Chapter One

1. Introduction

1.1. Introduction

The two basic principles of radiation protection of patient recommended by the ICRP are justification of practice and optimization of protection. In diagnostic radiology, periodic dose assessments should be made to encourage the optimization of the radiation protection of the patients. Dose measurements are required further to compare different radiological techniques and to comply with some international guidelines and regulations.

CT is one of the many technologies that were made possible by the invention of the computer. The clinical potential of CT became obvious during its early clinical use, and the excitement forever solidified the role of computers in medical imaging. Recent advances in acquisition geometry, detector technology, multiple detector arrays, and x-ray tube design have led to scan times now measured in fractions of a second. Modern computers deliver computational power that allows reconstruction of the image data essentially in real time. The invention of the CT scanner earned Godfrey Hounsfield of Britain and Allan Cormack of the United States the Nobel Prize for Medicine in 1979. CT scanner technology today is used not only in medicine but in many other industrial applications, such as nondestructive testing and soil core analysis (Jerrold T. Bushberg, and others, 2002).

To minimize radiation dose from CT through advances in technology, is better radiation dose estimation techniques, and to practically apply current dose reduction procedures. (David L. Coy, and others, 2015).

There exist patient-specific factors such as size, sex, **age**, and radiation sensitivity that can also affect the estimation of radiation dose and risk. (David L. Coy, and others, 2015)

1.2. **Literature review:-**

Huda and Ogden in their study(2008) in (Comparison of head and body organ doses in CT) compare head and body organ doses received by adult patients undergoing whole body scans operated using the same technique factors. Dosimetry data were obtained for six CT scanners (16 and 64 slice) from four vendors. Organ doses were obtained using the ImPACT CT dose software package for an adult male, together with the corresponding head and body CTDIw. The data provide a link between the CTDI doses generated on most commercial scanners for each clinical CT examination and doses to organs and tissues within the directly irradiated region of an adult patient. The average numerical ratio of the brain dose to the head phantom CTDIw is 0.84 ± 0.05, the average ratio of the lung dose and liver dose to the body phantom CTDIw is 1.65 ± 0.05 and 1.48 ± 0.05, respectively. When scanned under identical conditions, lung doses are similar to brain doses, and liver doses are only -10% lower. By comparison, the average body to head CTDIw ratio was 0.49 ± 0.06, which erroneously implies that doses to organs in the head are twice those of doses to organs in the body at the same techniques. Two CT dosimetry phantom sizes are therefore not required, and our findings support the need to reassess the role, if any, of current cylindrical acrylic dosimetry phantoms. (Walter Huda and Kent M Ogden et al 2008).

W. E. Muhogora, N. A. Ahmed in their study(2010) “paediatric CT Examinations in 19 Developing Countries: Frequency and Radiation

Dose" investigated the frequency of computed tomography (CT) examinations for paediatric patients below 15 y of age in 128 CT facilities in 28 developing countries of Africa, Asia and Eastern Europe and to assess the magnitude of CT doses. Radiation dose data were available from 101 CT facilities in 19 countries. The dose assessment was performed in terms of weighted CT dose index ($CTDI_W$), volume CT index and dose length product (DLP) for chest, chest (high resolution), lumbar spine, abdomen, and pelvis CT examinations using standard methods. The results show that on average the frequency of paediatric CT examinations was 20, 16 and 5 % of all CT examinations in participating centers in Africa, Asia and Eastern Europe, respectively. Eleven CT facilities in six countries were found to use adult CT exposure parameters for paediatric patients, thus indicating limited awareness and the need for optimization. CT images were of adequate quality for diagnosis. The $CTDI_W$ variations ranged up to a factor of 55 (Africa), 16.3 (Asia) and 6.6 (Eastern Europe). The corresponding DLP variations ranged by a factor of 10, 20 and 8, respectively. Generally, the $CTDI_W$ and DLP values in Japan are lower than the corresponding values in the three regions in this study. The study has indicated a stronger need in many developing countries to justify CT examinations in children and their optimization. Awareness, training and monitoring of radiation doses is needed as a way forwards. (W. E. Muhogora and N. A. Ahmed, et al, 2010).

M. Elnour, and A. Suleiman in their study(2009) "Optimization of Patient Dose in Abdominal Computerized Tomography" The purpose of this study was to optimize the radiation dose, estimate the effective dose and radiation risk during adult computed tomographic (CT) for abdomen. A total of 83 patients referred to The National Ribat University Hospital (NRUH) in the period of the study with abdominal disturbances. Data of

the technical parameters used in CT procedures was taken during May - October, 2009. The patients were divided into two groups: Control group (53patients) were examined with the own department protocol using multi-slice CT (MSCT) 16 slice (Siemens Sensation); and optimization group (30 patients). Optimization was achieved through; the design of dose efficient equipment, the optimization of scan protocol and improvement of referring criteria. Organ and surface dose to specific radiosensitive organs was estimated by using software from National Radiological Protection Board (NRPB). The mean age was 45.4±18 years while the mean weight was 67±14Kg. The DLP was 288.25 mGy.cm and CTDIvol was 9.7 mGy. Patient effective doses were 13.5 mSv before the optimization. Conversely, this was reduced to 4.3 mSv after dose optimization. Estimated radiation risk is 742 $x10^{-6}$ conversely the risk was reduced to 237 $x10^{-6}$. Dose optimized protocol lowered the effective doses to 31.9%. (M. Elnour and A. Suleiman, et al, 2009).

Justin E. Ngaile, and Peter K. Msaki in study (2006)" Estimation of patient organ doses from CT examinations in Tanzania" The aims of this study are, first, to determine the magnitude of radiation doses received by selected radiosensitive organs of patients undergoing CT examinations and compare them with other studies, and second, to assess how CT scanning protocols in practice affect patient organ doses. In order to achieve these objectives, patient organ doses from five common CT examinations were obtained from eight hospitals in Tanzania. The patient organ doses were estimated using measurements of CT dose indexes (CTDI), exposure-related parameters, and the ImPACT spreadsheet based on NRPB conversion factors. A large variation of mean organ doses among hospitals was observed for similar CT examinations. These variations largely originated from different CT scanning protocols used in

different hospitals and scanner type. The mean organ doses in this study for the eye lens (for head), thyroid (for chest), breast (for chest), stomach (for abdomen), and ovary (for pelvis) were 63.9 mGy, 12.3 mGy, 26.1 mGy, 35.6 mGy, and 24.0 mGy, respectively. **(**Justin E. Ngaile and Peter K. Msaki, et al, 2006).

1.3. **Problem of Study:-**

Radiation is a major risk in diagnostic and therapeutic medical imaging. The problem is caused from incorrect use of radiography equipment and from the radiation exposure to patients much more than required.

1.4. **Objectives:-**

1.4.1. **General Objective:-**

The main objective of this study is to Evaluate Patient Radiation Dose during CT of K.U.B in Khartoum (Modern Medical Center, Khartoum)

1.4.2. **Specific Objectives:-**

- ✓ To calculated Effective Dose (ED).
- ✓ To Estimate the radiation risks.

1.5. **Overview of the thesis: -**

Chapter one: Introduction and Literature review. It presents the statement of the study problems, objectives of the study.

Chapter two: radiological physics and back ground.

Chapter three: material and method.

Chapter four: results.

Chapter five: discussions, conclusions, recommendations and references.

