

Dedication

To

My parents

Anyone who taught me a letter

My friends

All my family

Acknowledgements

First and foremost, I would like to express my deepest gratitude to Dr. Abdelmoneim Adam Mohamed Sulieman and Dr Osman Mustafa Mokhtar for their support and guidance. Without their help this work could not have been accomplished.

I also would like to thank thanks Gafar Ibn Aof hospital staff and Alrbat Teaching Hospital staff and Alamal National Hospital staff and Royal Care Hospital and Royal Scan Center for their help.

Finally, I would like to sincerely thank my family for their consistent mental support, my wife for her unselfish help in the past years.

Contents

Item	Page
Dedication.....	i
Acknowledgements.....	ii
Contents.....	iii
List of abbreviations	ix
List of Tables.....	xi
List of Figures.....	xiv
Abstract [English]	xvii
المستخلص	xx
CHAPTER ONE: Introduction.....	1
1.1 Radiation in Medicine	1
1.2 Diagnostic Radiology	2
1.3 Types of Radiology	3
1.3.1 Diagnostic Radiology	3
1.3.2 Nuclear Medicine.....	4
1.3.3 Radiotherapy.....	4
1.4 Pediatric Radiology	4
1.5 Radiation Risk	5
1.6 Statement of the Problem.....	7

1.7 Objectives.....	8
1.8 Thesis Outline.....	8
1.9 Thesis outcome.....	9
CHAPTER TWO: Theoretical Background.....	10
2.1 Production of X-rays	10
2.1.1 Properties of X- rays	10
2.2 Classification of Radiation.....	11
2.2.1 Radiation.....	11
2.2.1.1 Ionizing Radiation.....	11
2.2.1.2 Non-ionizing Radiation.....	11
2.2.2 Radioactivity.....	11
2.3 CT Scan.....	12
2.3.1 Principles of CT.....	13
2.3.2 Principles of MSCT.....	13
2.3.3 MSCT Detectors.....	14
2.3.4 MSCT Era.....	15
2.3.5 MSCT Data Acquisition.....	15
2.3.6 Channels (16-slices) Scanners and More.....	17
2.3.7 MSCT Concepts: Differences between MSCT and SSCT.....	20
2.4 Optimization of MDCT Technique.....	20
2.4.1 CT Parameters.....	20
2.4.2 Tube Potential (kVp).....	20
2.4.3 Tube Current – Time Product (mAs).....	21
2.5 Radiation Quantities.....	21

2.5.1 Exposure.....	22
2.5.2 Air Kerma.....	22
2.5.3 Absorbed Dose.....	22
2.5.4 Entrance Surface Dose.....	23
2.5.5 Entrance Surface Air Kerma (ESAK)	23
2.5.6 Dose Area Product (DAP)	23
2.5.7 Equivalent Dose.....	23
2.5.8 Effective Dose.....	24
2.6 Radiation Units.....	26
2.6.1 Roentgen.....	26
2.6.2 Rad (Radiation Absorbed Dose)	26
2.6.3 Rem (Roentgen Equivalent Man)	26
2.6.4 Curie (Ci)	26
2.6.5 Gray (Gy)	27
2.6.6 Sievert (Sv)	27
2.6.7 Becquerel (Bq)	27
2.7 Dosimetry Methods.....	28
2.7.1 Ionization Chambers.....	28
2.7.2 Thermo Luminescence Dosimeters.....	28
2.7.3 Metal Oxide Semiconducting Field Effect Transistors.....	30
2.7.4 Radiochromic Film.....	31
2.7.5 Calculation of ESD from Exposure Factors.....	31
2.8 CT Dose Measurements.....	32
2.8.1 CT parameters that Influence the Radiation Dose.....	32

