures to be missed, especially in the adult category, which was identified based on DLP (Figure 3). It has been shown through this study that the use of RDMS is impactful for identifying high-dose procedures that require dose optimisation and that could go unnoticed without the application of a RDMS. Similar to Heilmaier *et al.*[32], the CT radiographers in this study were trained on how to use the RDMS template. Thus, the radiation dose for every protocol was checked by the radiographer before the scan was authorized which could have increased their dose awareness. However, the number of examinations identified as having high CTDIvol and DLP is of concern and calls for the retraining of radiographers in dose optimisation.

Figures 4 and 5 show local brain DRLs that were established in the median CTDIvol and DLP. Age groups 5–<10 and 10–<15 had higher CTDIvol and DLP than the adult. The reason could be due to the difference in the scan modes. The adults were scanned using the WV axial, while helical was used in the paediatric group. In all the three (3) groups, 120 kV was used, except for 2 out of 31 patients aged 10–<15 y, where the 100 kV was used (Table 2). However, the mAs for the adults were higher than the mean mAs for the 5–<10 and 10–<15 groups (Table 3). Thus, the reason for higher CTDIvol in paediatrics was determined to be the scan mode. A study conducted by Garba *et al.*[33] on the analysis of image quality and radiation dose between WV and helical has reported that the helical scan was associated with a significantly higher dose compared with the WV protocol. Similarly, in a study comparing WV and helical in children's brain CT by Jeon *et al.*[34], it was reported that WV reduced radiation dose compared with the helical scan mode. In addition, a study comparing WV and helical on paediatric chest CT by Ryu *et al.*[35] reported that WV decreases patient dose compared with the helical technique, though it may be associated with motion artefacts. Therefore, it is recommended to consider the WV protocol

for children between the ages of 10–15 as they are more likely to cooperate, and there would be a corresponding lower radiation dose advantage. However, it is recommended that the helical protocol in the <1, 1–<5 and 5–<10 should be maintained but optimised to reduce the dose in line with the ALARA principle.

The median DLP DRLs in this study were compared and found to be lower than the national DRLs by 45– 62% across all the age groups (Figure 7). Although the adult CTDIvol DRLs were compared as being lower by 33% to the national DRLs and similarly—<5 y and 10–<15 y by 16 and 8%, respectively,—the CTDIvol for the <1 y was comparably higher to the national DRLs (Figure 6). The reason for lower DLP in some age groups, despite having higher CTDIvol, could be related to the scan length used, as DLP is the product of CTDIvol and the scan length[1]. For example, the average scan length used in all the age groups ranges from 14 to 16 cm (Table 3). Meanwhile, in the national study, the average scan length for one of the age groups is 29 cm[15]. In this case, the scan length is longer than the recommended scan length, as reported in a study on dose metrics and patient age in CT by Huda and Tipnis[36]. They reported that the scan length could be increased from 15 cm in the <1 y to 20 cm in the adult. This shows that the values obtained in the current study could be considered to be within the recommended range. It, therefore, emphasises the need for collimating the beam to the requested region to avoid irradiation of an unnecessary anatomical area unless there is justification.

When compared with the international paediatric DRLs, the established local CTDIvol typical values were found to be higher except for 1–<5 y and 10–<15 y, which resulted in a lower comparative outcome (Figure 6). The CTDIvol typical values were higher than the international DRLs by 10–16% for the <1 to 5–<10, while the CTDIvol typical value was lower than the international in 1–<5 y and 10–<15 by 9–14%.

Similarly, the median DLP DRLs were comparably higher than the international DLP DRLs by 2–3 times across the age groups (Figure 8). The reason for higher DLP in the present study could be protocol-related and

therefore involving scan parameters. The DLP of the present and international studies was based on multiple scan acquisition. This aligns with ICRP 135, which reported that variation in patient dose due to body size in children is acceptable[14]. However, these authors continue to stress that variation in dose due to imaging protocol or clinical task is never appropriate and should be looked into for corrective actions[14]. In this one-centre study, it was found that the level of variation, especially in DLP, requires attention and possible optimisation of the imaging protocols.

Limitations of the study

The study is from a single centre; thus, while the findings can be used for comparison in other CT centres, they cannot be generalised nationally. The manual prospective dose management could be time-consuming and characterised by data entry errors. Thus, radiographers must exercise due diligence to ensure proper implementation of the dose management system.

Conclusion

The study has developed a manual RDMS that provides a prospective assessment of patient scan parameters and dosimetric information for brain CT. The CTDIvol and DLP notifications in RDMS have triggered the identification of procedures with radiation exposure above the notification values. Similarly, the dose record has shown that the paediatric DLP DRLs were 2–3 times higher than the international paediatric DLP DRLs. This calls for a review of CT protocol, considering local CT practice. The process increases radiographers' understanding of the scan protocol and its impact on dose and image quality. However the use of manual RDMS requires due diligence and proper scrutiny to minimise data entry errors. It is suggested that for those centres that do not have electronic RDMS, it is worthwhile to apply the manual system. To enable improved radiation protection, it is recommended that the developed RDMS template should be applied in this centre for other CT regions and in other centres across Nigeria to facilitate prospective dose monitoring, management and optimization.

Table 1: Notification values for brain CT established as the highest 5% value of the dose distribution.

Age groups	CTDIvol (mGy)	DLP (mGy*cm)
Adult (>15 years)	46	1562
<1 year	32	1392
1-<5 years	48	1724
5-<10 years	52	2202
10_<15 years	52	2108

Table 2: Demography and clinical indications based on age groups

Demographic/Indication		<1 year (n = 36)	1-<5 years (n = 38)	5-<10 years (n = 25)	10-<15 years (n = 31)	Adult: >15 years (n = 466)
Gender	Male: Female	19:17	19:20	19:6	20:11	293: 173
Age (years)	Mean ± SD Range	0.3 ± 0.3 0.01-0.9	2.4 ± 0.9 1-4	7 ± 1.2 5-9	11.5 ± 1.3 10-14	48.6 ± 20.4 15-112
Weight (kg)	Mean ± SD Range	5.3 ± 2.4 2-10	9.8 ± 4.1 2-19	20.0 ± 5.1 12-30	32.6 ± 16.0 4-79	63.3 ± 16.9 25-120
CVD			1 (0)			132 (50)
Trauma		2 (1)	7 (1)	5 (1)	8 (2)	49 (51)
Headache			1 (0)		4 (0)	28 (4)
ICSOL			2 (0)	3 (0)	2 (0)	18 (0)
Seizures disorder			3 (0)	1 (0)	1 (0)	10 (4)
Convulsion		1 (0)		1 (0)	2 (0)	9 (1)
Hydrocephalus		21 (0)	7 (0)	3 (0)		NIL
Others such as optic nerve atrophy, brain mass, slurred speech, retinoblastoma		11 (0)	17 (0)	11 (0)	11 (0)	96 (14)

contrast and non-contrast series (only non-contrast series); CVD: Cerebro-vascular disease; ICSOL: intracranial space-occupying lesion

Table 3: Scan parameters for the included patients

Scan parameters		<1 year (n = 36)	1-<5 years (n = 38)	5-<10 years (n = 25)	10-<15 years (n = 31)	Adult: >15 years (n = 466)
kV	100	35	22	NIL	2	NIL
	120	1	16	25	29	466
mAs	125	1	13	3	NIL	NIL
	135	35	22	NIL	NIL	NIL
	150	NIL	2	21	19	NIL
	225	NIL	1	1	12	466
Pitch		0.625	0.625	0.625	0.625	0.637
Scan length (mm)		141.4 ± 26.7 90-222	147.9 ± 20.5 90-195	159.7 ± 13.9 135-185	159.5 ± 4 141-200	154.6 ± 15.5 150-298.5
Number of slices		29 ± 5 20-48	31 ± 4 19-40	33 ± 3 28-44	32 ± 3 29-49	31.6 ± 2.5 31-60
Slice thickness (mm)		5	5	5	5	5
Number of scan series	One	1	1	1	116	
	Two	35	37	24	350	
Scan mode	Helical	36	37	24	9	
	WV	NIL	1	1	457	
Image reconstruction algorithm		AIDR 3D	AIDR 3D	AIDR 3D	AIDR 3D	AIDR 3D

AIDR 3D: Adaptive iterative dose reduction 3-dimensional; WV: wide volume

Table 4: Dose parameters for the included patients

Scan parameters		<1 year (n = 36)	1-<5 years (n = 38)	5-<10 years (n = 25)	10-<15 years (n = 31)	Adult:>15 years (n = 466)
CTDIvol (mGy)	Mean	30.4	35.7	47.7	45.7	42.7
	SD	2.1	6.9	3.8	4.5	3.6
	Range	27.5-39.6	27-52.3	39.6-52.3	30.9-52.3	41-68.7
	1st Q	30.2	30.9	47.3	41.4	41.4
	2nd Q	30.9	30.9	47.6	47.5	41.4
	3rd Q	30.9	43.6	52	47.6	41.7
Total DLP (mGy*cm)	Mean total	978.2	1174.4	1722.4	1548.4	1170
	SD	177.1	367.5	294.2	373.8	390.8
	Range	481.4-1429	528-2198	807-2246	625-2279	624-4314.1
	1st Q	870	934	1644.6	1249	781
	2nd Q	975.6	1072	1756.2	1661	1250
	3rd Q	1088	1446	1893.5	1837	1255
Single DLP (mGy*cm)	1st Q	481	528	807	625	625
	2nd Q	481	543	807	686	625
	3rd Q	481	559	807	1258	686

CT EXAMS REPORT SHEET

Patient & Dose Information

Name:				Age:			Clinic:		ADULT
Gender:				Weight (Kg):			Hosp. No.:		
Examination information		**Scan parameters**		**Indicate scan mode and image reconstruction used.**	**Examination Dose information**		**Notification values specific to this CT scanner**	**Cumulative dose in DLP for the previous CT**	**(Justify if above the notification values)**
Procedure:	Routine Brain CT	kV		Wide volume	CTDIvol (mGy)		CTDIvol: 46		
Indication:		mAs		Helical:	Total DLP (mGy*cm)				
		Slice thickness		IR	Scan length (mm):		Total DLP: 1562		
		No. of slices		FBI	No. of series:				
Note: This exposure is equivalent to 100 chest X-rays and 10 months of exposure to natural background radiation For further clarification, kindly contact the following number: +2348034532750									

_____ _____

Name of Radiographer **Sign & date**

Radiologist report

_____ _____

Name of Radiologist **Sign & date**

Figure 1: RDMS template

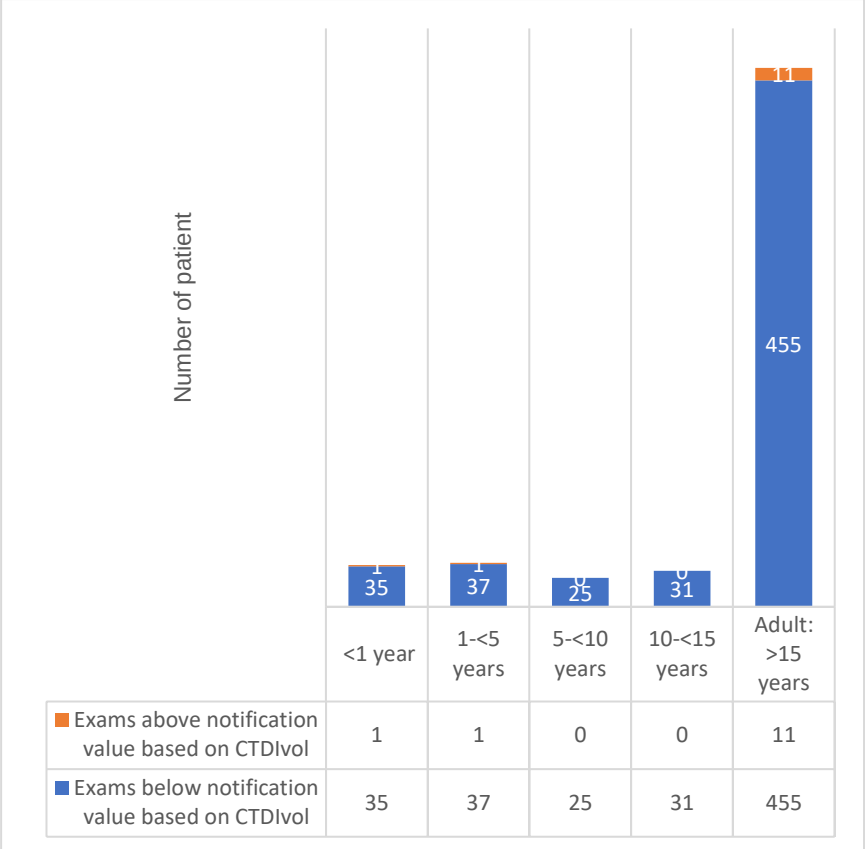

Figure 2: Number of examinations above and below the notification value based on CTDIvol