Chapter Two

2. **Theoretical background**

2.1. **Anatomy:-**

2.1.1. **Abdominal:-**

Esophagus:-

The esophagus is a tubular structure that joins the pharynx to the stomach. The esophagus pierces the diaphragm slightly to the left of the midline and after a short course of about 0.5 in. (1.25 cm) enters the stomach on its right side. It is deeply placed, lying behind the left lobe of the liver.

Stomach:-

The stomach is a dilated part of the alimentary canal between the esophagus and the small intestine. It occupies the left upper quadrant, epigastric, and umbilical regions, and much of it lies under cover of the ribs. Its long axis passes downward and forward to the right and then backward and slightly upward.

Small Intestine:-

The small intestine is divided into three regions: duodenum, jejunum, and ileum. The duodenum is the first part of the small intestine, and most of it is deeply placed on the posterior abdominal wall. It is situated in the epigastric and umbilical regions. It is a C-shaped tube that extends from the stomach around the head of the pancreas to join the jejunum. About halfway down its length the small intestine receives the bile and the pancreatic ducts.

The jejunum and ileum together measure about 20 ft (6 m) long; the upper two fifths of this length make up the jejunum. The jejunum begins at the duodenojejunal junction, and the ileum ends at the ileocecal junction. The coils of jejunum occupy the upper left part of the abdominal

cavity, whereas the ileum tends to occupy the lower right part of the abdominal cavity and the pelvic cavity.

Large Intestine:-

The large intestine is divided into the cecum, appendix, ascending colon, transverse colon, descending colon, sigmoid colon, rectum, and anal canal. The large intestine arches around and encloses the coils of the small intestine and tends to be more fixed than the small intestine.

The cecum is a blind-ended sac that projects downward in the right iliac region below the ileocecal junction. The appendix is a worm-shaped tube that arises from its medial side.

The ascending colon extends upward from the cecum to the inferior surface of the right lobe of the liver, occupying the right lower and upper quadrants. On reaching the liver, it bends to the left, forming the right colic flexure.

The transverse colon crosses the abdomen in the umbilical region from the right colic flexure to the left colic flexure. It forms a wide U-shaped curve. In the erect position, the lower part of the U may extend down into the pelvis. The transverse colon, on reaching the region of the spleen, bends downward, forming the left colic flexure to become the descending colon.

The descending colon extends from the left colic flexure to the pelvis below. It occupies the left upper and lower quadrants.

The sigmoid colon begins at the pelvic inlet, where it is a continuation of the descending colon. It hangs down into the pelvic cavity in the form of a loop. It joins the rectum in front of the sacrum.

The rectum occupies the posterior part of the pelvic cavity. It is continuous above with the sigmoid colon and descends in front of the sacrum to leave the pelvis by piercing the pelvic floor. Here, it becomes continuous with the anal canal in the perineum.

Liver:-

The liver is a large organ that occupies the upper part of the abdominal cavity. It lies almost entirely under cover of the ribs and costal cartilages zand extends across the epigastric region.

Gallbladder:-

The gallbladder is a pear-shaped sac that is adherent to the undersurface of the right lobe of the liver; its blind end, or fundus, projects below the inferior border of the liver.

Pancreas:-

The pancreas is a soft, lobulated organ that stretches obliquely across the posterior abdominal wall in the epigastric region. It is situated behind the stomach and extends from the duodenum to the spleen.

Spleen:-

The spleen is a soft mass of lymphatic tissue that occupies the left upper part of the abdomen between the stomach and the diaphragm. It lies along the long axis of the 10th left rib.

Kidneys:-

The kidneys are two reddish brown organs situated high up on the posterior abdominal wall, one on each side of the vertebral column. The left kidney lies slightly higher than the right (because the left lobe of the liver is smaller than the right). Each kidney gives rise to a ureter that runs vertically downward on the psoas muscle.

Suprarenal Glands:-

The suprarenal glands are two yellowish organs that lie on the upper poles of the kidneys on the posterior abdominal wall. (Richard S. Snell MD, PhD, eight editions)

2.1.2. **The Pelvis:-**

The pelvis is the region of the trunk that lies below the abdomen. Although the abdominal and pelvic cavities are continuous, the two regions are described separately.

The bony pelvis's main function is to transmit the weight of the body from the vertebral column to the femurs. In addition, it contains, supports, and protects the pelvic viscera and provides attachment for trunk and lower limb muscles. The bony pelvis is composed of four bones: the two hip bones, which form the lateral and anterior walls, and the sacrum and the coccyx, which are part of the vertebral column and form the back wall.

The two hip bones articulate with each other anteriorly at the symphysis pubis and posteriorly with the sacrum at the sacroiliac joints. The bony pelvis thus forms a strong basin-shaped structure that contains and protects the lower parts of the intestinal and urinary tracts and the internal organs of reproduction.

The pelvis is divided into two parts by the pelvic brim, which is formed by the sacral promontory (anterior and upper margin of the first sacral vertebra) behind, the iliopectineal lines (a line that runs downward and forward around the inner surface of the ileum) laterally, and the symphysis pubis (joint between bodies of pubic bones) anteriorly. Above the brim is the false pelvis, which forms part of the abdominal cavity. Below the brim is the true pelvis.(Richard S. Snell MD, PhD, eight edition)

2.2. **Physiology:-**

2.2.1. **Abdominal:-**

The complex of digestive processes gradually breaks down the foods eaten until they are in a form suitable for absorption. For example, meat, even when cooked, is chemically too complex to be absorbed from the alimentary canal. It therefore goes through a series of changes which release its constituent nutrients: amino acids, mineral salts, fat and vitamins. Chemical substances or enzymes (p. 26) which effect these changes are secreted into the canal by specialized glands, some of which are in the walls of the canal and some outside the canal, but with ducts leading into it. After absorption, nutrients are used to synthesize body constituents. They provide the raw materials for the manufacture of new cells, hormones and enzymes, and the energy needed for these and other processes and for the disposal of waste materials. The activities in the digestive system can be grouped under five main headings. **Ingestion.** This is the process of taking food into the alimentary tract. **Propulsion.** This moves the contents along the alimentary tract. **Digestion.** This consists of:

- Mechanical breakdown of food by, e.g. mastication (chewing)
- Chemical digestion of food by enzymes present in secretions produced by glands and accessory organs of the digestive system.

Absorption. This is the process by which digested food substances pass through the walls of some organs of the alimentary canal into the blood and lymph capillaries for circulation round the body. **Elimination.** Food substances which have been eaten but cannot be digested and absorbed are excreted by the bowel as faeces. (Anne Waugh and Allison Grant, 2001)

2.2.2. **Pelvis:-**

The functions of the female reproductive system are:

- Formation of female gametes, ova.
- Reception of male gametes, spermatozoa.
- Provision of suitable environments for fertilization of the ovum by spermatozoa and development of the resultant fetus.
- Parturition (childbirth).
- Lactation, the production of breast milk, which provides complete nourishment for the baby in its early life.

The functions of the male reproductive system are:

- Production of male gametes, spermatozoa.
- Transmission of spermatozoa to the female. (Anne Waugh and Allison Grant, 2001).

2.3. **Instrumentation:-**

2.3.1. **CT scanner:-**

The three major systems are housed in separate room as follows:-

- The imaging system is located in the scanner room.
- The computer system is located in the computer room.
- The display, recording, and storage system is located in the operator's room.

