AN AUDIT ON RADIATION DOSE RECEIVED BY THE PAEDIATRIC POPULATION UNDERGOING CT INVESTIGATIONS AT THE WITS ACADEMIC HOSPITALS

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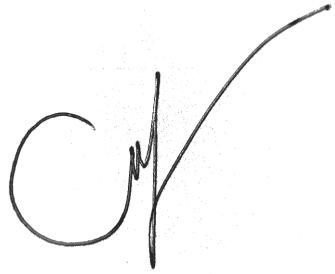
A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in fulfillment of the requirements for the degree of Masters of Medicine.

Johannesburg, 2019.

DECLARATION

I, Cornelis Marthinus van der Merwe (Student Number 1316793), declare that this research report is my own work. It is being submitted for the degree of Masters in Medicine (Diagnostic Radiology) at the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any other degree or examination to this or any other university.



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4 August 2019

PLAGIARISM DECLARATION

I, Cornelis Marthinus van der Merwe (Student number: 1316793), am a student registered for the degree of Masters in Medicine in the academic year 2019.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.

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- I have followed the required conventions in referencing the thoughts and ideas of others.

- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

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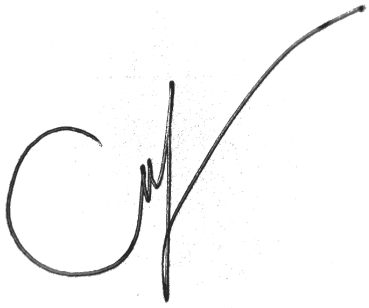
Signature:  Date: 2 August 2019

I dedicate this Research Report to my supporting wife, Bianca, and my three beautiful daughters, Heidi, Charlotte and Githe.

ACKNOWLEDGEMENTS:

I would like to thank the following people:

- Prof N Mahomed for her supervision and dedication to my research project.
- Mrs R van der Merwe for assistance in data collection.
- Dr M Viljoen for her help in results analysis.

PUBLICATION

This Research Report has been prepared in the submissible format according to the guidelines of the University of the Witwatersrand for examination.

Subsequently the results of the research has been published in the South African Journal of Radiology, which is a PUBMED Indexed journal.

The published artical has been added to the research report as Appendix C.

The citation for the published article is:

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ABSTRACT

Introduction:

Diagnostic Reference Levels (DRL) is a crucial element of auditing radiation dosages in paediatric computed tomography (CT). Currently, there are no national paediatric CT DRLs in South Africa.

Methods:

Computed Tomography Dose Index$_{volume}$ (CTDI$_{vol}$) and Dose Length Product (DLP) values were collected from paediatric CT examination done at two university hospitals, in patients aged 0 to 15 years. Four age groups were subcategorized. The 75th percentile of the data distribution was calculated for each CT examination type and age group and comparisons made using the quantile regression procedure.

Results:

During the retrospective audit from 1 November 2016 to 30 April 2017, a total of 1031 CT examinations were done. CT Brain examination was the most common examination done 755/1031 (72.23%), followed by CT of the abdomen 82/1031 (7.95%). There was increased DLP values in the afterhours categories at both hospitals with the largest increase compared to regular working hours in the age group 0-1 year (150.56%). In the 0-1-year age groups demonstrated higher values than expected for CT Abdomen and CT Chest.

Discussion:

The increased CTDI$_{vol}$ and DLP values for CT Abdomen and Chest in the 0-1-year group is most likely due to suboptimal protocols, and these should be reviewed. Strategies to limit radiation exposure in afterhours needs to be implemented. In comparison to international DRLs the radiation output levels compared favourably apart from the 0-1- year age category for CT Chest and CT Abdomen.

Conclusion:

CT body examination protocols for 0-1-year patients should be reviewed. In general, the proposed local DRLs compare favourably to international DRLs. The data of this study will be presented to the South African Society for Paediatric Imaging to aid in the establishment of national DRLs.

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LIST OF ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
CT	Computed Tomography
CMJAH	Charlotte Maxeke Johannesburg Academic Hospital
$CTDI_{100}$	Computed Tomography Dose Index over 100 mm.
$CTDI_{w}$	Computed Tomography Dose Index weighted for center and periphery of phantom
$CTDI_{vol}$	Computed Tomography Dose Index $_{volume}$
DLP	Dose Length Product
DRL	Diagnostic Reference Level
EDRL	European Diagnostic Reference Level
ICRP	International Commision on Radiological Protection
LDRL	Local Diagnostic Reference Level
LET	Linear Energy Transfer
mGy	milligray
mGy*cm	milligray-centimetre
MRI	Magnetic Resonance Imaging
NDRL	National Diagnostic Reference Level
PACS	Picture Archive and Communications System
RMMCH	Rahima Moosa Mother and Child Hospital
RLR	Reference Level Range
SSDE	Size Specific Dose Estimation

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CHAPTER 1: REVISED PROTOCOL

List of abbreviations:

ALARA	As Low As Reasonably Achievable
CT	Computed Tomography
CTDI	Computed Tomography Dose Index
DLP	Dose Length Product
DRL	Diagnostic Reference Level
ICRP	International Commission on Radiological Protection
LDRL	Local Diagnostic Reference Level
LET	Linear Energy Transfer
NDRL	National Diagnostic Reference Level
PACS	Picture Archive and Communications System
RLR	Reference Level Range
SSDE	Size Specific Dose Estimation

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1. Introduction

1.1. Increase in computed tomography investigations

Since the advent of computed tomography in the 1970s, there has been a marked increase in the use of this modality. It was estimated that more than 62 million CT investigations were performed in the United States of America in 2007 as compared to 3 million investigations in 1980. Four million of the 62 million investigations was performed on the paediatric population. (1). In Canada, there has been an increase in CT examinations of 44% in the period between 2004 and 2012. (2). This increase is a global tendency, especially in developed and developing countries. Several reasons have been postulated for the increase and can be attributed to the advances in technology, which led to an increased in speed, accuracy, versatility and availability of CT. The increase in speed and accuracy is responsible for a proportionally higher increase in the usage of computed tomography in the paediatric population. (1, 3).

1.2. Effects of Radiation

1.2.1. Radiation interaction with tissue

CT uses ionising radiation for image acquisition. Several factors determine the effect of radiation on biological tissue. Radiation factors affecting the interaction with tissue includes the absorbed dose, exposure rate, radiation source and energy. In the case of CT investigations, the radiation source and energy are constant. Several inherent biological factors of the tissue itself affect the effect of radiation on it.

Biological effects of radiation exposure can be classified as either stochastic or deterministic. Deterministic effects are achieved when there is cell death from radiation exposure. Thus, the tissue needs to be exposed to a certain level of radiation before a deterministic effect would take place. An increase in dose above this level will then also increase the severity of the effect. Deterministic effects require significantly higher doses than what is used in conventional radiography and are not applicable to CT radiation doses. (4).

However, the stochastic effect is defined as an increase in the probability of an effect to occur when there is an increase in the radiation dose. Thus, even minimal radiation dose exposure carries a risk for a stochastic effect. Furthermore, an increase in the radiation dose increases the risk for a stochastic effect to take place. (4).

The stochastic effects include risk for teratogenesis, carcinogenesis and genetic effects of radiation exposure. These risks are influenced by a complex interaction between radiation and organ and tissue characteristics.

1.2.2. Radiation in Children

In the paediatric population, the most important radiation effect to consider is the stochastic effect of carcinogenesis. (4).

Radiation factors that affect the risk of carcinogenesis are the radiation quality and dose rate. The radiation dose in CT (x-rays) is considered a low linear energy transfer (LET) and carries a significantly lower risk on tissue than high – LET radiation. The dose rate is vital in cases where the patient is exposed to repeated radiation. The shorter the period between the radiation exposure, the less time the affected organ has for the repair of the damaged tissue and the more likely carcinogenesis will take place (5).

The Law of Bergonie and Tribondeau states that radio-sensitivity is greatest for those cells which have a high mitotic rate, have a long mitotic future and are undifferentiated. The above factors explain the increased risk in in-utero radiation. The key factors to consider in the paediatric population is the high mitotic rate and long mitotic future. From this, it is hypothesised that the younger the patient is, the higher the risk is for carcinogenesis from radiation exposure. (4).

Radiation-induced malignancies exhibit a latency period from radiation exposure to clinical expression. Minimum latent period for leukaemia is 2-3 years and solid organ malignancies ranging from 5-40 years. This finding implies that the rate of expression of radiation-induced malignancy is inversely related to the age of the patient at the time of exposure (4).

1.3. As Low As Reasonably Achievable Principle

One year following Roentgens discovery, he was advised by the American Engineer, Wolfram Fuchs, to limit the time of exposure, to stand 30 cm away and to put Vaseline on the object (hand) being imaged. Since then, there has been a growing awareness of the detrimental effects of radiation and the idea of a radiation protection commission was born at the first international radiological congress in 1925. It was only after the second world war in 1950 that the International Commission on Radiological Protection was established (ICRP) (6).

ALARA is an acronym for As Low As Reasonably Achievable. It is a concept cultivated from the observation of the effects of radiation and the application of the Hippocratic philosophy to: “first do no harm”, by several regulatory bodies, including the ICRP (7). After the advent of CT and the increase in diagnostic imaging in the paediatric population, several regulatory organisations expressed the need for Diagnostic Reference Levels to monitor paediatric radiation doses in the different imaging modalities. Subsequently, there has also been the formation of the Image Gently campaign, that advocates for lower paediatric radiation doses and diagnostic reference levels.

1.4. Measurement of Radiation

In CT, radiation is measured as air kerma to the skin, which is expressed as Computed Tomography Dose Index$_{volume}$ or CTDI$_{vol}$. However, not all tissues are equally sensitive to the effects of radiation, and each tissue has an established tissue weighted factor that is multiplied by CTDI$_{vol}$ to determine the absorbed radiation of the tissue. The character of CT investigations is that it involves large areas of the body, encompassing several different tissues, and this measurement can become quite complicated. Therefore, most measurements include CTDI$_{vol}$ rather than CTDI$_{w}$ (4, 8).

The CTDI$_{vol}$ however, only gives an estimation of the air to skin kerma for one detector width. Therefore, the Dose Length Product (DLP) is necessary for a more accurate estimation of the radiation received. The DLP is the product of the CTDI$_{vol}$ and the length of the area being scanned.

All CT scanners need frequent, preferable daily, calibration and quality control. Quality control is usually done with a standardised phantom (16 cm for head and 32 cm for the body). The CT detector then determines the radiation for the specific test as a quality assurance function. Thus if an inappropriate phantom is used for a specific quality assurance check, the readout radiation values will be inaccurate and could potentially cause increased radiation exposure to the patient. (4)

1.5. Diagnostic Reference Levels

1.5.1. Definition

The European Union Basic Safety Standard defines Diagnostic Reference Levels as follows: "dose levels in medical radio-diagnostic or interventional radiology practices, or, in the case of radio-pharmaceuticals, levels of activity, for typical examinations for groups of standardised patients or standard phantoms for broadly defined types of equipment" (8).

The goal of developing and publishing diagnostic reference levels is to help ensure that radiation exposure to patients follows the ALARA principle (8).

The Diagnostic Reference Level for Paediatric Imaging workshop defined local DRL or LDRL as determined by the 75th percentile value of the distribution of patient doses received from radiology departments in a single large health centre or group of health centres within a defined district for a defined clinical imaging task for standardised patient groupings.

The Diagnostic Reference Level for Paediatric Imaging workshop further defined national diagnostic reference levels or NDRL which is based on the 75th percentile value of the 50th percentile value of the distribution of patient doses

obtained from a representative sample of radiology departments in the country, for a defined clinical imaging task in standardised patient groupings.

1.5.2. Diagnostic Reference Levels in Developed Countries

There have been several retrospective studies and surveys of to determine local and national diagnostic reference levels in the developed world, including United States of America, Canada, members of the European Union, Australia and Japan. Most NDRLs were determined by surveys and LDRLs by local data collection.

There was a significant variation in the design of these studies. The variation pertained to the following: 1) categories for the type of CT examination, 2) using age or weight for categorisation and 3) obtaining phantom versus patient data (2, 8,9,10,11).

The European Diagnostic Reference Levels for Paediatric Imaging workshop made suggestions for future studies after reviewing the research data from its member countries. These suggestion were based on the impact of the different studies and application of the studies to determine diagnostic reference levels (8).

The task team proposed that the best stratification for the type of CT examination is as follows: Head (routine, sinuses, inner ear, ventricular size), Chest (Chest, cardiovascular CT angiography), Abdomen (upper abdomen, abdomen and pelvis), trunk (neck and chest and abdomen as well as pelvis with regards to polytrauma or oncology), Spine (cervical, thoracic, lumbar) (8).

With regards to age categorisation, it recommended the following divisions: 1) that age be used for head CT: 0 to <3 months, 3 months to < 1 year, 1 year to < 6 years, > 6years. 2) weight is a more accurate denominator than age in determination of body CT doses: <5kg; 5-<15kg; 15-<30 kg; 30-<50 kg; 50-<80kg (8). If weight is not available age groups were suggested for body type CT examinations: 0 to <1 year, 1 to < 5 years, 5 to <10 years, 10 to <15 years and >15 years.

1.5.3. Diagnostic Reference Levels in African and other developing countries

There is only a limited amount of research for diagnostic reference levels and computed tomography doses in the paediatric population in Africa. A recent study on 19 developing countries included several North and East African countries as well as a survey of paediatric CT doses in Kenya (12, 13). The Kenyan study found that there was significant variation at the different centres and that in general, the received dose was higher than already established DRLs. Further review found significant variation in doses received by the paediatric population, likely the result of a high incidence in using adult protocols in paediatric CT examinations (12).

1.5.4. Diagnostic Reference Levels in South Africa.

There exists only one publication on developing local DRLs in South Africa. The study was at a tertiary hospital in the Western Cape and was limited to un-contrasted CT Brain examinations. The study population included 90 patients who presented to the trauma and emergency unit and was divided into three categories, according to age. The age categories were 0-2, >2-5 and >5-10 years. It concluded that the radiation received for the age group 0-2 years was out of the range of comparative diagnostic reference values (14).

The limitation of this study is as follows: a) limited to one centre, b) limited to one CT investigation, c) limited age stratification, d) small study population.

