Sudan University of Science and Technology

College of Graduate Studies and Scientific Research

Estimation of Pediatric Dose During CT Brain Imaging

تقدير جرعة الأطفال أثناء تصوير الدماغ بالأشعة المقطعية

A thesis submitted in fulfillment for the requirements

Of MCs degree in Medical Physics

By:

Jwyria Eltayeb Ahmed Mohammed

Supervisor

Dr. Hussein Ahmed Hassan

2020

الآية

قال تعالى:

(ربِّ قَدْ آتَيْتَنِي مِنْ الْمُلْكِ وَ عَلَّمْتَنِي مِنْ تَأْوِيلِ اْلْأَحَادِيثِ فَاطِرَ اْلسَّمَوَاتِ وَ اْلْأَرْضِ أَنْتَ وَلِّيّ فِي اْلدُّنْيَا وَاْلْأَخِرَةِ تَوَفَّنِي مُسْلِمَاً وَ أَلْحِقْنِي بِاْلصَّالِحِين)

سورة يوسُف (101)

Dedication

To my Father

To my Mother

To my consort

To all my family, And to my friends

Acknowledgements

I would like to send my deepest gratitude to Dr. **Hussain Ahmed Hassan** for his support and guidance.

I also would like to thank Dr. Almubarak Seddig Without his help this work could not have been accomplished.

My thanks also go to Alneelain Center. for their help.

Deep thanks to Mr. Alabbas Abdalhafeez, Finally, I would like to sincerely thank my family for their consistent mental support.

List of contents

List of tables

List of figures

ABBREVIATIONS

Symbols	Item
3D	Three dimension
AVM	Arterio venous Malformations
BMI	body mass index
BMI	Body mass index
BSF	the backscatter factor
CD	Cumulated Dose
Cine	cine angiography
CT	Computed Tomography
DAP	dose area product
DCS	Dynamic Cannula screw
DHS	Dynamic Hip screw
DHS	Dynamic hip screw
DRLs	Diagnostic Reference Levels
DSA	Digital subtraction angiography.
E	effective dose
E.N.U.H	ElmekNimer University Hospital
EPS	electrophysiological studies
ERCP	Endoscopic Retrograde Cholangiopancreatography
ESD	Entrance Surface Dose
EVAR	Endovascular Aneurysm Repair
F.t	Fluoroscopy time
FFD	Focal to film Distance
FSD	Focal to Skin Distance
H	Equivalent dose
HSG	Hysteron SalpingGraphy
IA	Image Amplifier
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IR	Intervention Radiology
	ABBREVIATIONS
K.S.C	Kuwait Special Center
K.T.H	Khartoum Teaching Hospital

KERMA	Kinetic Energy Released per unit Mass of Air
kVp	kilovolt peak
LPDF	Lock plate distal femur
MII	Mobile Image Intensifiers
MRI	Magnetic Resonance Image
Pa_0	Pacemaker type one
Pa_1	Pacemaker type two
Pa_2	Pacemaker type three
PAD	peripheral arterial disease
PCI	percutaneous coronary intervention
PSD	Peak skin dose
PTCA	Percutaneous Transluminal Coronary Angioplasty
QC	Quality control
R.C.C	Royal Care Center
RF	radiofrequency
RP	Radiation Protection
T_{dose}	Total Dose
TIPS	Transjugular Intrahepatic Portosystemic Shunt
UFE	UFE Uterine Fibroid Embolization
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VIR	Vascular Intervention Radiology
W_R	Radiation weighting factor
W_T	weighting factor for some organ or tissue
XRII	X-ray image intensifier

Abstract

Computed tomography (CT) is used worldwide; utilization it has increased rapidly over the past 15 years. CT is the most common source for radiation exposure. however, recent studies suggest that CT radiation exposure during childhood may be a risk factor for cancer.

The objective was to Estimation of pediatric dose during CT in brain image Alneelain Medical Center.

This was a retrospective study of pediatric patients < 12 years of age who underwent head CT scans in 2020 at Alneelain Medical Center.

The kv, (used which range between 120 to 130), mAs, DLP and CTD_{vol} from the CT scanners and calculated the effective radiation dose delivered. Patient demographics were abstracted from the CT computer. The relationship between effective dose and (CTDI and DLP) were evaluated for gender and age.

A total of 25 subjects were underwent head CT. The mean age years (0.01- 12) 68 % were male while 32% were female . The mean ± standard deviation for mAs, CTDI and DLP for male were 161.53 ± 21.00 , 32.52 ± 4.00 and 465.71 ± 78.55 respectively. respectively while for female were 175.13 ± 26.63 , 42.23 ± 26.41 and 638.38 ± 306.70 respectively. The mean ± standard deviation for mAs, CTDI and DLP for age (<= 2were 168.64 ±26.15 , 38.74 ± 23.18 and 546.55 ± 292.88 respectively , when for 2<age>=5 were 167.17 ± 29.23 , 31.49 ± 2.57, and 453.00 ± 22.01 respectively and for <5 &>=12) were 162.38 ± 21.55 , 34.44 ± 1.93 and 536.75 ± 56.32 respectively. The effective doses were found higher than the previous studies.

The correlation between the effective dose and CTDI and DLP were done which found increased by increasing DLP or CTDI or together increased which n this study were higher than some previous studies and so effective dose which are found in mid age more than others.

Our analysis suggested that radiation exposure from CT during childhood is associated with a subsequently elevated risk of cancer. However, caution is needed when interpreting these results because of the heterogeneity among the studies. The findings should be confirmed in further studies with longer follow-up periods. Significant radiation dose reduction can be achieved for routine pediatric head CT by weight-based decreases in kVp in addition to low mAs and observance for image quality.

الخلاصة

يُستخدم التصوير المقطعي المحوسب (CT) في جميع أنحاء العالم ؛ لقد زاد استخدامه بسرعة على مدار الخمسة عشر عامًا الماضية. يُعد التصوير المقطعي المحوسب المصدر الأكثر شيوعًا للتعرض للإشعاع. ومع ذلك ، تشير الدراسات الحديثة إلى أن التعرض للإشعاع المقطعي أثناء الطفولة قد يكون عامل خطر للإصابة بالسرطان.

كان الهدف هو تقييم الجرعة الفعالة للإشعاع أثناء الفحوصات الروتينية للرأس بالأشعة المقطعية للأطفال في مركز النيلين الطبي.

كانت هذه الدراسة لأطفال مرضى اعمارهم (0.01 -12) سنة الذين خضعوا لأشعة مقطعية للرأس في عام 2020في مركز النيلين الطبي.

(kv) (المستعمل والذي يتراوح بين 120إلى 130) mAs،(DLP) و (CTDvol) من مسح التصوير المقطعي ومن ثم تم حساب الجرعة الفعالة.

تم استخراج صفات المرضى من حاسوب جهاز الأشعة المقطعية . تم تقييم العلاقة بين الجرعة الفعالة و (CTDIو DLP) حسب الجنس والعمر.

خضع مجموعه 25شخصًا للتصوير المقطعي المحوسب. متوسط العمر (المدى الربيعي = 0.01إلى 12سنة) و 68٪ كانوا ذكور و 32٪ إناث.

كان متوسط الانحراف المعياري لـ mAsو CTDIو DLP للذكور 161.53 ± 21.00 و 32.52 ± 4.00 و 465.71 ± 78.55على التوالي. بينما كانت للإناث 175.13 ± 26.63، 42.23 ± 26.41و 638.38 ± 306.70على التوالي ، متوسط ± الانحراف المعياري لـ mAs و CTDIو DLP للعمر (<= 2 كانت 168.64± 26.15 و 38.74 ± 23.18 و546.55 ± 292.88 على التوالي ، عندما كان 2< العمر> = 5 كانت 167.17 ± 29.23 و 31.49 ± 2.57 و 453.00 ± 22.01 على التوالي ولأقل من 5 & > = 12) كانت 162.38 ± 21.55، 34.44 ± 1.93و 536.75 ± 56.32 على التوالي. حيث وجد أن الجرعات الفعالة أعلى من الدراسات السابقة.

تم عمل الارتباط بين الجرعة الفعالة و CTDIو DLPوالذي وجد زيادة عن طريق زيادة DLPأو CTDIأو زيادتهما معًا مما كانت هذه الدراسة أعلى من بعض الدراسات السابقة والجرعة الفعالة التي تم العثور عليها في منتصف العمر أكثر من غيرها.

اقترح تحليلنا أن التعرض للإشعاع للأطفال يرتبط بارتفاع خطر الإصابة بالسرطان لاحقًا. ومع ذلك ، يجب توخي الحذر عند تفسير هذه النتائج بسبب عدم التجانس بين الدراسات. يجب تأكيد النتائج في مزيد من الدراسات مع فترات متابعة أطول. يمكن تحقيق خفض كبير لجرعة الإشعاع بالنسبة لتصويرالأطفال الروتيني بالتصوير المقطعي المحوسب للرأس على أساس الوزن في خفض kVp و mAs مع مراعاة جودة الصورة.

Chapter One

Introduction

Chapter one

Introduction

X-ray Imaging for Pediatrics

Medical X-ray imaging has led to improvements in the diagnosis and treatment of numerous medical conditions in pediatric patients. The Federal Food, Drug, and Cosmetic Act (FD&C Act) defines pediatric patients as persons aged 21 or younger at the time of their diagnosis or treatment. Typically these are broken down into different groups based on age ranges (neonates, infants, children, and adolescents). For medical X-ray imaging, the pediatric patient's size is even more important to consider than age, because patient size determines how much radiation is needed to produce a quality medical image.

The individual risk from X-ray imaging is small when compared to the benefits that it can provide through helping with accurate diagnosis. Still, efforts should be made to minimize risk by reducing unnecessary exposure to ionizing radiation. This is important because:

Pediatric patients are more radiosensitive than adults (i.e., the cancer risk per unit dose of ionizing radiation is higher);

Use of equipment and exposure settings designed for adults may result in excessive radiation exposure if used on smaller patients;

Pediatric patients have a longer expected lifetime, putting them at higher risk of cancer from the effects of radiation exposure.

The FDA recommends that medical x-ray imaging exams, which include computed tomography (CT), fluoroscopy, and conventional X-rays, use the lowest radiation dos necessary, taking into account the size and age of the patient. Whether grouped by age or by size, an x-ray image should always be adjusted to meet the needs of the specific type of pediatric patient receiving the exam.