The purpose of the imaging system is to produce x- ray, shape and filter the x- ray beam to pass through only a defined cross-section of the patient, detect and measure the radiation passing through the cross-section, and convert the transmitted photons into digital information.

The major components of the imaging system are the x-ray tube and generator, collimators, filter, detectors, and detector electronics.

The computer system generally includes input-output devices central processing unit, array processor, interface devices, back-projector processors, storage devices, and communications hardware.

The computer system receives the digital data from the DAS and processes it to reconstruct an image of the cross-section anatomy.

The purpose of the image display, recording, storage, and communication system is as follow:-

- To display the output digital image from the computer.
- To provide a hard copy of the image on a recording medium they provide for a permanent copy of the reconstructed image and accommodate the preference of the radiologist during diagnostic interpretation.
- To facilitate the storage and retrieval of digital data.
- To communicate images, diagnostic reports, and patient demographic data in an electronic communications. (Euclid Seeram, 2001).

2.3.2. **Gantry:-**

The gantry is a mounted framework the surrounds the patient in a vertical plane. The gantry houses imaging components such as the slip rings, x-ray tube, high-tension generator, collimators, detectors, and DAS. Two important features of the gantry are the gantry aperture and gantry tilting rage. (Euclid Seeram, 2001).

2.3.3. **Patient couch:-**

The patient couch, or patient table, provides a platform or which the patient lies during the examination. The couch should be strong and rigid to support the weight of the patient. It should provide for safety and comfort of patient during the examination. (Euclid Seeram, 2001).

2.4. **Generations of Computed Tomography:-**

The previous description of a finely collimated x-ray beam and single detector assembly that translates across the patient and rotates between successive translations is characteristic of first-generation CT imaging systems.

The original EMI imaging system required 180 translations, which were separated from one another by a 1-degree rotation. It incorporated two detectors and split the finely collimated x-ray beam so that two contiguous slices could be imaged during each procedure. The principal drawback to these systems was that nearly 5 minutes was required to complete a single image. Therefore, shorter imaging times were possible. Because of the multiple detector arrays, a single translation resulted in the same number of data points as several translations with a first-generation CT imaging system. Consequently, translations were separated by rotation increments of 5 degrees or more. With a 10-degree rotation increment, only 18 translations would be required for a 180-degree image acquisition. (Stewart Carlyle Bushong, 2013).

(a) (b)

Figure (2-1a):- Conventional tomography results in an image that is parallel to the long axis of the body. Computed tomography (CT) produces a transverse image.

Figure (2-1b):- in its simplest form, a computed tomography (CT) imaging system consists of a finely collimated x-ray beam and a single detector, both of which move synchronously in a translate and rotate fashion. Each sweep of the source detector assembly results in a projection, which represents the attenuation pattern of the patient profile.

2.4.1. **First-generation:-**

The First-generation CT imaging systems can be considered a demonstration project. They proved the feasibility of the functional marriage of the source-detector assembly, mechanical gantry motion, and the computer to produce an image. (Stewart Carlyle Bushong, 2013).

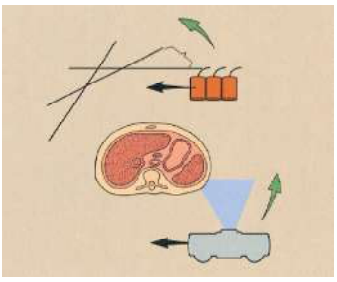
2.4.2. **Second-generation:-**

The second-generation imaging systems were also of the translate and rotate type. These units incorporated the natural extension of the single detector to a multiple detector assembly while intercepting a fan-shaped rather than a pencil-shaped x-ray beam. One disadvantage of the fan beam is the increased radiation intensity that occurs toward the edges of the beam because of body shape. This is compensated for with the use of a “bow tie” filter. These characteristic features of a first-versus a second-generation CT imaging system.

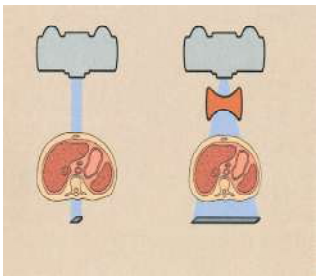
The principal advantage of the second-generation CT imaging system was speed. These imaging systems consisted of five to 30 detectors in the detector assembly;

The principal limitation of second-generation CT imaging systems was examination time. Because of the complex mechanical motion of

translation and rotation and the enormous mass involved in the gantry, most units were designed for imaging times of 20 seconds or longer. This limitation was overcome by third-generation CT imaging systems. With these imaging systems, the source and the detector array are rotated about the patient. As rotate-only units, third generation imaging systems can produce an image in less than 1 second. (Stewart Carlyle Bushong, 2013).



(a)



(b)

Figure (2-2a):- Second-generation computed tomography imaging systems operated in the translate and rotate mode with a multiple detector array intercepting a fan-shaped x-ray beam.

Figure (2-2b):- Profiles of two x-ray beams used in computed tomography (CT) imaging. With the fan-shaped beam of second generation, a bow-tie filter is used to equalize the radiation intensity that reaches the detector array. For first generation CT, a pencil x-ray beam is used.

2.4.3. **The Third-generation:-**

The Third-generation CT imaging system uses a curvilinear array that contains many detectors and a fan beam. The number of detectors and the width of the fan beam between 30 and 60 degrees are both substantially larger than for second-generation imaging systems.

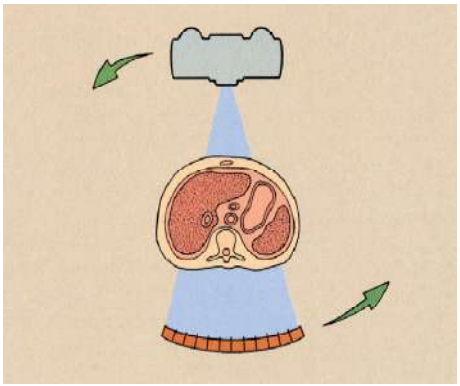
In third-generation CT imaging systems, the fan beam and the detector array view the entire patient at all times.

The curvilinear detector array produces a constant source-to-detector path length, which is an advantage for good image reconstruction. This feature

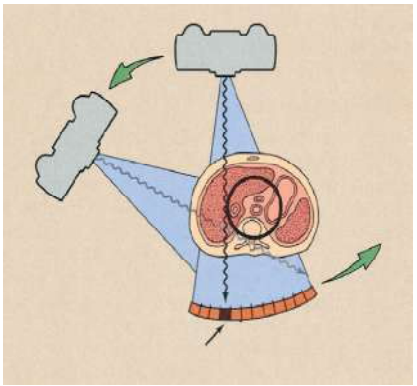
of the third generation detector assembly also allows for better x-ray beam collimation and reduces the effect of scatter radiation.

One of the principal disadvantages of third-generation CT imaging systems is the occasional appearance of ring artifacts. If any single detector or bank of detectors malfunctions, the acquired signal or lack thereof results in a ring on the reconstructed image (Figure 2-6b).

These ring artifacts were troublesome with early third generation CT imaging systems. Software-corrected image reconstruction algorithms now remove such artifacts. (Stewart Carlyle Bushong, 2013).