1.5.5. Table 1.1 Summary of relevant diagnostic reference level research

Study	Country/ Region	Data Source	Number of Centers	Study population	Patient grouping	Exam types	Dose value	Significant Radiation Findings	Comment
Järvinen et al., 2011(15)	Finland	Patient data	9	286	According to weight	Brain and Chest	3rd quartile DLP	Significant variation in radiation in Chest CT	Limited examination grouping
Järvinen et al., 2015	Finland	Patient data	4	1049	According to age for head and weight for body.	Head, Chest and Abdomen	3rd quartile $CTDI_{vol}$, DLP	Radiation was lower than comparison studies. National DRLs proposed.	
Roch & Aubert, 2013(16, 17)	France	Patient data	Not given	Not given.	1y /10kg 5y /20kg 10y/30kg	Brain, Facial bones, Chest, Abdomen/ Pelvis	3rd quartile $CTDI_{vol}$, DLP	Disconcordance between regulatory examinations and clinical practice.	Unable to comment on the size of the study population.
Granata et al. , 2015(17)	Italy	Patients	25	993	1-5y, 6-10y, 11-15y	Head, Chest, Abdomen	3rd quartile $CTDI_{vol}$, DLP	Wide variety in radiation doses between different centres.	Limited age and examination grouping.
Shrimpton et al., 2006(18)	United Kingdom	Sample Proto-cols	Not given.	126	0-1y, 5y, 10y	Head, Chest	3rd quartile $CTDI_{vol}$, DLP	50% reduction in dose since 1991.	Limited age and examination grouping. Small study population.
Galanski et al., 2006(9)	Germany	Survey on patient data	42	10100	New-born, <1yr, 1-5y 6-10y 11-15y	Brain, facial bones/sinuses, chest, abdomen/pelvis,	3rd quartile $CTDI_{vol}$, DLP	Radiation levels were lower than European guidelines at the time.	

						spine and miscellaneous.			
Wardlaw et al., 2014(2)	Canada	Survey patient data	Not given	721	0-3y 3-7y 7-13y	Head, Chest and Abdomen.	3rd quartile CTDIVOL, DLP	Radiation levels were comparative to international standards.	
Jackson et al., 2015(19)	Australia and New Zealand	Patient data	12	1462	0-15y Age for cranial examination and transverse diameter for body examinations	Head, temporal bone, paranasal sinuses, chest, HRCT chest, abdomen/pelvis	Diagnostic reference Range (DRR) defined by 25^{th} and 75^{th} percentiles.	Radiation levels comparative to international standards. SSDEs can be calculated for all patients.	
Sulieman et al., 2015(20)	Sudan	Patient data	8	296	6-10y	Head, abdomen and chest	Mean DLP	Radiation dose higher than other countries.	Limited age grouping.
Muhogora et al., 2016(21)	Tanzania	Patient data	Not given	Not given	1-5y 5-10y	Head, chest and abdomen	Mean DLP	Significant variation of radiation doses. Higher radiation doses than other countries.	Limited age grouping. Unknown study population size.
Vawda et al., 2016(14)	South Africa	Patient data	1	90	0-2y 2-5y 5-10y	Head	Mean DLP	Higher mean DLP in the age group < 2 years, compared to international DRLs.	Limited age and examination grouping. Small study population size.

2. Rationale

Diagnostic reference levels for different modalities have been developed in most developed countries to guide reduction in radiation exposure to the paediatric population. This was mostly in response to the ICRP recommendations and the Image Gently campaign. Currently, there are no diagnostic reference levels available for paediatric CT examinations in South Africa.

The intended outcome of this study is to provide enough data in order to establish local diagnostic reference levels for CT investigation in the paediatric population.

3. Aim of the Study

The aim of the study is to do an audit on the radiation doses received by the paediatric population (aged 0 to 15 years) undergoing CT investigations at two of the academically affiliated hospitals of the University of the Witwatersrand.

4. Study Objectives

4.1. Determine the radiation exposure of paediatric patients undergoing computed tomography examination in the affiliated University of Witwatersrand's academic hospitals and compare the results with existing European and international DRLs (8).

4.2 Determine type of phantom used, as well as other parameters which influence radiation exposure during computed tomography examination. (22, 23).

4.3. Determine at which time of day (during regular working hours, after-hours or weekends) the investigation was done and whether it affects the radiation exposure (22, 23).

5. Methods

5.1. Research paradigm

The research paradigm is a retrospective, descriptive study. The radiation doses received by the paediatric population was documented and categorised.

5.2. Study period

The study population was all paediatric patients who underwent CT investigations at either Charlotte Maxeke Johannesburg Academic Hospital or Rahima Moosa Mother and Child Hospital from 1 November 2016 to 30 April 2017.

5.2.1. Inclusion criteria

All CT examinations of patients aged between new-born and 15 years are included.

5.2.2. Exclusion criteria

Patient with incomplete data with regards to the $CTDI_{vol}$, DLP and type of examination were excluded.

5.3. Materials and Methods

Data collection was documented in an excel spreadsheet with the appropriate categories. See Appendix 1.

Table 1.2 Specifications of CT scanners' data, which was included in the study.

Hospital	CT Make and Model	Number of detector rows
Charlotte Maxeke Academic Hospital	Philips Ingenuity	128
	Philips Brilliance	64
Rahima Moosa Mother and Child Hospital	Philips Brilliance	16

These CT scanners are operated by CT trained radiographers. The radiation doses ($CTDI_{vol}$ and DLP) are automatically generated by the CT software after each examination. These values are then either documented in a logbook or saved onto the local PACS.

5.4. Data collection

5.4.1. Establish patient categories with regards to the type of examination and age of the patient.

The European literature review on diagnostic reference levels pointed out that inconsistency with categorisation led to incomparable studies and occasionally to a failure to develop diagnostic reference levels (8). The South African study on diagnostic reference levels concluded that the more narrow the age group category, the more the radiation parameters was outside the comparable diagnostic reference levels (14).

Although the European Guidelines suggest categorisation by weight for body CT examination, the two radiology departments included in the study does not consistently document the weight of the patient. A study by Vassileva et al. in 2015 proved that using age instead of weight for grouping of patients undergoing body CT examinations is acceptable in resource-limited countries, as long as each group studied contains more than 30 subjects (24). Therefore, the age categories will be the same for head and body examinations (0 < 1 year; 1 year- < 5years; 5 years - < 10 years; 10 years - < 15 years). Patients older than 15 years of age are not included in this study, as they are generally not considered paediatric patients in the studied academic hospitals. (8).

The examination types were: Brain, Temporal Bones, Paranasal sinuses, Orbits, Neck (soft tissue), Cervical spine, Spine, Trunk, Chest, Abdomen, Muskuloskeletal, Peripheral CT angiography(8).

5.4.2. Collection of data.

The data collected for each study included: a) date and day of the week of study, b) time of the study, c) age of the patient, d) body part and whether a single or multi-phase protocol was used (8-10, 14).

The data was retrieved from the PACS at the Charlotte Maxeke Johannesburg Academic Hospital and from the storage hard drive on the local area network at the Rahima Moosa Mother and Child Hospital. The radiation exposure levels ($CTDI_{vol}$ and DLP) was captured on a data sheet according to the categories named above. See Appendix 1.

5.5. Reliability and validity

The study would be easily reproducible due to specific parameters used and a well-defined study population.

This study design was based on previously published articles from which diagnostic reference levels have been successfully obtained and been able to compare. It is also following the recommendation of the European Guideline on diagnostic reference levels (2, 8-10).

5.6. Bias

No significant research bias is foreseen for this study design.

6. Data analysis and statistics

The radiation exposure levels ($CTDI_{vol}$ and DLP) was categorised according to age, date, time of study and body part.

Median, average and 75^{th} percentile of radiation exposure distribution was determined for each age and examination type category. Confidence intervals were obtained using the means procedure.

The results were compared between hospitals, as well as time categories using the quantile regression procedure to establish confidence intervals.

The 75^{th} percentile of the data distribution for each of the $CTDI_{vol}$ and DLP values of each of the age and examination type categories was determined and compared to the European and other countries' national diagnostic reference levels.

7. Outcome

The data was used to suggest Local Diagnostic Reference Levels, as well as to present the results to the South African Society of Paediatric Imaging (SASPI), with the end goal to eventually establish National Diagnostic Reference Levels.

8. Ethics

Ethics approval has been obtained by the Ethics committee of the University of the Witwatersrand as well as the individual hospitals. Ethics Clearance Certificate nr. M170634.

No consent will be needed as study numbers will be used (thus anonymously) to maintain patient confidentiality. There will be no harm to the patients, as this is a retrospective study, and in fact, the outcome of the study is to reduce harm to patients, by optimising radiation safety protocols. There is no financial implication for the patients involved in the study.

8. Time allocation:

Table 1.3

Literature search	July 2016-October 2016								
Reading literature		January 2017 – February 2017							
Summarising literature			March 2017 – April 2017						
Preparing Protocol			March 2017 – April 2017						
Protocol Assessment				June 2017					
Ethics application				June 2017					
Hospital consent				June – August 2017					

Collecting data					August 2017 – June 2018				
Data analysis						June 2018 – December 2018			
Writing up thesis							January 2018 – June 2019		
Submit: marking								August 2019	
Writing up paper									July 2019 – August 2019

9. Budget:

Table 1.4

Transport	R1000
Stationary	R500
Statistician	R4000
Total	**R5500**

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CHAPTER 1: REVISED PROTOCOL: APPENDIX I

Appendix 1: **An audit on radiation dose received by the paediatric population undergoing CT investigations at the WITS academic hospitals**

RADIATION EXPOSURE: PAEDIATRIC CT: DATA CAPTURE

Hospital:	
CT Scanner:	

Data Sheet Number : _____/_____

					Age group (tick appropriate)						Head							Neck		Chest				Abdomen and Pelvis		Spine			Peripheral CT angiogram	
											Brain		Sinuses		Temporal Bones		Ventricles			Chest		Cardiovascular								
	Study number	Date	Day of Week	Time (24hr)	0-<1m	1m-<1y	1y-<5y	5y-<10y	10-<15y	Value	Single	Multiple	Single	Multiple	Single	Multiple	Single	Single	Multiple	Single	Multiple	Single	Multiple	Single	Multiple	Cervical	Thoracic	Lumbar	Upper limbs	Lower limbs
1										CTDI																			
										DLP																			
2										CTDI																			
										DLP																			
3										CTDI																			
										DLP																			
4										CTDI																			
										DLP																			
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R14/49 Dr Cornelis Van Der Merwe

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170634

NAME: (Principal Investigator)	Dr Cornelis Van Der Merwe
DEPARTMENT:	Radiology Charlotte Maxeke Johannesburg Academic Hospital Chris Hani Baragwanath Academic Hospital Rahima Moosa Mother and Child Hospital
PROJECT TITLE:	An Audit on radiation Dose Received by the Paediatric Population Undergoing CT Investigations at the WITS Academic Hospitals
DATE CONSIDERED:	30/06/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Nasreen Mahomed
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	01/12/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review June and will therefore be due in the month of June each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

AN AUDIT ON PAEDIATRIC CT DOSES AT TWO SOUTH AFRICAN ACADEMIC HOSPITALS TO ESTABLISH DIAGNOSTIC DEFERENCE LEVELS.

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ABSTRACT

Background:

Diagnostic Reference Levels (DRLs) are a crucial element of auditing radiation doses in paediatric computed tomography (CT). Currently, there are no national paediatric CT DRLs in South Africa.

Methods:

Computed Tomography Dose Index$_{volume}$ (CTDI$_{vol}$) and Dose Length Product (DLP) values were collected from paediatric CT examination done at two university hospitals. The 75th percentile of the data distribution was calculated for each CT examination type and age group and comparisons made using the quantile regression procedure.

Results:

During the audit period, a total of 1031 CT examinations were done. CT Brain examination was the most common examination done, 755/1031 (72.23%), followed by CT of the abdomen, 82/1031 (7.95%). DLP values were increased in the after-hours categories compared to regular working hours at both hospitals, with the largest increase in the age group 0-1 year (150.56%). The 0-1-year age groups demonstrated higher values than expected for CT Abdomen and CT Chest.

Conclusion:

CT body examination protocols for 0-1-year old patients should be reviewed. Strategies should be implemented to limit higher doses in after-hours examinations. The proposed local DRLs compare favourably to international DRLs. The data of this study will be presented to the South African Society for Paediatric Imaging to aid in the establishment of national DRLs.

INTRODUCTION

Computed tomography (CT) has added tremendous value in diagnosis and in establishing treatment plans for patients since its advent in 1971. Since then, there has been an exponential increase in the usage of CT. [1]. This increase is due to several factors, including, but not limited to rapid evolvement of technology and advancements in hard- and software, which led to improved image quality and reduced duration for CT examinations. [2,3]. In addition, the geopolitical and socio-economic trends since the late 1990's also contributed to greater access to medical resources and equipment, specifically in the industrialised world. [4]. The number of CT scanners per million people in Japan increased from 14.36 to 107.14 from 1980 to 2017. This increase has been the most significant in the developed world, but an increase in the amount of CT scanners was also observable in the developing world, for example, in Turkey, where the number of CT scanners increased from 4.89 per million in 2002 to 14.53 per million people in 2016. [4]. The advances in availability and increase in applications, also made CT investigations popular in the paediatric patient population. In the Netherlands, the total number of paediatric CT scan examinations increased from 7731 in 1990 to 26 023 in 2012. [5]. Similar trends were established in the rest of the developed world. [6].

Even though there was suspicion of harmful effects from ionising radiation to the human body shortly after Roentgen took his first radiograph in 1895, the first International Radiation Congress only discussed possible radiation protection standards in 1925. In the aftermath of the Second World War, the International Commission of Radiation Protection (ICRP) and United Nations Scientific Committee on the Effects of Atomic Radiation was formed and has since played a major role in radiation research and protection. [7]. The concept of keeping radiation dose "As Low As Reasonably Achievable" (ALARA) has been around since 1915 and is compatible with the medical ethical mantra of "first do no harm". [8]. Furthermore, evidence from the second world war and radiation accidents has proved that the younger the patient is, the higher the risk is for adverse radiation effects. The increased risk is due to the presence of more undifferentiated cells, and the cells have a higher mitotic rate as well as a longer mitotic future. [1,9]

The IRCP has recommended diagnostic reference levels (DRL) for all diagnostic and interventional radiological procedures since 1991, as a measure to ensure radiation protection. [6]. The Image Gently Alliance and campaign, which started in 2007, promoted the ALARA principle and since then has become one of the primary considerations in paediatric imaging. [3]. Since 2007, there has been a reduction in the annual increase of paediatric CT examinations in the developed world. [5]. This increase is likely due to the successes of radiation awareness programs.

Following recommendations by the ICRP to establish DRLs, there have been a significant number of audits and DRL proposals in the developed world. As of 2013, the European Diagnostic Reference Levels for Paediatric Imaging (PiDRL) workshop has driven a campaign to establish European DRLs. [10].

There have been very few studies or audits on paediatric CT doses to establish CT specific DRLs in the developing world. There is only one other study from South Africa, auditing CT doses in a tertiary hospital on non-contrasted paediatric brain CT scans. [11].

South Africa is considered the most industrialised country and the second-largest economy in Africa but has one of the highest levels of inequality. Most of the population is medically underserviced due to resource constraints in the public health sector. [12]. Apart from a heavy workload required from the radiological equipment, there are also restraints on human resources and quality control. In addition to this, the absence of established DRLs limits the ability to do routine audits to ensure optimal radiation protection. It is, therefore, of utmost importance to audit paediatric CT doses in South Africa to establish DRLs.