2.8.2	CT Dose Descriptors.....	33
2.8.3	Computed Tomography Dose Index (CTDI)	33
2.8.4	Dose Length Product (DLP) Unit (mGy)	37
2.9	Imaging Techniques in Pediatric Radiography.....	39
2.9.1	Plain Radiography.....	39
2.9.2	Contrast Studies.....	40
2.9.2.1	Intravenous Urography (IVU).....	41
2.9.2.2	Micturating Cystourethrography.....	42
2.9.2.3	Barium Studies.....	45
2.9.2.4	Method of Investigation of Barium Studies.....	46
2.9.3	Computerized Tomography (CT)	47
2.10	Previous Studies.....	50
2.10.1	Plain Radiography.....	50
2.10.2	MCUG.....	53
2.10.3	IVU.....	59
2.10.4	Barium Studies.....	60
2.10.5	CT.....	61
	CHAPTER THREE: Materials and Methods.....	65
3.1	Introduction.....	65
3.2	Radiological Examinations.....	65
3.3	X-ray Machine.....	66
3.4	Patient Preparation.....	66
3.5	Image Protocol.....	66
3.6	Absorbed Dose Calculations.....	66

3.7 Special investigations.....	67
3.7.1 Intravenous Urography (IVU).....	67
3.7.1.1 Patient Preparation.....	68
3.7.1.2 Technique of (IVU).....	68
3.7.2 MCU.....	68
3.7.2.1 Patient Preparation.....	69
3.7.2.2 Technique of Micturating Cystourothography (MCUG).....	69
3.7.2.3 Indications.....	70
3.7.2.4 Contra Indications include.....	70
3.7.2.5 Contrast Medium and Materials.....	71
3.7.2.6 Patient and Co-Patient Preparation.....	71
3.7.3 Barium Studies.....	71
3.7.3.1 Patient Preparation.....	71
3.7.3.2 Examination Technique.....	72
3.7.3.2.1 Barium Swallow.....	72
3.7.3.2.2 Barium Meal and Follow-Through.....	72
3.7.3.2.3 Barium Enema.....	73
3.8 CT Examinations.....	73
3.8.1 CT Machines.....	73
3.8.2 Patient Data.....	73
3.8.3 CT Dose Measurements.....	74
3.8.4 Radiation dose optimization steps were included.....	75
3.8.5 Cancer Risk Estimation.....	75
3.9 Equation of the Effective Dose.....	76

3.10 Organ Dose Estimation.....	76
3.11 Cancer Risks Estimation.....	76
CHAPTER FOUR: Results.....	77
CHAPTER FIVE: Discussion.....	102
5.1 Conventional X-ray Examination.....	102
5.2 Radiation Dose Measurements in Special Investigation.....	112
5.2.1 IVU.....	112
5.2.2 Patient Dose Measurements during MCUG Procedures.....	117
5.2.3 Radiation Dose Measurement in Barium Studies.....	122
5.3 Patient dose measurements during MCUG procedures.....	125
5.4 Conclusion.....	131
5.5 Recommendations.....	133
5.6 Suggestions for future studies.....	134
References.....	135
Appendices	148

List of abbreviations

abbreviation	Full name
IVU	Intravenous urography
CT	Computed tomography
MRI	Magnetic resonance imaging
GIT	Gastrointestinal tract
LNT	Linear no-threshold theory
ICRP	International Commission on Radiation Protection
MSCT	Multi-slice CT
SSCT	Single slice CT
KVp	Tube Potential
mAs	Tube Current – Time Product
AEC	Automatic exposure control
Gy	Gray
ESAK	Entrance Surface Air Kerma
ESD	Entrance Surface Dose
DAP	Dose Area Product
LET	Linear energy transfer
Ci	Curie
Sv	Sievert
Bq	Becquerel
TLD	Thermo luminescence dosimeters
PMTs	photomultiplier tubes

CTDI	Computed Tomography Dose Index
DLP	Dose Length Product
MASD	Multiple Scans Average Dose
MCUG	Micturating cystourethrography
AP	Antroposterior projection
OBL	Oblique
VUR	vesico-ureteral reflux
FSD	Focus-to-skin distance
UIT	urinary tract infection
MDCT	Multi detectors row CT
SAEC	Sudan atomic energy commission