X-ray exams should be performed for children only when the child's physician believes they are necessary to answer the clinical question or to guide treatment. Medical imaging professionals should use techniques that are adjusted to administer the lowest radiation dose that yields an image quality adequate for diagnosis or intervention (i.e., radiation doses should be "As Low as Reasonably Achievable"). The technique factors used should be chosen based on the clinical indication, patient size, and anatomical area scanned, and the equipment should be properly maintained and tested. (FDA 2018).

Pediatric CT dose

Prior to the early 2000s, a distinction between pediatric and adult patients was rarely made, leading to poor management of radiation dose and image quality during CT scanning . During this time, acquisition techniques were rarely adjusted based on body size . Initial recommendations for radiation dose reduction appeared and were followed by amplification by the Image Gently Alliance in the United States and throughout the world . In 2010, the Image

Wisely campaign addressed similar concerns as they pertain to adult imaging . Advances in radiation awareness have occurred through education, hardware and software development, and available radiation dose indexes. These advances have stemmed from a collective desire among facilities, national and international associations, and CT manufacturers to improve health care for all patients, especially pediatric patients undergoing CT. In 2011, the size-specific dose estimate (SSDE) was developed to enable patient dose estimation with improved accuracy and precision in patients of every size. The American College of Radiology initiated its dose index registry (DIR) , which contained dose indexes for more than 45000000 CT examinations as of July 2017 . (Keith J.2019)

Radiation Risks from CT in pediatric

Major national and international organizations responsible for evaluating radiation risks agree that there probably is no low-dose radiation "threshold" for inducing cancers. In other words, no amount of radiation should be considered absolutely safe.

The first study to assess directly the risk of cancer after CT scans in childhood found a clear dose-response relationship for both leukemia and brain tumors: risk increased with increasing cumulative radiation dose. For a cumulative dose of between 50 and 60 milligray or mGy (mGy is a unit of estimated absorbed dose of ionizing radiation) to the head, the investigators reported a threefold increase in the risk of brain tumors; the same dose to bone marrow (the part of the body responsible for generating blood cells) resulted in a threefold increase in the risk of leukemia. For both findings, the comparison group consisted of individuals who had cumulative doses of less than 5 mGy to the relevant regions of the body.

The number of CT scans required to give a cumulative dose of 50-60mGy depends on the type of CT scan, the age of the patient, and the scanner settings. If typical current scanner settings are used for head CT in children, then two to three head CT scans would result in a dose of 50-60mGy to the brain. The same dose to red bone marrow would be produced by five to 10 head CT scans, using current scanner settings for children under age 15.

Previously, the potential cancer risk from CT use has been estimated using risk projection models derived primarily from studies of survivors of the atomic bomb explosions in Japan. The risks observed in the study described above were consistent with those previous estimates.

It is important to stress that the absolute cancer risks associated with CT scans are small. The lifetime risks of cancer due to CT scans, which have been estimated in the literature using projection models based on atomic bomb survivors, are about 1 case of cancer for every 1,000 people who are scanned, with a maximum incidence of about 1 case of cancer for every 500 people who are scanned.

The benefits of properly performed and clinically justified CT examinations should always outweigh the risks for an individual child; unnecessary exposure is associated with unnecessary risk. Minimizing radiation exposure from pediatric CT, whenever possible, will reduce the projected number of CT-related cancers. (Reston, Virginia 2019)

Maintaining Image Quality

There are many modalities of medical imaging procedures, in hospitals each of which uses different technologies and techniques, and uses ionizing radiation to generate images of the body. Radiation doses for imaging procedures such as a CT, X-ray or fluoroscopy are set according to the child's body size and the disease type.

Diagnostic equipment has special pediatric features, and includes a range of dose management settings that can be calibrated for safe use on infants, children and adolescents.

Recently there has been an increase of new healthcare technology to manage radiation dose for patients without losing image quality. Not long ago dose reduction in diagnostic imaging would lead to poorer images; now technology has put more tools into the hands of radiologists, enabling them to make adjustments based on the patient need, without sacrificing on the quality of the image (L Times 2012).

1.1. Radiation CT Dose

The amount of radiation energy deposited in a medium is called the radiation dose. Different x-ray modalities address radiation dose in different ways. For example, in chest radiography it is the entrance exposure (not the dose) that is the commonly quoted comparison entity. In mammography, the average glandular dose is the standard measure of dose. The distribution of radiation dose in CT is markedly different than in radiography, because of the unique way in which radiation dose is deposited. There are three aspects of radiation dose in CT that are unique in comparison to x-ray projection imaging because:

- a single CT image is acquired in a highly collimated manner, the volume of tissue that is irradiated by the primary x-ray beam is substantially small compared with, for example the average chest radiograph.
- the volume of tissue irradiated, is exposed to the x-ray beam from almost all angles during the rotational acquisition, and this more evenly distributes the radiation dose to the tissues in the beam. In radiography, the tissue irradiated by the entrance beam experiences exponentially more dose than the tissue near the exit surface of the patient.
- CT acquisition requires a high Signal to Noise Ratio (SNR) to achieve high contrast resolution, and therefore the radiation dose to the slice volume is much higher because the techniques used (kV and mAs) are higher. As a rough comparison, a typical PA (posterioranterior) chest radiograph may be acquired with the use of 120 kV and 5 mAs whereas a thoracic CT image is typically acquired at 120 kV and 200 mAs. (G.L Ogbole 2010).

Problem of study

The clinical value of medical use of radiation for the diagnosis and treatment of pediatric illness and injury is unquestionable. The benefits of radiological medical procedures far outweigh the radiation risks when these procedures are appropriately prescribed and properly performed. Justification of procedures and optimization of protection are particularly critical in children because:

- Children are especially vulnerable to environmental threats, such as ionizing radiation;
- Children are expected to have longer a life-span to develop long-term radiation-induced health effects; and
- When using ionizing radiation for medical imaging , such as CT scans, children might receive a higher radiation dose than necessary if the settings are not adjusted for their smaller body size.

Computed tomography (CT) is a powerful tool for the accurate and effective diagnosis and treatment of a variety of conditions because it allows high-resolution three-dimensional images to be acquired very quickly. However as the number of CT procedures performed globally have continued to increase; with growing concerns about patient protection. Currently, no system is in place to track patient doses and the lifetime cumulative dose from medical sources. The widespread use of CT even in developing countries has raised questions regarding the possible threat to public health especially in children. The pediatric CT significantly increased lifetime radiation risk over adult CT. use high milliampere-second (mAs) and high Kv.

1.2. Objectives

1.6.1 Main objective

The main objective of this study to Estimation of pediatric dose during CT in brain image

1.6.2 Specific objectives

The specific objective to:

To sampling pediatric CT dose indicators

To scan parameters across several age groups for typical pediatric CT examinations performed in many hospitals in Khartoum.

To measure the mean values of the dose indicators; (CTDIvol and DLP) and compare with international DRLs to facilitate benchmarking.

To enable optimization, further assessment of the scan parameters and dose indicators was undertaken to isolate and investigate the influence of each factor on dose across the different age groups.

Additionally, to estimate effective dose for each age group and type of CT examination.

1.3. Thesis Outline

This thesis is concerned with the Estimation of pediatric dose during CT in brain image. Accordingly, it is divided into the following chapters:

Chapter one is the introduction to this thesis. This chapter discusses the objectives and scope of work and introduces necessary background. It also provides an outline of the thesis.

Chapter two contains the literature and theoretical background material for the thesis. Specifically it discusses the dose for all absorbed dose measurements and calculations. This chapter also includes a summary of previous work performed in this field.

Chapter three describes the materials and a method used to measure dose for CT machines and explains in details the methods used for dose calculation.

Chapter four reveals and demonstrates the results of this study.

Chapter five presents the discussion, conclusion and recommendations of the thesis and gives suggestions for future work.

Chapter two

literature view

Chapter Two

Literature View

2.1. Components of the CT Scanners

CT scanners are composed of many different connected parts, with many different components involved in the process of creating an image. More to the complexity, different CT scan manufacturers often modify the design of various components. To understand the basic function of each components, and some of the major variations in their design. From a broad perspective, all make and models of CT scanner are similar in that they consist of a scanning gantry, x-ray generator, computer system, operator's console or the console panel and physician's viewing console. Although hard copy filming has largely been replaced by workstation viewing and electronic archiving, most CT system still include a laser printer for transferring CT images to film.

amplified three Segment of Image Processing

- Data Acquisition – Get data
- Image Reconstruction – Use Data
- Image Display – Display Data
- Data are acquired when the X-ray pass through a patient to strike a detector and are recorded. The major components that are involved in this phase of image creation are the gantry and the patient table. (Jiang 2009)

Figure (2.1) CT design from 3.bp.blogspot website

2.1.1. Gantry

The gantry is the donut like or ring shaped part of the CT scanner. It houses many of the components necessary to produce and detect X-rays. These components are mounted on a rotating scan frame.

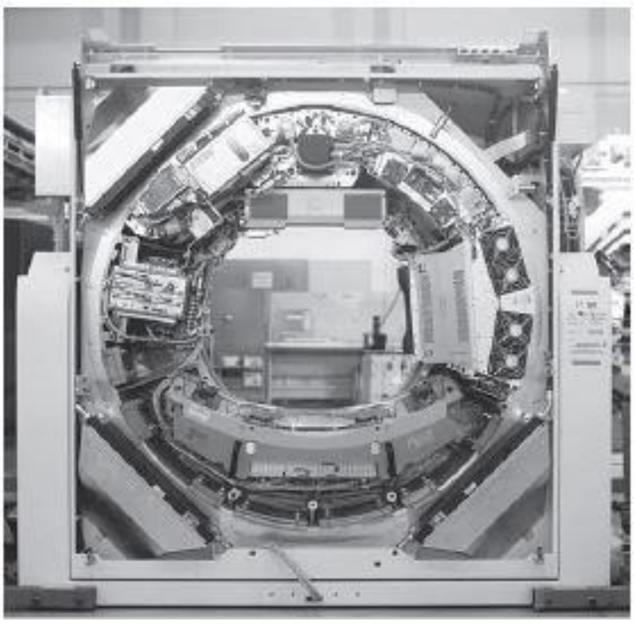

Figure (2.2) The gantry houses many of the components necessary to produce and detect x-rays. The gantry cover is removed on this third-

generation scanner configuration to reveal the components necessary for data acquisition, including the x-ray tube and detector array. Image courtesy of Siemens AG.