The aim of this study was to establish local paediatric DRLs for CT examinations in two major academic hospitals affiliated to the University of the Witwatersrand, Johannesburg, South Africa.

Other objectives were to audit radiation doses and compare paediatric CT investigations radiation output levels and to established DRLs in the developed and the developing world. An additional objective was to evaluate whether there was any difference between the hospitals, as well as between regular work hours and after hours.

MATERIALS AND METHODS

Design: The study was designed as a retrospective descriptive study.

Dosimetry: The European Guidelines suggest using the Computed Tomography Dose Index volume ($CTDI_{vol}$) and Dose Length Product (DLP) as CT dose descriptors. [10]. " $CTDI_{100}$ is a measure of the CT scanner's radiation output measured with a 10cm long ionization chamber at five positions in a cylindrical phantom of 16 cm diameter, for paediatric CT. The weighted CTDI ($CTDI_{w)}$, is calculated by establishing the $CTDI_{100}$ for the centre, as well as the periphery of a cylinder and combining these. In helical CT scanning, the dose is inversely related to the pitch (number of rotations of gantry per distance moved by the examination bed). $CTDI_w$ divided by the pitch equals $CTDI_{vol}$. $CTDI_{vol}$ is expressed in the international system of units (SI units) as milligray (mGy). DLP is the product of the length of the scanned area with the $CTDI_{vol}$. [13]. DLP is expressed in milligray-centimetre (mGy*cm).

Study population: The data collected was the $CTDI_{vol}$ and DLP -values for each CT examination of paediatric patients (age less than 15 years) during the six-month period from the 1st of November 2016 until the 30th of April 2017 at the following hospitals: Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) and Rahima Moosa Mother and Child Hospital (RMMCH). These hospitals are situated within the City of Johannesburg Municipality in Gauteng, South Africa.

Data Collection: The data was retrieved from the PACS system from CMJAH and the local area network at RMMCH. Data was categorised and tabled for each CT scanner and further categorised according to the type of study and the age group. The CT Brain data was also categorised into three different time categories, as follows: Weekdays (Monday to Friday from 08:00 – 16:00); Afterhours (00:00-08:00 and 16:00 – 24:00 from Mondays to Fridays); Weekends and public holidays (00:00 – 24:00 Saturdays and Sundays, as well as public holidays).

The categories were chosen as per recommendation from the European Diagnostic Reference Levels for Paediatric Imaging Workshop in 2013. [10]. All CT investigations were included and categorised according to the anatomical region of interest. The data could not be categorised according to indication, as the indication was not available on the database. The age groups were divided into 0 to <1 year; 1 Year to < 5 years, 5 years to <10 years and 10 years to <15 years. The European Commission suggests categorising the CT Body examinations according to weight, but patients' weight was not available from the database. The time of day and day of the week was recorded for each study.

Data Analysis:

The distribution of the CT examinations in this study sample was tabled using the frequency procedure.

For statistical analysis of the $CTDI_{vol}$ and DLP values, only the single-phase CT examinations were included in the study sample. In paediatric imaging, the most common reason for multi-phase scanning is usually due to a planning or technical error, in which case the data would

then be unreliable, and therefore the multi-phasic CT examinations were excluded. Furthermore, the data from CT orbits, CT paranasal sinuses, CT musculoskeletal, CT whole spine and CT peripheral angiography were excluded from further analysis as the sample sizes were too small.

From these categorised data sets for CT brain, CT temporal bones, CT neck, CT cervical spine, CT chest, CT trunk and CT abdomen, the dose distribution for each study type in each age category was determined for each hospital, in the case of CT brains, and the two hospitals combined for the other CT examination types.

Using the means procedure, the average, median and 75th percentile of the data distribution, with confidence intervals, was then calculated for each category for each examination type. Local Diagnostic Reference Levels are defined as the 75th percentile of the data distribution. [10]. The local DRLs in this study was the 75th percentile value for each category, rounded up to the nearest single digit for CTDI and the nearest 5 for DLP.

The data was then compared to similar studies with local and national DRLs.

In addition, the CT Brain results were compared between the two hospitals according to the following parameters: a) total number of single- vs multiphase scans using the frequency procedure, b) difference in $CTDI_{vol}$ and DLP 75th percentile values between the two hospitals for each age group and time category, using the Fisher's exact test. Furthermore, the quantile regression method was used to compare the 75th percentiles in different groups by calculating 95% confidence interval for the difference between percentiles. If the 95% confidence interval for the difference does not contain 0, the percentiles are significantly different.

RESULTS

Distribution and frequency of CT examinations:

The audit period for the six months from 1 November 2016 to 30 April 2017 included 1031 paediatric CT examinations from RMMCH and CMJAH. Refer to Table 1.

CT Brain examinations, 755/1031 (73.23%) was the most common CT examination, followed by CT of the abdomen, which was 82/1031 (7.95%). Refer to Table 1 and Figure 1.

The 1-5-year age group underwent the highest number of CT examination, which was 341/1031 (33.07%).

In the 0-1-year group, the most common examination was CT Brain (195/238 – 81.51%), followed by CT Chest (18/238 – 7.56%).

In the 1-5-year group, the most common examination was CT Brain, (263/341 – 77.13%), followed by CT Abdomen (24/341 – 7.04%), and CT of the cervical spine, (17/341 – 4.99%).

Similarly, in the 5-10-year age group, the most common examination was CT Brain, (159/236 – 67.37%%), followed by CT Abdomen (23/236 – 9.75%%), and CT of the cervical spine, (13/236 – 5.51%).

In the 10-15-year age group, the most common examination was CT Brain, (138/216 – 63.89%), followed by CT Abdomen, (27/216 – 12.5%), and CT of the temporal bones, (10/216 – 4.63%). (Table 1 and Figure 2).

Single- vs Multi-phasic CT examinations:

As mentioned before, the data used to calculate the data distribution included single-phase CT examinations only.

The highest amount of multi-phase CT studies were in the CT Brain 0-1-year age category, (26/195 - 13.33%). The 0-1-year age category also revealed the highest multi-phase studies for CT of the chest, (6/18 - 33.33%) and CT of the abdomen, (4/8 - 50%). Refer to Figure 3.

During the six months, there was a total of 755 CT brain studies between the two hospitals. 554/755 (73.38%) of the scans were done at CMJAH. The highest number of CT Brain examinations were done during weekdays regular hours (464/755 - 61.46%). 38/554 (6.86%) of the CT Brains at CMJAH were multi-phasic examinations compared to 30/201 (14.93%). All the multi-phasic CT Brains at RMMCH were done during regular hours on weekdays with a total number of 30/161 (18.63%). Refer to Figure 4.

Radiation doses:

From all the study types done during the study period, there were only 7 study types with enough cases in different age groups to allow data distribution calculation. These included CT brain, -temporal bones, -neck, -cervical spine, -trunk, -chest and -abdomen (Total n for analysis

= 905). The 75th percentile of both the $CTDI_{vol}$ and DLP of each of these examination types in the various age groups are demonstrated in Table 2, with a 95% Confidence Interval.

The CT brain data sets were used to compare the two different hospitals, as well as to evaluate for potential variation in different time categories. At CMJAH, there was an increase in the 75th percentile of the data distribution in the weekend and after-hours group compared to regular weekdays. The most significant increase in dose was in the 0-1-year after-hours group with a 150.56% (691.3mGy*cm vs 275.9mGy*cm) increase in DLP compared to the 0-1-year group during routine weekdays[a]. The second most significant increase in dosage was in the 5-10-year weekend group. Here there was a 78.07% (760.7mGy*cm vs 427.2mGy*cm) increase in DLP, compared to 5-10y routine weekday group[b]. Refer to Table 3 and Table 4.

Similarly, the data from RMMCH demonstrated an increase in $CTDI_{vol}$ and DRL for after-hours and weekends compared to regular weekdays, although the increase was not as marked as at CMJAH. The most pronounced increase in dose was in the 1-5-year after-hours group, with an increase in DLP of 40.46% (570.7mGy*cm vs 406.3mGy*cm)[b]. The second-highest increase in dose compared to routine weekdays was in the 0-1-year after-hours category with an increase of 25.92 % (418.3mGy*cm vs 332.2mGy*cm) in DLP[a]. Refer to Table 5 and 6.

The comparison of the dosages during CT brain investigation between the two hospitals revealed a general lower DLP at CMJAH for the 0-1y[b], 1-5y[b] and 5-10[a] year groups, compared to RMMCH. The 10-15-year stratified groups demonstrate lower DLP values at RMMCH compared to CMJAH. Refer to Figure 5.

[a] Not statistically significant, as 0 is included in the 95% CI.
[b] Statistically significant, as 0 is not included in th 95% CI.

DISCUSSION:

Distribution and frequency of CT Examinations:

The higher number of investigations at the CMJAH compared to RMMCH was expected, as it is considered a central hospital in South Africa, a level one trauma centre and major referral centre for the province. [19]. The CT brain percentage of total investigations was marginally higher in comparison to international studies in the first world, whereas the CT Abdomen percentage compared to the CT utilisation trends in other countries is similar. [5, 6, 20]. The reason for the higher percentage of CT Brains done at the studied facilities is likely because the initial neuroimaging investigation in the public health sector of South Africa for a child presenting with the first episode of convulsion is a CT Brain instead of an MRI Brain, as recommended by the American Academy of Neurology. [21]. CT for neurological disease in South Africa is a reasonable initial investigation as the incidence of neurological infections is higher than that of first world countries. [22]. MRI availability and anaesthetic support are limited in the South African public health sector. Furthermore, CMJAH is a level 1 trauma centre and will have an increased percentage of CT Brains for trauma indication.

The increase in CT of the cervical spine after the age of 1 is expected in a level 1 trauma centre. The number of temporal bone CT investigations in the 5-10- and 10-15-year age groups, is consistent with previous studies demonstrating the majority of patients with temporal bone pathology, being between 11 and 20 years of age[23].

Single- vs Multi-phase examinations:

According to the general paediatric CT guidelines and protocol by the South African Society of Paediatric Imaging published in 2013, no multiphase studies should be done on paediatric patients. [24]. Thus, the percentage of multiphase studies for CT brain, chest and abdomen is unfavourable, as these investigations are considered high dose investigations and the scan field includes high-risk radiation target organs. Possible reasons for this finding could be an unfamiliarity to the South African guidelines by both the radiologists and radiographers. These centres are both training facilities, and there is the possibility that occasionally scans were incorrectly planned by junior/training radiologists or incorrectly acquired by junior/training radiographers.

Radiation doses:

Both hospitals demonstrated an increase in the DLP values of CT Brain during after-hours and some of the weekend categories. During after-hours, there is less staff present on the floor and often fewer senior staff to guide procedures, which could lead to an incorrect choice of parameters or selection of scan area, with a resultant increase in radiation dose to the patient. The increase in values is more marked in CMJAH than in RMMCH. RMMCH radiology department is almost an exclusive paediatric radiology department, with staff trained for paediatric radiology. CMJAH's radiology department, however, is a large combined adult and paediatric academic radiology department. At CMJAH, there are dedicated time slots for

paediatric CT examinations during the week, but after-hours urgent paediatric CTs are done in between adult patient CTs, which could lead to an incorrect parameter and CT protocol selection when examining children. Previous research has shown that the potential exists for a significant DLP variation between radiographers, even in the setting of a dedicated paediatric hospital. [25].

Although the finding of increased DLP values in the 0-1-year age group were found not to be statistically significant, follow up investigation in this age group is suggested, as the findings might suggest clinical significance.

The increased $CTDI_{vol}$ and DLP values for RMMCH compared to CMJAH could be ascribed to hardware and software variables between the two departments. CMJAH Philips machines have more detector rows (64 and 128) as well as utilisation of the i-Dose software by Philips. [26,27].

Comparison to other studies and DRLs:

The combined DLP and $CTDI_{vol}$ 75th percentile values were compared to DRLs from the European guidelines, UK, Germany, Japan, Kenya and Brazil. [10,14,15,16,17,18]. Refer to Table 7 and 8.

The $CTDI_{vol}$ and DLP values for CT brain were found to be less than the comparative DRL values in most cases, except for the European DRL in the age category for 10-15 years. The $CTDI_{vol}$ and DLP values for CT Chest were significantly higher than the European DRLs, but better than those from Japan, Kenya and Brazil. The exception was the increased value compared to Brazil in the 0-1-year age category. Overall, the 75th percentile $CTDI_{vol}$ and DLP values for CT Brain compared very favourably to published data.

The $CTDI_{vol}$ values for CT Abdomen were lower than the international DRLs, except for the 0-1-year category, which was higher than the EDRL and Brazilian values. The 0-1-year category for CT Abdomen DLP values was also higher than those from Brazil. Although only the 10-15-year category DLP values were within the EDRL range, the rest of the values were lower than the other international DRLs. Upon further review, it was found that most of the higher $CTDI_{vol}$ and DLP values in this age group, was associated with higher kV settings. The South African Society of Paediatric Imaging suggests reducing kV settings in paediatric examinations. [24]. The CT abdomen studies with $CTDI_{vol}$ and DLP values comparable to international DRL ranges were done with a reduction of kV from 120 to 100. It is suggested that the CT Abdomen protocol for both RMMCH and CMAH be reviewed, adjusted and applied to all cases.

The $CTDI_{vol}$ and DLP values of CT Chest examinations are higher than the European DRLs. Although the values compare well against the other international DRLs, it is also suggested that the protocols for CT Chest be reviewed and adjusted.

Furthermore, when there is a discrepancy in the comparison of $CTDI_{vol}$ and DLP values for a specific examination in a specific age category, it can be assumed that during the planning of the scan, the pre-selected scan area is extended beyond routine anatomical landmarks for the study. [25,26].

Outcome:

From the data analysis, diagnostic reference levels are proposed for the most frequent examinations. Local DRLs are not suggested for 0-1-year, except for CT brain, as the 75th percentile values are higher than the older age groups and compare unfavourably to international DRLs. Table 9.

In recent similar international studies and according to the guidelines from the European guidelines, it is proposed that DRLs could be presented in a graph format, instead of table form. See the DRL graph and curve for CT Abdomen in figure 6 and for CT Brain in figure 7. This type of graph is created by plotting all the different values for each age on an x: y scatter plot, establishing the 75th percentile for each age and creating a polynomial, exponential graph. [28].

Presentation of a DRL in a graph format can aid in the comparison of results as well as be an easy visual reference in the department.

Limitations:

One of the limitations of the study is that the European guidelines suggest that body CTs should be categorised according to weight, but the weights were not documented on PACS for RMMCH and CMJAH, during the study period.

Further limitations included the significant percentage of multi-phasic CT scans, specifically in the 0-1-year age group, which limited the statistical significance of the findings.

Although the data collection would have initially included data from the Chris Hani Baragwanath Academic Hospital, it was, unfortunately, not available to the researchers for the particular study period.

CONCLUSION

Overall, the $CTDI_{vol}$ and DLP values for the studies are comparable with most of the international DRLs. CT Chest and Abdomen protocols should be revised, and staff should be trained specifically for dose reduction in paediatric patients at the two hospitals.