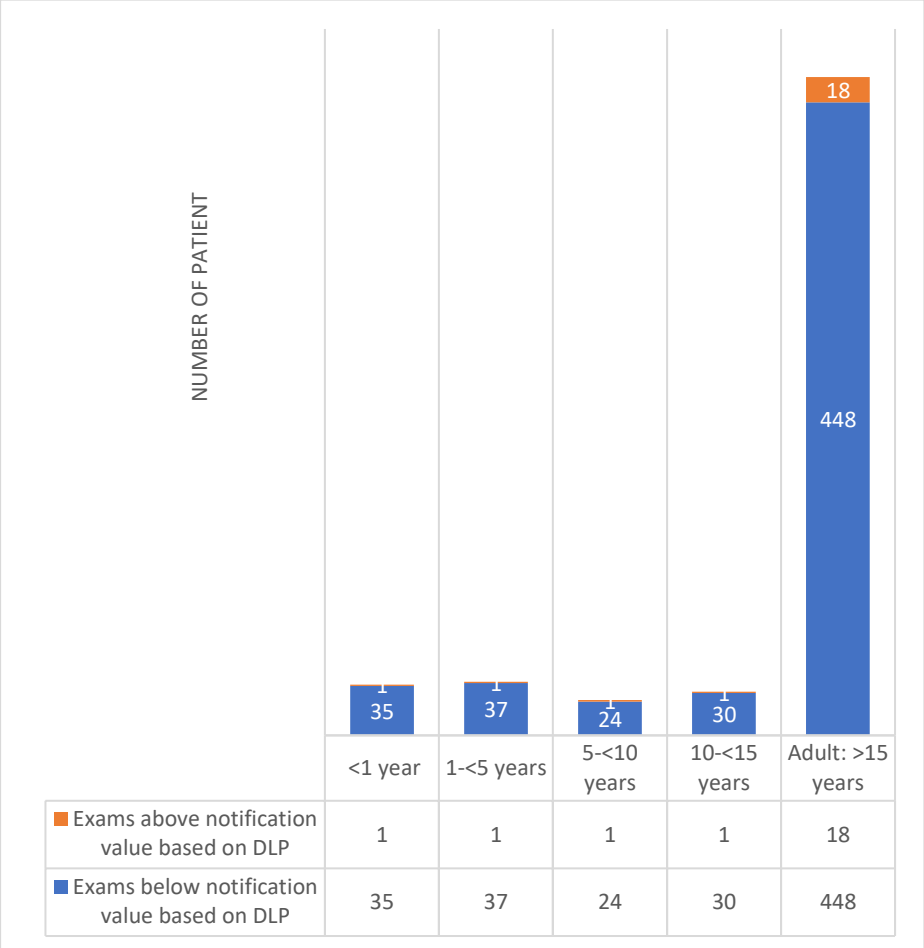

Figure 3: Number of examinations above and below the notification value based on DLP

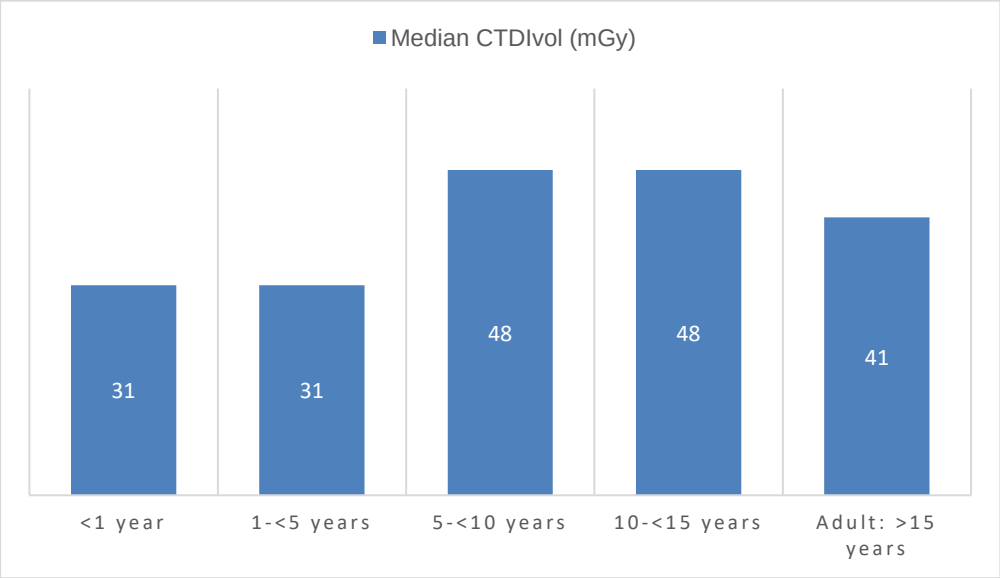

Figure 4: Median brain CTDIvol for different age groups

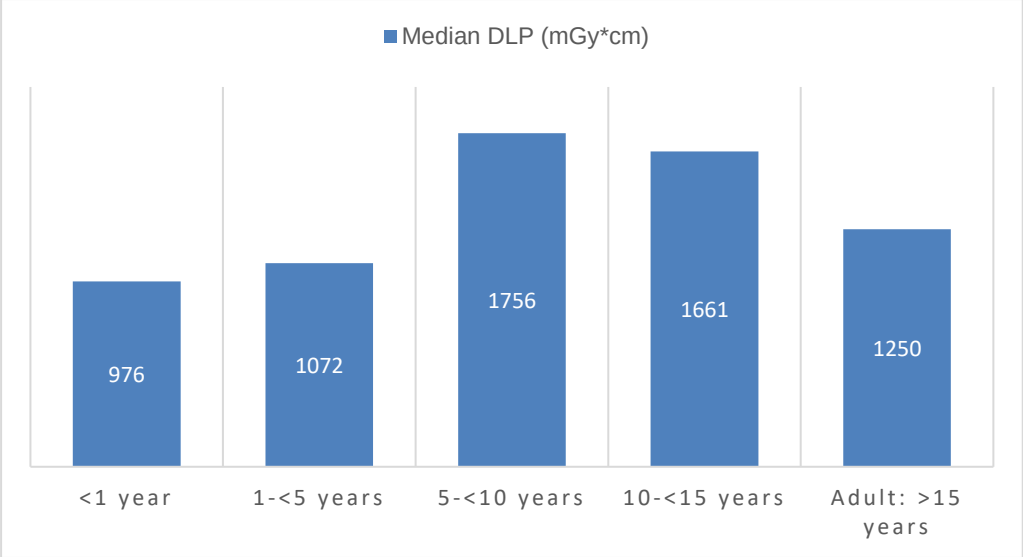

Figure 5: Median brain DLP for different age groups

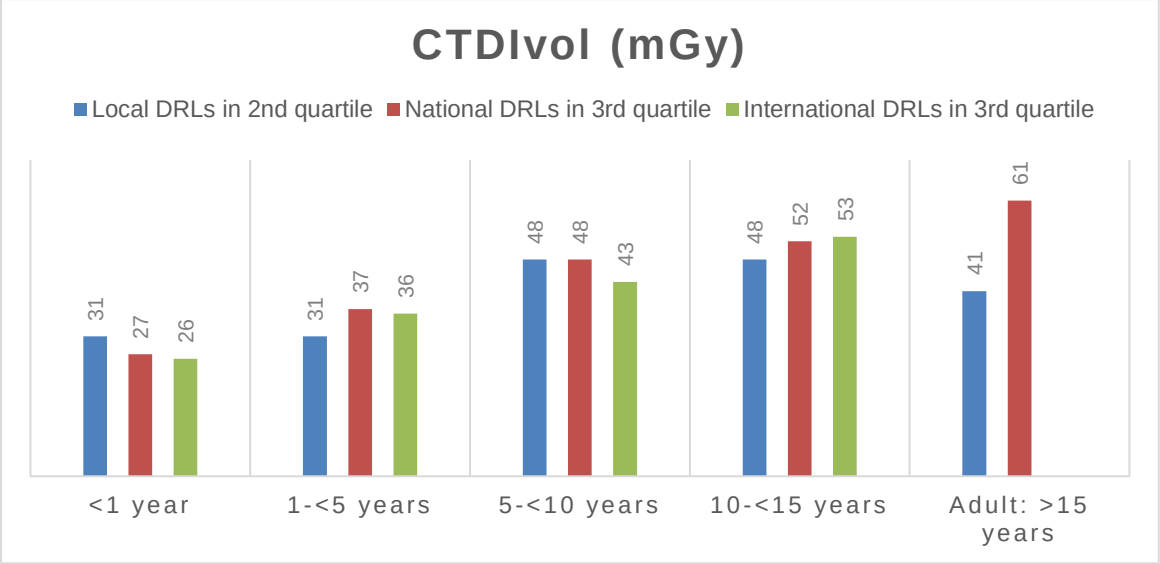

Figure 6: Local DRLs in comparison with the national and international values

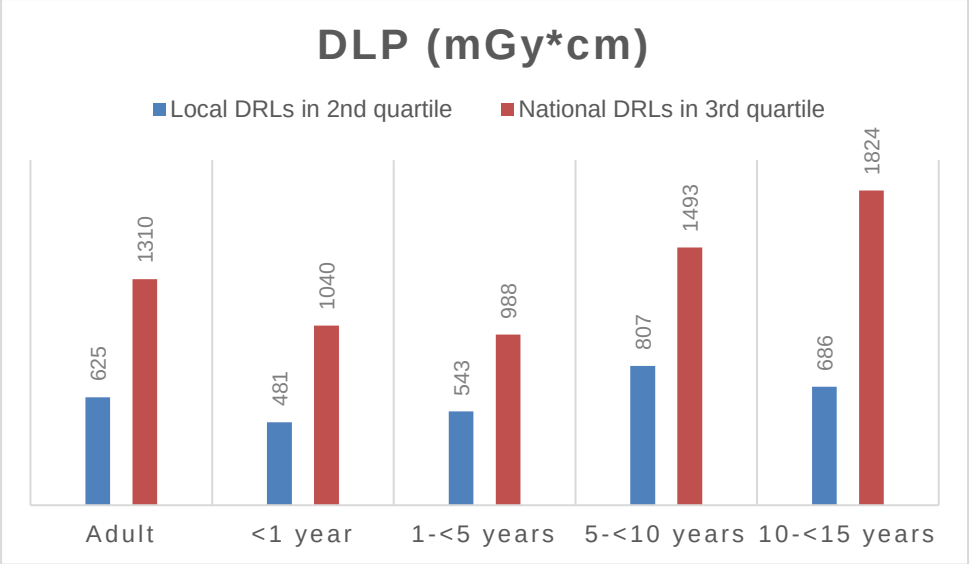

Figure 7: Established median DLPs compared to the national DRL values based on a single series.

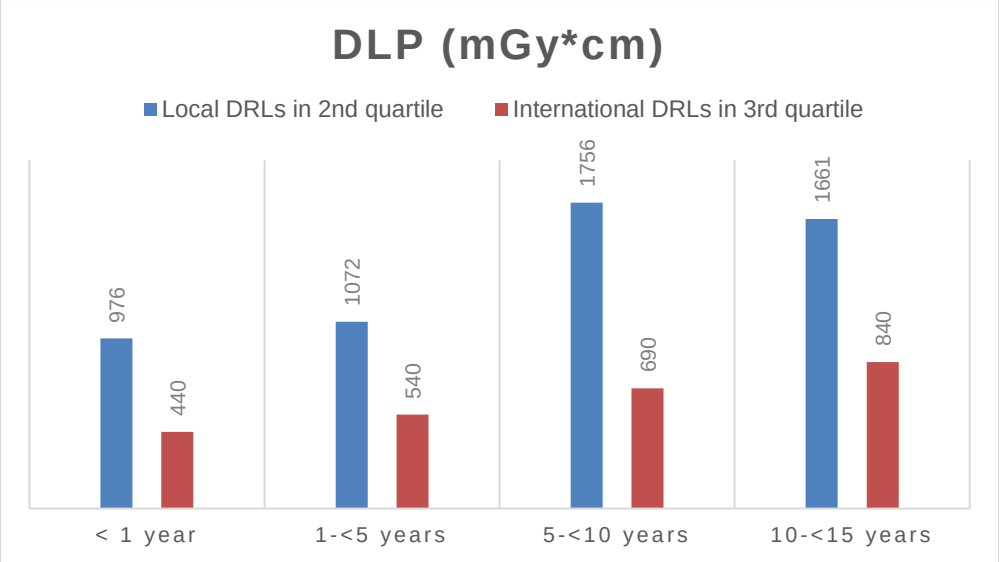

Figure 8: Established median DLPs compared to the international DRL values based on a total DLP.