Component of the gantry are mounted on a rotating scan frame. Gantries vary in total size as well as in the diameter of the opening or aperture. The range size of aperture is typically 70 to 90 cm. The gantry is designed to be tilted either forward or backward as needed to accommodate a variety of patients and examination protocols. The gantry can be tilted varies among systems, but more or less 15 degrees to 30 degrees is usual. The gantry also include a laser light that is used to position the patient within the scanner. Control panels located on either side of the gantry opening allow the radiologic technologist to control the alignment lights, gantry tilt, and movement of the table. In most scanners, these functions may also be controlled via the operator's console. A microphone is installed in the gantry to allow communication between the patient and the radiologic technologist throughout the scanning procedure. (Jiang 2009)

2.1.2. Slip Rings

Old model design CT scanner used recoiling system cables to rotate the gantry frame. This design limited the scan method to the step and shoot mode and considerably limited the gantry rotation times. Newer systems use electromechanical devices called slip rings. Slip rings use a brush like apparatus to provide continuous electrical power and electronic communication across a rotating surface. They permit the gantry frame to rotate continuously, eliminating the need to straighten twisted system cables. Slip rings allows the gantry frame to rotate continuously making helical scan modes possible. (Jiang 2009)

2.1.3. Generator

High frequency generator is currently used in CT scanners. The generator are designed to be small enough so that it can be located within the gantry. Highly stable 3-phase generators have also been used, but because these are stand-alone units located near the gantry and require cables, they have become obsolete.

Generators produce high voltage and transmit it to the X-ray tube. The power capacity of the generator is listed in kilowatts (kW). The power capacity of the generator determines the range of exposure techniques like kV and mA settings, available on a particular system. CT generator produce high kV generally 120 – 140 kV to increase the intensity of the beam and thereby reduce patient dose. In addition, a higher kV setting will help to reduce the heat load on the X-ray tube by allowing a lower mA setting and reducing the heat load on the X-ray tube will extend the life of the tube. (Jiang 2009)

2.1.4. Cooling Systems

Cooling mechanisms are included in the gantry. They can take different forms, such as blowers, filters, or devices that perform oil to air heat exchange. Cooling mechanisms are important because many components can be affected by temperature fluctuations.

2.1.5. X-ray Source – CT X-ray tube

X-ray tubes produce the X-ray photons that create the CT image. Their design is a modification of a standard rotating anode tube, such as the type used in angiography. Tungsten, with an atomic number of 74, is often used for the anode target material because it produces a higher intensity X-ray beam. This is because the intensity of X-ray production is approximately proportional to the atomic number of the target material. CT scan tubes often contain more than one size of focal spot; 0.5 and 1.0 mm are the common size of focal spot. Just like as in standard X-ray tubes, because of reduced penumbra small focal spot in Computed tomography tubes produce sharper images like better spatial resolution, but because they concentrate heat onto smaller area of the anode they cannot tolerate as much of the heat.

A very large amount of stress is places on the CT scan tube. Scanning protocols often require multiple long exposures performs on numerous patients per day. A CT scan tube must be designed to handle such stress. The way a tube dissipate the heat that is created during X-ray production is critical. All manufacturers list generator and tube cooling capabilities in their product specifications. These specification usually list the system generator's maximum power in kW. Also listed is the anode hear capacity in million hear units MHU and the maximum anode heat dissipation rate in thousand heat units KHU. These specification can be help to differentiate the various CT Scan systems. It is important to remember that these values represent the highest limit of tube performance. It is also important to compare the length of protocols that the tube will allow and how quickly they can be repeated. (Jiang 2009)

2.1.6. Filtration.

Compensating filters are used to shape the X-ray beam. They reduce the radiation dose to the patient and help to minimize image artifact. As our teachers tough us that, radiation emitted by CT scan X-ray tube is polychromatic. Filtering the X-ray beam helps to reduce the range of X-ray energies that reach the patient by removing the long wavelength or soft X-rays. These long-wavelength X-rays are readily absorbed by the patient, therefore they do not contribute to the CT image but do contribute to the radiation dose to the patient. In addition, creating a more uniform beam intensity improves the CT image by reducing artifacts that result from beam hardening.

Filtering the X-ray beam helps to reduce the radiation dose taken by the patient and it also improves the image quality of the CT scanners. Different filters are used when scanning the body then when scanning the head. Human body anatomy having distinctive quantities has a round cross section that is thicker in the middle than in the outer area. Hence, body scanning filters are used to reduce the beam intensity at the periphery of the beam, corresponding to the thinner areas of a patient’s anatomy. Because of their shape they are often referred to as bow tie areas. (Jiang 2009)

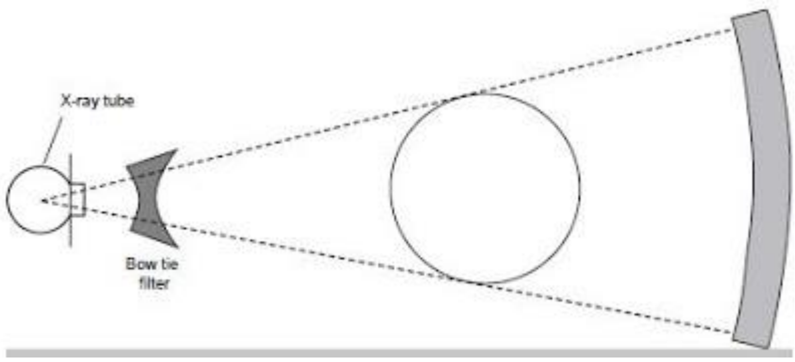

Figure (2.3) Filtering shapes the x-ray beam intensity. Removing low-energy x-rays minimizes patient exposure and produces a more uniform beam.

2.1.7. Collimation

Collimation restrict the X-ray beam to a specific area, as a result it helps reduce scatter radiation. This scatter radiation reduces image quality and increase the radiation dose to the patient. Reducing the scatter radiation improves contrast resolution and decrease patient dose. Collimation control the slice thickness by narrowing or widening the X-ray beam.
The source collimator is located near the X-ray source and limits the amount of X-ray beam before it passes through the patient it is sometimes referred to as patient dose and determines how the dose is distributed across the slice thickness like the dose profile. The source collimation resembles small shutters with an opening that adjusts, dependent on the operator’s selection of slice thickness. In MDCT systems, slice thickness is also influenced by the detector element configuration. Scanner vary in the choices of slice thickness available. Choices range from 0.5 to 10 mm.

Some CT scan systems also use predictor collimation. This is located below the patient and above the detector array. Because this collimation shapes the beam after it has passed through the patient it is sometimes referred to as post patient collimation. The primary functions of pre detector collimations are to ensure the beam is the proper width as it enters the detector and to prevent scatter radiation from reaching the detector. (Jiang 2009)

2.1.8. Detectors

The detectors is a component of CT scan machine which collect information regarding the degree to which each anatomic structure attenuated the beam. In Conventional radiography we used a film screen system to record the attenuated information. In CT, we use detectors to collect the information. The term detector refers to a single element or a single type of detector used in a CT system. The term detector array is used to describe the entire collection of detectors included in a CT scan system. Specifically the detector array comprises detector elements situated in an arc or a ring, each of which measures the intensity of transmitted X-ray radiation along a beam projected from the X-ray source to that particular detector element. Also, included in the array are elements referred to as reference detectors that help to calibrate data and reduce artifacts. Detectors can be made from different substances, each with their own advantage and disadvantages. (Jiang 2009)

2.1.8.1. Optimal Characteristics of a Detector

- High detector efficiency – it is the ability of detector to capture transmitted photons and change them to electronic signals.
- Low or no Afterglow – is a brief, persistent flash of scintillation that must be taken into account and subtracted before image reconstruction.
- High Scatter Suppression
- High Stability – which allow a system to be used without the interruption of frequent calibration. (Jiang 2009)

2.1.8.2. Other term to describe the aspect of a detector efficiency

- Capture efficiency – refers to the ability with which the detector obtains photons the passed through the patient
- Absorption efficiency - refers to the number of photons absorbed by the detector and dependent on the physical properties of the detector face like: thickness and material.
- Response time – is the time required for the signal from the detector to return to zero after stimulation of the detector by X-ray radiation so that it is ready to detect another X-ray event.

The detector response is generally a function of the detector design. Dynamic range is the ratio of the maximum signal measured to the minimum signal the detectors can measure. (Jiang 2009)

2.1.8.3. TYPES OF DETECTORS

2.1.8.3.1. Xenon Gas Detectors

Pressurized xenon gas fills hollow chamber to produce detectors that absorb of approximately 60% to 87% of the photons that reach them. Xenon gas is used because of its ability to remain stable under pressure. Xenon gas are significantly less expensive compared with the solid – state variety, it is also somewhat easier to calibrate and are highly stable.

2.1.8.3.1.1. Method of Xenon Gas Detector works

A xenon detector channel consists of 3 tungsten plates. When a photon enters the channel, it ionizes the xenon gas. These ions are accelerated and amplified by the electric field between the plates. The collection charge produces an electric current. This current is then processed as raw data. A disadvantage of xenon gas is that it must be kept under pressure in a certain extent. Loss of X-ray photons in the casing window and the space taken up by the plates are the major factors hampering detector efficiency.

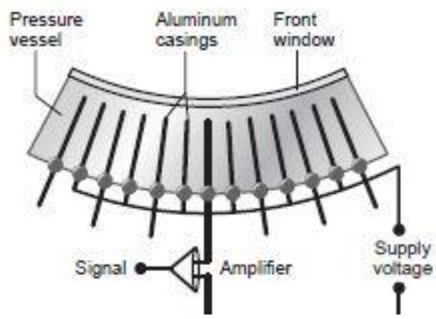

Figure (2.4) Structure of a xenon gas detector array.

2.1.8.3.2. Solid State Crystal Detector

Solid state detectors are also called scintillation detectors because they use a crystal that fluoresces when struck by a X-ray photon. A photodiode is attached to the crystal and transforms the light energy into electrical (analog) energy. The individual detector elements are affixed to a circuit board.

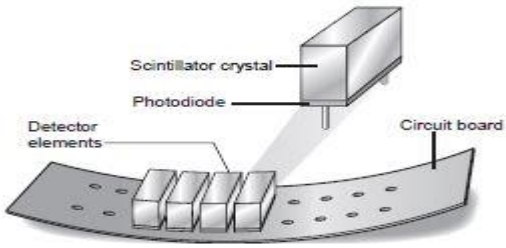

Figure (2.5) Structure of a solid-state detector array.