The DRL values in Table 9 is suggested as local DRL for the University of Witwatersrand academically affiliated hospitals as well as their referral hospitals.

The results of this study will be presented to the South African Society of Paediatric Imaging to aid in the establishment of national diagnostic reference levels for paediatric CT examinations.

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Figure 2.1: Chart of the Computed Tomography (CT) examination types as a fraction of the total number of CT studies. (n=1031).

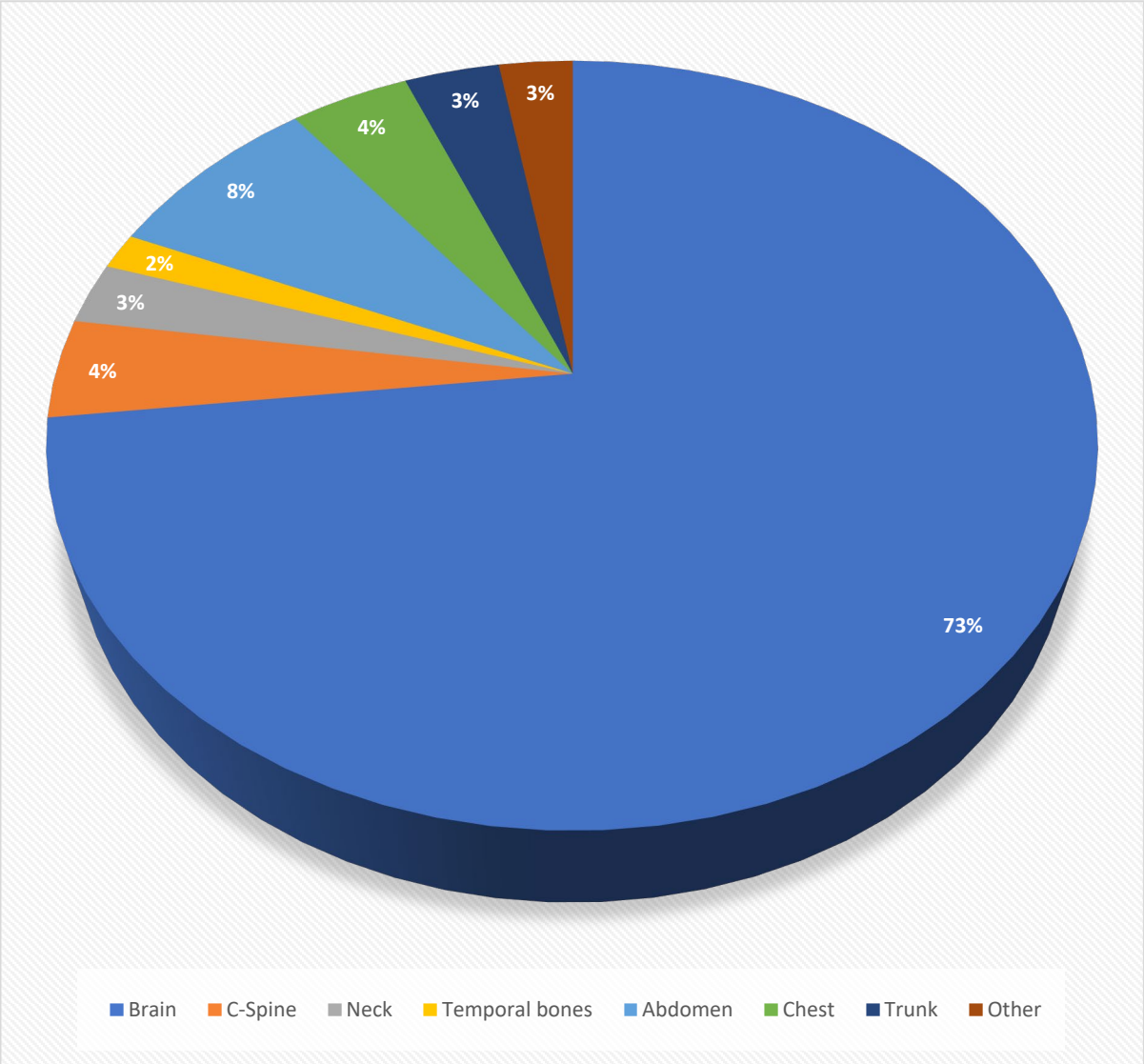

Figure 2.2: Proportional comparison of different study types per age category. (n=1031)

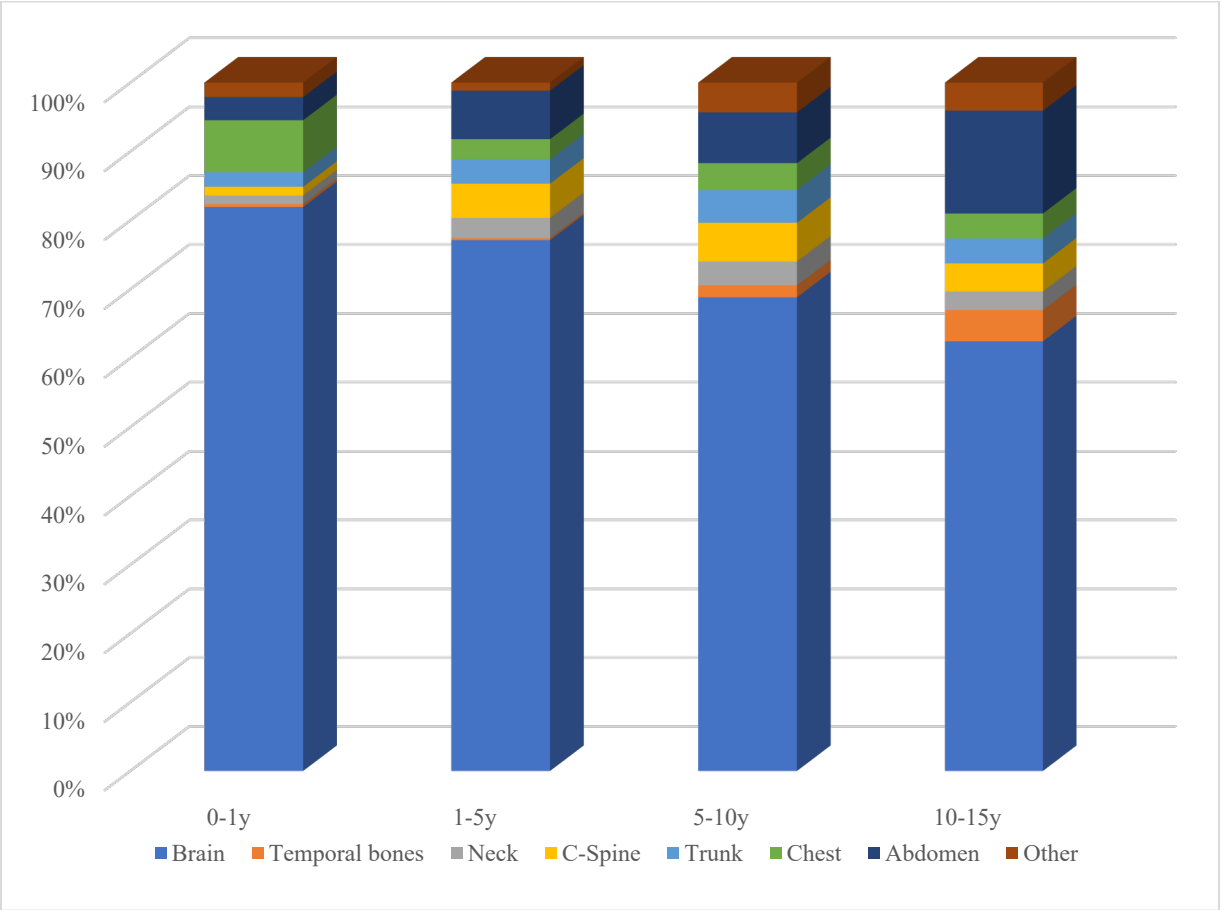

Figure 2.3 Comparison of single vs multi-phase studies in each age category presented as a percentage. (n=822)

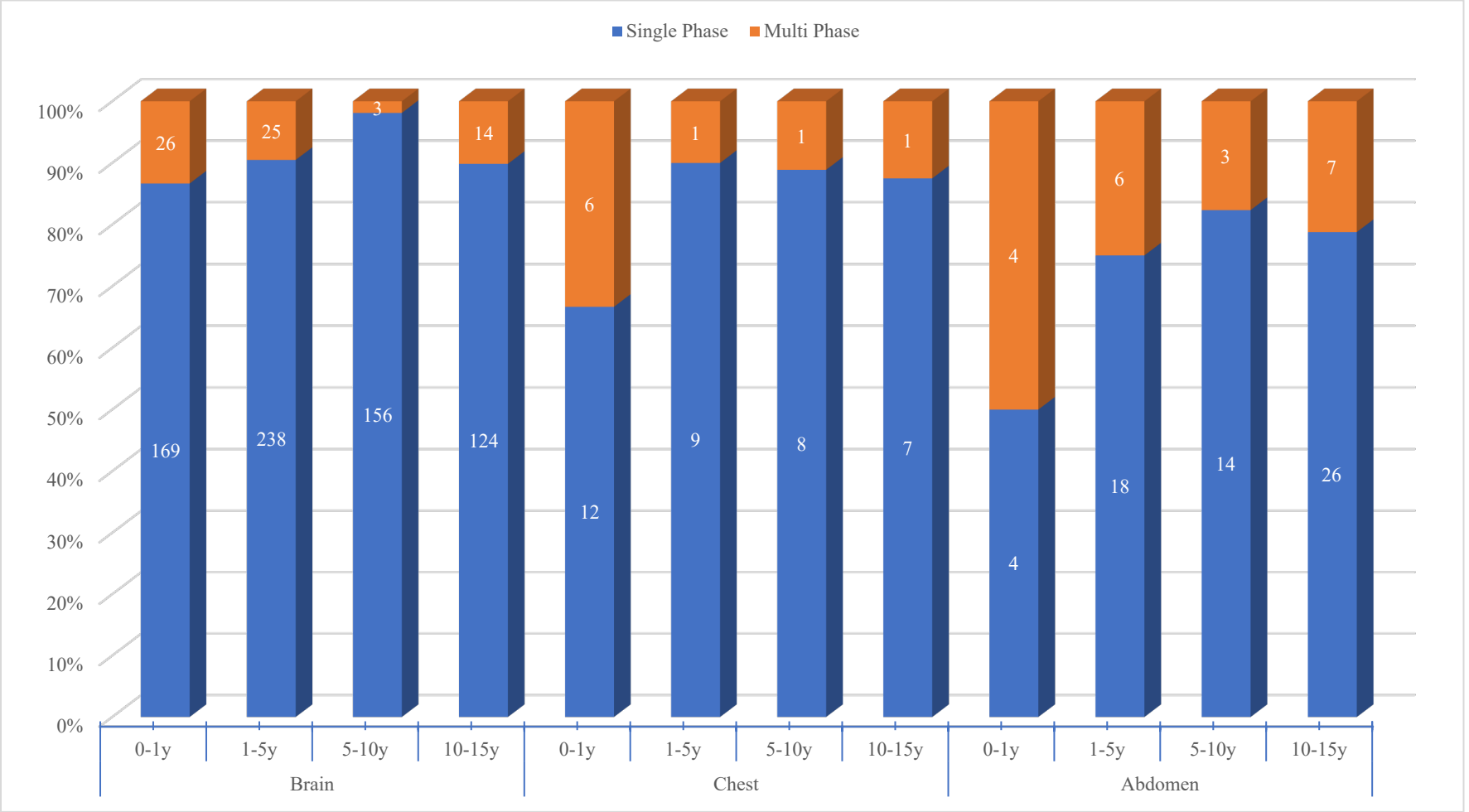

Figure 2.4. Comparison of multi vs single phase CT Brain studies as a function of time category at each of Charlotte Maxeke Johannesburg Academic- and Rahima Moosa Mother and Child Hospitals. (n=755).

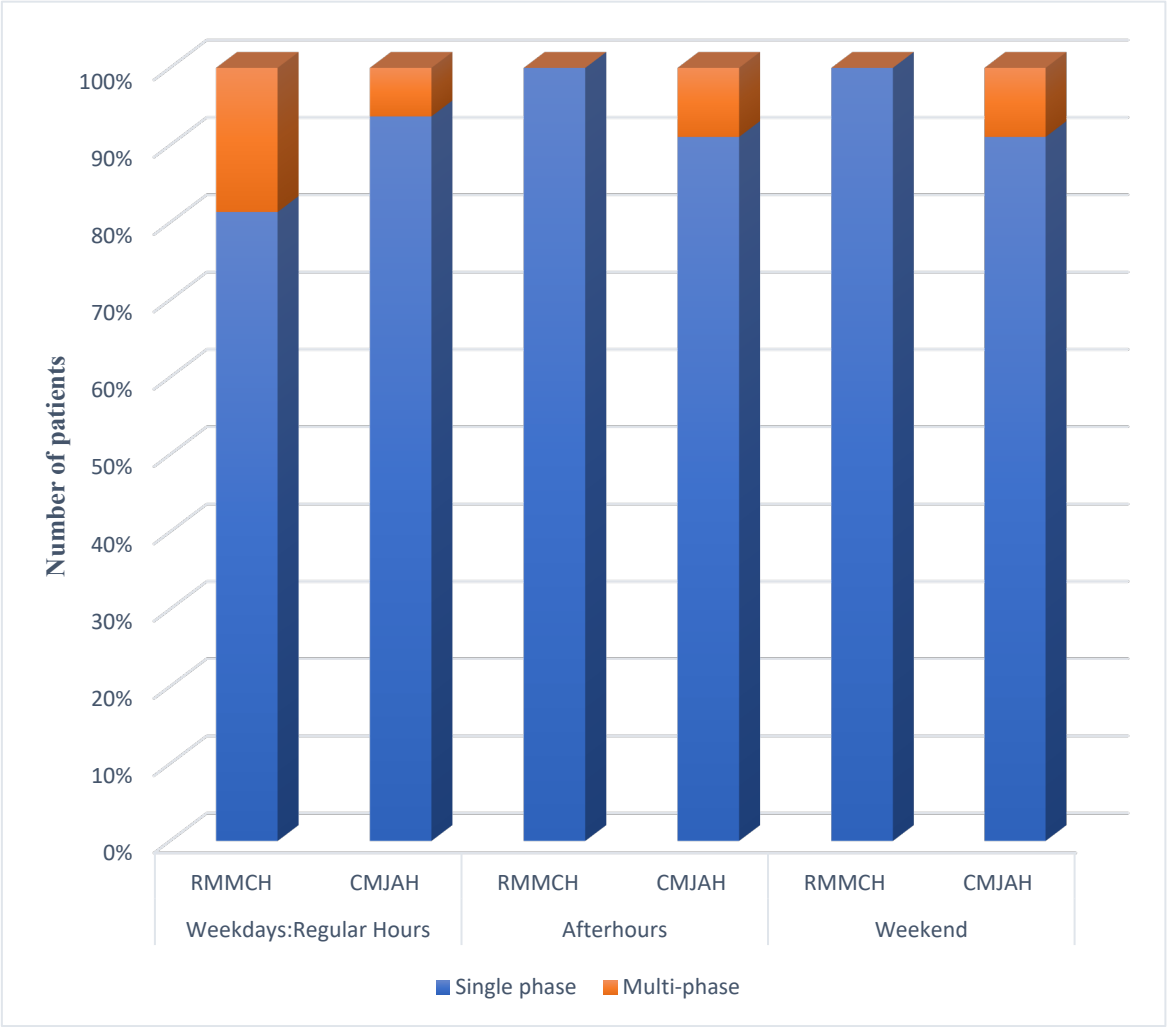

Figure 2.5. Comparative 75th percentile values for Dose Length Product (DLP) in mGy*cm for each time category for CT Brain at Charlotte Maxeke Johannesburg Academic (CMJAH)- and Rahima Moosa Mother and Child Hospitals (RMMCH). (n=687)