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CHAPTER SEVEN: SUMMARY AND CONCLUSION

7.1 Introduction

This chapter summarises the discussions from the articles. The step-by-step approach to the implementation of DRLs and the outcome of the clinical implementation of RDMS is presented in the chapter. Conclusions from the articles and recommendations for future studies are also presented in the chapter.

Computed Tomography Practice

The use of CT in medical diagnostic imaging has expanded worldwide with numerous benefits for millions of people each year (Seeram 2022). The CT procedure is associated with a high radiation dose in comparison to other X-ray examinations. The high dose is capable of causing radiation injuries such as the possibility of cancer induction (Tsapaki 2020). Although modern CT scanners are associated with lower radiation doses even small doses could lead to radiation-related injuries (Perez 2013; IAEA 2016). This implies that the optimisation principle is vital in mitigating the possible radiation risks (Perez 2013; Sherer et al. 2021). Therefore, the main aim of this study was to develop a prospective manual RDMS for brain CT as a tool for dose optimisation.

Radiation Dose Management Systems (RDMS)

To develop and implement the first RDMS at the research site, it was necessary to conduct a systematic literature review on RDMS. Findings from the review form part of the development of RDMS that was used in this study.

To this end, several publications on radiation dose management systems (RDMS) were reviewed and published as a systematic review (Garba et al. 2023b). The radiation dose management systems identified, all allowed for tracking, monitoring, and analysis of patient radiation exposure (IAEA 2023). The dose management systems were categorised into three: CT scanner vendor-specific, commercially available and those produced for local use (Garba et al. 2023b). The CT scanner-specific RDMSs, such as

DoseWise by Philips (NICE 2017), and DoseWatch by GE (Crowley et al. 2021) were manufactured by the CT scanner vendors. They provide automatic tracking and monitoring of radiation doses for individual patients during CT procedures to promote dose optimisation and justification. The commercially available RDMSs are in the market and produced by different companies such as Radimetrics, a dose-monitoring software, produced by Bayer Healthcare that provides comprehensive and real-time monitoring of patient doses (Radimetrics 2022). The locally produced RDMSs such as RADIANCE are open-source dose monitoring software for real-time dose tracking (Cook et al. 2013). Similarities and differences were highlighted in the RDMS review (Garba et al. 2023b).

There are two different methods for radiation dose data collection and tracking: electronic and manual means (Garba et al. 2023b; IAEA 2023). The electronic data collection and recording method facilitates a purposeful analysis of patient radiation dose data, especially for regional or national dose monitoring (IAEA 2023). The electronic software uses different DICOM methods such as Radiation Dose Structured Report (RDSR); Modality Performed Procedure Steps (MPPS); Optical Character Recognition (OCR) and image file header to gather radiation dose information for every patient procedure performed (NICE 2017; Garba et al. 2023b).

Manual data collection involves recording the scan parameters and dose information on a developed template or Excel sheet (IAEA 2023). The use of a manual dose monitoring system is recommended for places without electronic or digital means or in a single hospital or department (IAEA 2023). This was the case for the radiology department at the research site. The manual method provides an efficient starting point for dose data analysis and reporting as mentioned in the previous section (IAEA 2023). Using the manual approach, the dose data are recorded on a RDMS developed from the findings of the first study of this thesis. Typically recorded on RDMS as developed in this study or entered in an Excel sheet such as presented by the IAEA (2023). In the Garba et al., (2023b) review, a few studies were noted to have carried out manual dose monitoring. However, it was indicated that the manual method is time-consuming and associated with

data entry errors (Garba et al. 2023b). The advantages and disadvantages of both manual and electronic methods have been discussed in the systematic review (Garba et al. 2023b).

As previously stated, DRLs are a dose optimisation tool in medical imaging (ICRP 2017). The IAEA document has highlighted the importance of RDMSs in implementing DRLs in the clinical setting. This was achieved through dose monitoring of typical dose data and making comparisons with local, regional and national DRLs to promote dose optimisation (IAEA 2023). The systematic review by Garba et al., (2023b) has highlighted several RDMS studies where DRLs were established and compared with existing DRLs to promote the implementation of DRLs in clinical settings. However, none of the RDMS studies reviewed came from African countries (Garba et al. 2023b). This indicates that the use of DRLs was yet to be implemented and published for clinical settings in the African community. This, in turn, creates a niche for developing manual RDMS as a starting point to promote the implementation of DRLs in Africa for dose optimisation in clinical practice (Garba et al. 2023b). To have a better understanding of RDMS, knowledge of the concept of dose optimisation and justification is essential. Therefore the second study of this thesis was aimed at assessing the knowledge of dose optimisation and justification amongst radiographers, radiologists and referring physicians.

Concept of dose justification and optimisation

According to Mayo-Smith et al., (2014), optimisation and justification principles are only effective when radiologists, referring doctors, and patients have appropriate knowledge of CT indications and the imaging system. The clinical indications guide the choice of the imaging device and protocols (Perez 2013). Further, different indications require different exposure parameter settings as one size does not fit all, which enhances dose optimisation (Kalra et al. 2015). Findings from this study showed that both radiographers and radiologists knew the scan parameters including their impact on dose and image quality, albeit more so in the radiographers' cohort (Garba et al. 2023a). This is encouraging as it promotes dose optimisation and facilitated the implementation of RDMS in the study area

as a later phase of the research project. Further, more than half of the referring physicians (54.4%) indicated that a CT request is ordered based on the clinical indication and patient age (Garba et al. 2023a). The use of clinical indications and patient age to request CT could curb the number of CT procedures that may not add diagnostic value to the patient medical condition (McCollough et al. 2009). On the other hand, less than half (45.6%) of the participant physicians indicated that CT should be requested based on indication only (Garba et al. 2023a). This is worrisome as lack of consideration of clinical indications could pose a challenge as many unjustifiable requests could be processed which would impact patient dose and RDMS (Garba et al. 2023a). In addition, if clinical indications are considered, some patient conditions could be addressed using non-ionising radiation procedures such as magnetic resonance imaging (MRI) or an ultrasound scan (USS) (McCollough et al. 2009). This could prevent unwarranted radiation exposure that may not be essential for managing their medical condition (Tahvonen et al. 2013). Therefore, clinical indications remain a strong justification and optimisation tool that should be used to regulate CT requests and optimise the protocol. The justification and optimisation principles are necessary for promoting dose management systems. Therefore, health professionals, including radiographers and radiologists, must have dose justification and optimisation knowledge for effective dose management.

Another important aspect that promotes justification is the use of the referral guidelines for imaging (Perez 2013). Unfortunately, knowledge regarding the existence of referral guidelines among referring physicians was noted to be low, as 65.2% did not know about the referral guidelines. In addition, 72.8% of the referring physicians indicated that they never used the referral guidelines before requesting a CT procedure (Garba et al. 2023a). This is a critical finding and it calls for continuous advocacy among physicians regarding the availability and usage of the referring guidelines for imaging to promote the course of dose justification Therefore, it is acknowledged that patient dose monitoring could encourage the use of the referral

guideline as physicians are expected to justify every request based on the imaging guidelines before completing a request form.

Optimisation of the procedure is also achieved using diagnostic reference levels as a tool to identify a high-dose procedure (ICRP 2017). To facilitate the optimisation of CT protocol, knowledge of DRLs must be understood. Interestingly, knowledge of DRLs was noted as moderate among radiographers and radiologists in this study (Garba et al. 2023a). This has helped in the implementation of RDMS for dose optimisation in the study locality.

Another factor for consideration in effective radiation dose management to promote dose justification and optimisation is teamwork between the concerned professionals (Tsapaki 2020). The optimisation team which comprises the radiologists, medical physicists and radiographers should have sufficient knowledge of their specific optimisation task (Tsapaki 2020). In collaboration with the referring physicians, the radiographers and radiologists justify the specific examination that will most benefit a patient and the appropriate imaging protocol is optimised to ensure an acceptable image quality requirement is established (Parakh et al. 2016; Tsapaki 2020). The present study found that the majority of both radiographers and radiologists indicated that protocol development should be teamwork and they encouraged the need to strengthen dose optimisation in CT (Garba et al. 2023a). Therefore, professionals should be supported and encouraged to carry out their roles effectively for proper dose justification and optimisation in medical imaging.

The findings from this study (Garba et al. 2023a) showed that health professionals have the knowledge to track and monitor the radiation dose of patients during CT procedures, also acknowledging the need for continuous training in dose optimisation and justification in CT. Thus the third phase in this thesis focused on the implementation of the manual RDMS that was developed from the systematic literature review.

Implementation of RDMS

The developed RDMS was prospectively used to monitor and manage radiation dose and scan parameters of patients who were referred for brain CT procedures (Garba et al. 2024). According to Tsalafoutas et al. (2020) and IAEA (2023), a dose monitoring system must provide scan parameters and dosimetric records to allow monitoring of the exposure history of each patient. In addition, a RDMS must be robust and it should be able to identify examinations with doses above the programmed threshold value (Parakh et al. 2016; Osman et al. 2020). The manual RDMS used in this study identified brain CT participants, mostly adult patients, that had high doses above the notification values mostly in DLP (Garba et al. 2024). In addition, the paediatric DLP DRLs, established from the dosimetric data, were found to be two to three times higher than the international paediatric DLP DRLs (Garba et al. 2024). This calls for protocol review and optimisation taking into consideration the local CT practice (Garba et al. 2024). A similar study by Osman et al., (2020), though using automatic dose tracking software, revealed some examinations including brain CT with higher DLP values. This is a concern as higher DLP might imply that a large anatomical area has been exposed to radiation (McCollough et al. 2009; ICRP 2017). This calls for an investigation into the cause of higher DLP in CT. Higher DLP could be considered as poor CT practice. This could be lack of understanding of the impact of the scan parameters such as the scan length or dose parameters such as CTDIvol on patient dose. Therefore, the need for continuous training of medical imaging professionals especially radiographers (Rawashdeh et al. 2018; Aldahery 2023).

As reported in the IAEA, (2023) document, the manual RDMS has several limitations. The limitations include some of the following: data entry errors such as too few or too many entered digits, unreadable paper-based text entries, the number of scan series not aligned with the reported doses, missing dose entries, and the use of wrong units such as mGy or cGy. Some of these limitations were noted in the present study (Garba et al. 2024). However, brain CT patients with incomplete records such as missing dose entries were excluded from the analysis but noted for the lessons that can

be learnt about the effective implementation of a manual dose monitoring system. Other studies have also highlighted the limitations of manual dose monitoring (NICE 2017; Tsapaki et al. 2018; Osman et al. 2020).

Despite the obvious limitations and preference for the introduction of an electronic system of dose monitoring, data collection for national or international purposes still relies on manual dose monitoring, especially in resource-constrained countries such as Nigeria (IAEA 2023). The research environment did not have a facility for electronic dose monitoring, therefore, we had to rely on the use of a manual RDMS as a potential improvement on no monitoring system. The implemented manual RDMS for the first time has provided documented records for both the scan and dose information for each brain CT patient performed during the study period from 1 August to 31 December 2022 (Garba et al. 2024). The documented record of examination information, such as indications and accompanying doses, could be used as a guide in justifying future CT requests (Rehani 2017). In addition, from the document record, the number of patients identified as having high doses above the notification values was noted (Garba et al. 2024). Radiation dose data from the entire recorded procedure were used in establishing DRLs based on the ICRP guidelines (ICRP 2017). Paediatric DLP DRLs were noted to be higher calling for dose optimisation (Garba et al. 2024). Radiation dose optimisation in paediatrics is more of a concern than in adults due to their more radiosensitive cells and longer life expectancy for cancer to develop (Brenner et al. 2001; Mathews et al. 2013; Krille et al. 2015; Alzimami et al. 2021). The findings of these three studies strongly support CT centres to employ the use of the manual dose monitoring system as a starting point where an electronic option does not exist. The system has proven effective for dose monitoring and also facilitates the implementation of DRLs (Järvinen et al. 2017; Samara et al. 2019; Loose et al. 2021). To my knowledge, this was the first study that employed the use of RMDS to manage patient radiation dose and scan parameters for brain procedures in Nigeria for dose optimisation (Garba et al. 2024). The use of RDMS in this study, in addition to providing patient dose records has also promoted the implementation of established DRLs in

clinical practice (Garba et al. 2024). Other studies have also reported the implementation of DRLs through patient dose monitoring (Parakh et al. 2016; Osman et al. 2020; Loose et al. 2021). The following section describes the clinical implementation of DRLs in the clinical site.