Solid state crystal detectors have been made from a variety of material, including cadmium tungstate, bismuth germinate, cesium iodide, and ceramic rare earth compounds such as gadolinium or yttrium. Because these solids have high atomic numbers and high density in comparison to gases, solid state detectors have higher absorption coefficients. They absorb nearly 100% of the photons that reach them. (Jiang 2009)

2.2. Anatomy of head

Head, in human anatomy, the upper portion of the body, consisting of the skull with its coverings and contents, including the lower jaw. It is attached to the spinal column by way of the first cervical vertebra, the atlas, and connected with the trunk of the body by the muscles, blood vessels, and nerves that constitute the neck. The term also is used to describe the anterior or fore part of animals other than humans. (Michael Ray, 2020)

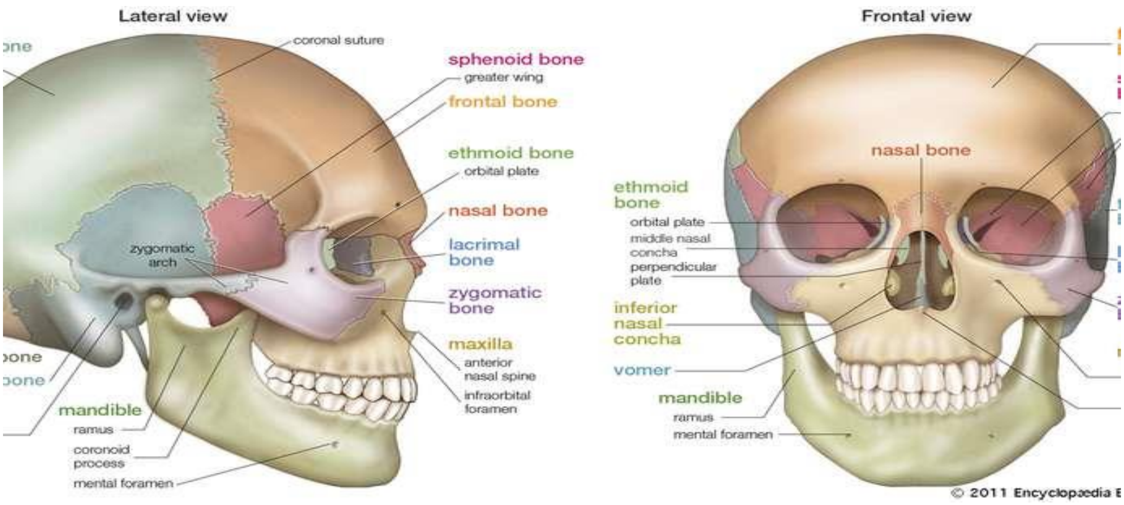

Figure (2.6) (Left) Lateral and (right) frontal views of the human skull.

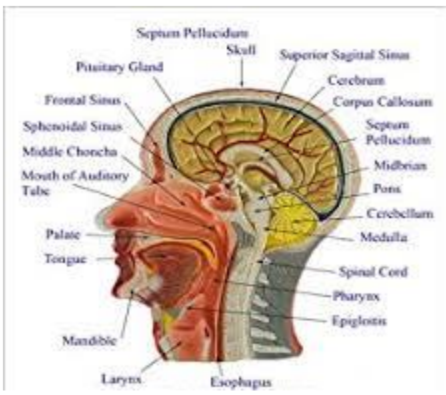

Figure (2.7) Head and neck anatomy

2.3. Dosimetry Quantities and Units

2.3.1. Basic Dosimetry Quantities

2.3.1.1. Particle Number N

The particle Number N is the number of particles that are emitted transferred, or received Unit: 1

2.3.1.2. Radiant Energy R

The Radiant Energy R is the energy (excluding rest energy) of particles that are emitted, transferred, or received.

Unit: j (ICRU Report 51).

2.3.1.3. Fluence Φ

The Fluence ϕ, is the quotient dN by dA, where dN is the number of particles incident on of cross-sectional area a sphere. $\Phi = dNdA$……………………..1.2

The unit of particle Fluence is m-2 [Podgorsak].

2.3.1.4. Energy fluence ψ

The Energy Fluence ψ, is the quotient of d E by dA, where d E is the radiant energy incident on a sphere of cross-sectional area dA [Podgorsak].

$$\Psi = dEdA \text{………………..} 2.2.$$

2.3.1.5. Kerma K

The Kerma K is an acronym for kinetic energy released per unit mass. Kerma is defined as the mean energy transferred from the indirectly ionizing radiation to charged particles (electrons) in the medium $d\bar{E}$ per unit mass dm: $K = d\bar{E}dm$……………. 3.2

The unit of kerma is joule per kilogram (J/kg). The name for the unit of kerma is the gray (Gy), where 1 Gy = 1 J/kg [Podgorsak].

2.3.1.6. Energy imparted

The mean energy imparted to the matter in volume equals the radiant energy, Rin of all those charged and uncharged ionizing particles which enter the volume minus the radiant energy, Rout of all those charged And uncharged ionizing particles, which leave the volume plus the sum ΣQ, of all changes of the rest energy of nuclei and elementary particles which occur in the volume, thus[IAEA Dosimetry]:

$$E= \Sigma Rin-Rout+Q \ldots\ldots\ldots\ldots 4.2.$$

2.3.1.7. Absorbed Dose D

The Absorbed Dose D, is the quotient of dĒ by dm, where dĒ is the mean energy imparted by ionizing radiation to matter of mass dm thus

$$D=d\bar{E}dm \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.2$$

Unit: J/ Kg

The special name for the unit of absorbed dose is gray (Gy) [ICRU Report 51].

2.3.2. Quantities for CT dosimetry

2.3.2.1. Computed Tomography Dose Index CTDI

The CTDI is the primary dose measurement concept in CT, Where

$$CTDI=1N\int D\infty-\infty(z)dz \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6.2$$

D (z) = the radiation dose profile along the z-axis

Where: N is the number of tomographic section imaged in a single axial. This is equal to the number of data channels used in a particular scan T= the width of the tomographic section along the z-axis imaged by one data channel. In multiple-detector-row (multiline) CT scanner, several detector elements may be grouped together to form one data channel. In single-detector-row (single-slice) CT, the z-axis collimation (T) is the nominal scan width CTDI represents the average absorbed dose, along the z-axis forma series of contiguous irradiations. It is measured form one axial CT scan (one rotation of the x-ray tube), and is calculated by dividing the integrated absorbed dose by the nominal total beam collimation. The CTDI is always measured in the axial scan mode for a single rotation of the x-ray source, and theoretically estimates the average dose within the central region of scan volume consisting of multiple, contiguous CT scans [Multiple Scan Average Dose (MSAD)] for the case where the scan length is sufficient for the central dose to approach its asymptotic upper limit. The MSAD represents the average dose over a small interval (-1/2, 1/2) about center of the scan length (z=0) for scan interval 1, but requires multiple exposure for its direct measurement. The CTDI offered a more convenient yet nominally equivalent method of estimating this value, and required only a single-scan acquisition, which in the early days of CT, saved a consider- able amount of time[Beck,1993].

2.3.2.2. CTDI$_{FAD}$:

Theoretically, the equivalence of the MSAD and the CTDI requires that all contributions from the tails of the radiation dose profile be included in the CTDI dose measurement. The exact integration limits required to meet this criterion depend upon the width of the nominal radiation beam and the scattering medium. To standardize CTDI measurements (infinity is not a likely measurement parameter), the FDA introduced the integration limits of ±7T, where to represent the nominal slice width Interestingly, the original CT scanner, the EMI Mark I, was a dual detector -row system. Hence, the nominal radiation beam width was equal to twice the nominal slice width (i.e., NxTmm).To account for this, the CTDI value must be normalized to 1/NT:

As described in equal below [Beck,1993].

$$CTDI_{FAD}=1NT\int(z)dz7T-7T\text{..........................}7.2.$$

2.3.2.3. 2.4.2.3. CTDI100

CTDI$_{100}$ represents the accumulated multiple scan dose at the center of a 100-mm scan and underestimates the accumulated dose for longer Scan lengths. It is thus smaller than the equilibrium dose or the MSAD. The CTDI$_{100}$, like the CTDI$_{FAD}$ requires integration of the radiation dose profile froma single axial scan over specific integration limits. In the case of CTDI$_{100}$, the integration limits are ±50 mm, which corresponds to the 100-mm length of the commercially available “pencil” ionization chamber as described in equ below [Beck,1993].

$$CTDI_{100}=1NT\int(z)dz_{50}-50\text{...............}8.2.$$

2.3.2.4. CTDI Weighted

The CTDI varies across the field of view (FOV). For example, for body CT imaging, the CTDI is typically a factor or two higher at the surface than at the center of the FOV. The average CTDI across the FOV is estimated by the Weighted CTDI ($CTDI_W$),

Where $CTDI_W$=13⁄$CTDI_{100}$, $center$ +23⁄$CTDI_{100}$, $edge$ The values of 1/3 and 2/3 approximate the relative areas represented by the center and edge values. CTD_W is a useful indicator of scanner radiation output for a specific Kvp and mAs [Beck,1993].

2.3.2.5. Volume $CTDI_{VOL}$

To represent dose for a specific scan protocol, which almost always involves series of scans, it is essential to take into account any gaps or overlaps between the x-ray beams from consecutive rotations of the X-ray source. This is accomplished with use of a dose descriptor known as the Volume $CTDI_W$ ($CTDI_{VOL}$),

Where $CTDI_{VOL}=NTI\times CTDI_W$……. 9.2

Where: I = the table increment per axial scan (mm) Since the pitch is defining as the ratio of the table travel per rotation (I) to the total nominal beam width (N×T)

$pitch=INT$………………10.2

Thus, the volume CTDI can expressed as

$CTDIvol=1pitch\times CTDI_W$……….11.2

Whereas $CTDIW$ represents the average absorbed radiation dose over the x and y directions at the center of the scan from a series of axial scans where the scatter tails are negligible beyond the 100-mm integration limit, $CTDIvol$ represents the average absorbed radiation dose over the x, y, and z directions. The $CTDIvol$ provides a single CT dose parameter, based on a directly and easily measured quantity, which represents the average dose within the scan volume for a standardized (CTDI) phantom. The SI units are milligray (mGy) [Beck,1993].