List of tables

Table	Item	Page
2.1	Tissue Weighting Factors.....	25
2.2	Computerized tomography (CT) radiation dosing	48
2.3	Pediatric reference dose levels from UK 2003 survey mean values....	63
2.4	Organ absorbed dose for CT examination in a 6-years old Patient phantom.....	64
3.1	number and type of examination in Gafar Ibn Oaf.....	65
3.2	3:2 Characteristic of x-ray machine.....	66
3.3	Number and Type of examination in Alrbat Hospital.....	67
3.4	Characteristic of Fluoroscopy Machine.....	67
3.5	number and type of examination CT examination.....	74
3.6	Radiation risk for adults and workers.....	75
4.1	Diagnostic radiology clinical indications.....	80
4.2	Patient demographic data for pediatric patients in conventional procedures.....	81
4.3	Patient exposure parameters and ESD (mGy) in conventional procedures.....	81
4.4	Clinical indications for patients in IVU procedures.....	82
4.5	Patient age and range during IVU procedure.....	82
4.6	Patient exposure parameter during IVU procedure.....	83
4.7	Patient dose during IVU procedure.....	83
4.8	Organ dose estimation during IVU and cancer risk estimation.....	84
4.9	Clinical indications for MCU procedures.....	85

4.10	Patient age in MCUG procedures.....	85
4.11	Exposure parameters and patient doses during MCUG procedures....	86
4.12	Patient ESD during MCUG procedures.....	86
4.13	Organ dose estimation during MCU and cancer risk estimation.....	87
4.14	Diagnostic radiology clinical indications.....	88
4.15	Exposure parameters during barium studies.....	89
4.16	Patient doses during barium studies.....	89
4.17	Patient organ doses and radiation risks during barium studies.....	91
4.18	Patient demographic data during brain imaging.....	92
4.19	Exposure parameters during brain scan (control group).....	92
4.20	Exposure parameters during brain scan (Optimisation group).....	93
4.21	Patient dose and effective doses during brain scan(control group).....	93
4.22	Patients dose and effective doses during brain scan (optimization)....	94
4.23	Patient age during Abdomen CT imaging.....	95
4.24	Exposure parameters during abdominal CT (control group).....	95
4.25	Exposure parameters during abdominal CT (optimization group).....	95
4.26	Patients dose and effective doses during abdominal CT(control).....	95
4.27	Patients dose and effective doses during abdominal CT(optimization).....	97
4.28	Patient ages during chest CT.....	98
4.29	Exposure parameters during CT Chest (control group).....	99
4.30	Exposure parameters during CT Chest (optimization).....	99
4.31	Patient effective doses during chest CT examination (control).....	100
4.32	Patient effective doses during chest CT examination (optimization)).	100

5.1	Comparison between mean ESD (mGy) in different and previous studies in Sudan.....	109
5.2	Comparison of mean ESDs obtained in present work with some international reference dose values (in μGy).....	111
5.3	Previous studies results during IVU procedure.....	116
5.4	The mean patient parameters, screening time, number of radiographic images, ESD and effective dose in various studies (range is in parenthesis).....	121
5.5	Comparison of obtained dose characteristics of barium examinations with published result.....	124