Step-by-step implementation of DRL using RDMS

A translational research model was followed for implementing DRLs using a RDMS. The translational research model takes and transforms scientific findings into a new approach that improves treatment or clinical practice (Polgar & Thomas 2020).

The focus of translational research is to implement the results of the scientific studies to deliver their anticipated benefits. For example, in Nigeria, several CT DRL studies have been conducted as presented in Table 2.1. However, findings from these studies are yet to be applied in the medical imaging community for the benefit of patients. As performed in this study, the translation research model promotes the implementation of research findings, whereby in this study, the already established DRLs were put into use for optimisation of CT protocols. Continuous dose monitoring and making comparisons with DRLs promote dose optimisation which benefits society and individual patients (Järvinen et al. 2017; IAEA 2023).

According to Rubio et al. (2010) and Polgar and Thomas (2020), translational research involves four different phases. Translational phase 1 (T1 phase) involves transforming a research finding into a health application. In the current study, this was the stage for establishing DRLs. The DRLs have been established in the studies presented in Table 2.1, but what remained was the implementation and translation of these units into the clinical settings as a means of radiation dose management and optimisation.

The T2 phase involves developing evidence-based guidelines to provide for the optimal implementation of the research findings (Polgar & Thomas 2020). This was the stage of developing a RDMS template for the clinical implementation of the brain DRLs. A systematic literature review on RDMS studies was conducted and findings from the review and other readings

guided the development of the manual RDMS used in this study (Garba et al. 2023b).

The T3 phase involves moving the research findings to a stage of implementation (Polgar & Thomas 2020). In the study, this was the stage where the RDMS was implemented to monitor compliance with the calculated typical brain CT doses with the established brain CT DRLs (clinical usage of DRLs). For effective implementation of RDMS, knowledge of the CT dose optimisation and justification was sought among radiographers, radiologists and referring physicians, and findings were published as part of this study (Garba et al. 2023a).

The T4 phase was the final stage of translational research and it involves the evaluation of the impact of the intervention (Polgar & Thomas 2020). In this phase, the impact of RDMS in the clinical setting was assessed. Findings from the implementation of RDMS are presented in Chapter Six.

Figure 7.1 shows the phases of the translational research model indicating a step-by-step approach to the clinical implementation of DRLs through radiation dose monitoring.

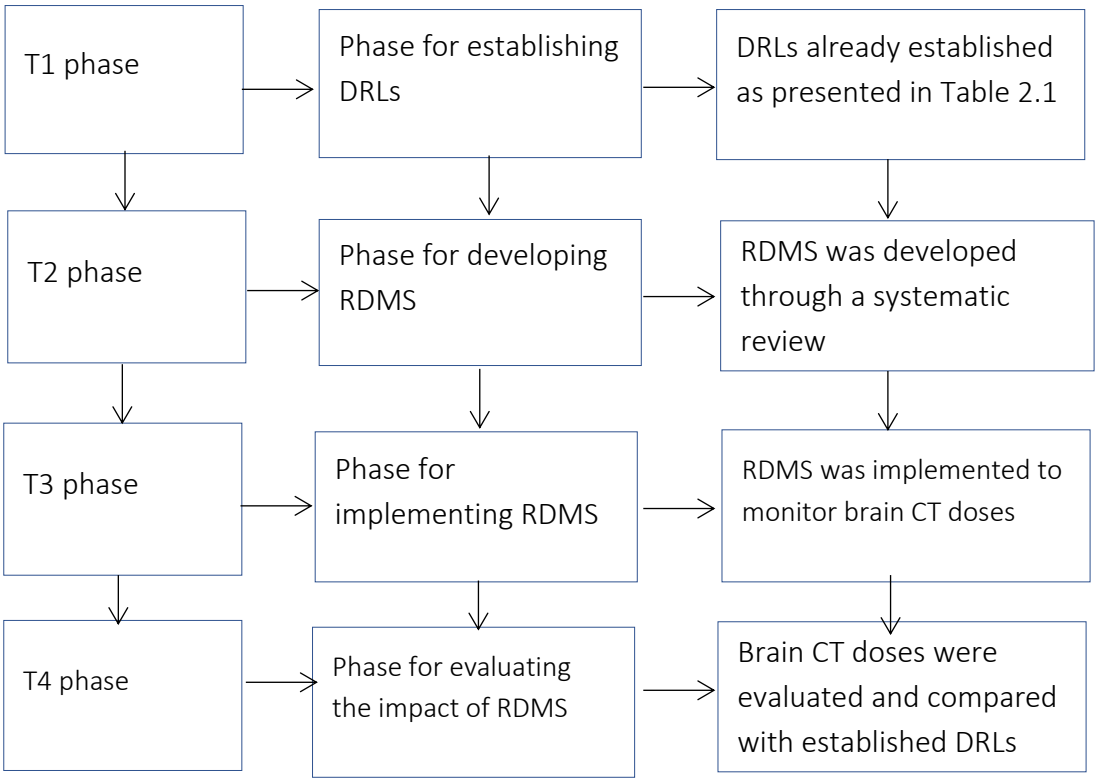

Figure 7.1: Diagram showing the study in phases

Evaluation of the study outcomes based on the RE-AIM framework

The findings of this study were evaluated and integrated into the Reach, Effectiveness, Adoption and Implemented (RE-AIM) framework to determine the impact of the study in the clinical area (Kwan et al. 2019). The RE-AIM framework is an efficient system for planning and evaluation of community-based research (Kwan et al. 2019). The systematic approach of RE-AIM was followed in evaluating the impact of RDMS in this study, and this is presented in Table 7.1.

Table 7.1: RE-AIM framework evaluating the impact of RDMS in the study area (Kwan et al. 2019).

Dimension	Definition
Reach: Identifies the target population and their characteristics	▪ Patients who presented for brain CT in the study centre. ▪ Radiographers that perform the procedures. ▪ Radiologists that interpret the images. ▪ Referring physicians who refer and manage the patients.
Effectiveness: defines the effectiveness of RDMS in clinical settings.	▪ The radiation dose of patients who presented for brain CT was recorded and monitored using RDMS. This provides an insight into the amount of radiation patients receive for every brain CT procedure performed, and determines whether it complies with the established DRLs. ▪ Notification value as the gatekeeper in RDMS identified brain CT procedures with high doses which require radiographers' attention. ▪ The Dose from RDMS was used for establishing typical brain DRL values and was compared with the national and international DRLs. Paediatric DLP DRLs were noted to be higher than the international DRLs which calls for protocol review and optimisation. ▪ Dose optimisation results in lower doses which are beneficial to patients as the possibility of radiation-induced injuries such as cataracts could be mitigated.
Adoption: identify departments that are likely to use RDMS.	▪ RDMS was used in the selected Radiology department for brain CT as the test ionising radiation procedure. ▪ Also, the information was used in all departments that refer patients for radiological procedures involving the use of ionising radiation.
Implementation: defines the period the programme was offered.	▪ RDMS was implemented for five months. ▪ Radiographers were asked to use the RDMS template for every brain CT patient performed and ensured the template was transmitted to radiologists and referring physicians. ▪ The cost was low as the RDMS is a developed template that accompanies the request form for every patient.
Maintenance: defines the sustainability of the programme over time.	The sustainability of the dose monitoring after five months post-implementation provides: ▪ Number of patients still being monitored using RDMS template.

	▪ Records of radiation dose monitored for both adults and paediatric brain CT at the facility. ▪ Plan for periodic sensitisation and retraining of radiographers through the routine departmental programme to ensure the sustainability of RDMS over a long time. ▪ Periodic supervision and auditing of the departmental records, to ensure compliance with RDMS. ▪ Extension beyond brain CT to include abdomen and chest CT as the next most frequently performed procedures.

7.2 Limitations of the study

The study has some limitations as presented below.

The radiation dose management system was studied in a single centre. Although the findings could be used for comparison in other CT centres they cannot be generalised nationally. In addition, a relatively small number of radiographers and radiologists participated in the study. This is similar to the findings of the previous studies by Foley et al. (2013) and Almohiy et al. (2020), and also typical of a questionnaire study (Foley et al. 2013). Therefore, the findings cannot be generalised to the entire population of radiographers, radiologists, and referring physicians in Nigeria. In the present study, all participants had an equal chance of participation using either a web-based or paper-based questionnaire. The questionnaires were content-validated to ensure the questions did not favour a particular group of participants.

The manual prospective dose management could be time-consuming and characterised by data entry errors. However, it can be used as a starting point for dose monitoring in a resource-constrained environment. The radiographers using the manual RDMS must exercise due diligence to ensure proper implementation of the dose management system. Furthermore, the notification values set were based on the AAPM recommended values and national DRLs in Nigeria. The set values may not be appropriate for all local CT practices and this might explain the reason

why many procedures were identified based on DLP and none were identified based on CTDIvol.

Although the study has limitations, the thesis has important novelty for introducing the first prospective manual radiation dose management system (RDMS) that has been tested and found suitable for use in places where there is no automated system. The RDMS, besides providing patient scan and dose parameters records, could be analysed to identify procedures resulting in higher than expected doses. Also, it serves as a source of data for establishing DRLs for dose optimisation. In addition, the use of an RDMS improves radiographers' understanding of the scan protocol and its impact on dose and image quality as every patient exposure has to be scrutinised during image acquisition. The systematic review conducted explored the different RDMS established in CT, their strengths and weaknesses, and provided a recommendation on how the RDMS system could be improved. In addition, the study revealed the radiographers' and radiologists' knowledge on matters relating to radiation dose and image quality as well as DRLs. Furthermore, knowledge of the concept of dose justification and availability of the referral guidelines was explored amongst the referring physicians.

7.3 Conclusion

The study can lead to some conclusions.

The systematic review conducted as part of this study identified different RDMS methods and their strengths and weaknesses. This guided the development of a manual RDMS for brain CT procedures.

The developed and implemented manual RDMS has proven effective in tracking and providing records of patient scan parameters and dosimetric information for brain CT patients.

The use of RDMS has shown strength in identifying brain CT procedures with high doses which require optimisation.

The manual RDMS has also facilitated the implementation of DRLs for brain CT procedures based on the translational research model approach. The

established typical paediatric DLP values were noted to be two to three folds higher than the international paediatric DLP DRLs which calls for total protocol review and optimisation.

In strengthening the use of a RDMS, knowledge of dose justification and optimisation principles among radiographers, radiologists and referring physicians was investigated and noted as moderate. However, there is a need for continuous retraining to keep all those involved in medical imaging abreast of the new optimisation techniques.

The use of the referral guidelines remains key in dose justification. However, the referring physicians were noted to have had limited awareness and knowledge of referral guidelines. This calls for proper orientation and building of awareness as well as retraining the referring physicians on the use of referral guidelines to promote the concept of dose justification.

7.4 Recommendation based on the findings of the study

A manual RDMS could be implemented in CT centres that do not have automated systems for dose monitoring. Although the RDMS is for a brain procedure, it could be easily adjusted for extension to other body regions and imaging procedures.

For CT centres with an automated RDMS, the manual RDMS could be employed for quality assurance purposes.

Continuous retraining of radiographers, radiologists and referring physicians on the impact of scan parameters on dose and image quality as well as the use of the referral guidelines for imaging is essential for effective dose optimisation.

Message from the thesis

The use of radiation in clinical practice offers a lot of benefits in the diagnosis of diseases. However, it is worthy of note that the use of radiation is associated with health challenges such as the possibility of cancer induction in the exposed individuals. Radiation dose justification and optimisation using DRLs as a tool remain the most effective principles of patient radiation protection. The use of radiation dose management

promotes the application of dose justification and optimisation in clinical practice. Although electronic RMDS is efficient, manual RDMS remains the most feasible and has proven effective as a dose-monitoring system in resource-constrained environments like ours. However, lessons learned from the use of a manual system could be used when there is a full migration to a digital RDMS.