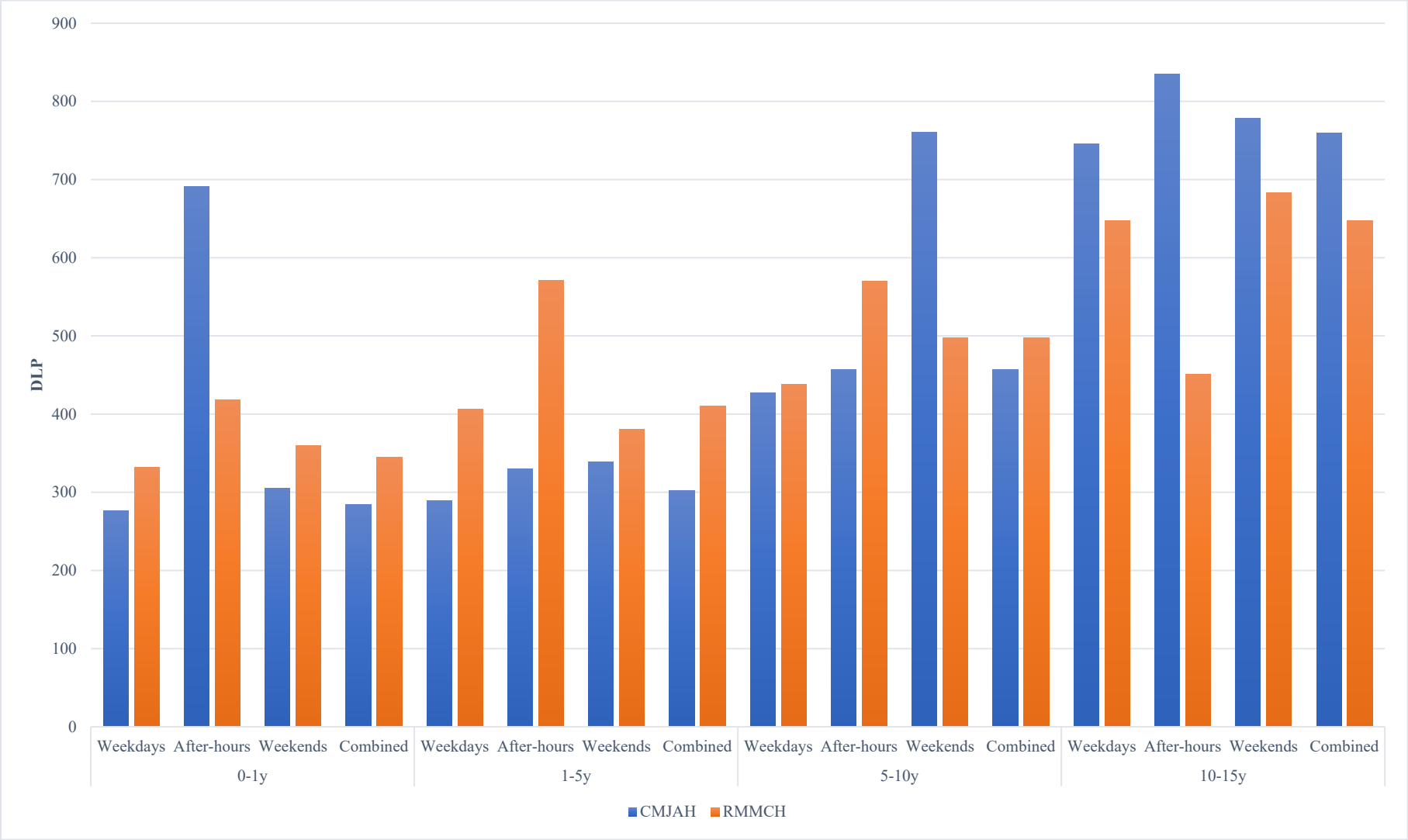

Figure 2.6. Polynomial exponential curve for the purpose of presenting Diagnostic Reference Levels (DRLs) for CT Abdomen for specific ages. The dataset used in this graph was the Dose Length Product (DLP) for CT abdomen examinations, corrected for each year in age. (n=82).

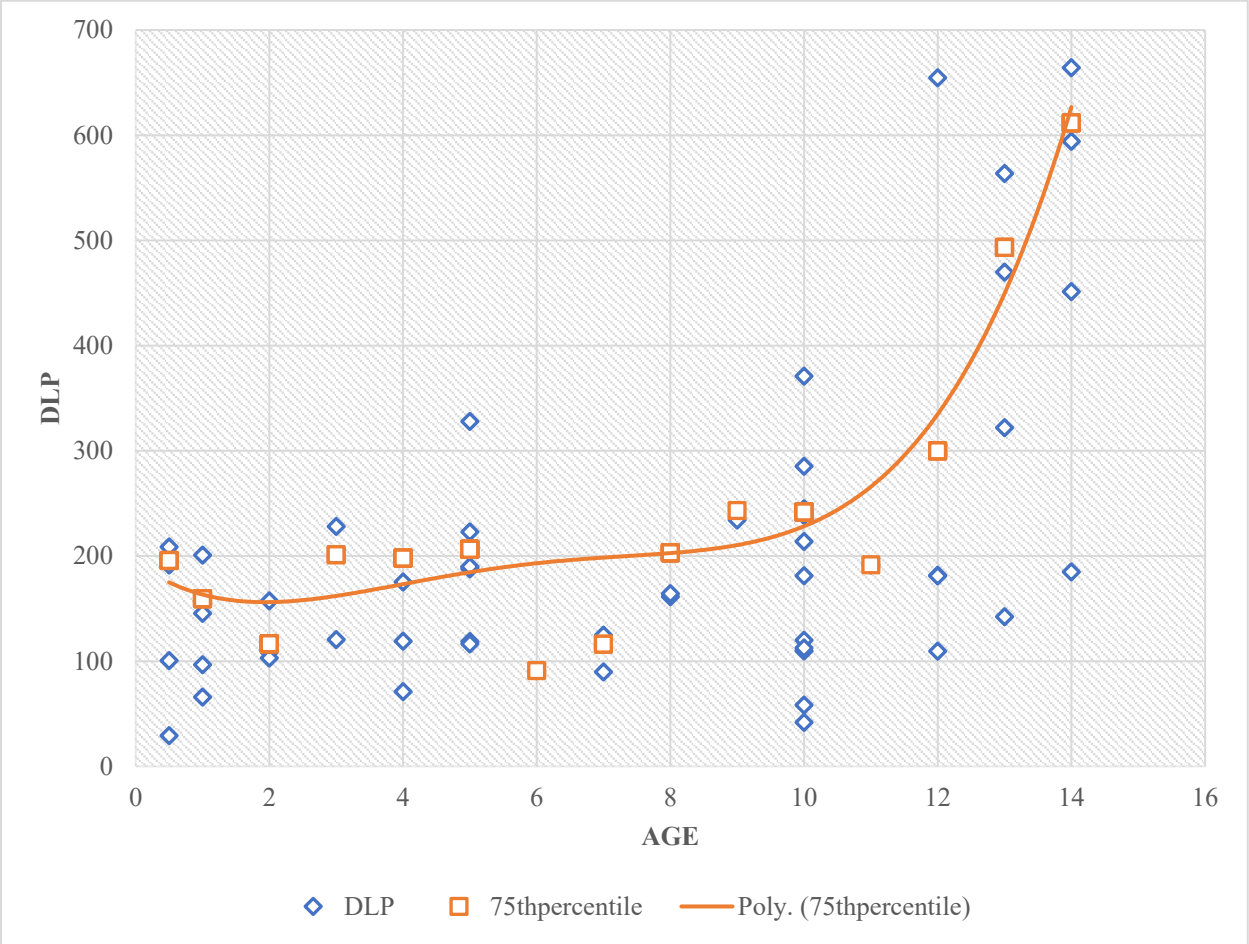

Figure 2.7. Polynomial exponential curve for the purpose of presenting Diagnostic Reference Levels (DRLs) for CT Brain for specific ages. The dataset used in this graph was the Dose Length Product (DLP) for CT Brain examinations, corrected for each year in age. (n=687).

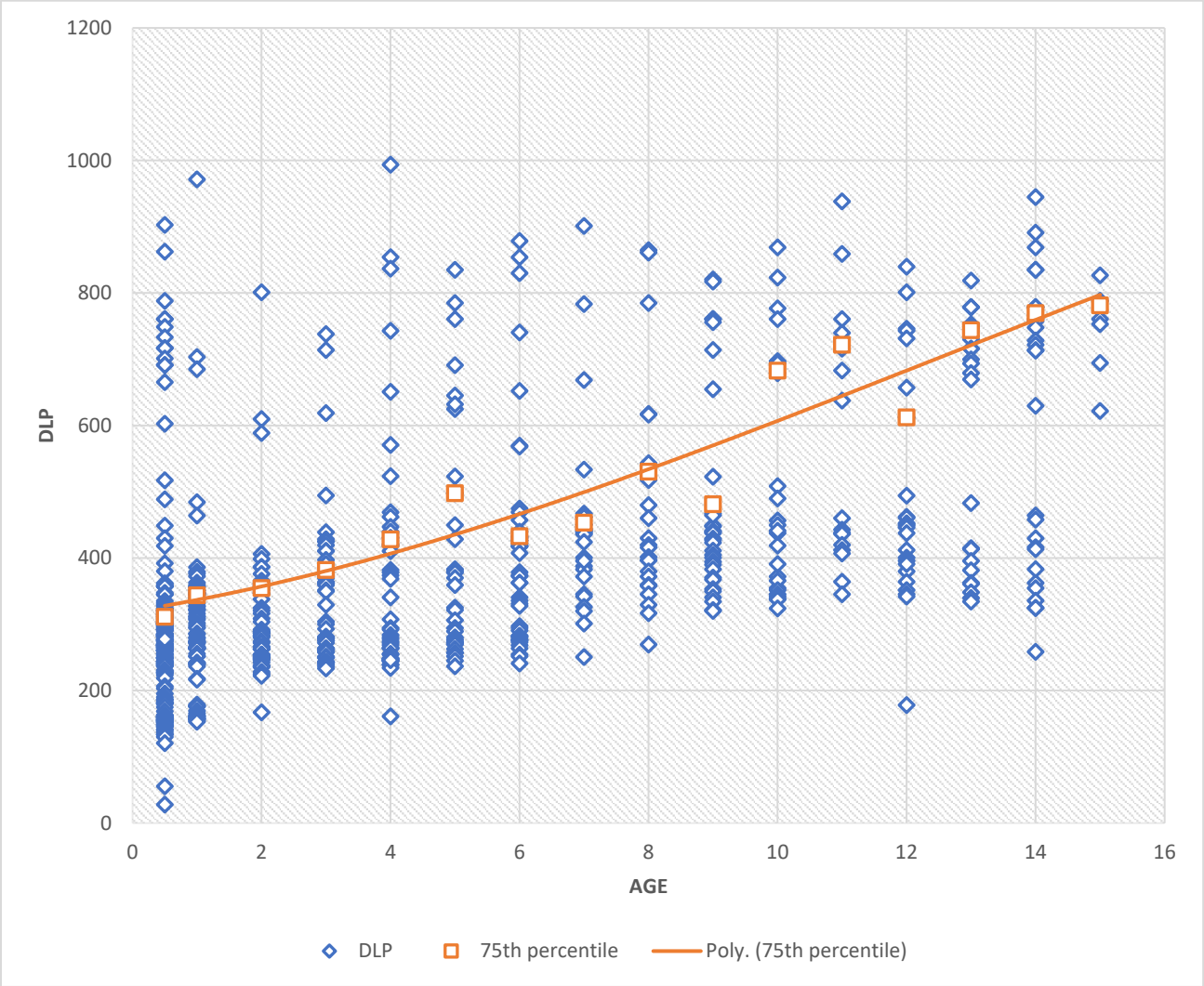

Table 2.1. Total number of scans included in study per Computed Tomography examination type for each age category. (n=1031).

Examination type	0-1y	1-5y	5-10y	10-15y	Total
CT Brain	195	263	159	138	755(73.23%)
CT Temporal Bones	1	1	4	10	16(1.55%)
CT Paranasal Sinuses	1	1	2	2	6(0.58%)
CT Orbits	0	0	4	0	4(0.39%)
CT Neck	3	10	8	6	27(2.62%)
CT Cervical Spine	3	17	13	9	43(4.17%)
CT Whole spine	1	2	1	0	4(0.39%)
CT Trunk	5	12	11	8	36(3.49%)
CT Chest	18	10	9	8	45(4.36%)
CT Abdomen	8	24	17	33	82(7.95%)
CT MSK	0	1	3	5	9(0.87%)
Peripheral CT angiography	3	0	0	2	5(0.48%)
Total	238 (23.08%)	341 (33.07%)	231 (22.41%)	221 (21.44%)	1031 (100%)

Table 2.2 75th percentile of Computed Tomography Dose Index$_{vol}$ (CTDI$_{vol}$) and Dose Length Product (DLP) for each Computed Tomography examination type, in each age group, as well as total number of contributing studies per category. (n=905).