2.3.2.6. Dose Length Product DLP

To better represent the overall energy delivered by a given scan protocol, the absorbed dose can be integrated along the scan length to compute the Dose-Length Product (DLP) where

$$DLP \text{ (mGy-cm)} = CTDI\text{vol (mGy) x } \textit{scan length} \text{ (cm)} \ldots\ldots\ldots 12.2$$

The DLP reflects the total energy absorbed (and thus the potential biological effect) attributable to the complete scan acquisition. Thus, an abdomen-only CT exam might have the same $CTDIvol$ as an abdomen/pelvis CT exam, but the latter exam would have a greater DLP, proportional to the greater *z*-extent of the scan volume [Beck,1993].

2.3.3. Quantities Related to Stochastic and Deterministic Effect

2.3.3.1. Organ and Tissue Dose D_T

The mean absorbed dose in a specified tissue or organ. It is equal to the ratio of the energy imparted, $\bar{E}_T$, to the tissue or organ to the mass, M_T, of the tissue or organ, thus

$$D_T = E_T m_T \ldots\ldots\ldots\ldots 13.2$$

The mean absorbed dose in a specified tissue or organ is sometimes simply referred to as the organ dose [IAEA Dosimetry].

2.3.3.2. Equivalent dose HT

The equivalent dose, H_T, to an organ or tissue, T, is defined for a single type of radiation, R, it is the product of a radiation weighting factorWR, for radiation R and the organ dose, D_T, thus:

$$H_T = W_R D_T \ldots\ldots\ldots 14.2$$

Unit: J/Kg.

The special name for the unit of equivalent dose is Sievert (Sv) The radiation weighting factor,, allows for differences in the relative biological effectiveness of the incident radiation in producing stochastic effects at low doses in tissue or organ, T. For x-ray energies use in diagnostic radiology, $W_R$is taken to be unity[ICRU Report 51].

Table 2.1: Radiation Weighting Factors W_R

Radiation	Radiation Weighting Factors (W_R)
Photons all energies	1
Electrons and muons, all energies	1
Neutrons	
< 10 Kev	2.5
10 – 100 Kev	2.5 to10
100 – 2 Mev	10 to 20
2 – 20 Mev	7 to 17.5
>20Mev	5 to 7
Protons, energy > 2 Mev	2
Alpha particles, fission fragment, heavy nuclei	20

2.3.3.3. Effective dose E

The effective dose, E, is defined for the sum over all the organ and tissue of the body of the product of the equivalent dose, H_R, to the organ or tissue and at Tissue weighting factor,W_T, for that organ or tissue, thus: $E= \Sigma H_T\ W_T$……..15.2

The tissue weighting factor, W_T for organ or tissue T represents the relative contribution relative contribution of that organ or tissue to the total detriment arising from stochastic effects for uniform irradiation of the whole body.

Unit: J/Kg.

The special name for the unit of effective dose is Sievert (Sv)[IAEA Dosimetry].

Table 2.2: Tissue Weighting Factors W_T

Tissue (T)	Weighting Factors (W_T)
Gonads	0.08
Breast	0.12
Red bone marrow	0.12
Lung	0.12
Thyroid	0.04
Bone surface	0.01
Colon	0.12
Stomach	0.12
Bladder	0.04
Esophagus	0.04
Liver	0.04
Brain	0.01
Salivary glands	0.01
Skin	0.01
Remainder	0.12

2.4. Previous studies

Nor Hanani, et, al Computed Tomography Dose in Paediatric Care: Simple Dose Estimation Using Dose Length Product Conversion Coefficients, 2018, They aimed to estimate the effective doses (EDs) of a variety of paediatric computed tomography (CT) examinations in five age groups using recently published age- and region-specific dose length products (DLPs) as effective dose conversion coefficients. Their method A retrospective review was performed over a 12-month period. Patients were assigned to one of five age groups: neonatal, 1-, 5-, 10- and 15-years-old. Age- and region-specific conversion coefficients were applied to the DLP data displayed on the CT console in order to estimate the ED. Their Results was Over the 12-month period, there were a total of 283 CT scans, 211 of which were selected for study. The ED estimates for plain CT brain scans in neonatal, 1-, 5-, 10- and 15-yearolds were 2.5, 1.5, 1.4, 1.3 and 0.8 mSv, respectively. For the corresponding CT abdominal scans, the results were 18.8, 12.9, 7.8, 8.6 and 7.5 mSv; these were the highest values recorded. High resolution CT (HRCT) temporal scans showed EDs of 2.9, 1.8, 1.5 and 1.1 mSv in 1-, 5-, 10- and 15-years-old, respectively. CT scans of the helical thorax had an estimated ED of 4.8, 4.2 and 7.0 mSv in 5-, 10- and 15-years-old, respectively. They Concluded that An inverse relationship between age and effective dose was demonstrated

in CT scans of the brain and abdomen/pelvis. In general, our study showed lower overall EDs compared to other centers

Ruixue Huang, et, al, Radiation Exposure Associated With Computed Tomography in Childhood

and the Subsequent Risk of Cancer: A Meta-Analysis of Cohort Studies,2020. Their methods they evaluated children aged < 18 years who did and did not undergo CT in terms of radiation dose, years to development

of cancer, age at first CT, gender, and CT frequency.

They retrieved all papers published from January 1990 to November 2018. Cancer incidence (the RR) was compared between children who did and did not undergo CT. Doses

were divided into < 30, 30 to 50, and > 50 mGy. Years to cancer development were divided into 2, 5, and 10 years.

Age at first CT was divided into 0 to 5, 6 to 15, and >15 years. We considered the doses absorbed into red bone marrow (RBM, mGy)14 and combined the doses for all organ.

Their Results Seven studies with 1180 987 children enrolled were included. The risk of later cancer was 1.32-fold higher for children exposed to CT than those without exposure. Compared to those not exposed to pediatric CT, the relative risk (RRs) were larger for the higher doses but with wider CIs (RR for 5-10 mGy: 0.90, 95% CI: 0.69-1.12; RR for 10-15 mGy: 1.02, 95% CI: 0.86-1.18; RR for

>15 mGy: 1.13, 95% CI: 0.97-1.30), the leukemia risk was higher in exposed children (RR: 1.23, 95% CI: 1.10-1.36), and brain cancer risk was higher in exposed children (RR: 1.54, 95% CI: 0.84-2.45).

Concluded their analysis suggested that radiation exposure from CT during childhood is associated with a subsequently elevated risk of cancer. However, caution is needed when interpreting these results because of the heterogeneity among the studies. The findings should be confirmed in further studies with longer follow-up periods.

Anupam B., et, al, Analysis of Radiation Dose to Pediatric Patients During Computed Tomography Examinations 2015, They were objective to measure the effective dose of radiation delivered during routine head and abdominal CT examinations at a children's hospital. Their methods was a retrospective study of emergency department (ED) patients < 20 years of age who underwent head or abdominal CT scans in 2012 at a single children's hospital. They done relationship between effective dose and age, patient weight, and reason for examination were evaluated they Resulted A total of 478 subjects were included: 255 underwent head CT, and 223 underwent abdominal CT. The median age was 8.1 years (interquartile range = 2.71 to 14.40 years) and 56.9% were male. The median effective dose for head CT was 2.68 mSv (95% confidence interval [CI] = 2.54 to 2.84 mSv) and decreased as age increased. For abdominal CT, the median effective dose was 5.06 mSv (95% CI = 4.58 to 6.03 mSv) and increased as age increased (3.67 to 11.12 mSv, $p < 0.001$). For abdominal CT, 8% of 5- to 10-year-olds, 28% of those 10 to 15 years, and 60% of patients over age 15 years received effective doses over 10 mSv. Their Conclusions was The amount of radiation delivered to pediatric patients during routine CT examinations of the head and abdomen was low. Regardless, a large proportion of older patients were exposed to elevated effective doses of radiation during abdominal CT.

Walter Huda1, et, al , Patient Radiation Doses from Adult and Pediatric CT, 2001, They purposed study was to determine typical organ doses, and the corresponding effective doses, to adult and pediatric patients undergoing a single CT examination. They focus Heads, chests, and abdomens of patients ranging from neonates to oversized adults (120 kg) were modeled as uniform cylinders of water. Monte Carlo dosimetry data were used to obtain average doses in the directly irradiated region. Dosimetry data were used to compute the total energy imparted, which was converted into the corresponding effective dose using patient-size-dependent effective-dose-per-unit-energy-imparted coefficients. Representative patient doses were obtained for scanning protocols that take into account the size of the patient being scanned by typical MDCT scanners.

They concluded that Representative organ absorbed doses in CT are substantially lower than threshold doses for the induction of deterministic effects, and effective doses are comparable

to annual doses from natural background radiation.

HIDEKI OBARA1,, et, al, Estimation of effective doses in pediatric X-ray computed tomography examination, 2017, their Abstract was X-ray computed tomography (CT) images are used for diagnostic and therapeutic purposes in various medical disciplines. In Japan, the number of facilities that own diagnostic CT equipment, the number of CT examinations and the number of CT scanners increased by ~1.4-fold between 2005 and 2011. CT operators (medical radiological technologists, medical physicists and physicians) must understand the effective doses for examinations at their own institutions and carefully approach each examination. In addition, the patients undergoing the examination (as well as his/her family) must understand the effective dose of each examination in the context of the cumulative dose. In the present study, the numbers of pediatric patients (aged 0-5 years) and total patients who underwent CT at Hirosaki University Hospital (Hirosaki, Japan) between January 2011 and December 2013 were surveyed, and effective doses administered to children aged

0, 1 and 5 years were evaluated. Age- and region-specific conversion factors and dose-length products obtained from the CT scanner were used to estimate the effective doses. The numbers of CT examinations performed in 2011, 2012 and 2013 were 16,662, 17,491 and 17,649, respectively, of which 613 (1.2%) of the overall total involved children aged 0-5 years. The estimated effective doses per examination to children aged 0, 1 and 5 years were 6.3±4.8, 4.9±3.8 and 2.7±3.0 mSv, respectively. This large variation was attributed to several factors associated with scan methods and ranges in actual setting. In conclusion, the requirement for individual patient prospective exposure management systems and estimations of low-dose radiation exposure should be considered in light of the harmful effects of exposure.

Nik Norhasrina, et al, Evaluation of radiation dose in pediatric head CT examination: a phantom study, they aimed to evaluate radiation dose in pediatric head computed tomography examination, they reported that reducing tube voltage can reduce the dose to the patients significantly.