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ANNEXURES

Annexure 1: CPUT Ethics approval

Cape Peninsula University of Technology

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

P.O. Box 1906 • Bellville 7535 South Africa
Symphony Road Bellville 7535
Tel: +27 21 959 6917
Email: sethn@cput.ac.za

09 February 2022
REC Approval Reference No:
CPUT/HW-REC 2022/H1

Faculty of Health and Wellness Sciences

Dear Ms Garba

Re: APPLICATION TO THE HW-REC FOR ETHICS CLEARANCE

Approval was granted by the Health and Wellness Sciences-REC to **Ms I Garba** for ethical clearance. This approval is for research activities related to research for **Ms I Garba** at Cape Peninsula University of Technology.

TITLE: Development of local dose management system for computed tomography procedures

Supervisor: Prof P Engel-Hills and Dr F Davidson

Comment:

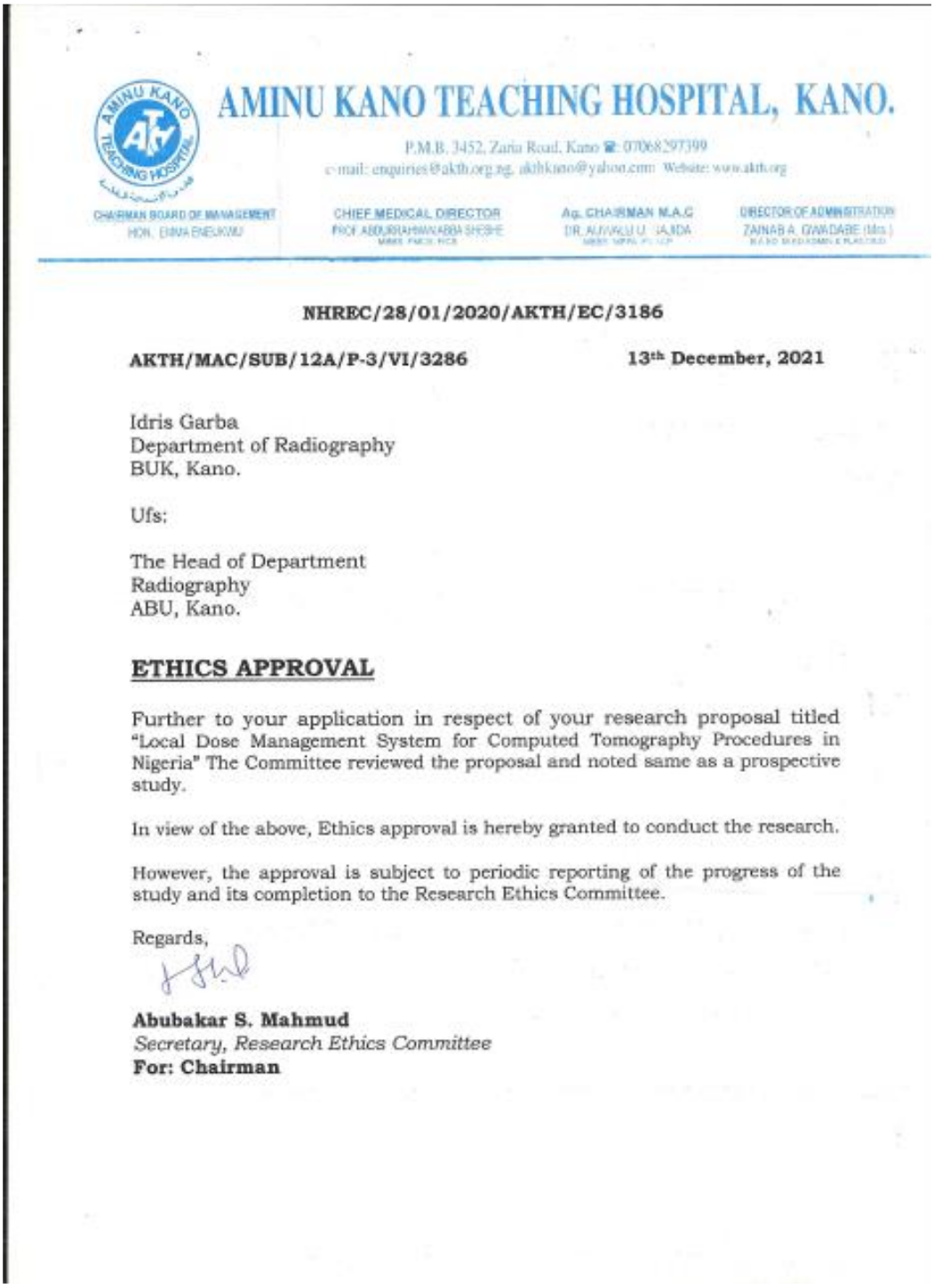
Approval will not extend beyond 10 February 2023. An extension should be applied for 6 weeks before this expiry date should data collection and use/analysis of data, information and/or samples for this study continue beyond this date.

The investigator(s) should understand the ethical conditions under which they are authorized to carry out this study and they should be compliant to these conditions. It is required that the investigator(s) complete an **annual progress report** that should be submitted to the HWS-REC in December of that particular year, for the HWS-REC to be kept informed of the progress and of any problems you may have encountered.

Kind Regards

Ms Carolynn Lackay
Chairperson – Research Ethics Committee
Faculty of Health and Wellness Sciences

Annexure 2: AKTH ethics approval



AMINU KANO TEACHING HOSPITAL, KANO.

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Ag. CHAIRMAN M.A.C
DR. ALIYAGU U. LAMDA

DIRECTOR OF ADMINISTRATION
ZAINAB A. GWADABE (Mrs.)

NHREC/28/01/2020/AKTH/EC/3186

AKTH/MAC/SUB/12A/P-3/VI/3286 **13th December, 2021**

Idris Garba
Department of Radiography
BUK, Kano.

Ufs:

The Head of Department
Radiography
ABU, Kano.

ETHICS APPROVAL

Further to your application in respect of your research proposal titled "Local Dose Management System for Computed Tomography Procedures in Nigeria" The Committee reviewed the proposal and noted same as a prospective study.

In view of the above, Ethics approval is hereby granted to conduct the research.

However, the approval is subject to periodic reporting of the progress of the study and its completion to the Research Ethics Committee.

Regards,

Abubakar S. Mahmud
Secretary, Research Ethics Committee
For: Chairman

Annexure 3:

Questionnaire:

Radiologists' and Radiographers' knowledge of radiation dose from Computed tomography (CT) and the use of diagnostic reference levels (DRLs)

My name is Idris GARBA a Doctor of Radiography student in the Department of Medical Imaging and Therapeutic Sciences at the Cape Peninsula University of Technology South Africa under the supervision of Prof. Penelope Engel-Hills, Dr Florence Davidson and Dr Anas Ismail. The study aims to develop a local dose management system for CT examinations for dose optimisation. To manage patient radiation doses for CT imaging you need to have knowledge of CT doses and the use of DRLs. We would appreciate your kindness if you could take about 15 minutes of your time to respond to the following questions. Participation in this study is voluntary, you have the right to withdraw from the study at any given time without prior notice. Information provided will be solely used for this research and will be treated with the utmost confidentiality.

Demographic information

1. Speciality:
   ☐ Radiographer ☐ Radiologist ☐ Medical physicist
2. Gender:
   ☐ Male ☐ Female ☐ Other
3. Qualifications:
   ☐ Diploma ☐ Bachelor ☐ Masters
   ☐ PhD ☐ Fellowship
4. Years in clinical experience
   ☐ ≤5 ☐ 6-10 ☐ 11-15
   ☐ 16-20 ☐ >20
5. Did you attend specialised CT training?
   ☐ Yes ☐ No

Knowledge and awareness of CT radiation doses

6. Do you know the common dose indices used to express dose in CT?

   ☐ Yes ☐ No

7. If yes, can you state them?_____ and/or _____

8. Routine scan parameters such as kV, mAs, pitch, reconstruction algorithms and slice thickness should be changed according to which of the following procedures?

Questions	Yes	No	Don't know
Study indication			
Patient age			
Patient size			
Anatomical area			

9. Regarding the use of automatic tube current modulation (ATCM)

Questions	True	False
ATCM has been shown to decrease the patient dose on average		
Z-axis ATCM reduces the dose along the z-axis of the patient		
XY-axis ATCM reduces the dose along the XY-axis of the patient		
ATCM increases the patient dose in the brain region compared to the neck region		
ATCM is affected by centring the patient within the gantry		
Is ATCM useful for dose saving?		

10. Regarding image noise setting

Questions	True	False
A non-contrast CT of the abdominal requires the same noise (mAs setting) as the contrast phase		
Radiation dose influences image noise		
Image noise influences image quality		

11. Changing the kV from 120 to 140 causes an increase in the CTDI value.

    ☐ Yes ☐ No

12. Reducing the kV from 120 to 100 during an angiography CT procedure with other parameters kept constant.

Questions	True	False
Reduces the radiation dose		
Reduces the image contrast		
Increases the image noise		
Increases the vessel enhancement		

13. Regarding the tube current (mA)

Questions	True	False
mA has a linear relationship with the radiation dose		
Reducing mA by 50% also increases noise by 50%		
Reducing mA by 50% also reduces the dose by 50%		

14. Regarding the “pitch” (table movement per tube rotation/nominal beamwidth)

Questions	True	False
Pitch may impact the image quality		
Pitch may impact the patient's dose		
Spiral artefacts are reduced at a lower pitch value		
For single-slice CT, the higher the dose the higher the pitch		

15. Decreasing gantry rotation time

Questions	True	False
Decreases patient dose in a linear fashion		
Increases the image noise		

16. Regarding slice thickness

Questions	True	False
Increasing the slice thickness increases the spatial resolution		
Increasing the slice thickness decreases the dose		
Decreasing the slice thickness reduces “partial volume” artefacts		

Decreasing the slice thickness will increase the scan time		

17. Regarding reconstruction parameters, choosing

Questions	True	False
A smooth reconstruction kernel increases the visualisation of noise		
Wider window settings reduce the image contrast setting		
Wider window settings reduce the visual perception of noise		

18. Image noise is influenced by the following factors, kindly respond to all the factors

Questions	True	False	Questions	True	False
kV			Helical pitch		
mA			Exposure time		
Window width			Window level		
Collimation			Reconstruction algorithms		
Slice thickness					

Knowledge and awareness of CT DRLs

19. Are you aware of what diagnostic reference levels (DRL) are?

☐ Yes ☐ No ☐ Don't know

20. If yes, briefly explain your understanding._____

21. How often do you consider DRLs while selecting a protocol for a CT procedure?

☐ Never ☐ Occasionally ☐ Frequently

☐ Always

22. Is the use of DRLs implemented in your centre?

☐ Yes ☐ No ☐ Don't know

23. Are you aware of the established Nigerian DRLs for the adult routine brain?

☐ Yes ☐ No ☐ Don't know

24. If yes, can you state the value? CTDIvol_____ and DLP_____

25. Which of the following describes the function of DRLs? Kindly choose only one option

☐ It is used for justification of procedure?
☐ It is used for organ dose assessment?
☐ It is used for the optimisation of protocol?

26. Who is responsible for developing protocols for procedures in your CT scanner?

☐ Radiographer ☐ Radiologist ☐ Medical physicist

☐ Application specialist ☐ Is a team approach

27. Are you allowed to modify CT protocols to reduce the patient's dose?

☐ Yes ☐ No

28. Do you have the confidence to modify CT protocols to reduce patient dose?

☐ Yes ☐ No

I appreciate the time taken to respond to these questions. Should you have any queries regarding the nature of the study do not hesitate to contact me.

Yours Sincerely

Idris Garba
Student
Email: igarba.radg@buk.edu.ng
Tel:+2348034532750

Prof. Penelope Engel-Hills
Lead Supervisor
Email: engelhillsp@cput.ac.za

Annexure 4:

Questionnaire

Referring physicians' awareness of radiation dose justification and the use of referral guidelines

My name is Idris GARBA a Doctor of Radiography (PhD) student in the Department of Medical Imaging and Therapeutic Sciences at the Cape Peninsula University of Technology South Africa under the supervision of Prof. Penelope Engel-Hills, Dr Florence Davidson and Dr Anas Ismail. The study aims to develop a local dose management system for CT examinations for dose optimisation. To manage patient radiation doses for CT imaging you need to have knowledge of the radiation dose, justification and the use of referral guidelines for imaging. We would appreciate your kindness if you could take about 15 minutes of your time to respond to the following questions. Participation in this study is voluntary, you have the right to withdraw from the study at any given time without prior notice. Information provided will be solely used for this research and will be treated with the utmost confidentiality.