(a)



(b)

Figure (2-3a):- Third-generation computed tomography imaging systems operate in the rotate-only mode with a fan x-ray beam and a multiple detector array revolving concentrically around the patient.

Figure (2-3b):- Ring artifacts can occur in third-generation computed tomography imaging systems because each detector views an annulus (ring) of anatomy during the examination. The malfunction of a single detector can result in the ring artifact.

2.4.4. **The fourth-generation:-**

The fourth-generation design for CT imaging systems incorporates a rotate and stationary configuration. The x-ray source rotates, but the

detector assembly does not. Radiation detection is accomplished through a fixed circular array of detectors (Figure 2-7), which contains as many as 4000 individual elements. The x-ray beam is fan shaped with characteristics similar to those of third-generation fan beams. These units are capable of sub second imaging times, can accommodate variable slice thickness through automatic pre-patient collimation, and have the image manipulation capabilities of earlier imaging systems.

The fixed detector array of fourth-generation CT imaging systems does not result in a constant beam path from the source to all detectors, but it does allow each detector to be calibrated and its signal normalized for each image, as was possible with second-generation imaging systems. Fourth-generation imaging systems were developed because they are free of ring artifacts.

Huge jumps occurred in development between the first and second generations, and even larger developments occurred between the second and third generations. The third-generation version became the de facto baseline model from which later generations were advanced. Today, CT imaging systems are helical, multi-slice third generation. (Stewart Carlyle Bushong, 2013).

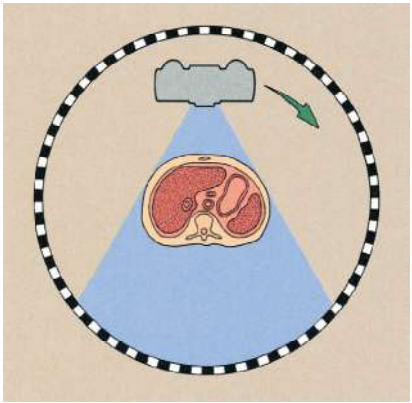


Figure (2-4):- Fourth-generation computed tomography imaging systems operate with a rotating x-ray source and stationary detectors.

2.4.5. **Fifth Generation: Stationary/Stationary:-**

A novel CT scanner has been developed specifically for cardiac tomography imaging. This "cine-CT" scanner does not use a conventional x-ray tube; instead, a large arc of tungsten encircles the patient and his directly opposite to the detector ring.

x-rays are produced from the focal track as a high-energy electron beam strikes the tungsten. There are no moving parts to this scanner gantry. The electron beam is produced in a cone-like structure (a vacuum enclosure) behind the gantry and is electronically steered around the patient so that it strikes the annular tungsten target. Cine-CT systems, also called electron beam scanners, are marketed primarily to cardiologists. They are capable of 50-msec scan times and can produce fast-frame-rate CT movies of the beating heart. (Jerrold T. Bushberg, and others, 2002).

2.4.6. **Sixth Generation: Helical:-**

Actually, the gantry motion in multi-slice helical CT is not like a slinky toy; it just appears that way. When the examination begins, the x-ray tube rotates continuously. While the x-ray tube is rotating, the couch moves the patient through the plane of the rotating x-ray beam. The x-ray tube is energized continuously, data are collected continuously, and an image then can be reconstructed at any desired z-axis position along the patient. (Stewart Carlyle Bushong, 2013).

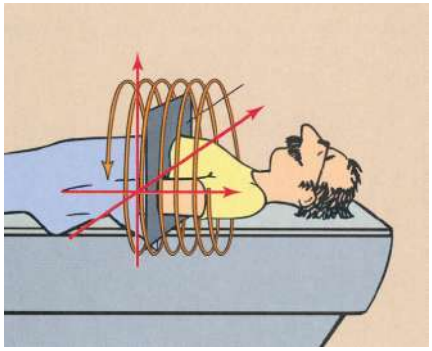


Figure (2-5):- Transverse images can be reconstructed at any plane along the z-axis.

2.4.7. **Seventh Generation: Multiple Detector Array**

Multiple detector array CT scanner may operate with four contiguous, 5-mm detector arrays and 20-mm collimator spacing. For the same technique (kilo-voltage [kv] and mAs), the number of x-rays being detected is four times that of a single detector array with 5-mm collimation. Furthermore, the data set from the 4 × 5 mm multiple detector arrays can be used to produce true 5-mm slices or data from adjacent arrays can be added to produce true 10-, 15-, or even 20-mm slices, all from the same acquisition. The flexibility of CT acquisition protocols and increased efficiency resulting from multiple detector array CT scanners allows better patient imaging; however, the number of parameters involved in the CT acquisition protocol is increased as well. (Jerrold T. Bushberg, and others, 2002).

2.5. **Radiation Quantities and Units:-**

Radiation dose in CT is classified according to the examinations that use radiation at low-dose rates. Although the risk of cancer incidence from radiation exposure with low-dose rate is lower than that high-dose rate, when a human is exposed to the same radiation dose, the International Commission on Radiation Protection (ICRP) recommends using a dose and dose-rate effectiveness factor (DDREF). The radiation dose for each CT examination should be managed according to the LNT model because the risk of cancer incidence from radiation exposure on CT examinations cannot be excluded completely. (Luca Saba, and Jasjit S. Suri, 2014).

Milligray: is a measure of the absorption of ionizing energy per unit mass of matter and is measured in joules per kilogram. The milligray is used as a unit of measure for both the radiant ionizing energy from the

scanner ($CTDI_{vol}$) and absorbed radiation dose in the patient. (www.pubs.rsna.org).

Millisievert: is a unit of effective radiation dose that is dependent on both the amount of absorbed radiation (in milligrays) and the relative radiosensitivity of the exposed organs. It is derived from the absorbed dose to a generic reference (both sexes, all ages, standard-size patient) and is meant to normalize stochastic risk by a representative average whole-body dose. (www.pubs.rsna.org).

2.5.1. **Absorbed dose:-**

Absorbed dose is a measure of the energy deposited in a medium by ionizing radiation and is equal to the energy deposited per unit mass of medium, which is measured as joules per kilogram (J/kg) and represented by gray (Gy). When it is applied to patient dose measurement the dose is averaged over the whole volume of each tissue or organ. (Luca Saba, and Jasjit S. Suri, 2014).

2.5.2. **Equivalent Dose:-**

Equivalent dose is used in radiation protection and is not measurable in practice. It accounts for the biological damage potential of different multiplying the absorbed dose for each organ or tissue by the radiation weighting factor (x-ray is defined as 1). It can be calculated from the following equation:

$$H_T = W_R D_T \qquad (1)$$

Where H_T is the equivalent dose (in sieverts, Sv), W_R is the radiation weighting factor, D_T is the absorbed dose for each organ or tissue. (Luca Saba, and Jasjit S. Suri, 2014).

2.5.3. **Effective dose:-**

Effective dose is also used in radiation protection and is not measurable in practice. It can compare the stochastic risk of a no uniform exposure to ionizing radiation with the risk caused by a uniform exposure of the whole body. The effective dose is obtained by calculating a weighted average of the whole-body equivalent dose to different body tissues with tissue weighting factor, which are designed to reflect the different radio-sensitivities of the tissues. It can be calculated from the following equation:

$$E = \sum_T W_T H_T \qquad (2)$$

Where E is the effective dose (Sv) and W_T is the tissue weighting factor. The effective dose is defined and estimated in a reference person and provides a value that considers the given exposure conditions but not the characteristics of a specific individual. (Luca Saba, and Jasjit S. Suri, 2014).