Study	Age	CTDI$_{vol}$: 75th percentile[1] *(95%CI)*	DLP: 75th percentile[2] (95%CI)	Nunber of studies
CT Brain	0-1y	20.3 *(19.68 – 20.91)*	311.30 *(291.94 – 330.66)*	169
	1-5y	20.3 *(19.72 – 20.89)*	362.40 *(342.38 – 382.42)*	238
	5-10y	22.33 *(18.18 – 25.14)*	457.20 *(395.78 – 518.62)*	156
	10-15y	32.14 *(32.10 – 32.18)*	746.10 *(719.41 – 772.80)*	124
CT Temporal Bone	5-10y	41.78 *(11.31 – 64.02)*	305.80 *(135.73 -475.87)*	4
	10-15y	57.37 *(38.19 – 76.55)*	547.20 *(445.24 – 649.16)*	10
CT Cervical Spine	0-1y	13.16 *(0.92 – 25.40)*	303.90 *(-4.64 – 612.44)*	3
	1-5y	6.44 *(-4.12 – 17.00)*	186.00 *(-67.56 – 439.56)*	17
	5-10y	7.07 *(5.53 – 8.61)*	186.7 *(129.87 – 243.53)*	13
	10-15y	8.5 *(7.42 – 9.58)*	227.9 *(137.53 – 318.27)*	9
CT Neck	0-1y	7.85 *(7.62 – 8.08)*	195.40 *(59.33 – 331.47)*	3
	1-5y	6.93 *(-5.43 – 19.29)*	215.20 *(69.09 – 361.30)*	10
	5-10y	7.85 *(-1.12 – 16.82)*	142.30 *(60.20 – 224.40)*	7
	10-15y	15.99 *(-1.70 – 33.68)*	269.70 *(166.02 – 373.38)*	6
CT Trunk	0-1y	19.29 *(13.78 – 24.8)*	1362.30 *(194.15 – 2530.45)*	5
	1-5y	4.73 *(4.73 – 4.74)*	212.7 *(193.99 – 231.41)*	12
	5-10y	6.51 *(2.68 – 10.34)*	238.80 (-58.11 – 535.71)	11
	10-15y	4.73 *(1.57 – 7.89)*	290.20 *(178.94 – 401.46)*	8
CT Chest	0-1y	5.66 *(1.89 – 9.43)*	153.50 *(20.16 – 286.84)*	12
	1-5y	3.27 *(2.39 – 4.15)*	105.10 *(56.56 – 153.64)*	9
	5-10y	4.73 *(-3.49 – 12.95)*	136.40 *(85.90 – 186.90)*	8
	10-15y	6.97 *(3.69 – 10.25)*	325.10 *(205.96 – 444.24)*	7
CT Abdomen	0-1y	6.17 *(3.52 – 8.82)*	191.50 *(67.36 – 315.64)*	4
	1-5y	4.73 *(3.52 – 5.94)*	187.80 *(144.28 – 231.32)*	18
	5-10y	4.73 *(3.21 – 6.25)*	203.30 *(145.18 – 261.42)*	14
	10-15y	8.40 *(2.64 – 14.16)*	371.10 *(195.10 – 547.10)*	26

1. CTDI$_{vol}$ values presented in mGy. 2. DLP values presented in mGy*cm.

Table 2.3. 75th percentile Computed Tomography Dose Index$_{vol}$ (mGy) of data distribution, categorised for time and age for CT Brain examinations at Charlotte Maxeke Johannesburg Academic Hospital. (n=515).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0-1y	12.91	32.14	12.91	12.91
1-5y	11.82	12.91	14.33	12.91
5-10y	19.37	19.37	32.14	19.37
10-15y	32.14	32.14	32.14	32.14

Table 2.4. 75th percentile of Dose Length Product (mGy*cm) data distribution, categorised for time and age for CT Brain examinations at Charlotte Maxeke Johannesburg Academic Hospital. (n=515).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0-1y	275.90	691.30	304.90	284.10
1-5y	289.40	329.50	339.35	301.80
5-10y	427.20	457.20	760.70	457.20
10-15y	746.10	834.90	778.60	759.05

Table 2.5. 75th percentile Computed Tomography Dose Index$_{vol}$ (mGy) of data distribution, categorised for time and age for CT Brain examinations at Rahima Moosa Mother and Child Hospital. (n=172).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0-1y	20.30	23.00	20.30	20.03
1-5y	21.65	23.00	21.66	21.65
5-10y	23.00	23.00	23.00	23.00
10-15y	35.18	23.00	35.18	35.18

Table 2.6. 75th percentile of Dose Length Product (mGy*cm) data distribution, categorised for time and age for CT Brain examinations at Rahima Moosa Mother and Child Hospital. (n=172).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0-1y	332.20	418.30	359.70	345.00
1-5y	406.30	570.70	380.25	410.60
5-10y	437.70	569.70	497.90	497.90
10-15y	647.45	450.90	683.00	647.45

Table 2.7. Computed Tomography Dose Index$_{volume}$ 75th percentiles (mGy) of Johannesburg hospitals compared to international Diagnostic Reference Levels.

	Johannesburg *(95%CI)*	EDRL[3]	UK[4]	Germany[5]	Japan[6]	Kenya[7]	Brazil[8]
CT Brain							
0-1y	20.30 *(19.69 – 20.91)*	24	25	30	38	38	18
1-5y	20.3 *(19.72 – 20.88)*	28	40	35	47	50	30
5-10y	21.66 *(18.18 – 25.14)*	40	60	50	60	55	35
10-15y	32.14 *(32.10 – 32.18)*	50		55			44
CT Chest							
0-1y	5.66 *(1.90 – 9.42)*	1.4-1.8		1.7	11		5
1-5y	3.27 *(2.39 – 4.15)*	1.8-2.7		2.6	14	11	7
5-10y	4.73 *(-3.49 – 12.95)*	2.7-3.7		4	15		
10-15y	6.97 *(3.52 – 8.82)*	3.7-5.4		6.5		11	
CT Abdomen							
0-1y	6.17 *(3.51 – 8.82)*	3.5			11		4
1-5y	4.73 *(3.52 – 5.94)*	3.5-5.4			16	11	5
5-10y	4.73 *(3.21 – 6.25)*	5.4-7.3		5	17		
10-15y	8.47 *(2.63 – 14.16)*	7.3-13		7			

Blocks in orange indicate higher international values and blocks in blue indicate lower international values, when compared to the values of this study.

[3] European Commision (2018) Radiation Protection No 185. [10].
[4] Doses from Computed Tomography (CT) Examinations in the UK -2011. [14].
[5] Bundesamt fur Strahlenschutz (2016). [15]
[6] Japan Network for research and Information on Medical exposures (2015). [16].
[7] National Diagnostic Reference Level Initiative for Computed Tomography examinations in Kenya (2016). [17].
[8] A Contribution to the Establishment of Diagnostic Reference Levels in Computed Tomography in Brazil (2015). [18].

Table 2.8. Dose Length Product 75th percentile (mGy*cm) of Johannesburg hospitals compared to international Diagnostic Reference Levels.

	Johannesburg (95%CI)	EDRL[1]	UK[2]	Germany[3]	Japan[4]	Kenya[5]	Brazil[6]
Brain							
0-1y	311.30 (291.94 – 330.65)	300	350	300	50	1005	290
1-5y	362.40 (342.38 – 382.42)	385	650	450	660	1395	550
5-10y	457.20 (395.77 – 518.62)	505	620	650	850	1608	670
10-15y	746.10 (719.41 – 772.79)	650		800			880
Chest							
0-1y	153.50 (20.16 – 286.84)	35-50		25	210		64
1-5y	105.10 (56.56 – 153.64)	50-70		55	300	215	130
5-10y	136.40 (85.90 – 186.90)	70-115		110	410		
10-15y	325.10 (205.96 – 444.24)	115-200		200		453	
Abdomen							
0-1y	191.50 (67.36 – 315.64)	45-120			220		110
1-5y	187.80 (144.28 – 231.32)	120-150			400	764	170
5-10y	203.30 (145.18 – 261.41)	150-210		185	530		220
10-15y	371.10 (195.10 – 547.10)	210-480		310			

Blocks in orange indicate higher international values and blocks in blue indicate lower international values, when compared to the values of this study.

[1] European Commision (2018) Radiation Protection No 185. [10].
[2] Doses from Computed Tomography (CT) Examinations in the UK -2011. [14].
[3] Bundesamt fur Strahlenschutz (2016). [15]
[4] Japan Network for research and Information on Medical exposures (2015). [16].
[5] National Diagnostic Reference Level Initiative for Computed Tomography examinations in Kenya (2016). [17].
[6] A Contribution to the Establishment of Diagnostic Reference Levels in Computed Tomography in Brazil (2015). [18].

Table 2.9. Proposed local diagnostic reference levels for Computed Tomography Dose Index$_{volume}$ and Dose Length Product for Paediatric Computed Tomography examinations.

Study	Age	$CTDI_{vol}$: 75th percentile (mGy)	DLP: 75th percentile (mGy*cm)
CT Brain	0-1y	21	315
	1-5y	21	365
	5-10y	23	460
	10-15y	33	750
CT Temporal bones	5-10y	40	315
	10-15y	56	515
CT Cervical Spine	1-5y	7	190
	5-10y	8	190
	10-15y	9	230
CT Neck	1-5y	7	200
	5-10y	7	145
	10-15y	15	260
CT Trunk	1-5y	5	215
	5-10y	6	235
	10-15y	6	285
CT Chest	1-5y	4	110
	5-10y	7	145
	10-15y	7	290
CT Abdomen	1-5y	5	185
	5-10y	5	230
	10-15y	9	460

APPENDIX A

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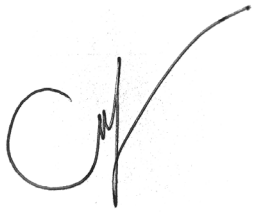
(1st author): Cornelis M van der Merwe Signature:  Date: 04/08/2019

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An audit of radiation doses received by paediatric patients undergoing computed tomography investigations at academic hospitals in South Africa

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Background: Diagnostic reference levels (DRLs) are a crucial element of auditing radiation doses in paediatric computed tomography (CT). Currently, there are no national paediatric CT DRLs in South Africa.

Objectives: The aim of this article was to establish local paediatric DRLs for CT examinations at two academic hospitals and to compare paediatric CT radiation output levels with established DRLs in the developed and developing world.

Method: Computed Tomography Dose Index$_{volume}$ (CTDI$_{vol}$) and dose length product (DLP) values were collected from CT examinations performed at two university hospitals for patients aged 0–15 years, during 01 November 2016–30 April 2017. The 75th percentile of the data distribution was calculated for each CT examination type and age group, further categorised into routine working hours and after-hours for both hospitals and statistically compared.

Results: Of the 1031 CT examinations performed, CT brain examination was the most common (755/1031; 72.23%). DLP values were increased in the after-hours categories compared to regular working hours at both hospitals. The largest increase was in the 0–1 year age group (150.56%). With the exception of CT Chest and CT abdomen in the 0–1 year age group, the CTDI$_{vol}$ and DLP values compared favourably to international standards.

Conclusion: Most of the calculated DRLs are acceptable and internationally comparable. This likely indicates effective reduction techniques and protocols. Computed tomography body examination protocols for 0–1 year patients should be reviewed. Strategies should be implemented to limit higher doses in after-hours examinations.

Keywords: Radiation dose; Computed tomography (CT); Paediatric patients; Diagnostic Reference Level (DRL); Computed Tomography Dose Index$_{volume}$ (CTDI$_{volume}$).

Introduction

Since its advent in 1971, computed tomography (CT) has added tremendous value for diagnosis and establishing treatment plans for patients. Since then, there has been an exponential increase in the usage of CT.[1] This increase is because of several factors, including, but not limited to, rapid evolvement of technology and advancements in hardware and software, which led to improved image quality and reduced duration for CT examinations.[2,3] In addition, the geopolitical and socio-economic trends since the late 1990s also contributed to greater access to medical resources and equipment, specifically in the industrialised world.[4] The number of CT scanners per million people in Japan increased from 14.36 in 1980 to 107.14 in 2017. This increase has been the most significant in the developed world; however, an increase in the amount of CT scanners was also observable in the developing world, for example, in Turkey, where the number of CT scanners increased from 4.89 per million people in 2002 to 14.53 per million people in 2016.[4] The advances in availability and increase in applications also made CT investigations popular in the paediatric patient population. In the Netherlands, the total number of paediatric CT scan examinations increased from 7731 in 1990 to 26 023 in 2012.[5] Similar trends were established in the rest of the developed world.[6]

Even though there was suspicion about harmful effects of ionising radiation on the human body shortly after Roentgen took his first radiograph in 1895, the first International Radiation Congress only discussed possible radiation protection standards in 1925. In the aftermath of the Second World War, the International Commission on Radiation Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation were formed and have since then played

Note: Special Collection: Paediatric Radiology.

a major role in radiation research and protection.[7] The concept of keeping radiation dose 'as low as reasonably achievable' (ALARA) has been around since 1915 and is compatible with the medical ethical mantra of 'first do no harm'.[8] Furthermore, evidence from the Second World War and radiation incidents has proved that the younger the patient is, the higher is the risk for adverse radiation effects. The increased risk is because of the presence of more undifferentiated cells, and the cells have a higher mitotic rate as well as a longer mitotic future.[1,9]

The ICRP has recommended diagnostic reference levels (DRLs) for all diagnostic and interventional radiological procedures since 1991 as a measure to ensure radiation protection.[6] The Image Gently Alliance and campaign, which started in 2007, promoted the ALARA principle and since then has become one of the primary considerations in paediatric imaging.[3] Since 2007, there has been a reduction in the annual increase of paediatric CT examinations in the developed world.[5] This reduction is likely because of the successes of radiation awareness programmes.

Following recommendations by the ICRP to establish DRLs, there have been a significant number of audits and DRL proposals in the developed world.[10] As of 2013, the European Diagnostic Reference Levels for Paediatric Imaging (PiDRL) workshop has driven a campaign to establish European DRLs.[10]

There have been very few studies or audits on paediatric CT doses to establish CT-specific DRLs in the developing world. There is only one study from South Africa auditing CT doses in a tertiary hospital on non-contrasted paediatric brain CT scans.[11]

South Africa is considered the most industrialised country and the second largest economy in Africa but has one of the highest levels of inequality. Most of the population is medically underserviced because of resource constraints in the public health sector.[12] Apart from a heavy workload required from the radiological equipment, there are also restraints on human resources and quality control. In addition, the absence of established DRLs limits the ability to do routine audits to ensure optimal radiation protection. It is therefore of utmost importance to audit paediatric CT doses in South Africa to establish DRLs.

The aim of this study was to establish local paediatric DRLs for CT examinations in two major academic hospitals affiliated to the University of the Witwatersrand, Johannesburg, South Africa.

Other objectives were to audit radiation doses and compare paediatric CT investigations' radiation output levels to established DRLs in the developed and developing world. An additional objective was to evaluate whether there was any difference between the hospitals, as well as between regular work hours and after-hours.

Materials and methods

Design

The study was designed as a retrospective, descriptive study.

Dosimetry

European guidelines suggest the usage of the Computed Tomography Dose Index$_{volume}$ (CTDI$_{vol}$) and dose length product (DLP) as CT dose descriptors.[10] CTDI$_{100}$ is a linear measure of the dose distribution in a 10 cm ionization chamber inserted into a 16 cm phantom for paediatric CT. The weighted CTDI (CTDI$_w$) is calculated by establishing the CTDI$_{100}$ for the centre and the periphery of a cylinder and combining these. In helical CT scanning, the dose is inversely related to the pitch (number of rotations of the gantry per distance moved by the examination bed). Computed Tomography Dose Index$_w$ divided by the pitch equals CTDI$_{vol}$, which is expressed in the international system of units (SI units) as milligray (mGy). Dose length product is the product of the length of the scanned area with the CTDI$_{vol}$[13] and is expressed in milligray-centimetre (mGy*cm).