Demographic information

1. Speciality:
   ☐ Medicine ☐ Paediatrics ☐ Family physician
   ☐ Neuro surgery ☐ O & G ☐ Other (pls. specify)_____
2. Gender:
   ☐ Male ☐ Female ☐ Other
3. Qualifications:
   ☐ Bachelor ☐ Masters ☐ PhD
   ☐ Fellowship
4. Years in clinical experience:
   ☐ ≤5 ☐ 6-10 ☐ 11-15
   ☐ 16-20 ☐ >20

Justification on the use of ionising radiation

5. How often do you check whether the CT procedure is justified before filling a request form?

   ☐ Never ☐ Occasionally ☐ Frequently

   ☐ Always

6. How often do you use referral guidelines to help you justify the procedure?

   ☐ Never ☐ Occasionally ☐ Frequently

   ☐ Always

7. How often do you ask patients about previous examinations involving radiation?

   ☐ Never ☐ Occasionally ☐ Frequently

   ☐ Always

8. How frequently do you use clinical indications to prescribe CT scans irrespective of the previous history of CT scans?

   ☐ Never ☐ Occasionally ☐ Frequently

   ☐ Always

9. How often in your clinical practice has the history of previous CT scans helped you in making a clinical decision?

   ☐ Never ☐ Occasionally ☐ Frequently

   ☐ Always

10. Does the number of CT scans the patient has had in the past affect your decision to request another scan?

    ☐ Yes ☐ No

11. If a patient has undergone radiological examinations such that the estimated dose is about 100 mSv, will this make it difficult for you to prescribe another CT scan?

    ☐ Yes ☐ No

12. Do you think having a system by which you have quick information about patients' doses will be helpful?

☐ Yes ☐ No

13. Do you think that a CT scan should be prescribed totally based on:

☐ Clinical indication

☐ Age

☐ Both

Knowledge about radiation exposure

14. What is the number of chest X-rays (PA) that produce an equivalent radiation dose for an adult brain CT?

☐ 50 ☐ 120

15. Which imaging modality imparts the highest radiation dose to the patient?

☐ MRI ☐ CT ☐ Ultrasound

☐ General X-ray machine

16. What is the expected mSv received during one adult brain CT scan?

☐ 2 mSv ☐ 10 mSv

17. Which age group is the most sensitive to radiation?

☐ Children ☐ Adult

Appropriateness of the use of referral guidelines

18. Are you aware of referral guidelines for medical imaging examinations?

☐ Yes ☐ No ☐ Don't know

19. Do you have referral guidelines for medical imaging in your workplace?

☐ Yes ☐ No ☐ Don't know

20. How often do you use referral guidelines for imaging before you request a CT examination?

☐ Never ☐ Occasionally ☐ Frequently

☐ Always

I appreciate the time taken to respond to these questions. Should you have any queries regarding the nature of the study do not hesitate to contact me.

Yours Sincerely

_____ _____

Idris Garba
Student
Email: igarba.radg@buk.edu.ng
Tel:+2348034532750

Prof. Penelope Engel-Hills
Lead Supervisor
Email: engelhillsp@cput.ac.za

Annexure 5: raw data

Responses on knowledge and awareness of CT radiation dose among radiographers and radiologists

Demographic information						Knowledge and awareness of CT radiation doses																																												
SN	A	B	C	D	E	A2	B2	C21	C22	C23	C24	D21	D22	D23	D24	D25	D26	E21	E22	E23	F2	G21	G22	G23	G24	H21	H22	H23	I21	I22	I23	I24	J21	J22	K21	K22	K23	K24	L21	L22	L23	M21	M22	M23	M24	M25	M26	M27	M28	M29
1	Radiographer	F	Bachelor	>20	No	Yes	CTDI and DLP	Yes	Yes	Yes	Yes	TRUE	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	Yes	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	TRUE
2	Radiographer	F	Bachelor	<5	Yes	Yes	mSv	Yes	Yes	Don't know	Yes	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE	Yes	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
3	Radiographer	F	Bachelor	<5	No	No	NIL	Yes	Yes	Yes	Yes	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	Yes	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
4	Radiographer	F	Bachelor	<5	No	Yes	CTDI, DLP and ED	Yes	Yes	Yes	Yes	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	Yes	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
5	Radiologist	F	Bachelor	11-15	No	Yes	kV and mA	Yes	Yes	Yes	Yes	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	No	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE
6	Radiologist	F	Masters	6-10	No	No	NIL	Yes	Yes	Yes	Yes	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	Yes	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
7	Radiographer	F	PhD	>20	No	Yes	CTDI and DLP	No	Yes	Yes	Yes	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	Yes	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE
8	Radiographer	M	Bachelor	<5	No	Yes	CTDI100	Yes	Yes	Yes	No	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	Yes	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
9	Radiographer	M	Bachelor	<5	No	No	NIL	Yes	Yes	Yes	Yes	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	Yes	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
10	Radiographer	M	Bachelor	6-10	Yes	Yes	CTDI and DLP	Yes	No	Yes	Yes	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	No	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE

Responses on knowledge and awareness of CT DRLs among radiographers and radiologists

Demographic information						Knowledge and awareness of CT DRLs									
SN	A	B	C	D	E	A3	B3	C3	D3	E3	F3	G3	H3	I3	J3
1	Radiographer	F	Bachelor	>20	No	Yes	NIL	Occasionally	Don't know	Yes	NIL	It is used for the optimisation of protocol	It is a team approach	Yes	Yes
2	Radiographer	F	Bachelor	<5	Yes	No	NIL	Never	Don't know	No	NIL	It is used for justification of procedure	Radiographer	Yes	No
3	Radiographer	F	Bachelor	<5	No	Yes	It is the preset procol for pediatric and adult.which suits them and reduce patient dose	Always	Yes	No	No idea	It is used for justification of procedure	It is a team approach	Yes	Yes
4	Radiographer	F	Bachelor	<5	No	Yes	They are protocol for different patients size, age and region of interest.Do different radiation dose.	Frequently	Yes	Don't know	No idea	It is used for justification of procedure	It is a team approach	Yes	Yes
5	Radiologist	F	Bachelor	11-15	No	No	NIL	Never	Yes	No	NIL	It is used for organ dose assessment	It is a team approach	Yes	Yes
6	Radiologist	F	Masters	6-10	No	Dont know	NIL	Never	Don't know	Don't know	NIL	It is used for organ and dose assesment	It is a team approach	Yes	Yes
7	Radiographer	F	PhD	>20	No	Yes	DRL is an indication of an acceptable range of radiation doses for specific imaging exams and locations	Never	No	No	NIL	It is used for the optimisation of protocol	It is a team approach	Yes	Yes
8	Radiographer	M	Bachelor	<5	No	Yes	Is a specific radiation dose for a given imaging study that is not expected to be exceeded	Occasionally	Yes	Yes	NIL	It is used for organ dose assessment	Radiographer	Yes	Yes
9	Radiographer	M	Bachelor	<5	No	Yes	Amount of radiation required to provide diagnostic images	Always	Yes	Don't know	NIL	It is used for justification of procedure	It is a team approach	Yes	Yes
10	Radiographer	M	Bachelor	6-10	Yes	Yes	Modefying of protocol	Occasionally	Yes	Don't know	Don't know	It is used for justification of procedure	Radiographer	Yes	Yes

Responses on knowledge of dose justification and use of the referral guidelines among the referring physicians