2.5.4. **Organ dose determinations**: -

The organ dose conversion factor f (organ, z) was obtained from the NRPB datasets (NRPB-SR250) based on the Monte Carlo simulations. The CT Dose software supplied by the ImPACT group was used. $CTDI_{air}$ normalized to 100 mAs ($nCTDI_{air}$), CT scanner manufacturer and model, and typical scanning parameters such as kv, mA, exposure time, pitch, slice thickness, gender, and start and end positions of each scan were used as input data to the CT Dose spreadsheet in organ dose estimations. (M. Elnour, and A. Suleiman, 2009).

2.5.5. **Cancer risk estimation**: -

The risk (R_T) of developing cancer in a particular organ (T) following ERCP after irradiation was estimated by multiplying the mean organ equivalent (H_T) dose with the risk coefficients (f_T) obtained from ICRP.

$$R_T = H_T \cdot f_T$$

The overall lifetime mortality risk (R) per procedure resulting from cancer/heritable was determined by multiplying the effective dose (E) by the risk factor (f). The risk of genetic effects in future generations was obtained by multiplying the mean dose to the ovaries by the risk factor. (M. Elnour, and A. Suleiman, 2009).

$$R = E \cdot f = \sum R_T \qquad (3)$$

2.6. **Radiation Dose Descriptors in CT:-**

2.6.1. **CT Dose index:-**

The principal dosimetric quantity used in CT is the CT dose index (CTDI). This is defined as the integral along a line parallel to the axis of rotation (z) of the dose profile (D (z)) for a single rotation and a fixed table position, divided by the nominal thickness of the x-ray beam. CTDI can be conveniently assessed using a pencil ionization chamber with an active length of 100 mm, so as to provide a measurement of $CTDI_{100}$, expressed in terms of absorbed dose to air

$$CTDI = \left(\frac{1}{nT}\right) \int_{-\infty}^{\infty} D(z)dz \qquad (1)$$

Where n is the number of slices, T is the slice thickness and D (z) is the dose profile along the z-axis from a single acquisition

$CTDI_{100}$ is measured in units of exposure (C/Kg) and is converted to absorbed dose (mGy). A pencil type ionization chamber that has a 100 mm active length is inserted within the phantom's holes to measure the absorbed dose. Therefore, $CTDI_{100}$ is defined and calculated using the absorbed dose within a 100 mm length along the z-axis within the chamber. (Luca Saba, and Jasjit S. Suri, 2014).

Weighted CTDI:- Absorbed doses between central and peripheral regions of an object are different in CT scans. To take this difference into consideration, the weighted CTDI ($CTDI_w$) is defined by the following equation:

$$CTDI_w = \frac{1}{3} CTDI_{100,c} + \frac{2}{3} CTDI_{100,p} \qquad (2)$$

Normalized ($nCTDI_w$):- is $CTDI_w$ per 100mAs. (Luca Saba, and Jasjit S. Suri, 2014).

Volume weighted CT dose index ($CTDI_{vol}$):-

The volume weighted CTDI has been defined by the International Electro-technical Commission (2003)

$$CTDI_{VOL} = \frac{CTDIw}{CT\ pitch\ factor} \qquad (mGy) \qquad (3)$$

Where

$$CT\ pitch\ factor = \frac{\Delta d}{N \times T}$$

And Δd is the distance (mm) moved by the patient support in the z-direction between consecutive serial scans or per rotation in helical scanning; NxT (mm) is the nominal beam collimation (Equation 1). $CTDI_{vol}$ is recommended for display on the CT scanner console (IEC, **2003).**

$CTDI_{vol}$ represents the average value of the weighted CTDI throughout the volume scanned in a particular sequence. (Assessment of patient Dose in CT, 2004).

Volumetric CTDI: To represent the dose for a consecutive CT scan, it is essential to take pitch, gaps, or overlaps into consideration. Volumetric ($CTDI_{vol)}$ is defined by the following equation:-

$$CTDI_{vol} = \frac{nT}{I} CTDI_w \text{ for sequential scans}$$

$$CTDI_{vol} = \frac{1}{P} CTDI_w \text{ for helical scans}$$

I: is the table increment between each scan.

From these equations, the local absorbed dose for a specific CT protocol can be obtained.

$CTDI_{vol}$ is the most familiar dose parameter because it is displayed on the console of CT scanners.

One should know that although $CTDI_{vol}$ is not the absorbed dose of an actual patient, patient organ dose may be estimated from it. (Pelvis = 0.019 normalized effective dose per DLP for adult) (Luca Saba and Jasjit S. Suri, 2014).

2.6.2. **Dose-Length Product:-**

The dose-Length Product (DLP) for a complete examination is defined as:

$$DLP = \sum_i n\ CTDI_w \times (N \times T) \times n \times C \qquad \text{(mGy cm)} \quad (1)$$

where í: is the number of scan sequences in the examination, each with n rotations of nominal beam collimation N×T (Equation 1, but expressed in cm) and radiographic exposure C mAs per rotation; $nCTDI_w$ is the

normalized weighted CTDI (mGy $mA^{-1}s^{-1}$) appropriate for the applied potential and total nominal beam collimation.

Alternatively, the DLP for each scan sequence is given by (McNitt-Gray, 2002):

$$DLP = CTDI_w \times L \quad \text{(mGy cm)} \quad (2)$$

Where L is the scan length (cm), limited by the outer margins of the exposed scan range, irrespective of pitch (which is, of course, already included in $CTDI_{vol}$). For a helical scan sequence, this is the total scan length that is exposed during (raw) data acquisition, including any additional rotation(s) at either end of the programmed scan length necessary for data interpolation. For serial scanning, L is the distance between the outer margins of the first and last slices in a sequence. (Assessment of patient Dose in CT, 2004).

Dose-Length Product is defined by the following equation:

$$DLP = CTDI_{vol} \times \text{exposure length.} \quad (3)$$

The unit of DLP is mGy.cm. The patient effective dose can be estimated from DLP using the following equation:

$$E = K_E . DLP \quad (4)$$

Where K_E is the effective dose conversion factor ($mSv.mGy^{-1}.cm^{-1}$) that depends on patient age and scanning regions. (Luca Saba and Jasjit S. Suri, 2014).

$$CTDIvol = CTDI_w / Pitch$$

$$EFD = DLP \times EFDLP \quad (5)$$

EFD = Effective dose

EFDLP = is the normalized EFD is associated with as specific scan region of the body ($mSv/mGy^{-1}\ cm^{-1}$).

The normalized Effective dose of Pelvis region equal 0.019 and the normalized effective dose of abdominal region equal 0.015. (Paula J. Visconti and E. Russell Ritenour, 6 editions).

2.6.3. **Multiple Scan Average Doses (MSAD):-**

Multiple Scan Average Dose was also devised as a dose descriptor in CT. In this descriptor, dose profile from consecutive multiple scans are added, and the maximum dose is treated as MSAD, which is an absorbed dose for a certain part of a patient. The dose can be measured for a scan using a specific CT protocol after placing dosimeter at a certain position. Theoretically, MSAD and CTDI are equivalent dose values because MSAD equals the dose value integrated over the dose profile for one rotation, which is equal to CTDI. (Luca Saba and Jasjit S. Suri, 2014).