List of figures

Figure	Item	Page
1.1	Wilhelm Conrad Rontgen.....	1
2.1	X- ray Tube	10
2.2	Electromagnetic spectrum with radiation types	12
2.3	SSCT & MSCT arrays.....	14
2.4	Flexible uses of detectors in 4 slice MSCT scanners.....	17
2.5	Diagrams of various 16-slices detector designs (in z-direction)..	18
2.6	Diagram of various 64-slice detector designs (z-direction).....	18
2.7	Section of a 16-slice detector with scatter removal septa.....	19
2.8	Radiation quantities and units.....	21
2.9	Absorbed Dose	22
2.10	The Concept of Effective Dose.....	25
2.11	Ionizing radiation quantities and Units.....	27
2.12	TLD glow curve	30
2.13	Basic schematic of a MOSFET detector.....	31
2.14	Computed Tomography Dose Index (CTDI)	34
2.15	The Concept of Computed Tomography Dose Index (CTDI).....	35
2.16	The average level of the total dose profile (MSAD).....	36
2.17	A profile of radiation dose delivered during a single CT scan....	37
2.18	Dose length product (DLP) in CT.....	38
2.19	The Concept of Dose Length Product.....	39
2.20	Plain film KUB	42

2.21	MCUG.....	43
2.22	MCUG. Male infant with prenatally detected bilateral hydronephrosis.....	44
2.23	Barium enema.....	47
2.24	Axial sections of CT scan	48
3.1	Fluoroscopy machine.....	69
3.2	Types of barium studies	71
4.1	Comparison of patient doses during conventional procedures....	82
4.2	ESD components	83
4.3	Patient organ doses (mSv) during IVU procedure.....	84
4.4	Clinical indications for MCUG procedures	85
4.5	Radiation dose components for MCUG procedures	87
4.6	Patient organ doses (mGy) during MCUG procedure.....	88
4.7	Radiation dose components during barium studies	90
4.8	ESD in barium studies.....	90
4.9	Organ dose (mSv) during barium studies.....	91
4.10	Comparison of effective dose (mSv) in the three hospitals.....	94
4.11	Comparison of effective doses in the three hospitals.....	97
4.12	Comparison of patient effective doses in the three hospitals.....	98
4.13	Comparison of patient effective doses reduction in the three hospitals during chest CT.....	102
5.1	Correlation between patient dose (mGy) and tube voltage (kVp)	105
5.2	Correlation between patient dose (mGy) and patient weight (kg)	106
5.3	Correlation between patient dose (mGy) and SSD (cm).....	106

5.4	Correlation between patient dose (mGy) and BMI (kg/m ²).....	107
5.5	Correlation between patient dose (mGy) and tube current time product (mAs).....	107
5.6	Correlation between patient dose (mGy) and patient age (y).....	108
5.7	Patient doses during chest x rays in Sudan.....	110
5.8	Patient doses during Skull x rays in Sudan.....	110
5.9	Patient doses during abdomen x rays in Sudan.....	110
5.10	Comparison of mean ESDs during chest x rays obtained in present work with some international reference dose values (in μ Gy).....	112
5.11	Correlation between patient dose (mGy) and number of films...	114
5.12	Correlation between patient dose (mGy) and tube current(mAs)	114
5.13	Correlation between patient dose (mGy) and tube voltage (kVp)	115
5.14	Comparison of effective doses with previous studies.....	117
5.15	Correlation between ESD and time in MCUG procedures.....	118
5.16	Correlation between ESD and tube current time product (mAs) in MCUG procedures.....	119
5.17	Correlation between ESD and tube voltage in MCUG procedures.....	119
5.18	Comparison of patient dose (pediatric) with previous studies (adults).....	125
5.19	Radiation dose during brain scan (CTDIvol).....	127

ABSTRACT

Infants and children constitute 10% of the total number of radiological examinations. Diagnostic radiology plays an important role in the assessment and treatment of the patients in the modern medicine. It is often necessary to perform a large number of radiographic examinations depending upon the infant's problems. Radiographic examination of children, especially neonates, attracts particular interest because of the increased opportunity for expression of delayed radiogenic cancers as a consequence of relative longer life expectancy. The yield of certain forms of radiation-induced cancer, particularly leukemia, appears to be some five times higher in children than in adults. Radiation dosimetry is well established for adults' radiological examinations, but there are limited pediatric data available.