Adam M., et, al, A pediatric CT dose and risk estimator, 2010, they Abstracted that they present a web-based pediatric CT dose tool that estimates effective dose based on dose length product, patient age and region of body scanned. The tool also provides an estimate of additional lifetime risk of cancer from CT exams. These estimations are based on the interpolation of factors from published methods. The calculator serves as an educational tool that can be used by radiologists and clinicians to better understand CT dose and its associated risks.

Keith J., et, al , Radiation Dose for Pediatric CT: Comparison of Pediatric versus Adult Imaging Facilities, 2018, their Materials and Methods was : A retrospective study of doses (mean patient age, 12 years; age range, 0–21 years) was performed by using data from the National Radiology Data Registry (year range, 2016–2017) (n = 239 622). Three examination types were evaluated: brain without contrast enhancement, chest without contrast enhancement, and abdomen-pelvis with intravenous contrast enhancement. Three dose indexes—volume CT dose index (CTDIvol), size-specific dose estimate (SSDE), and dose-length product (DLP)—were analyzed by using six different size groups. The unequal variance t test and the F test were used to compare mean dose and variances, respectively, at academic pediatric facilities with those at other facility types for each size category. The Bonferroni- Holm correction factor was applied to account for the multiple comparisons.

Their results: Pediatric radiation dose in academic pediatric facilities was significantly lower, with smaller variance for all brain, 42 of 54 (78%) chest, and 48 of 54 (89%) abdomen-pelvis examinations across all six size groups, three dose descriptors, and when compared with that at the other three facilities. For example, abdomen-pelvis SSDE for the 14.5–18-cm size group was 3.6, 5.4, 5.5, and 8.3 mGy, respectively, for academic pediatric, nonacademic pediatric, academic adult, and nonacademic adult facilities (SSDE mean and variance P , .001). Mean SSDE for the smallest patients in nonacademic adult facilities was 51% (6.1 vs 11.9 mGy) of the facility's adult dose.

They Concluded: Academic pediatric facilities use lower CT radiation dose with less variation than do nonacademic pediatric or adult facilities for all brain examinations and for the majority of chest and abdomen-pelvis examinations.

Yasunori Nagayama,, et, al, Radiation Dose Reduction at Pediatric CT: Use of Low Tube Voltage and Iterative Reconstruction, 2018, Given the growing awareness of and concern for potential carcinogenic effects of exposure of children to ionizing radiation at CT, optimizing acquisition parameters is crucial to achieve diagnostically acceptable image quality at the lowest possible radiation dose. Among currently available dose reduction techniques, recent technical innovations have allowed the implementation of low tube voltage scans and iterative reconstruction (IR) techniques into daily clinical practice for pediatric CT. The benefits of lowering tube voltage include a considerable reduction in radiation dose and improved contrast on images, especially when an iodinated contrast medium is used. The increase in noise, which is attributed to decreased photon penetration, is a major drawback but is not as severe as that at adult CT because of the small body size of children. In addition, use of IR algorithms can suppress increased noise, yielding wider applicability for low tube voltage scans. However, a

careful implementation strategy and methodologic approach are necessary to maximize the potential for dose reduction while preserving diagnostic image quality under each clinical condition. The potential pitfalls of and topics related to these techniques include (a) the effect of tube voltage on the surface radiation dose, (b) the effect of window settings, (c) accentuation of metallic artifacts, (d) deterioration of low contrast detectability at low-dose settings, (e) inter scanner variation of x-ray spectra, and (f) a comparison with the use of a spectral shaping technique. Appropriate use of low tube voltage and IR techniques is helpful for radiation dose reduction in most applications of pediatric CT.,

They concluded that a Cumulative evidence has elucidated the potential risk for carcinogenesis and dose-response relationships in pediatric CT. Accordingly, optimization of acquisition parameters is crucial, and those involved in radiation imaging must incorporate strategies for dose reduction into clinical practice. The low tube voltage technique yields substantial reduction in radiation dose while improving the image contrast, especially when an iodinated contrast medium can be used. Increased image noise due to less photon penetration is a major drawback of this technique; however, the degree of this adverse effect is highly dependent on patient body size and thus is not much of a problem in pediatric CT. In conjunction with body habitus, the diagnostic task and the anatomic region of interest should be taken into consideration for selection of optimal tube voltage settings, because the degree of contrast improvement and noise tolerability depends on these factors. Combined use of IR algorithms can effectively suppress image noise, which maximizes the benefit of a low tube voltage technique and yields wider applicability to obtain diagnostic image quality at the lowest radiation dose. As outlined in this article, appropriate use of low tube voltage imaging and IR techniques enables dramatic dose reductions for pediatric CT while maintaining or improving diagnostic image quality for most clinical conditions.

Hussain Almohiy, Pediatric computed tomography radiation dose: A review of the global dilemma, 2014, he abstracted that Computed tomography (CT) has earned a well-deserved role in diagnostic radiology, producing cross sectional and three-dimensional images which permit enhanced diagnosis of many pathogenic processes. The speed, versatility, accuracy, and non-invasiveness of this procedure have resulted in a rapid increase in its use. CT imaging, however, delivers a substantially higher radiation dose than alternative imaging methodologies, particularly in children due to their smaller body dimensions. In addition, CT use in children produces an increased lifetime risk of cancer, as children's developing organs and tissues are inherently more vulnerable to cellular damage than those of adults. Though individual risks are small, the increasing use of CT scans in children make this an important public health problem. Various organizations have recommended measures to minimize unnecessary exposures to radiation through CT scanning. These include elimination of multiple or medically unnecessary scans, development of patient specific dosing guidelines, and use of alternative radiographic methodology wherever possible. Another important factor in excessive CT exposures, however, is a documented lack of awareness among medical practitioners of the doses involved in CT usage as well as its significant potential dangers. This review examines the effects of pediatric CT radiation, discusses the level of medical practitioner awareness of these effects, and offers recommendations on alternative diagnostic methods and practitioner education.

He concluded Over the past two decades CT scanning rates have increased greatly, and this has increased the average radiation dose delivered to pediatric patients. This literature review has found that medical practitioners are not adequately aware of the stochastic effects of CT, or of diagnostic alternatives to CT. Because of the stochastic effects of ionizing radiation, dose reduction in CT examinations, especially for pediatric patients, must occur. Dose reduction is being implemented by CT manufacturers, but medical imaging professionals must not rely on this alone. Improvements to CT protocols, referral practices and imaging professionals' education are needed realize that CT scans increase the lifetime risk of cancer. They also reported that radiologists are unable to provide accurate estimates of CT dose regardless of their level of experience. In addition, a 2003 questionnaire based survey and interview of doctors of all grades, including consultant radiologists, indicated that only 2% of the participants could successfully estimate the relative doses of common diagnostic procedures. A significant proportion of the interviewees could only answer questions that involved ultrasound, which is non-ionising. The degree of knowledge was inversely proportional to seniority, with consultants scoring less than junior colleagues. It was revealed in a 2004 survey that 53% of radiologists and 91% of emergency room physicians surveyed did not believe that CT scans increased the lifetime risk of cancer.

Chapter three

Material & Method

Chapter there

Material and method

X-ray computed tomography (CT) is a medical imaging technique in which computer-processed X-ray projections are used to produce tomographic images or slices of specific areas of the body. Since 2000, the importance of multi-detector CT, which permits faster scanning and a wider range of clinical applications, has been recognized . (HIDEKI 2017)

3.1. Materials

3.1.1. patients

This study was carried out on 25 patients (17 males and 8 females) consisting of Pediatric (21days _ 12 years) who visited or referred to Radiology Department in (Alnilein Medical Diagnostic Centre) which locate in Khartoum state.

3.1.2. CT equipment-specific information

The hospital in this study was used CT 32 slice model Siemens Germany 2018 - The X-Ray High Voltage Generator output (150 kv 320 mAs) .

3.2. Methods

3.2.1. CT protocol

In Alnilein hospitalthe protocol included the Kvp 120 kv, mAs is ranged from 110 to 130 mA, slice thickness is 5 mm, collimation from 24 to 32 mm and scan length from 12 to 20 cm.

3.2.2. Dosemetric calculations

CT Expo software was used to calculate common CT dose descriptors: (i) CT Dose Index volume dose index ($CTDIvol$) provides an indication of the average absorbed dose in the scanned region, (ii) CT Dose –Length Product (DLP) the integrated absorbed dose along a line parallel to the axis of rotation for the complete CT examination, and (iii) Equivalent dose HT (E): a method for estimation and comparing the Equivalent dose of lens of eyes from different diagnostic procedures in Alnilein Medical Diagnostic Centre . In this study was used CT-Expo Version 2.5 software tool for dose calculations and CT-Expo tools—based on Monte Carlo data published by the Research Center for Environment and Health in Germany—for dose calculation. Dose estimation is done based on mathematical phantoms for adult (ADAM and EVA). The software allows the calculations of the CT dose descriptors ($CTDIvol$ and DLP), Equivalent dose in accordance with new recommendations of the international commission for radiological protection ICRP 103 (A_Suliman II, et,al ,2014).

3.3. Place and time of study

This study was performed at three radiology department in Alnilein Medical Diagnostic Centre , during the period from (August to November 2020).

3.4. Data analysis

All dose parameters will have registered from Data collection sheet, then used as input to the Microsoft excel and SPSS software for analysis.

A retrospective study of doses (mean patient age, 12 years; age range, one day – 12 years) was performed by using data from
brain with or without contrast enhancement.

Dose indexes—Weight CT dose index (CTDIw), and dose-length product (DLP)—were analyzed by using gender groups age groups to evaluate equivalent and effective dose to the pediatric patients whom referred to head CT examination in Alnilein Medical Diagnostic Centre.

3.5. Brain CT scan Technique

- Most clinical indications are adequately covered by 3 mm sections parallel to the floor of the anterior cranial fossa, from the foramen magnum to the midbrain, with 7 mm sections to the vertex (or contigious 3 mm slices throughout). In all trauma cases, window width and level should be adjusted to examine bone and any haemorrhagic, space occupying lesions. Review of all trauma studies should be done on brain windows, bone and blood windows.

- In suspected infection, tumours, vascular malformations and subacute infactions, the sections should be repeated following intravenous (i.v) contrast enhancement, if MRI is not available. Standard precautions with regard to possible adverse reactions to contrast medium should be taken.
- Dynamic studies using iodinated contrast are increasingly being used as a routine in high velocity head trauma, the assessment of ruptured arteriovenous shunts and dural venous sinus thrombosis. CT angiography (CTA) on a typical 64 slice multidetector scanner is performed using 70-100 ml of contrast and 50 ml saline chaser, injected at 4 ml/s with a delay of 15s or triggered by bolus tracking with ROI in the aortic arch. Overlapping slices of 0.75 – 1.25 mm are reconstructed. CT venography (CVT) involves injecting 90-100 ml of contrast with a delay of 40s. Images are usually reviewed both as three dimensional rendered data and multiplanar reformats (MPRs).