Study population

The data collected were the CTDI$_{vol}$ and DLP values for each CT examination in paediatric patients (age less than 15 years) during the 6-month period from 01 November 2016 to 30 April 2017 at the following hospitals: Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) and Rahima Moosa Mother and Child Hospital (RMMCH). These hospitals are situated within the City of Johannesburg Municipality in Gauteng province, South Africa.

Data collection

Data were retrieved from the Picture Archiving and Communication System (PACS) from CMJAH and the local area network at RMMCH. Data were categorised and tabled for each CT scanner and further categorised according to the type of study and the age group. The CT brain data were also categorised into three different time categories as follows: weekdays (Monday to Friday from 08:00 to 16:00), after-hours (00:00–08:00 and 16:00–24:00 from Monday to Friday) and weekends and public holidays (00:00–24:00 on Saturday and Sunday, as well as on public holidays).

The categories were chosen as per recommendations made by the European Diagnostic Reference Levels for Paediatric Imaging Workshop in 2013.[10] All CT investigations were included and categorised according to the anatomical region of interest. The data could not be categorised according to indication, as the indication was not available on the database. The age groups were divided into 0 to < 1 year; 1 year to < 5 years, 5 years to < 10 years and 10 years to < 15 years. The European Commission suggests categorising the CT body examinations according to weight, but patients' weight was not available from the database. The time of day and day of the week was recorded for each study.

Data analysis

The distribution of the CT examinations in this study sample was calculated using frequencies.

For statistical analysis of the $CTDI_{vol}$ and DLP values, only the single-phase CT examinations were included in the study sample. Radiation output data for CT orbits, CT paranasal sinuses, CT musculoskeletal, CT whole spine and CT peripheral angiography were excluded from further analysis as the sample sizes were too small for statistical significance.

Data sets were categorised for CT brain, CT temporal bones, CT neck, CT cervical spine, CT chest, CT trunk and CT abdomen. The dose distribution for CT brain in each age category was determined for each hospital. Data for each of the other CT examination types were combined for the two hospitals.

The mean, average, median and 75th percentile of the data distribution, with confidence intervals (CIs), were then calculated for each category for each examination type. Local DRLs are defined as the 75th percentile of the data distribution.[10] The local DRLs in this study were the 75th percentile value for each category, rounded up to the nearest single digit for CTDI and the nearest 5 for DLP.

The data were then compared to similar studies with local and national DRLs.

In addition, the CT brain results were compared between the two hospitals according to the difference in $CTDI_{vol}$ and DLP 75th percentile values between the two hospitals for each age group and time category, using the Fisher's exact test. Furthermore, the quantile regression method was used to compare the 75th percentiles in different groups by calculating the 95% CI for the difference between percentiles. If the 95% CI for the difference did not contain 0, the percentiles were significantly different.

Ethical considerations

Ethical approval to conduct the study was obtained from the Human Research Ethics Committee (Medical) of the University of the Witswatersrand (approval number: M170634).

Results

Distribution and frequency of computed tomography examinations

The audit period for the 6 months from 01 November 2016 to 30 April 2017 included 1031 paediatric CT examinations from RMMCH and CMJAH.

Computed tomography brain examinations (755/1031; 73.23%) were the most common CT examination, followed by CT of the abdomen, which amounted to 82/1031 (7.95%) (see Table 1).

Radiation doses

From all the study types conducted during the study period, there were only seven study types with enough cases in different age groups to allow data distribution calculation. These included CT brain, CT temporal bones, CT neck, CT cervical spine, CT trunk, CT chest and CT abdomen (total number for analysis = 905). The 75th percentile of both the $CTDI_{vol}$ and DLP of each of these examination types in the various age groups is demonstrated in Table 2, with a 95% CI.

TABLE 1: Total number of scans included in the study per computed tomography examination type for each age category (n = 1031).

Examination type	0–1 years	1–5 years	5–10 years	10–15 years	Total
CT Brain	195	263	159	138	755(73.23%)
CT Temporal Bones	1	1	4	10	16(1.55%)
CT Paranasal Sinuses	1	1	2	2	6(0.58%)
CT Orbits	0	0	4	0	4(0.39%)
CT Neck	3	10	8	6	27(2.62%)
CT Cervical Spine	3	17	13	9	43(4.17%)
CT Whole spine	1	2	1	0	4(0.39%)
CT Trunk	5	12	11	8	36(3.49%)
CT Chest	18	10	9	8	45(4.36%)
CT Abdomen	8	24	17	33	82(7.95%)
CT Limbs	0	1	3	5	9(0.87%)
Peripheral CT angiography	3	0	0	2	5(0.48%)
Total	**238 (23.08%)**	**341 (33.07%)**	**231 (22.41%)**	**221 (21.44%)**	**1031 (100%)**

CT, computed tomography.

The CT brain data sets were used to compare the two different hospitals, as well as to evaluate for potential variation in different time categories. At CMJAH, there was an increase in the 75th percentile of the data distribution in the weekend and after-hours group compared to regular weekdays. The greatest increase in dose was in the 0–1-year after-hours group with a 150.56% (691.3 mGy*cm vs. 275.9 mGy*cm) increase in DLP compared to the 0–1-year group during routine weekdays. The second most significant increase in dosage was in the 5–10-year weekend group. Here, there was a 78.07% (760.7 mGy*cm vs. 427.2 mGy*cm) increase in DLP compared to 5–10 years routine weekday group (see Tables 3 and 4).

Similarly, the data from RMMCH demonstrated an increase in $CTDI_{vol}$ and DRL for after-hours and weekends compared to regular weekdays, although the increase was not as significant as it was at CMJAH. The most pronounced increase in dose was in the 1–5-year after-hours group, with an increase in DLP of 40.46% (570.7 mGy*cm vs. 406.3 mGy*cm). The second highest increase in dose compared to routine weekdays was in the 0–1-year after-hours category, with an increase of 25.92% (418.3 mGy*cm vs. 332.2 mGy*cm) in DLP (see Tables 5 and 6).

The comparison of the dosages during CT brain investigation between the two hospitals revealed in general a lower DLP at a lower DLP at CMJAH for the 0–1y, 1–5y and 5–10y groups, compared to RMMH (statistically significant in the 0–1y and 5–10y groups only, as 0 is not included in the 95% CI). The 10–15-year stratified groups demonstrated lower DLP values at RMMCH compared to CMJAH (see Figure 1).

TABLE 2: 75th percentile of Computed Tomography Dose Index$_{vol}$ and Dose Length Product for each computed tomography examination type, in each age group, as well as total number of contributing studies per category (n = 905).

Study	Age	CTDI$_{vol}$: 75th percentile†		DLP: 75th percentile‡		Nunber of studies
		95%	CI	95%	CI	
CT Brain	0–1 years	20.3	19.68–20.91	311.30	291.94–330.66	169
	1–5 years	20.3	19.72–20.89	362.40	342.38–382.42	238
	5–10 years	22.33	18.18–25.14	457.20	395.78–518.62	156
	10–15 years	32.14	32.10–32.18	746.10	719.41–772.80	124
CT Temporal Bone	5–10 years	41.78	11.31–64.02	305.80	135.73–475.87	4
	10–15 years	57.37	38.19–76.55	547.20	445.24–649.16	10
CT Cervical Spine	0–1 years	13.16	0.92–25.40	303.90	−4.64–612.44	3
	1–5 years	6.44	−4.12–17.00	186.00	−67.56–439.56	17
	5–10 years	7.07	5.53–8.61	186.7	129.87–243.53	13
	10–15 years	8.5	7.42–9.58	227.9	137.53–318.27	9
CT Neck	0–1 years	7.85	7.62–8.08	195.40	59.33–331.47	3
	1–5 years	6.93	−5.43–19.29	215.20	69.09–361.30	10
	5–10 years	7.85	−1.12–16.82	142.30	60.20–224.40	7
	10–15 years	15.99	−1.70–33.68	269.70	166.02–373.38	6
CT Trunk	0–1 years	19.29	13.78–24.8	1362.30	194.15–2530.45	5
	1–5 years	4.73	4.73–4.74	212.7	193.99–231.41	12
	5–10 years	6.51	2.68–10.34	238.80	−58.11–535.71	11
	10–15 years	4.73	1.57–7.89	290.20	178.94–401.46	8
CT Chest	0–1 years	5.66	1.89–9.43	153.50	20.16–286.84	12
	1–5 years	3.27	2.39–4.15	105.10	56.56–153.64	9
	5–10 years	4.73	−3.49–12.95	136.40	85.90–186.90	8
	10–15 years	6.97	3.69–10.25	325.10	205.96–444.24	7
CT Abdomen	0–1 years	6.17	3.52–8.82	191.50	67.36–315.64	4
	1–5 years	4.73	3.52–5.94	187.80	144.28–231.32	18
	5–10 years	4.73	3.21–6.25	203.30	145.18–261.42	14
	10–15 years	8.40	2.64–14.16	371.10	195.10–547.10	26

CTDI$_{vol}$, Computed Tomography Dose Index$_{volume}$; CT, computed tomography; DLP, Dose Length Product.
†, CTDI$_{vol}$ values presented in mGy; ‡, DLP values presented in mGy*cm.

TABLE 3: 75th percentile Computed Tomography Dose Index$_{vol}$ (mGy) of data distribution, categorised for time and age for computed tomography brain examinations at Charlotte Maxeke Johannesburg Academic Hospital (n = 515).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0–1 years	12.91	32.14	12.91	12.91
1–5 years	11.82	12.91	14.33	12.91
5–10 years	19.37	19.37	32.14	19.37
10–15 years	32.14	32.14	32.14	32.14

TABLE 4: 75th percentile of Dose Length Product (mGy*cm) data distribution, categorised for time and age for computed tomography brain examinations at Charlotte Maxeke Johannesburg Academic Hospital (n = 515).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0–1 years	275.90	691.30*	304.90	284.10
1–5 years	289.40	329.50	339.35	301.80
5–10 years	427.20	457.20	760.70**	457.20
10–15 years	746.10	834.90	778.60	759.05

*Not statistically significant, as 0 is included in the 95% CI.
**Statistically significant, as 0 is not included in the 95% CI.

TABLE 5: 75th percentile Computed Tomography Dose Index$_{vol}$ (mGy) of data distribution, categorised for time and age for computed tomography brain examinations at Rahima Moosa Mother and Child Hospital (n = 172).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0–1 years	20.30	23.00	20.30	20.03
1–5 years	21.65	23.00	21.66	21.65
5–10 years	23.00	23.00	23.00	23.00
10–15 years	35.18	23.00	35.18	35.18

TABLE 6: 75th percentile of Dose Length Product (mGy*cm) data distribution, categorised for time and age for computed tomography brain examinations at Rahima Moosa Mother and Child Hospital (n = 172).

Age	Weekdays Regular hours	After-hours	Weekends	Combined
0–1 years	332.20	418.30*	359.70	345.00
1–5 years	406.30	570.70**	380.25	410.60
5–10 years	437.70	569.70	497.90	497.90
10–15 years	647.45	450.90	683.00	647.45

*Not statistically significant, as 0 is included in the 95% CI.
**Statistically significant, as 0 is not included in the 95% CI.

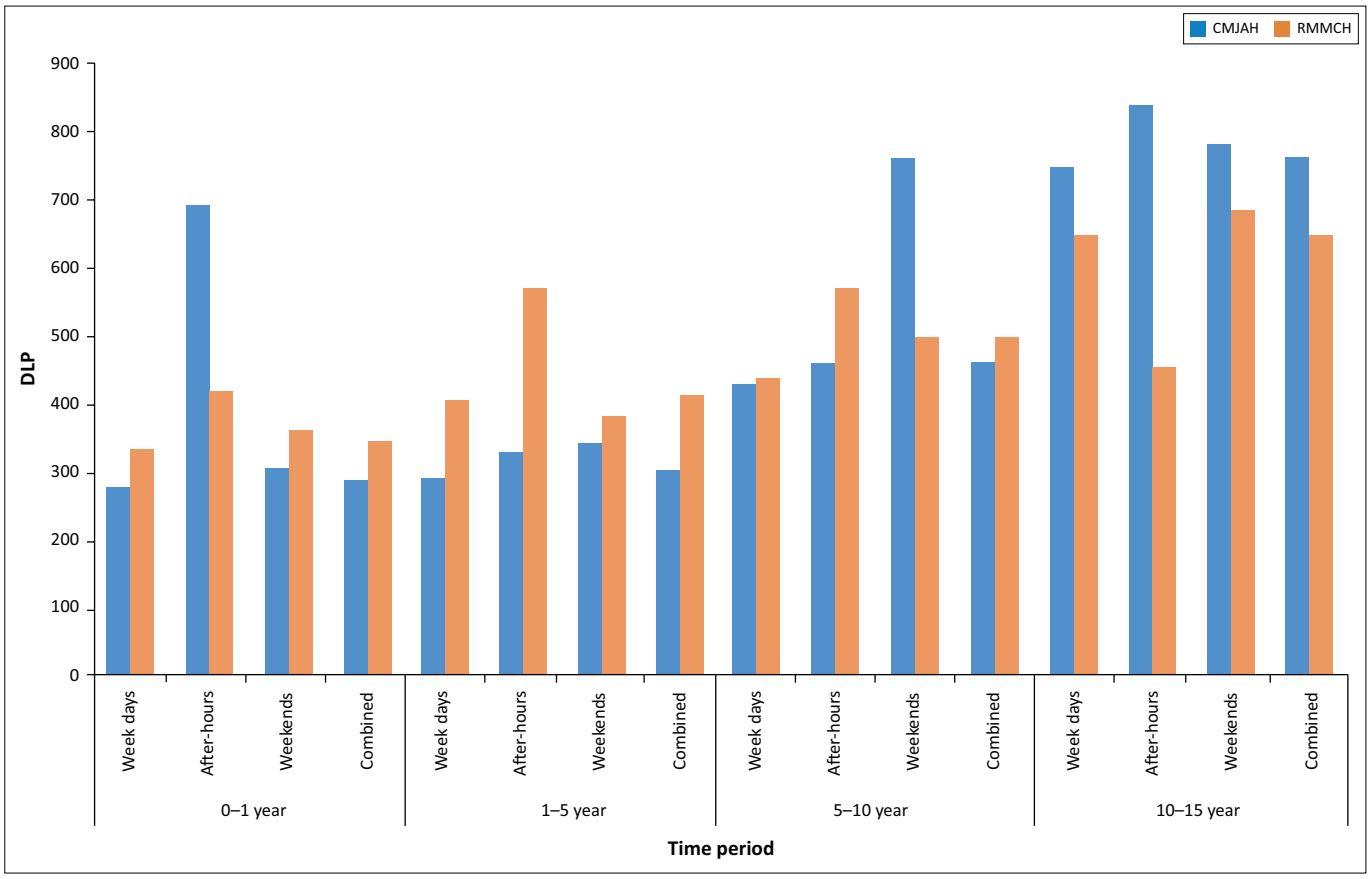
Comparison to other studies and diagnostic reference levels

The combined DLP and CTDI$_{vol}$ 75th percentile values were compared to DRLs from the European guidelines, UK, Germany, Japan, Kenya and Brazil[10,14,15,16,17,18] (see Tables 7 and 8).