The current study intends to: Evaluate the radiation dose to 303 pediatric patients during: pediatric: CT, planar radiography and special investigation (intravenous urography (IVU), Barium studies, and maturing cystourethrography (MCU), and Barium studies) and estimate the risk of the aforementioned procedures. The data used in this Study was collected from five hospitals: Gafar Ibn Oaf pediatric hospital and Aribat teaching hospital, Royal care hospital, Alamal national hospital and Royal scan center. Khartoum, Sudan.

Measurements of ESD using output parameters were carried out in a sample of 303 pediatric patients who underwent various radiological examinations.

The ESDs in this study were calculated using DoseCal software. For dose measurement using the software, the relationship between X-ray unit current time product (mAs) and the air kerma free in air was established at a reference point of 100 cm from tube focus for the range of tube potentials encountered in clinical practice. The X-ray tube outputs, in mGy (mAs), were measured using Unfors Xi dosimeter (Unfors Inc., Billdal, Sweden). Effective doses (E) were calculated using

published conversion factors and methods recommended by the national Radiological Protection Board (NRPB).

The mean radiation dose for the patient during conventional radiography was ranged between 0.05 mGy to 0.6 mGy per procedures. The mean patient dose in the IVU study was 4.9 mGy and the range from 2.4 to 10.4 mGy. The mean ESD and E resulting from MCUG procedure has been estimated to be 5.9 mGy and 0.8 mSv, respectively for the total patient population. The patient effective dose was ranged between 1.0 mSv to 0.2 mSv during barium studies. The overall mean effective dose during CT examinations was 45.9 mSv.

Radiation dose optimization was adopted during CT examinations. A reduction values achieved was 55%, 71% and 77% in Alamal, Royal care and Royal scan hospital during brain scan, respectively. A dose reduction was achieved up to 89% during abdominal, chest scans without compromising the image quality. Radiation dose optimizations were achieved via exposure factors reduction and pitches and slice thickness increment

The study revealed the urgent need for dose reduction techniques in pediatric imaging.

In routine imaging, the findings illustrate that the radiation dose were comparable with some previous studies. The doses received by children were three to four times higher than reference levels.

In special investigation, IVU section, the radiation dose to patients is within the previous studies result, in the light of the current practice. The results encourage the technologist for further dose optimization. While in MCUG procedures the results indicates the need of radiation exposure reduction to patients and underlines the importance of the protection in busy urology departments. For the GIT, this study indicates the need of radiation exposure reduction to patients and examiners, and

underlines the importance of the protection in pediatric imaging for GIT. The unnecessary radiation exposure can be reduced significantly by reducing the number of exposure and screening time.

Regarding CT examinations, the assessment of radiation dose to pediatric patient undergoing CT brain, abdomen and chest was investigated. In this study variation in doses were observed. The radiation dose in Al amal hospital as higher compared to other two hospitals. The main contributor for this high dose was the use for adult protocol, which justify the important of use child protocol. The individual risk from the radiation associated with a CT scan is quite small compared to the benefits that accurate diagnosis and treatment can provide.

المستخلص

الفحوصات الإشعاعية للأطفال تشكل 10% من كافة الفحوصات الإشعاعية. يلعب التصوير الإشعاعي دوراً هاماً في تشخيص وعلاج الأمراض في الطب الحديث. عادة من الضروري، يجري للمريض عدد كبير من الفحوصات الطبية المختلفة بغرض التشخيص.

الفحوصات الإشعاعية للأطفال لها أهمية خاصة لان الاطفال لديهم احتمال اكبر للاصابة بالسرطان مقارنة بالبالغين نسبة لطول العمر المتوقع لديهم مقارنة بالكبار مما يتيح فرصة لحدوث الاثار المتأخرة للإشعاع وايضا نسبة للانقسام السريع لخلايا الاطفال. اجريت دراسات كثيرة بشأن التعرض الاشعاعي للبالغين لكن ما زالت الدراسات قليلة بالنسبة للاطفال.