2.7. **Scanning parameters:-**

CT scanning parameters play an important role and should be carefully selected as they can greatly affect contrast enhancement and noise level in DCE

CT images and hence the diagnostic accuracy of CTP study. Radiation dose is also dependent on the scanning parameters chosen. (Luca Saba and Jasjit S. Suri, 2014).

2.7.1. **Tube voltage:-**

The optimal setting of tube voltage is different between different CTP applications. Ideally, CTP imaging should be performed at the lowest tube voltage available (80kv), at this kilovolt setting the mean photon

energy is closer to the K-edge of iodine (≈33kev) increasing the contrast-to-noise ratio of the TDCs due, input, to greater photoelectric effect. (Luca Saba and Jasjit S. Suri, 2014).

2.7.2. **Tube current:-**

The choice of tube current (in mA) or tube current-seconds (the product of tube current and gantry rotation speed, in mA/s) should be adjusted according to the patient body size or expected attenuation and the radio-sensitivity of the organ / tissue of interest.

Although radiation dose reduction is in proportion to reduction in mA/s, is noise increases by 40% if the mA/s is reduced by half (noise α $\frac{1}{\sqrt{mA/s}}$) the choice of mA/s should lead to a good balance between image quality and radiation dose level. (Luca Saba and Jasjit S. Suri, 2014).

2.7.3. **Gantry rotation speed:-**

Gantry rotation speed controls the temporal resolution of a CT image. The tube current should be adjusted according to gantry speed to ensure a reasonable photon flux level (mA/s). (Luca Saba and Jasjit S. Suri, 2014).

2.7.4. **Scan Duration:-**

Scan duration defines the amount of dynamic data acquired for perfusion analysis. Ideally, the acquisition time should be long enough to cover the entire first pass of contrast in tissue if no estimation of the permeability surface area product (PS) of the micro vasculature is required. Extending the scanning time, however, increases the patient's radiation exposure. (Luca Saba and Jasjit S. Suri, 2014).

2.7.5. **Scan Coverage**:-

The volume of organ included in a quantitative (cine) CTP study is restricted by the CT scanner detector width. To avoid potential side effects from multiple injections of contrast, scanner with a large detector width. (Luca Saba and Jasjit S. Suri, 2014).

Chapter three

3. **Material and Method**

The data used in this study were collected from CT/room in Modern Medical Center Khartoum, Sudan. Data of the technical parameter used in CT procedures was taken during (April, 2016 – May, 2016).

3.1. **Material:-**

A total of 50 Patients (parted to 25 Males and 25 Female) referred to Modern Medical Center in the period of the study within two months**.**

3.1.1. **Subject:-**

Radiation is a major risk in diagnostic and therapeutic medical imaging. The problem is caused from incorrect use of radiography equipment and from the radiation exposure to patients much more than required. The main objective of this study is to Evaluate Patient Radiation Dose during CT K.U.B in Khartoum.

3.1.2. **Machine:-**

The General Electric / dual CT scanner was installed in 1984. Further simulations have been performed for an operating tube voltage of 120 kV and slice thickness of 7 mm. The operating parameters are user selectable for a protocol. All quality control tests were performed to the machine prior any data collection. The tests were carried out by experts from Sudan Atomic Energy Commission (SAEC). All the data were within acceptable range.

3.2. **Method:-**

3.2.1. **Technique used:-**

The selected protocol used Abdominal Pelvis region, Kvp (120), mAs (60 – 160), start scan area using slice thickness 7mm. Start with scout view to localize start and end position.

3.2.2. **CT Dose Measurement:-**

The patient dose estimate from CT examination using the monte-carlo technique requires measurements of CTDI and conversion coefficient. In theory the CTDI, which is measure of the dose from single-slice irradiation, is defined as integral along a line parallel to the axis of rotation (z) of the dose profile, D(z), divided by the nominal slice thickness,(t). In this study dose quantity was obtained (CTDI, DLP) from displayed at the operator's console. CTDI and DLP do not include patient specifics such as size and organ radio-sensitivity.

3.2.3. **Data analysis:-**

All dose parameters will registered from the display monitor in Modern Medical Center CT/room and they use in calculation for the effective dose using conversion factor to CT of Abdomen and Pelvis region examination .then will use as input to the statistical software Excel.

Chapter four

4. **Result**

4.1. **Results':-**

In this study, a total of 50 patients were examined in Modern Medical Center in Khartoum, the study data are presented in the following table and graphs

Table [4-1] shows age distribution in frequency and percentage.

Age / yr	Frequency	Percentage
15-36	26	52%
36-56	15	30%
56-76	9	18%
Total	50	100%

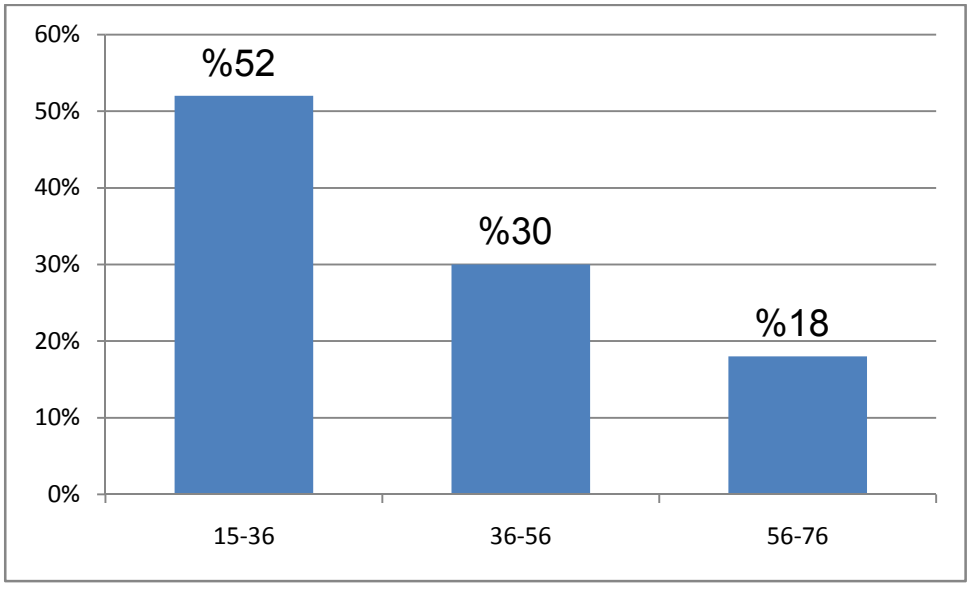


Figure [4-1]:- shows age range and percentage.

Table [4-2]:- Female radiation dose value and estimating risk.

Value	CTDI mGy	DLP mGy	EFD (Pelvis) (mSv)	EFD (ABD) (mSv)	EST (Liver)x 10^{-4} mSv/Sv	EST (Stomach) x10^{-4} mSv/Sv	EST (Ovaries) x10^{-4} mSv/Sv	EST (Uterus) x10^{-4} mSv/Sv
Average	9± 3.1	288± 24.15	5.472 ±0.46	4.320 ±0.36	129.589 ±10.87	341.252 ±28.638	114.902 ±9.634	716.772 ±60.099
Max	28.9	345.4	6.563	5.181	155.43	409.3	137.815	859.701
Min	5.65	213.5	4.057	3.203	96.1	253.01	85.19	531.43

Table [4-3]:- Male radiation dose value and estimating risk.