Chapter four

Results

Chapter four

The results

Over the 4-month period, there were a total of 25 CT scans, which were selected for study. The ED estimates for plain CT brain scans for pediatric from 1 day to twelve years old in Alnilain medical centre at Khartoum state. A total of 25 patients 17 male and 8 female (11 under two years, 6 over 2 years and under 5 years and 8 over 5 years).the result was done as following:

Table (4.1) demographic data for gender of the patients

Gender	Age(Years)	Weight(Kg)	Height(meter)	BMI
Male	4.55±4.19 (0.70 – 12)	15.87± 9.02 (6.5 – 32)	0.99 ± 0.27 (0.68 –1.54)	15.24 ± 2.57 (12.54 –21.31)
Female	5.26 ± 4.79 (0.06 – 12.00)	17.66 ±11.66 (3.40 –38.00)	1.01 ± 0.33 (0.52– 1.47)	15.67 ±3.015 (11.42– 20.81)
Total	4.78 ± 4.30 (0.06 –12.00)	16.44 ± 9.73 (3.40_38.00)	0.99 ± 0.28 (0.52_1.54)	15.38 ± 2.67 (11.42 - 2131)

Table (4.2) parameters used for gender of the patients

Gender	S(sec)	kVp	MAs
Male	4.44 ± 0.42 (3.6 0 – 4.90)	120.59 ±10.29 (110 – 130)	161.53 ± 21.00 (125 – 213)
Female	4.85 ± 0.66 (4.40 –6.40)	120 ±10.69 (110 –130)	175.13 ± 26.63 (140 – 213)
Total	4.57 ± 0.53 (3.60 – 6.40)	120.40 ±10.20 (110 – 130)	159.30 ± 26.47 (125 – 213)

Table (4.3) CTDI and DLP for gender of the patients

Age	CTDI	DLP
Male	32.52 ± 4.00 (26.45 _41.10)	465.71 ± 78.55 (316.00_612.00)
Female	42.23 ± 26.41 (29.22_ 107.28)	638.38 ± 306.70 (437.00_1325.00)
Total	35.63 ±15.35 (26.45_107.28)	520.96 ± 195.72 (316.00_1325.00)

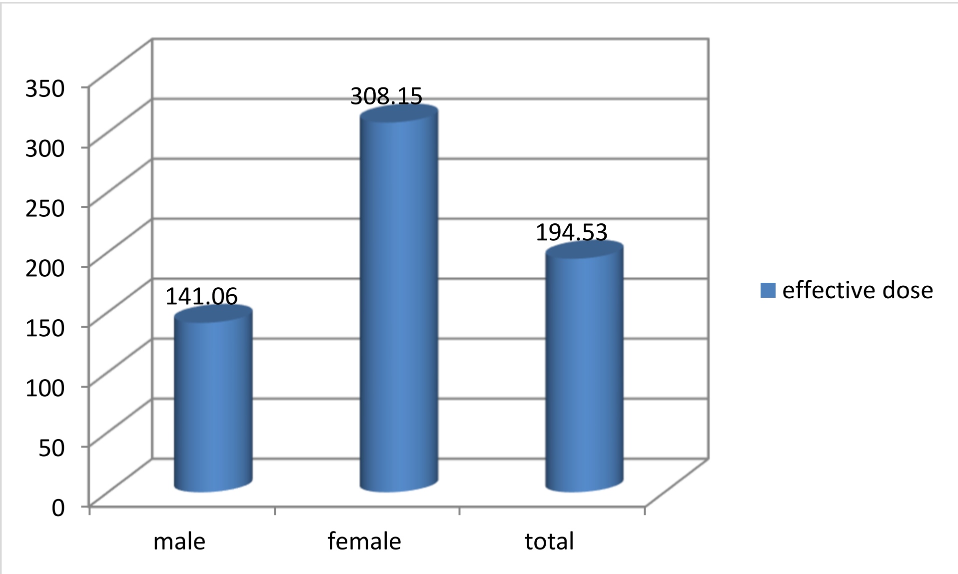

Figure (4.1) effective dose to the gender of the patients

Table (4.4) demographic data of the patients due to the age distribution

Age	Weight	Height	BMI
<= 2	7.96 ± 2.27 (3.40 – 12.50)	0.72 ± 0.09 (0.52 – 0.86)	14.99 ± 2.57 (12.57 –20.54)
2<age>=5	15.40 ±1.05 (14.40 –17.00)	1.06 ± 0.10 (0.96 – 1.22)	13.91±1.66 (11.42–15.73)
Age > 5	28.90 ± 4.97 (22.50 – 38.00)	1.31 ± 0.15 (1.14 – 1.54)	17.00 ± 2.80 (13.49 –21.31

Table (4.5) parameters used due to the age

Age	S	Kv	mAs
<= 2	4.46 ± 0.78 (3.60 – 6.40)	115.45 ±9.34 (110 –130)	168.64 ±26.15 (125 – 213)
2<age>=5	4.55 ± 0.21 (4.40 – 4.9)	120 ±10.95 (110 – 130)	167.17 ± 29.23 (138 – 213)
Age > 5	4.75 ± 0.18 (4.4 – 4.9)	127.5±7.07 (110 – 130)	162.38 ± 21.55 (140 – 213)

Table (4.6) CTDI and DLP to the age of the patients

Age	CTDI	DLP
<= 2	38.74 ± 23.18 (26.45 – 107.28)	546.55 ± 292.88 (316.00 – 1325.00)
2<age>=5	31.49±2.57 (29.22 – 34.69)	453.00±22.01 (436 .00– 485.00)
Age > 5	34.44± 1.93 (31.95 – 37.66)	536.75 ± 56.32 (466.00– 612.00)