	Demographiic information				Justification on the use of ionising radiation									Knowledge about radiation exposure				The use of referral guidelines		
SN	A	B	C	D	A2	B2	C2	D2	E2	F2	G2	H2	I2	A3	B3	C3	D3	A4	B4	C4
1	Medicine	Male	Bachelor	<5	Never	Never	Never	Never	Never	Yes	Yes	Yes	Clinical inidcation	50	MRI	2 mSv	Children	Yes	Yes	Never
2	Medicine	Male	Bachelor	<5	Always	Occasionally	Occasionally	Frequently	Frequently	Yes	No	Yes	Both	120	CT	10 mSv	Children	Yes	No	Occasionally
3	Medicine	Male	Masters	11-15	Always	Frequently	Occasionally	Occasionally	Occasionally	No	No	Yes	Clinical inidcation	50	CT	10 mSv	Children	Yes	Don't know	Occasionally
4	Family physician	Male	Fellowship	11-15	Occasionall	Never	Never	Always	Occasionally	No	No	Yes	Clinical inidcation	50	CT	2 mSv	Children	Yes	No	Never
5	Family physician	Female	Fellowship	11-15	Always	Occasionally	Occasionally	Never	Always	Yes	Yes	Yes	Clinical inidcation	120	MRI	10 mSv	Children	No	No	Never
6	Dental	Female	Bachelor	<5	Occasionall	Occasionally	Never	Never	Frequently	Yes	Yes	No	Clinical inidcation	NIL	MRI	10 mSv	Children	No	No	Never
7	Opthalmology	Male	Bachelor	6-10	Always	Occasionally	Frequently	Frequently	Always	No	No	Yes	Clinical inidcation	50	CT	NIL	Children	No	No	Never
8	Opthalmology	Female	Bachelor	6-10	Frequently	Frequently	Never	Always	Frequently	Yes	Yes	Yes	Clinical inidcation	120	X-ray machine	10 mSv	Children	No	No	Never
9	Opthalmology	Male	Bachelor	6-10	Always	Always	Occasionally	Occasionally	Frequently	Yes	Yes	Yes	Clinical inidcation	50	CT	10 mSv	Children	Yes	Yes	Occasionally
10	Opthalmology	Male	Fellowship	16-20	Always	Frequently	Always	Occasionally	Always	Yes	NIL	Yes	Both	50	CT	NIL	Children	Yes	No	Occasionally
11	Opthalmology	Male	Bachelor	<5	Frequently	Never	Occasionally	Frequently	Frequently	No	No	Yes	Both	50	CT	10 mSv	Children	No	Don't know	Never
12	Dental	Female	Bachelor	<5	Always	Frequently	Occasionally	Never	Never	Yes	No	Yes	Clinical inidcation	50	X-ray machine	2 mSv	Children	Yes	Don't know	Never
13	Dental	Female	Bachelor	<5	Occasionall	Never	Never	Occasionally	Never	Yes	No	Yes	Clinical inidcation	50	CT	2 mSv	Children	Don't know	Don't know	Never
14	Dental	Male	Bachelor	<5	Frequently	Never	Always	Occasionally	Occasionally	No	Yes	Yes	Clinical inidcation	50	X-ray machine	10 mSv	Adult	No	Don't know	Never
15	Dental	Male	Bachelor	<5	Never	Occasionally	Occasionally	Occasionally	Never	No	No	Yes	Both	50	MRI	10 mSv	Children	No	No	Never
16	Dental	Female	Fellowship	11-15	Always	Never	Always	Always	Always	No	No	Yes	Clinical inidcation	NIL	CT	NIL	Children	Don't know	Don't know	Never
17	Dental	Male	Fellowship	11-15	Frequently	Frequently	Never	Frequently	Frequently	Yes	Yes	Yes	Both	NIL	CT	NIL	Children	Yes	No	Occasionally
18	Dental	Female	Fellowship	16-20	Never	Never	Never	Never	Never	NIL	NIL	NIL	Both	NIL	X-ray machine	NIL	Children	NIL	Don't know	Never
19	Opthalmology	Male	Bachelor	6-10	Always	Never	Frequently	Frequently	Occasionally	Yes	NIL	Yes	Both	50	CT	10 mSv	Children	No	Don't know	Never
20	ENT	Male	Bachelor	6-10	Frequently	Occasionally	Frequently	Frequently	Occasionally	Yes	No	No	Clinical inidcation	50	CT	10 mSv	Children	No	Don't know	Never
21	ENT	Male	Fellowship	11-15	Always	Frequently	Occasionally	Always	Frequently	Yes	No	Yes	Both	NIL	CT	10 mSv	Children	No	No	Never
22	Opthalmology	Male	Bachelor	>20	Frequently	Occasionally	Frequently	Occasionally	Frequently	Yes	No	Yes	Clinical inidcation	50	X-ray machine	10 mSv	Children	Yes	Yes	Occasionally
23	ENT	Male	Bachelor	6-10	Always	Frequently	Frequently	Occasionally	Frequently	Yes	NIL	NIL	NIL	NIL	CT	NIL	Children	NIL	NIL	NIL
24	Paeditrics	Female	Bachelor	<5	Always	Never	Always	Occasionally	Always	Yes	No	Yes	Clinical inidcation	50	X-ray machine	10 mSv	Children	No	No	Never
25	Medicine	Female	Bachelor	<5	Occasionall	Never	Occasionally	Never	Occasionally	Yes	No	Yes	Clinical inidcation	120	X-ray machine	2 mSv	Adult	No	No	Never
26	Surgery	Male	Bachelor	11-15	Frequently	Occasionally	Occasionally	Frequently	Always	Yes	No	Yes	Both	50	CT	10 mSv	Children	Yes	No	Occasionally
27	O & G	Female	Bachelor	<5	Always	Occasionally	Occasionally	Never	Never	No	No	Yes	Clinical inidcation	120	CT	10 mSv	Children	Don't know	No	Never
28	Surgery	Male	Bachelor	11-15	Always	Occasionally	Occasionally	Always	Always	Yes	Yes	Yes	Both	50	CT	10 mSv	Children	No	Don't know	Never
29	Surgery	Male	Fellowship	6-10	Always	Never	Occasionally	Always	Frequently	Yes	No	Yes	Clinical inidcation	50	CT	2 mSv	Children	Don't know	No	Never
30	Surgery	Male	Bachelor	11-15	Always	Always	Always	Always	Always	Yes	No	Yes	Clinical inidcation	120	CT	10 mSv	Children	Yes	Yes	Frequently
31	Surgery	Male	Fellowship	6-10	Always	Frequently	Frequently	Frequently	Occasionally	Yes	Yes	Yes	Both	NIL	CT	NIL	Children	Yes	Don't know	NIL
32	Surgery	Male	Bachelor	6-10	Always	Occasionally	Occasionally	Occasionally	Never	No	Yes	Yes	Clinical inidcation	120	CT	10 mSv	Children	No	Don't know	Never
33	Orthopaedics	Male	Bachelor	6-10	Frequently	Frequently	Occasionally	Frequently	Frequently	No	Yes	Yes	Clinical inidcation	120	CT	10 mSv	Children	Yes	No	Occasionally
34	Surgery	Male	Bachelor	6-10	Always	Occasionally	Never	Always	Frequently	Yes	No	Yes	Clinical inidcation	NIL	CT	NIL	Children	Don't know	No	Never
35	Dental	Male	Fellowship	16-20	Frequently	Occasionally	Occasionally	Frequently	Occasionally	Yes	Yes	Yes	Both	NIL	MRI	10 mSv	Adult	No	No	Never
36	Orthopaedics	Male	Fellowship	16-20	Always	Occasionally	Frequently	Occasionally	Frequently	Yes	No	Yes	Clinical inidcation	50	CT	10 mSv	Children	Don't know	No	Never
37	Surgery	Male	Bachelor	11-15	Frequently	Never	Occasionally	Always	Occasionally	Yes	Yes	Yes	Both	120	CT	10 mSv	Children	Don't know	Don't know	Never
38	Surgery	Male	Fellowship	16-20	Always	Frequently	Occasionally	Frequently	Occasionally	No	Yes	Yes	Clinical inidcation	120	CT	10 mSv	Adult	No	No	Never
39	Family physician	Female	Bachelor	6-10	Always	Frequently	Frequently	Frequently	Frequently	Yes	Yes	Yes	Both	50	CT	NIL	Children	No	Don't know	Never
40	Family physician	Female	Fellowship	11-15	Always	Always	Frequently	Occasionally	Occasionally	Yes	NIL	Yes	Both	50	CT	2 mSv	Children	No	No	Never
41	Surgery	Male	Fellowship	11-15	Always	Occasionally	Always	Always	Always	Yes	Yes	Yes	NIL	50	CT	2 mSv	Children	Yes	Don't know	Occasionally
42	Surgery	Male	Bachelor	6-10	Frequently	Frequently	Occasionally	Occasionally	Frequently	No	Yes	Yes	Clinical inidcation	120	CT	10 mSv	Adult	Yes	No	Occasionally
43	Surgery	Male	Masters	<5	Always	Frequently	Frequently	Always	Occasionally	Yes	No	Yes	Clinical inidcation	120	CT	10 mSv	Children	No	Don't know	Never
44	Surgery	Male	Bachelor	6-10	Always	Always	Occasionally	Always	Always	Yes	No	Yes	Clinical inidcation	50	MRI	10 mSv	Children	No	No	Occasionally
45	Paediatrics	Female	Fellowship	11-15	Occasionall	Never	Frequently	Frequently	Occasionally	No	NIL	Yes	Both	120	X-ray machine	NIL	Children	Don't know	Don't know	Never
46	Paediatrics	Female	Fellowship	>20	Always	Occasionally	Frequently	Frequently	Occasionally	Yes	NIL	Yes	Both	NIL	CT	NIL	Children	No	No	Never
47	Paediatrics	Male	Fellowship	11-15	Always	Frequently	Never	Always	Frequently	No	No	Yes	Clinical inidcation	NIL	CT	NIL	NIL	Yes	Don't know	Never
48	Paediatrics	Male	Bachelor	6-10	Frequently	Frequently	Occasionally	Occasionally	Frequently	Yes	Yes	Yes	Both	50	CT	NIL	Children	Yes	Don't know	Never
49	Paediatrics	Male	Bachelor	6-10	Frequently	Occasionally	Never	Occasionally	Occasionally	Yes	Yes	Yes	Clinical inidcation	50	X-ray machine	10 mSv	Children	Don't know	Don't know	Never
50	Paediatrics	Female	Bachelor	6-10	Always	Never	Frequently	Frequently	Occasionally	No	Yes	Yes	Both	NIL	CT	NIL	Children	Don't know	Don't know	Never

Adult patients' scan and dosimetric data collected using RDMS

SN	Age	Gendar	Weight	Indication	kV	mAs	ST	NS	SM	IR	CTDI	DLP	SL	NS	NV	
1	15	F	39	Trauma	120	225	5	31	Wide volume	IR	41	625	150.25	1	Comply	
2	15	M	46.1	Epilepy	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
3	15	M		CVD	120	225	5	31	Wide volume	IR	45	687	150	1	Comply	
4	16	M	38	Siezure disorder	120	225	5	31	Wide volume	IR	45	1374	150.5	2	Comply	
5	16	F			120	225	5	31	Wiide volume	IR	42	1250	150	2	Comply	
6	16	F	70	CVD	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
7	17	M	62.7	Siezures disorders	120	225	5	31	Wide volume	IR	42	625	150	1	Comply	
8	17	M			120	225	5	39	Wide volume	IR	46	859	180	1	Comply	
9	17	M	61	Headache	120	225	5	31	Wide volume	IR	41	1250	151	2	Comply	
10	17	M		Headache	120	225	5	31	Wide volume	IR	46	686	150	1	Comply	
11	17	F	30	Headache	120	225	5	31	Wiide volume	IR	45	1374	150	2	Comply	
12	17	F	65.6	Epilepsy	120	225	5	31	Wiide volume	IR	41	1249	151	2	Comply	
13	17	M	49	Siezures disorder	120	225	5	31	Wide volume	IR	45	1373	150	2	Comply	
14	18	M	51	Siezures disorders	120	225	5	31	Wide volume	IR	45	1374	150	2	Comply	
15	18	F	48.5	Fibro displasia of the	120	225	5	38	Wide volume	IR	42	1562	187.5	2	Comply	
16	18	F	58	Trauma	120	225	5	31	Wide volume	IR	45	1373	150	2	Comply	
17	18	M		Trauma	120	225	5	31	Wide volume	IR	45	1312	150	2	Comply	
18	18	M		Trauma	120	225	5	31	Wide volume	IR	41	625	150	1	Comply	
19	18	F			120	225	5	31	Wiide volume	IR	41	1249	150.7	2	Comply	
20	18	M	50	Trauma	120	225	5	31	Wide volume	IR	41	625	150	1	Comply	
21	18	M		Trauma	120	225	5	31	Wide volume	IR	41	625	150	1	Comply	
22	18	M		Trauma	120	225	5	31	Wide volume	IR	41	625	150.5	1	Comply	
23	19	F	49.7	ICSOL	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
24	19	M		Pneumocephalus	120	225	5	31	Wiide volume	IR	41	1250	151	2	Comply	
25	20	M	75	ICSOL	120	225	5	31	Wide volume	IR	46	1374	151	2	Comply	
26	20	M	62		120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
27	20	M	29	CVD	120	225	5	31	Wide volume	IR	41	1250	151	2	Comply	
28	20	F	75	Macroadenoma	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
29	20	M		Trauma	120	225	5	31	Wiide volume	IR	45	687	150.5	1	Comply	
30	20	M		Trauma	120	225	5	31	Wiide volume	IR	41	1250	150	2	Comply	
31	20	M		Trauma	120	225	5	31	Wiide volume	IR	41	624	150	1	Comply	
32	20	F	48	Cranioplasty	120	225	5	31	Wide volume	IR	41	1405	167	2	Comply	
33	20	F	37	Trauma	120	225	5	31	Wide volume	IR	41	1249	150	2	Comply	
34	20	M	47	Trauma	120	225	5	31	Wide volume	IR	41	1250	150.75	2	Comply	
35	21	F	42	Pituitary adenoma	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
36	21	F	42	Convulsion	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
37	21	M	36	Movement disorder	120	225	5	31	Wiide volume	IR	41	1249	150	2	Comply	
38	21	M	56	Trauma	120	225	5	31	Wiide volume	IR	45	687	150	1	Comply	
39	21	M	70	Headache	120	225	5	31	Wiide volume	IR	41	1250	150	2	Comply	
40	21	F	55.4	ICSOL	120	225	5	31	Wide volume	IR	41	1250	150.5	2	Comply	
41	21	M	64.5	Amnesia	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
42	21	M	77	ICSOL	120	225	5	38	Wide volume	IR	42	1562	187	2	Comply	
43	21	F		Trauma	120	225	5	31	Helical	IR	63	4314	262	2	CTDI AND DLP exceed NV	
44	21	M	60	Trauma	120	225	5	31	Wide volume	IR	42	1562	187.5	2	Comply	
45	22	M		ICSOL	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
46	22	M	58.2	Trauma	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply	
47	22	M	56	Trauma	120	225	5	31	Wide volume	IR	41	624	150	1	Comply	
48	22	M		Trauma	120	225	5	31	Wiide volume	IR	41	624	151	1	Comply	
49	22	M		ALL	120	225	5	31	Wiide volume	IR	41	1249	151	2	Comply	
50	22	M		Trauma	120	225	5	60	Wide volume	IR	42	1250	298.5	1	Comply	

Paediatric patients (<1 year) scan and dosimetric data collected using RDMS

SN	Age	Gendar	Weight	Indication	kV	mAs	ST	NS	SM	IR	CTDI	DLP	SL	NS	NV
1	0.3	M	3	Hudrocephalus	100	135	5	31	Helical	IR	31	839	135	2	Comply
2	0.3	F	4.5	Hudrocephalus	100	135	5	35	Helical	IR	31	1210	170	2	Comply
3	10	M	6.5	cerebralpalsy	100	135	5	28	Helical	IR	31	1024	140	2	Comply
4	10	M	10	Hydrocephalus	100	135	5	48	Helical	IR	28	1429	222	2	DLP exceeds NV
5	11	F	8.4	Hudrocephalus	100	135	5	34	Helical	IR	28	1044	165	2	Comply
6	11	M	7	Trauma	100	135	5	28	Helical	IR	31	962	90	2	Comply
7	11	F	10	Hudrocephalus	100	135	5	38	Helical	IR	28	1154	185	2	Comply
8	0.5	M	4	Hudrocephalus	100	135	5	29	Helical	IR	31	1024	150	2	Comply
9	0.53	F	3.2	Encephalus	100	135	5	25	Helical	IR	31	870	120	2	Comply
10	0.63	M	2	Hudrocephalus	100	135	5	20	Helical	IR	31	747	95	2	Comply
11	1	F	6.2		100	135	5	37	Helical	IR	28	1099	180	2	Comply
12	1	M	3.5	Encephaloceole	100	135	5	28	Helical	IR	31	962	135	2	Comply
13	0.67	M	3.5	Scalp swelling	100	135	5	24	Helical	IR	31	886	120	2	Comply
14	0.7	F		Hudrocephalus	100	135	5	26	Helical	IR	28	824	125	2	Comply
15	2	M	2.3	Hydrocephalus	100	135	5	24	Helical	IR	31	870	120	2	Comply
16	2	M		Hydrocephalus	100	135	5	28	Helical	IR	31	852	135	2	Comply
17	2	F		Hydrocephalus	100	135	5	32	Helical	IR	28	989	159	2	Comply
18	2	F	5	Severe asphysia	100	135	5	31	Helical	IR	28	799	120	2	Comply
19	3	M	5	Hudrocephalus	100	135	5	28	Helical	IR	31	995	135	2	Comply
20	3	F		Hudrocephalus	100	135	5	29	Helical	IR	31	1030	140	2	Comply
21	1.5	M		Convulsion	100	135	5	26	Helical	IR	31	900	130	2	Comply
22	0.13	F	3	Microcephaly	100	135	5	22	Helical	IR	31	778	105	2	Comply
23	0.13	M	4	Trauma	100	135	5	24	Helical	IR	31	901	120	2	Comply
24	4	M	4	Trauma	100	135	5	28	Helical	IR	31	481	140	1	Comply
25	4	F	5	hydrocephalus	100	135	5	37	Helical	IR	28	1099	180	2	Comply
26	4	F	6.7	Post op	120	125	5	31	Helical	IR	40	1386	150	2	CTDI exceeds NV
27	4	F	10	hydrocephalus	100	135	5	31	Helical	IR	31	1055	150	2	Comply
28	5	F	5.4	Post op	100	135	5	34	Helical	IR	31	1148	165	2	Comply
29	5	F	7	Hudrocephalus	100	135	5	31	Helical	IR	31	1055	150	2	Comply
30	6	M	7.5	Hydrocephalus	100	135	5	32	Helical	IR	31	1117	155	2	Comply
31	0.23	M	3	Hydrocephalus	100	135	5	25	Helical	IR	31	870	134	2	Comply
32	1.63	F		Sutural diasthesis	100	135	5	25	Helical	IR	31	870	120	2	Comply
33	9	M	8	Hudrocephalus	100	135	5	27	Helical	IR	30	1117	160	2	Comply
34	9	F		Hudrocephalus	100	135	5	25	Helical	IR	31	901	120	2	Comply
35		M	3	Hydrocephalus	100	135	5	31	Helical	IR	31	1055	150	2	Comply
36	0.53	M	3.2		100	135	5	25	Helical	IR	31	870	120	2	Comply