Value	CTDI (mGy)	DLP (mGy)	EFD (Pelvis) (mSv)	EFD (ABD) (mSv)	EST (Liver) x10^{-4} mSv/Sv	EST (stomach) x10^{-4} mSv/Sv	EST (Testicle) x10^{-4} mSv/Sv
Average	7.396± 0.784	296.578 ±35.673	5.635± 0.678	4.449± 0.562	133.464 ±16.055	351.455 ±42.278	112.702 ±13.558
Max	9.46	374.81	7.121	5.622	168.66	444.138	142.42
Min	5.95	225.05	4.276	3.376	101.28	266.704	85.52

Table [4-4]:- Compared between this study and previous.

Previous Study	Results	This study
Huda and Ogden (2008)	liver doses are only -10% lower	Liver estimate (131.53±13.46)×10^{-4} mSv/Sv

Justin E. Ngaile (2006)	Stomach dose (35.6mGy) Ovary dose (24.0mGy)	Stomach estimate $(346.35\pm35.46)\times10^{-4}$ mSv/Sv Ovaries estimate risk $(114.902\pm9.634)\times10^{-4}$ mSv/Sv
M. Elnour (2009)	Abdomen (4.3 mSv) Estimate risk 237 $x10^{-6}$ DLP was 288.25 mGy CTDIvol was 9.7 mGy	Abdomen(4.38±0.46mSv) Estimate risk $(11.49\pm0.96)\times10^{-6}$ DLP (292.29±29.91mGy) CTDIvol (8.2±1.94mGy)
W. E. Muhogora (2010)	DLP variations ranged by a factor of 10, 20 and 8	DLP(292.29±29.91mGy)

Figure [4-2]:- Relation between age and mAs.

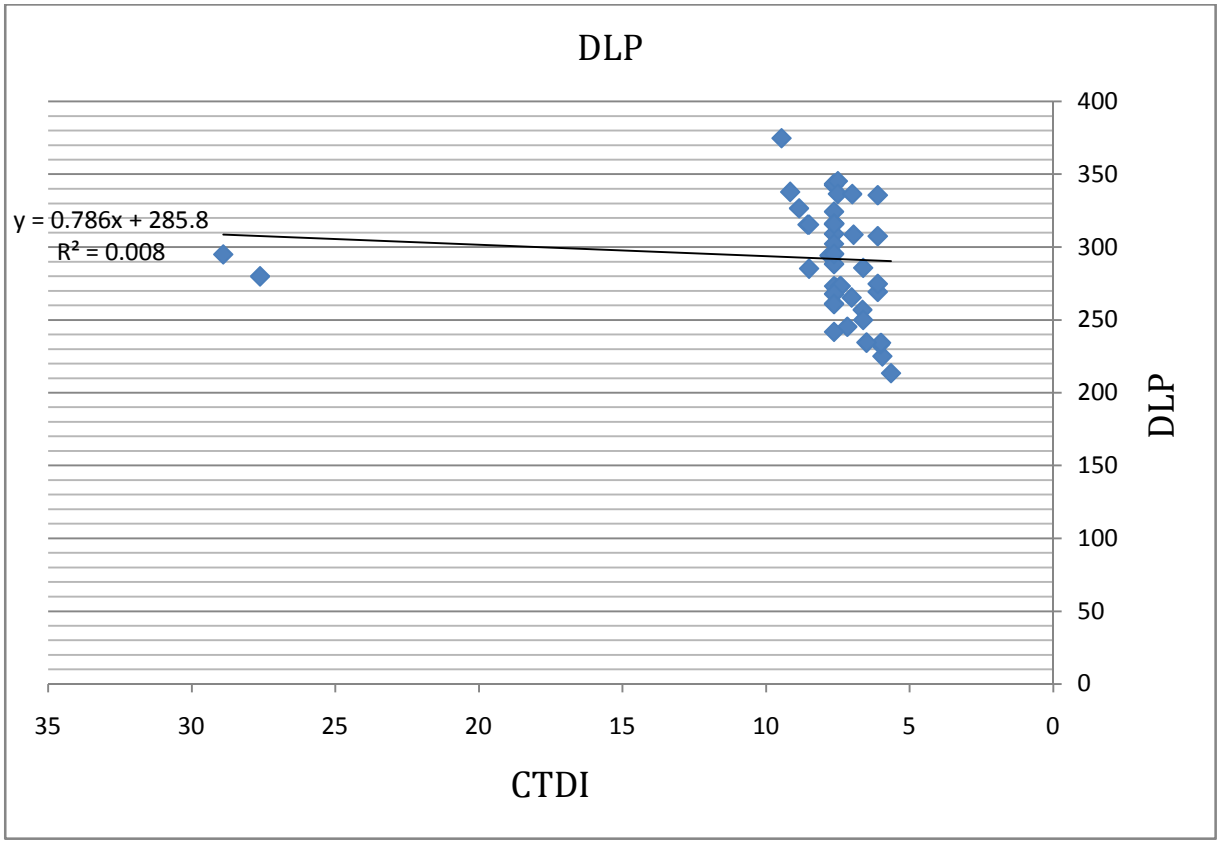


Figure [4-3]:- Relation between CTDI and DLP.

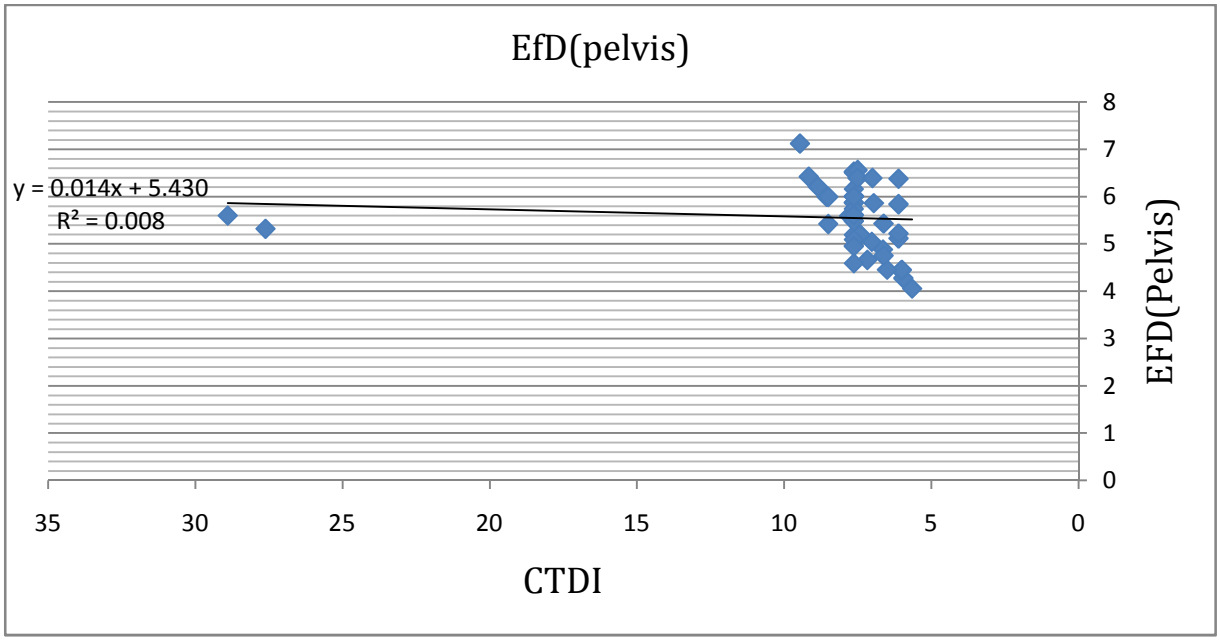


Figure [4-4]:- Relation between CTDI and EFD (Pelvis).