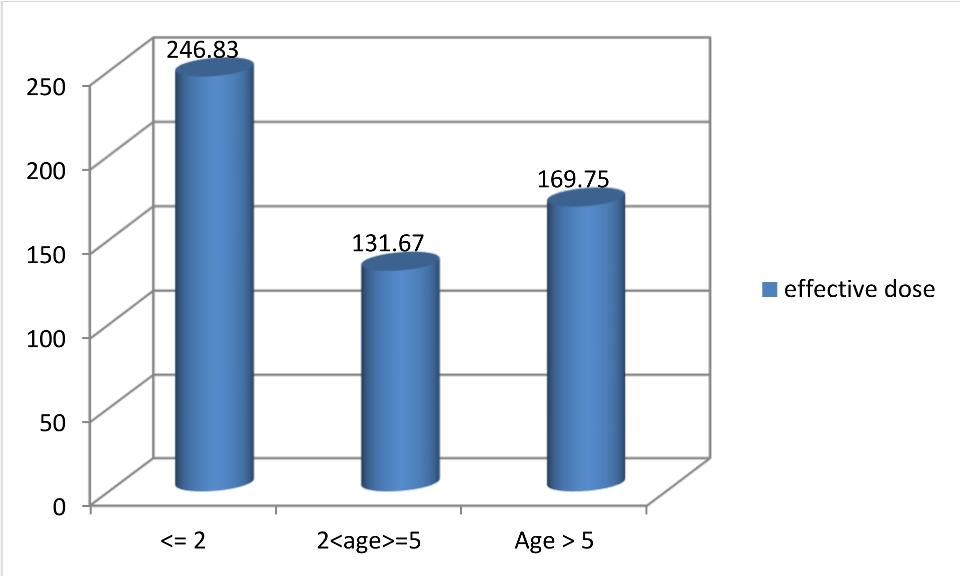

Figure (4.2) effective dose to the age of the patients

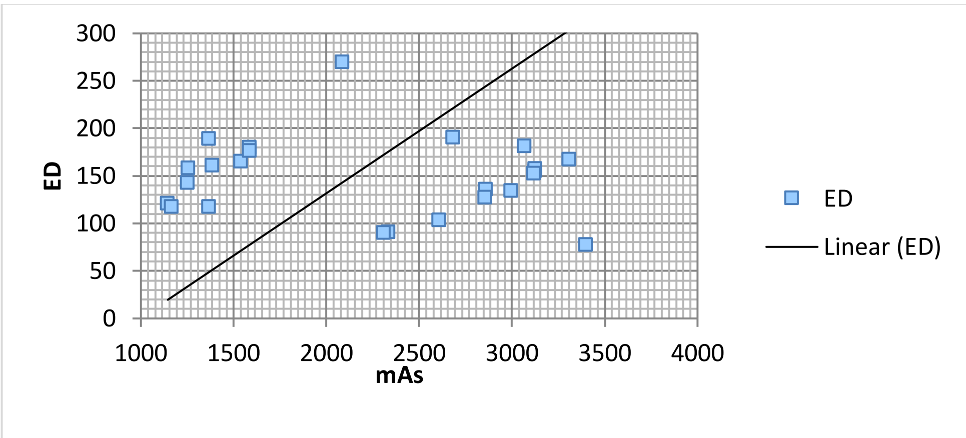

Figure (4.3) correlation between mAs and ED

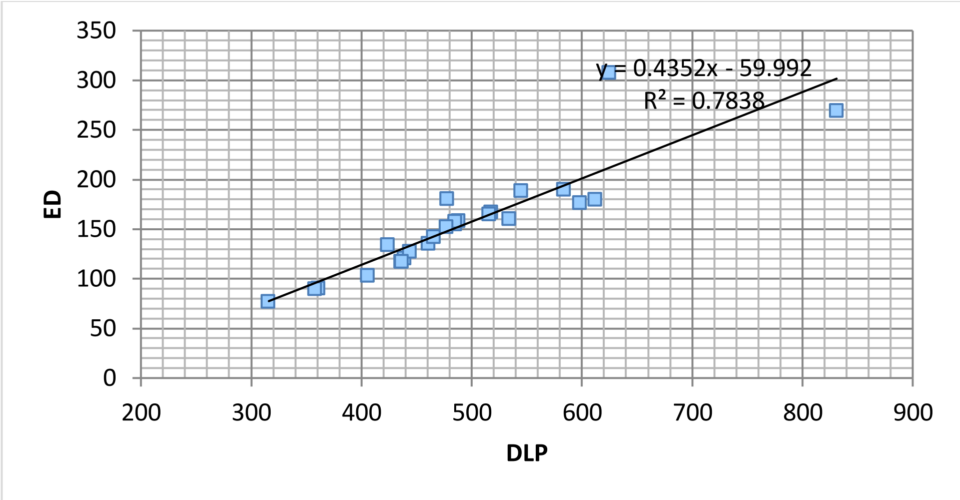

Figure (4.4) correlation between DLP and ED

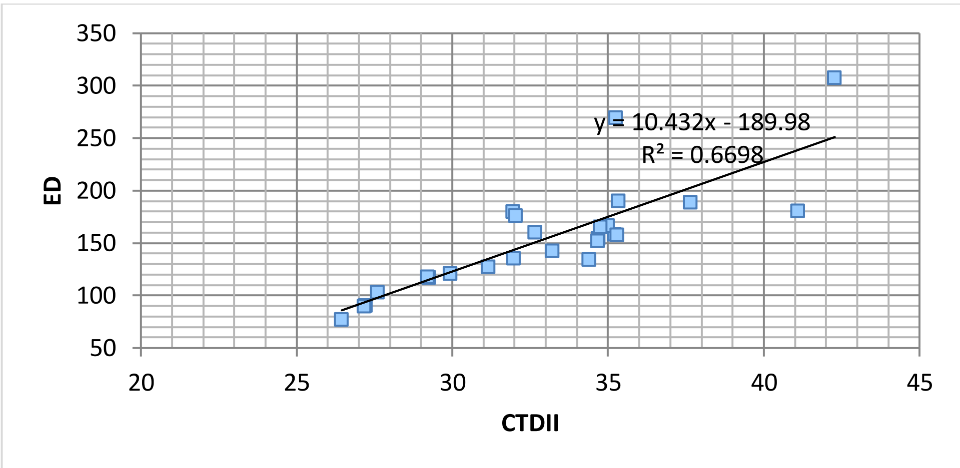

Figure (4.5) correlation between CTDI and ED

Chapter five

Discussion

Chapter five

Discussion

5.1. Discussion

This study intends to Estimation of pediatric dose during CT in brain image in Alneelain medical Center. A total of 25 pediatric patients were exposed to one CT machine 17 male and 8 female. The demographic data were analysis to them according to the gender and age. Show in Tables (4.1- 4.4).

The kv were selected for both male and female was between 110 and 130. the mean mAs and S for male were 161.53 and 4.44 respectively and for female were 175.13 and 4.85 respectively. Show in Tables (4.2). In table 4.5 S, Kv and mAs tabulated during to the age which appeared different variation in selection.

The mean CTDI for the male and female were 32.52 and 42.23 respectively while CTDI for ages <= 2 , 2< age >=5 and Age > 5 were 38.74, 31.49, and 34.44 mGy respectively. When The mean DLP for the male and female were 465.71 and 638.38 mGy.Cm^2 respectively while DLP for ages <= 2, 2<age>=5 and Age > 5 were 546.55, 453.00, and 536.75 mGy.Cm^2 respectively.

Figures (4.2 – 4.3) shows the effective dose and variation of them due to selections of different parameters, kv, s, mAs, CTDI and DLP.

CTDI and DAP were the highest in Female thus the highest one in ED while male the lowest in every tings of them. When CTDI and DLP was lower in medium age than the highest age and the lowest age which recorded the highest measured in CTDI and DLP and so ED this due to duration of exam and numbers of positions and so for the highest selection of kv and mAs.

In this study correlation; between effective dose ED (mGy) compared to current of the exam (mAs), Computed tomography Dose Index (CTDI) and dose area product DAP ($mGy.Cm^2$); R^2 are 0.671, 0.784 and 0.670 respectively which are good in all of them. Also the correlation between ED increased by0.13, 0.435 and 10.43 unit per 1 mAs, DLP and CTDI unitrespectively. Show Figures (4.3- 4.4 – 4.5).

5.2. Conclusions

Over the past two decades CT scanning rates have increased greatly, and this has increased the average radiation dose delivered to pediatric patients. This literature review has found that medical practitioners are not adequately aware of the stochastic effects of CT, or of diagnostic alternatives to CT. Because of the stochastic effects of ionizing radiation, dose reduction in CT examinations, especially for pediatric patients, must occur. Dose reduction is being implemented by CT manufacturers, but medical imaging professionals must not rely on this alone. Improvements to CT protocols, referral practices and imaging professionals' education are needed to minimize the amount of unnecessary CT dose that is delivered. By undertaking these changes and with continual vigilance, the benefits of CT can be obtained at low radiation dose and the minimum of harmful effects to pediatric patients.

5.3. Recommendations

- Kv, mAs and S mus be minimize to pediatric brain CT.
- An experience and mature staff in department must be found to trainee the new staff.
- Quality control must be done.

References

- Biological shield". United States Nuclear Regulatory Commission.
- (ICRP 2008a) (Line placements i.e. Permacath / Hickman, Transjugular Biopsies, TIPS Stent, Embolisations) Cardiac Studies (PTCA).
- (Roobottom CA, Mitchell G, Morgan-Hughes G2010.”Radiation-reduction strategies in cardiac computed tomographic angiography”). Clin Radial65).
- AERB/RSD/MDX.CT/QAR/2010, Acceptance/Performance Test for Computed Tomography (CT) Scanner. 2010. [Last accessed on 2016 Nov 14]. Available from: http://www.aerb.gov.in/cgi-bin/X-Ray/XRAYuserform.asp .
- Asulieman , k.theodorou,M.Viychou,T.topaltzikis,C.Rounds,ifezoulidis and C.Kappas.radiation dose measurement and Risk estimation for patient under going micturating cystoure thrography.the British journal of radiology.(2007) 80,731-737.
- Asulieman k.theodorou,M.Viychou,T.topaltzikis,C.Rounds,ifezoulidis and C.Kappas.radiation dose optimization and risk to patient and staff during hysterosalpingography radiation protection dosimetery 128,2(2);217-226.
- Asuliman K. Theodouro,M , vlye Hou, T-Top Al T, Kis, C, Roundas I, Fezoulids and C appas Radiation dose optimization and risk estimation to patient is and Staff during hystero sapling agraphy Radiation protection dosimetry 2008.
- Balter S. Interventional fluoroscopy: physics, technology, safety. New York: Wiley-Liss, 2001.
- BALTER, S. Capturing patient doses from fluoroscopically based diagnostic and interventional systems. Health Phys 95 5 (2008) 535-540.

- BALTER, S., HOPEWELL, J.W., MILLER, D.L., WAGNER, L.K., ZELEFSKY, M.J., Fluoroscopically guided interventional procedures: A review of radiation effects on patients' skin and hair. Radiology 254 2 (2010) 327-341.
- Broadhead DA,chapple ,BA,andK Faulkner,the impact of digital imaging on patient doses durink barium studies .the British journal of radiology (1995) 68,992-996.
- CIRAJ-BJELAC, O., REHANI, M. M., SIM, K. H., LIEW, H. B., VANO, E., KLEIMAN, N. J., Risk for radiation induced cataract for staff in interventional cardiology: is there reason for concern? Catheter. Cardiovasc. Interv. 76 (2010) 826–834.
- CT Dose Profiler, Probe for Evaluation of CT Systems Manual-Version 5.2A, RTI, Sweden. [Last accessed on 2019 August 20]. Available from: http://www.rtise/
- Donnelly LF, Emery KH, Brody AS, Laor T, Gylys-Morin VM, Anton CG, et al. Minimizing radiation dose for pediatric body applications of single-detector helical CT: Strategies at a large Children's Hospital. AJR Am J Roentgenol. 2001;176:303–6.[PubMed] [Google Scholar]
- ESam Eltom evaluation of qulity control in diagnostic radiology .M.SCthesis.collage of medical radiological sciences.
- European Guidelines on DRLs for Pediatric Imaging, Final Complete Draft for PiDRL Workshop. 2015. Sep 30, [Last accessed on 2015 Nov 05]. p. 38. Available from: http://www.eurosafeimaging.org .
- EvANO . et al (1991) Radiologists (wlto-isH,1997, Faulkner, 1997) .
- Fend Shannoun Maria Blettner. Radiation Protection in Diagnostic Radiology,
- G.I. Ogbole, radiation dose in paediatric computed tomography: risks and benefits, 2010 Dec; 8(2): 118–126.

- http://www.nrc.gov/reading-rm/basic-ref/glossary/biological-shield.html. Retrieved 13 August 2011
- IYAH LIM, CT Scan Components, SUNDAY, MARCH 5, 2017
- *Jiang Hsieh*, et, al, Computed Tomography: Principles, Design, Artifacts, and Recent Advances, Second Edition, 2009.
- L. Lau (Rapporteur), Global Initiative on Radiation Safety in Health Care Settings Workshop Report , Radiation Risk Communication in Paediatric Imaging, 2nd December 2012.
- ***LA Times***, 'Use of imaging tests soars, raising questions on radiation risk', 2012.
- Lam W, Wendy WM Lam. Pediatric CT radiation risks: What you should know. Med Bull. 2006;11:5–7. [Google Scholar]
- McCollough CH, Rochester MN. Diagnostic Reference Levels, American College of Radiology. 2010. [Last accessed on 2016 Nov 10]. Available from: http://WWW.IMAGEWISELY.ORG .
- Nationwide Evaluation of X-ray Trends (N.E.X.T). Tabulation and Graphical Summary of 2000 Survey of Computed Tomography. 2007. [Last accessed on 2016 Nov 14]. Available from: http://www.crcpd.org/PDF/NEXT2000CTProl.pdf .
- Nor Hanani, et, al, Computed Tomography Dose in Paediatric Care: Simple Dose Estimation Using Dose Length Product Conversion Coefficients, 30 Aug 2018.
- Saravanakumar A, Vaideki K, Govindarajan KN, Jayakumar S, Devanand B. Cost-effective pediatric head and body phantoms for computed tomography dosimetry and its evaluation using pencil ion chamber and CT dose profiler. J Med Phys. 2015;40:170–5.[PMC free article] [PubMed] [Google Scholar]

Saravanakumar A, Vaideki K, Govindarajan KN, Jayakumar S. Establishment of diagnostic reference levels in computed tomography for select procedures in Pudhuchery, India. J Med Phys. 2014;39:50–5. [PMC free article] [PubMed] [Google Scholar].لِ