Paediatric patients (1-<5 years) scan and dosimetric data collected using RDMS

SN	Age	Gendar	Weight	Indication	kV	mAs	ST	NS	SM	IR	CTDI	DLP	SL	NS	NV
1	1.17	M		Trauma	100	135	5	31	Helical	IR	28	934	150	2	Comply
2	1.25	F	8	Forehead swelling since birth	100	135	5	28	Helical	IR	28	852	135	2	Comply
3	1.5	F	8	Siezure disorder	100	135	5	33	Helical	IR	31	559	155	1	Comply
4	1.67	M		Orbit protrusion	100	135	5	31	Helical	IR	31	1086	130	2	Comply
5	1	M	8	Hydrocephalus	100	135	5	31	Helical	IR	28	962	150	2	Comply
6	1	F	6	Convulsion	100	135	5	26	Helical	IR	31	932	100	2	Comply
7	1	M	12	Trauma	100	135	5	31	Helical	IR	31	1086	155	2	Comply
8	1	M	13	Hydrocephalus	120	125	5	36	Helical	IR	39	1584	170	2	Comply
9	1.5	F	7	Hydrocephalus	100	135	5	30	Helical	IR	31	1055	150	2	Comply
10	2	M	9	Cerebral palsy	100	135	5	26	Helical	IR	31	932	139	2	Comply
11	2	F	6.7	Hydrocephalus	100	135	5	31	Helical	IR	31	1086	150	2	Comply
12	2	F	19	Orbital tumour	120	150	5	37	Helical	IR	48	1899	150	2	DLP exceeds NV
13	2	M	2		100	135	5	29	Helical	IR	31	1024	140	2	Comply
14	2	M	5	Hydrocephalus	100	135	5	27	Helical	IR	27	851	135	2	Comply
15	2	F	12.8	Trauma	100	135	5	31	Helical	IR	31	1055	145	2	Comply
16	2	F	7	Hydrocephalus	100	135	5	35	Helical	IR	28	1072	174	2	Comply
17	2	F	4	Hydrocephalus	100	135	5	27	Helical	IR	31	963	135	2	Comply
18	2	M	7		100	135	5	31	Helical	IR	31	1086	150	2	Comply
19	2	F	10	Trauma	100	135	5	30	Helical	IR	31	528	150	1	Comply
20	2	M	7.3	Headache	100	135	5	31	Helical	IR	31	1056	139.2	2	Comply
21	2	M	6		100	135	5	34	Helical	IR	31	1148	165	2	Comply
22	2.5	F	11	CVD	100	135	5	29	Helical	IR	31	1024	140	2	Comply
23	2.5	F	9	Micricephaly	100	135	5	19	Helical	IR	31	716	90	2	Comply
24	2.5	F	8.3	ICSOL	120	125	5	26	Helical	IR	44	1315	112	2	Comply
25	3	M	13	Trauma	120	125	5	37	Helical	IR	40	1623	180	2	Comply
26	3	M	13	Retino blastoma	120	125	5	40	Helical	IR	40	1703	195	2	Comply
27	3	F	13	Siezure disorder	120	125	5	29	Helical	IR	44	1446	144	2	Comply
28	3	F	12.2	Trauma	120	125	5	31	Helical	IR	44	767	150	2	Comply
29	3	F		Craniophrygioma	120	125	5	32	Helical	IR	40	1426	155	2	Comply
30	3	M	12	Craniophrygioma	120	125	5	28	Helical	IR	44	1402	135	2	Comply
31	3	F	16	Siezure disorder	100	125	5	29	Helical	IR	44	773	155	2	Comply
32	3	M		Rt orbital abscess	120	150	5	35	Helical	IR	52	1023	175	2	CTDI exceeds NV
33	3	M	10	ICSOL	120	125	5	29	Helical	IR	44	1446	140	2	Comply
34	4	F	17	Abnormal walk	120	125	5	31	Helical	IR	44	1533	155	2	Comply
35	4	M	16	CSF leakage	120	125	5	37	Helical	IR	40	1715	189	2	Comply
36	4	M	16	Trauma	120	225	5	29	Wide volume	IR	44	1446	144.9	2	Comply
37	4	F	6	Loss of vision	100	135	5	31	Helical	IR	31	963	135	2	Comply
38	4	M	4.5	Trauma	120	125	5	31	Helical	IR	44	1533	154.8	2	Comply

Paediatric patients (5-<10 years) scan and dosimetric data collected using RDMS

SN	Age	Gendar	Weight	Indication	kV	mAs	ST	NS	SM	IR	CTDI	DLP	SL	NS	NV
1	5	M	15	Surgical site discharge	120	125	5	31	Helical	IR	44	1685	150	2	Comply
2	5	M	23	Autism	120	125	5	32	Helical	IR	40	1405	155	2	Comply
3	5	M	12	Failure to walk at 5yrs	120	125	5	29	Helical	IR	40	1307	140	2	Comply
4	6	F		Trauma	120	225	5	31	Wide volume	IR	41	1250	150	2	Comply
5	6	M	16	Vomitting and prolonged sleep	120	150	5	33	Helical	IR	47	1756	165	2	Comply
6	6	M	18.6		120	150	5	32	Helical	IR	48	1709	155	2	Comply
7	6	M	18.3	Hydrocephalus	120	150	5	34	Helical	IR	48	1756	165	2	Comply
8	6	M		Brain abscess	120	150	5	31	Helical	IR	52	1889	155	2	Comply
9	7	F		Cebral abscess	120	150	5	31	Helical	IR	48	1661	150	2	Comply
10	7	M	27	Trauma	120	150	5	34	Helical	IR	48	1756	165	2	Comply
11	7	M	13	Hydrocephalus	120	150	5	31	Helical	IR	48	1899	180	2	Comply
12	7	M		Siezures disorder	120	150	5	29	Helical	IR	52	1733	140	2	Comply
13	7	M	14	ICSOL	120	150	5	28	Helical	IR	52	1628	135	2	Comply
14	7	M	18	Neurofibroma	120	150	5	44	Helical	IR	48	2246	185	2	DLP exceeds NV
15	7	F		Convuision	120	150	5	31	Helical	IR	52	1994	169.8	2	Comply
16	8	M	21	Hudrocephalus	120	150	5	35	Helical	IR	48	1851	170	2	Comply
17	8	M	26	Trauma	120	150	5	35	Helical	IR	47	1851	170	2	Comply
18	8	M		ICSOL	120	150	5	37	Helical	IR	48	1898	180	2	Comply
19	8	M	26	Headache	120	150	5	31	Helical	IR	48	1662	155	2	Comply
20	8	F	30	Trauma	120	150	5	34	Helical	IR	48	1804	170	2	Comply
21	8	M		Trauma	120	150	5	37	Helical	IR	52	2098	180	2	Comply
22	8	M	21.4		120	150	5	29	Helical	IR	48	1566	140	2	Comply
23	8	F	21	ICSOL	120	150	5	32	Helical	IR	52	1889	155	2	Comply
24	9	M	19	Trauma	120	150	5	30	Helical	IR	48	807	150	1	Comply
25	9	F	20.5		120	150	5	34	Helical	IR	52	1942	162	2	Comply

Paediatric patients (10-<15years) scan and dosimetric data collected using RDMS

SN	Age	Gendar	Weight	Indication	kV	mAs	ST	NS	SM	IR	CTDI	DLP	SL	NS	NV
1	10	M	33	Subdural drainage	120	150	5	31	Helical	IR	52	1837	150	2	Comply
2	10	F	28	Scalp swelling	120	150	5	34	Helical	IR	48	1756	155	2	Comply
3	10	F	20	VP shunt malfunction	120	150	5	34	Helical	IR	51	1994	164	2	Comply
4	10	M	15	ICSOL	120	150	5	31	Helical	IR	48	1661	154	2	Comply
5	10	M		Convulsion	120	150	5	32	Helical	IR	48	1709	185	2	Comply
6	10	F	28.8	Trauma	120	150	5	34	Helical	IR	48	1756	170	2	Comply
7	10	M		Trauma	120	150	5	49	Helical	IR	48	1258	200	1	Comply
8	10	M	14	Siezures disorder	120	150	5	32	Helical	IR	48	1709	155	2	Comply
9	10	M	26	Trauma	120	150	5	31	Helical	IR	47	1661	154	2	Comply
10	10	F	29	Trauma	120	225	5	31	Wide volume	IR	45	686	150	1	Comply
11	11	F	33		120	150	5	32	Helical	IR	52	1889	160	2	Comply
12	11	M	26	Osteoma of the skull	120	150	5	32	Helical	IR	48	1708	155	2	Comply
13	11	M	41	Headache	120	150	5	31	Helical	IR	48	1898	172	2	Comply
14	11	M		Brain lesion	120	225	5	31	Wiide volume	IR	41	1249	150	2	Comply
15	11	M	34	Hypocalvaria	120	150	5	32	Helical	IR	48	2279	176.25	2	DLP exceeds NV
16	11	M		Trauma	120	150	5	32	Helical	IR	52	1889	155	2	Comply
17	12	M			120	225	5	31	Wide volume	IR	45	1373	150	2	Comply
18	12	F	23	lost of eye sight	120	150	5	33	Helical	IR	52	1837	163	2	Comply
19	12	M		Trauma	120	225	5	31	Wiide volume	IR	41	1249	151	2	Comply
20	12	F	79.2	Trauma	120	225	5	31	Wiide volume	IR	41	1249	150	2	Comply
21	12	F	49	Convulsion	120	150	5	35	Helical	IR	48	1803	180	2	Comply
22	12	M	35.5	Post craniotomy	100	150	5	31	Helical	IR	48	1661	154.8	2	Comply
23	12	F	50	Headache	120	225	5	31	Wide volume	IR	45	1851	150	2	Comply
24	12	M		Trauma	120	150	5	32	Helical	IR	45	1709	155	2	Comply
25	13	M	33	Trauma	120	225	5	31	Wide volume	IR	41	625	150	1	Comply
26	13	F		ICSOL	120	225	5	31	Wide volume	IR	45	1373	150	2	Comply
27	13	M	32.5	VP shunt	120	225	5	31	Wide volume	IR	41	1249	150	2	Comply
28	13	M		Headache	120	225	5	31	Wide volume	IR	42	1562	187	2	Comply
29	13	M		Trauma	120	225	5	31	Wide volume	IR	41	1249	150	2	Comply
30	14	M	52	Headache	120	225	5	31	Wide volume	IR	41	1249	150	2	Comply
31	14	F	3.5	Occiputal swelling	100	135	5	29	Helical	IR	31	1024	141	2	Comply