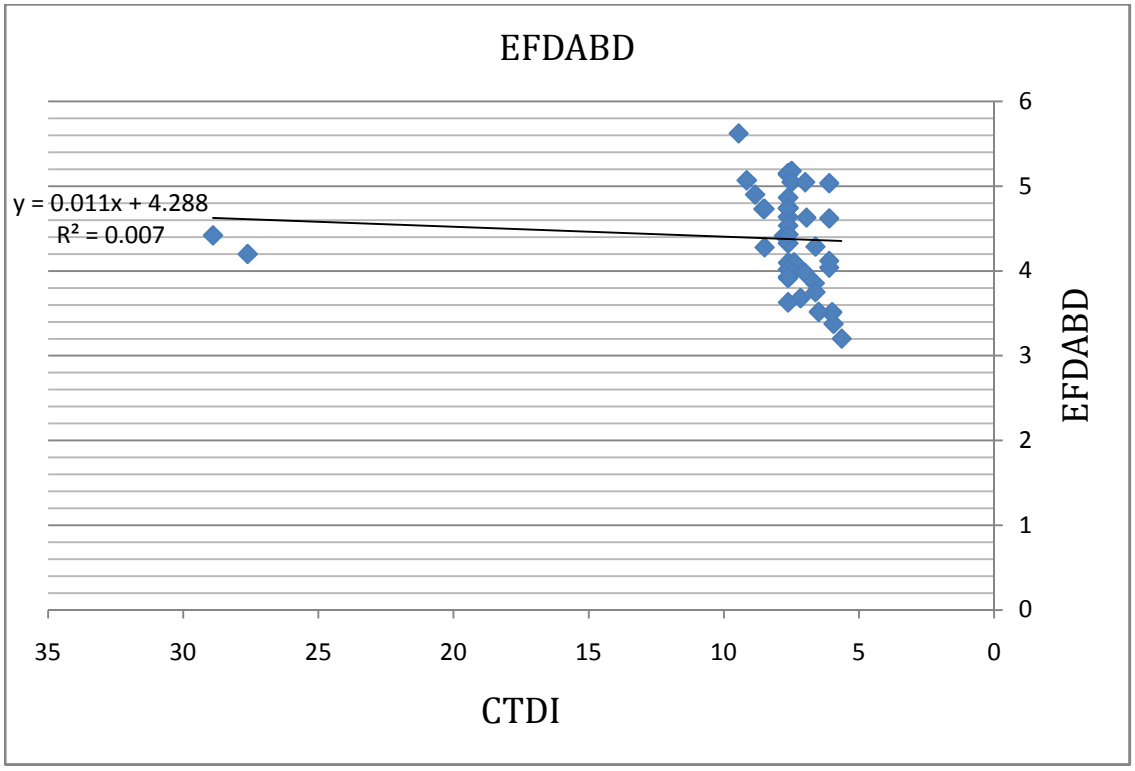


Figure [4-5]:- Relation between CTDI and EFD (Abdomen).

Chapter Five

5. Discussion, Conclusion and Recommendation

5.1. Discussion

CT is versatile and valuable imaging modality in the medical industry. A CT's image quality determines its ability to aid in the care and management of the patient. Recent technical advancements in CT have resulted in remarkable growth in the use of CT imaging in clinical practice. Offering faster acquisition, CT scanner have increased availability of CT imaging and expanded its clinical indications. Exposure to high levels of radiation causes cancer. This is a fact well documented and accepted. What remains controversial, however, is whether low levels of ionizing radiation, such as medical x-rays, are definitively carcinogenic. Based on the assumption that there is no lower threshold for carcinogenesis, the authors try to estimate the radiation dose in CT K.U.B.

This study shows the age range from (15 – 75) years. As expected, most of patients are below 40 years old.

5.1.1. Radiation dose:-

There may be justifiable reasons for some variability in practice, of which the most important one is the difference in clinical indication. This difference is greater if operators and practitioners are insufficiently educated in newly emerging technology. Further, increasing demand in radiology may induce radiologists to use over-intense protocols for CT, for viability to supervise the examination directly while engaged in other work. It is perceived that this is more likely to occur with relatively inexperienced workers and it is also possible that

some examinations are carried out more intensively than needed as a means of clinical risk limitations. Also the study shows average DLP (292.29±29.91mGy/cm), the average CTDIvol (8.2±1.94mGy).

5.1.2. **Effective dose:-**

The value of the effective dose or the equivalent dose to individuals in planned exposure situations that are not to be exceeded. The quantity *E*, defined as a summation of the tissue or organ equivalent doses, each multiplied by the appropriate tissue weighting factor.
The average Effective Dose of Pelvis region (5.55±0.57mSv) and the average Effective Dose of abdominal region (4.38±0.46mSv).

5.1.3. **Estimating risk:-**

The total cancer risk per absorbed dose of 10 mSv is estimated to be to about 5×10^{-4}. This means that out of 10 000 people being irradiated with 10 mSv, on average five of these will develop cancer. It is generally assumed that the relation between the probability to develop cancer and the absorbed dose is linear The average risk factor for radiation effects, which can be inherited in the first two generations, is estimated to be 10^{-4} per 10 mSv. Also a quadratic dependence of the cancer probability on the equivalent dose is discussion. The average estimating radiation risk for organ the liver (for abdomen), the stomach (for abdomen), the testicle (for pelvis), the ovaries (for pelvis), and the uterus (for pelvis) were (13.15), (34.64), (11.27), (11.49), (71.68) Cancer probability per million respectively.

5.2. **Conclusions**

Radiation dose from CT procedures varies from patient to patient. The main dose variations in the same CT unit could be attributed to the different techniques, which justify the important of use radiation dose optimization technique and technologists training. Dose reduction strategies must be well understood and properly used. This can be achieved through optimal selection of scanning parameters based on indication of study, body region of interest being scanned, and patient size.

5.3. **Recommended**

- CT Operators must optimize the patient dose to reduce patient cancer risks. Should be uses the best strategies available for reducing radiation dose to allow for mAs reduction in relation to the patient's size and weight. Such as weight with fixed tube current scanning.
- Maintain accurate operating conditions (balance between image quality and radiation exposure) in order to reduce dose while maintaining diagnostic image quality.
- Continuous training is important for improving the techniques and protocols used in CT.
- Continuous education is highly recommended specially in radiation effect, and radiation protection field.
- Avoided repetition test without clinical justification.
- Considerate ALARA principle.
- Clear justification of examination is highly recommended.
- Further studies are highly encouraged in this field with larger samples and different CT modalities.

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Appendices

Appendix -1

Sudan University of Science and Technology

College of Graduate Studies

Collecting Data sheet

No	Gender	Age	Kvp	Total mAs	Total CTDI	Total DLP	Effective dose