The CTDI$_{vol}$ and DLP values for CT brain were found to be less than the comparative DRL values in most cases, except for the DLP values compared to the European DRL in the age category for 10–15 years.

The CTDI$_{vol}$ and DLP values for CT chest were higher than the European DRLs, but better than those from Japan, Kenya and Brazil. The exception was the increased value compared to Brazil in the 0–1-year age category.

The CTDI$_{vol}$ values for CT abdomen were lower than the international DRLs, except for the 0–1-year category, which was higher than the European Diagnostic Reference Levels (EDRL) and Brazilian values. The 0–1-year category for CT abdomen DLP values was also higher than those from



DLP, dose length product; CMJAH, Charlotte Maxeke Johannesburg Academic Hospital; RMMCH, Rahima Moosa Mother and Child Hospital.

FIGURE 1: Comparative 75th percentile for dose length product in mGy*cm for each time category for computed tomography brain at Charlotte Maxeke Johannesburg Academic Hospital and Rahima Moosa Mother and Child Hospital (n = 687).

TABLE 7: Computed Tomography Dose Index$_{volume}$ 75th percentiles (mGy) of Johannesburg hospitals compared to international diagnostic reference levels.

Examination	Johannesburg		EDRL†	UK‡	Germany§	Japan¶	Kenya††	Brazil‡‡
	95%	CI						
CT Brain								
0–1 years	20.30	19.69–20.91	24	25	30	38	38	18
1–5 years	20.3	19.72–20.88	28	40	35	47	50	30
5–10 years	21.66	18.18–25.14	40	60	50	60	55	35
10–15 years	32.14	32.10–32.18	50	-	55	-	-	44
CT Chest								
0–1 years	5.66	1.90–9.42	1.4–1.8	-	1.7	11	-	5
1–5 years	3.27	2.39–4.15	1.8–2.7	-	2.6	14	11	7
5–10 years	4.73	−3.49–12.95	2.7–3.7	-	4	15	-	-
10–15 years	6.97	3.52–8.82	3.7–5.4	-	6.5	-	11	-
CT Abdomen								
0–1 years	6.17	3.51–8.82	3.5	-	-	11	-	4
1–5 years	4.73	3.52–5.94	3.5–5.4	-	-	16	11	5
5–10 years	4.73	3.21–6.25	5.4–7.3	-	5	17	-	-
10–15 years	8.47	2.63–14.16	7.3–13	-	7	-	-	-

EDRL, Europe diagnostic reference levels; CT, computed tomography.
†, European Commision (2018) Radiation Protection No 185.[10]
‡, Doses from Computed Tomography (CT) Examinations in the UK-2011.[14]
§, Bundesamt fur Strahlenschutz (2016).[15]
¶, Japan Network for research and Information on Medical exposures (2015).[16]
††, National Diagnostic Reference Level Initiative for Computed Tomography examinations in Kenya (2016).[17]
‡‡, A Contribution to the Establishment of Diagnostic Reference Levels in Computed Tomography in Brazil (2015).[18]

TABLE 8: Dose Length Product 75th percentile (mGy*cm) of Johannesburg hospitals compared to international diagnostic reference levels.

Examination	Johannesburg		EDRL†	UK‡	Germany§	Japan¶	Kenya††	Brazil‡‡
	95%	CI						
Brain								
0–1 years	311.30	291.94–330.65	300	350	300	50	1005	290
1–5 years	362.40	342.38–382.42	385	650	450	660	1395	550
5–10 years	457.20	395.77–518.62	505	620	650	850	1608	670
10–15 years	746.10	719.41–772.79	650	-	800	-	-	880
Chest								
0–1 years	153.50	20.16–286.84	35–50	-	25	210	-	64
1–5 years	105.10	56.56–153.64	50–70	-	55	300	215	130
5–10 years	136.40	85.90–186.90	70–115	-	110	410	-	-
10–15 years	325.10	205.96–444.24	115–200	-	200	-	453	-
Abdomen								
0–1 years	191.50	67.36–315.64	45–120	-	-	220	-	110
1–5 years	187.80	144.28–231.32	120–150	-	-	400	764	170
5–10 years	203.30	145.18–261.41	150–210	-	185	530	-	220
10–15 years	371.10	195.10–547.10	210–480	-	310	-	-	-

EDRL, Europe diagnostic reference levels.

†, European Commission (2018) Radiation Protection No 185.[10]

‡, Doses from Computed Tomography (CT) Examinations in the UK-2011.[14]

§, Bundesamt fur Strahlenschutz (2016).[15]

¶, Japan Network for research and Information on Medical exposures (2015).[16]

††, National Diagnostic Reference Level Initiative for Computed Tomography examinations in Kenya (2016).[17]

‡‡, A Contribution to the Establishment of Diagnostic Reference Levels in Computed Tomography in Brazil (2015).[18]

Brazil. Although only the 10–15-year category DLP values were within the EDRL range, the rest of the values were lower than that of the other international DRLs.

Discussion

Distribution and frequency of computed tomography examinations

The higher number of investigations at the CMJAH compared to RMMCH was expected, as it is considered a central hospital in South Africa, a level 1 trauma centre and major referral centre in the country.[19] The CT brain percentage of total investigations was marginally higher in comparison to international studies in the developed world, whereas the CT abdomen percentage compared to the CT utilisation trends in other countries was similar.[5,6,20] The reason for the higher percentage of CT brains performed at the studied facilities is likely because the initial neuroimaging investigation in the public health sector of South Africa for a child presenting with the first episode of convulsion is a CT brain instead of a magnetic resonance imaging (MRI) brain, as recommended by the American Academy of Neurology.[21] Computed tomography brain for neurological disease in South Africa is a reasonable initial radiological investigation, as the incidence of neurological infections is higher than that of developed countries.[22] Magnetic resonance imaging availability and anaesthetic support are limited in the South African public health sector. Furthermore, CMJAH is a level 1 trauma centre and will have an increased percentage of CT brains for trauma indications.

The increase in CT of the cervical spine after the age of 1 year is expected in a level 1 trauma centre. The number of temporal bone CT investigations in the 5–10- and 10–15-year age groups is consistent with previous studies, which demonstrated the majority of patients with temporal bone pathology to be between the ages of 11 and 20 years.[23]

Radiation doses

Both hospitals demonstrated an increase in the DLP values of CT brain during after-hours and some of the weekend categories. During after-hours, there is less staff present on the floor and often fewer senior staff to guide procedures, which could lead to an incorrect choice of parameters or selection of scan area, with a resultant increase in radiation dose to the patient. The increase in values is more significant in CMJAH than in RMMCH. The Radiology Department at RMMCH is almost an exclusive paediatric radiology department, with staff trained in paediatric radiology. On the contrary, the Radiology Department at CMJAH is a large combined adult and paediatric academic radiology department. At CMJAH, there are dedicated time slots for paediatric CT examinations during the week, but after-hours urgent paediatric CTs are performed in between adult patient CTs, which could lead to an incorrect parameter and CT protocol selection when examining children. Previous research has shown that probability exists for a significant DLP variation between radiographers even in the setting of a dedicated paediatric hospital.[24]

Although the finding of increased DLP values in the 0–1-year age group was considered not to be statistically significant, follow-up investigation in this age group is suggested, as the findings might suggest clinical significance.

The increased $CTDI_{vol}$ and DLP values for RMMCH compared to CMJAH could be ascribed to hardware and

software variables between the two departments. Charlotte Maxeke Johannesburg Academic Hospital Philips machines have more detector rows (64 and 128) as well as utilisation of the i-Dose software by Philips.[25,26]

Comparison to other studies and diagnostic reference levels

The $CTDI_{vol}$ and DLP values for CT brain compare well against previously established DRLs and suggest consistent application of well-developed protocols at the different facilities.

Most of the higher $CTDI_{vol}$ and DLP values in the 0–1-year age group for CT abdomen were associated with higher kV settings. The South African Society of Paediatric Imaging suggests the reduction of kV settings in paediatric examinations.[27] The CT abdomen studies with $CTDI_{vol}$ and DLP values comparable to international DRL ranges were performed with a reduction of kV from 120 to 100. It is suggested that the CT abdomen protocol for both RMMCH and CMJAH should be reviewed, adjusted and applied to all cases.

Although the $CTDI_{vol}$ and DLP values for CT chest compare well against some of the international DRLs, it is also suggested that the protocols for CT chest should be reviewed and adjusted.

A discrepancy in the comparison of $CTDI_{vol}$ and DLP values for a specific examination in a specific age category is likely because of a larger-than-expected pre-selected scan area for the particular study.[24,25] This and the fact that the CT brain values compared better than the CT chest and abdomen values could be a result of using age, rather than weight, as an input parameter for CT chest and abdomen examination in children.[10]

Outcome

From the data analysis, DRLs are proposed for the most frequent examinations. Local DRLs are not suggested for 0–1-year age group, except for CT brain, as the 75th percentile values are higher than the older age groups and compare unfavourably to international DRLs (Table 9).

In recent similar international studies and according to the European guidelines, it is proposed that DRLs could be presented in a graph format instead of tabular format. See the DRL graph and curve for CT abdomen in Figure 2 and for CT brain in Figure 3. This type of graph is created by plotting all the different values for each age on an *x*:*y* scatter plot, establishing the 75th percentile for each age and creating a polynomial, exponential graph.[28]

Presentation of a DRL in a graph format can aid in the comparison of results and also could be an easy visual reference in the department.

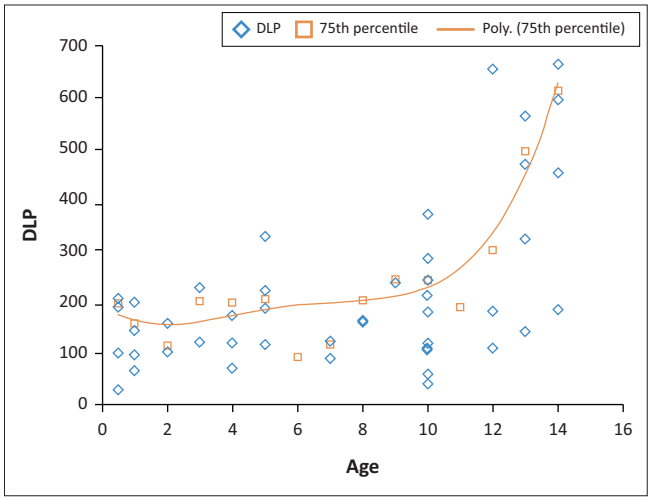
Limitations

One of the limitations of this study is that the European guidelines suggest that body CTs should be categorised according to weight, but the weights were not documented on PACS for RMMCH and CMJAH during the study period. Further limitations included the significant percentage of multiphasic CT scans, specifically in the 0–1-year age group, which limited the statistical significance of the findings.

TABLE 9: Proposed local diagnostic reference levels for Computed Tomography Dose $Index_{volume}$ and Dose Length Product for paediatric computed tomography examinations.

Study	Age	$CTDI_{vol}$: 75th percentile (mGy)	DLP: 75th percentile(mGy*cm)
CT Brain	0–1 years	21	315
	1–5 years	21	365
	5–10 years	23	460
	10–15 years	33	750
CT Temporal bones	5–10 years	40	315
	10–15 years	56	515
CT Cervical Spine	1–5 years	7	190
	5–10 years	8	190
	10–15 years	9	230
CT Neck	1–5 years	7	200
	5–10 years	7	145
	10–15 years	15	260
CT Trunk	1–5 years	5	215
	5–10 years	6	235
	10–15 years	6	285
CT Chest	1–5 years	4	110
	5–10 years	7	145
	10–15 years	7	290
CT Abdomen	1–5 years	5	185
	5–10 years	5	230
	10–15 years	9	460

$CTDI_{vol}$, Computed Tomography Dose $Index_{volume}$; CT, computed tomography; DLP, Dose Length Product.

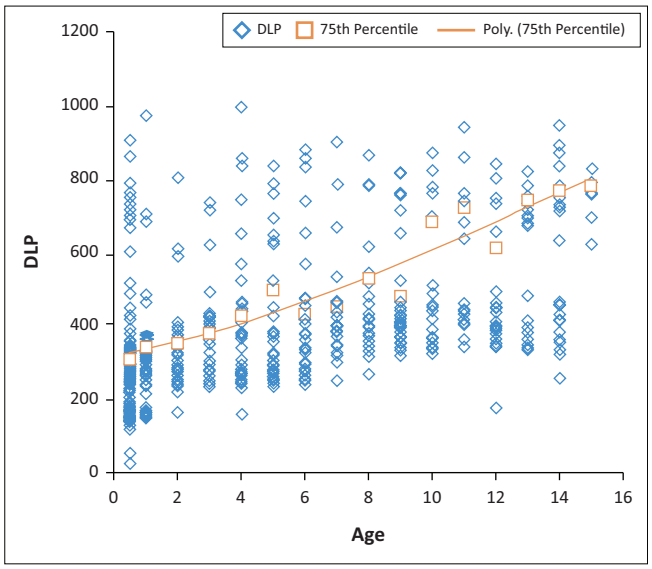


DLP, dose length product.

FIGURE 2: Polynomial exponential curve for the purpose of presenting diagnostic reference levels for computed tomography abdomen for specific ages. The data set used in this graph was the dose length product for computed tomography abdomen examinations, corrected for each year in age (n = 82).

Conclusion

Overall, the $CTDI_{vol}$ and DLP values for the studies are comparable with most of the international DRLs. Computed tomography chest and abdomen protocols should be revised, specifically in the 0–1-year age groups. A suggestion would be to use weight as an input parameter instead of age for CT chest and abdomen examinations.



DLP, dose length product.

FIGURE 3: Polynomial exponential curve for the purpose of presenting diagnostic reference levels for computed tomography brain for specific ages. The data set used in this graph was the dose length product for computed tomography brain examinations, corrected for each year in age (n = 687).

The DRL values in Table 9 are suggested as local DRLs for the University of the Witwatersrand academically affiliated hospitals as well as their referral hospitals.

The results of this study will be presented to the South African Society of Paediatric Imaging to aid in the establishment of national DRLs for paediatric CT examinations.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this research article.

Authors' contributions

Dr C.M. van der Merwe is the principal investigator for the Master of Medicine (MMed) study at the University of the Witwatersrand. Prof. N. Mahomed is the MMed supervisor of this study at the University of the Witwatersrand.

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Data availability statement

Full data sharing is available for all aspects of this study.

Disclaimer

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