هدفت هذه الدراسة الي تقويم جرعة الاشعاع للاطفال لعدد 303 مريض أثناء الفحوصات الآتية: الأشعة المقطعية ، الأشعة العادية فحص المثانة الاحليلي اثناء التبول ، فحص الجهاز البولي وفحوصات الباريوم. كما هدفت الي تقويم الخطر الاشعاعي للمذكورة اعلاه.

تم جمع البيانات من خمس مستشفيات بولاية الخرطوم: جعفر بن عوف، الرباط الجامعي، رويال كير، الامل الوطني ورويال سكان. تم حساب الجرعة الاشعاعية للمرضي باستخدام برنامج دوس كالم وعوامل التصوير لجهاز الاشعة. تم قياس الجرعة اثناء الاشعة المقطعية بعد معايرة الاجهزة بواسطة خبراء من هيئة الطاقة الذرية السودانية. قيس خرج الاشعاع باستخدام جهاز انفورس من السويد. استخدم برنامج كمبيوتر من الهيئة الوطنية للوقاية من الاشعاع لحساب جرعة الاعضاء والجرعة الفعالة للإشعاع.

تراوحت الجرعة الاشعاعية اثناء فحوصات الاشعة العادية بين 0.05 ملي قري و 0.6 ملي قري للفحص الواحد، تراوحت بين 2.4 ملي قري و 10.4 ملي قري لفحص الجهاز البولي. بلغ متوسط الجرعة السطحية اثناء فحص المثانة الاحليلي 5.9 ملي قري والجرعة الفعالة لنفس الفحص 0.8 ملي سيفرت. تراوحت الجرعة الاشعاعية الفعالة بين 1.0 ملي سيفرت الي 0.2 ملي سيفرت لفحوصات الباريوم. اما بالنسبة للاشعة المقطعية فبلغت الجرعة 9.45 ملي سيفرت للفحص الواحد.

في هذه الدراسة، تمت امثلة الجرعة الاشعاعية اثناء فحوصات الاشعة المقطعية. تم خفض الجرعة الاشعاعية بنسبة 55%، 71% و 77% بكل من مستشفى الامل ، رويال كير ورويال سكان علي الترتيب. بالإضافة الي ذلك تم خفض الجرعة الاشعاعية بنسبة تصل حتي 89% دون التأثير علي جودة الصورة الاشعاعية.

كشفت الدراسة الحاجة الملحة لتقنيات تخفيض جرعة في مجال التصوير للأطفال. في مجال التصوير الروتينية، فإن النتائج توضح أن جرعة إشعاع متقاربة مع بعض الدراسات السابقة. في تحقيق خاص. بالنسبة لفحوصات الجهاز البولي فان جرعة الاشعاع للمرضى مقبولة وذلك في ضوء الممارسة الحالية. بينما في فحص المثانة الاحليلي فان النتائج تشير إلى الحاجة للحد من التعرض للإشعاع على المرضى ويشدد على أهمية حماية الاطفال للفحوصات الخاصة. يمكن الحد من التعرض للإشعاع غير الضروري بشكل كبير عن طريق الحد من عدد من الأفلام وخفض زمن التعرض. الجرعات التي يتلقاها الأطفال اثناء الفحوصات قد تصل الي ثلاثة ا وأربعة أضعاف المستويات المرجعية. فيما يتعلق بفحوصات الاشعة المقطعية فقد لوحظ في

هذه الدراسة التباين في جرعات بين المرضى. جرعة الإشعاع في مستشفى الأمل أعلى بالمقارنة مع المستشفيات الأخرين. وكان المساهم الرئيسي لهذه الجرعات العالية لاستخدام بروتوكول الكبار، والتي تبرر أهمية بروتوكول استخدام بروتوكول خاص بالأطفال. خطر الفرد من الإشعاع المرتبطة الأشعة المقطعية هي صغيرة جدا بالمقارنة مع الفوائد التي تعود على التشخيص الدقيق والعلاج يمكن أن يقدم.