Sudan University of Science and Technology

College of Graduate Studies

Estimation of Patient Effective Dose During Adult Brain CT Examination

تقدير الجرعة الفعالة للمرضى البالغين في تصوير الدماغ بالأشعة المقطعية

A thesis submitted for the partial fulfillment for the academic requirements of the award of Master Degree in Medical Physics

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الآيـــــــــــة

قـــــــــــال تعالى :

(وَيَسئَــلُونَكَ عَنِ الـرُوحِ قُل الـرُوحُ مِن أَمر رَبِي ، وَمَـا أُوتِـيتُم مِنَ العِـلمِ إِلا قَـلِيلاً)

صدق الله العظيم

الإسراء الآيه ٨٥

Dedication

This thesis is dedicated to

My father,

My mother,

Brothers & sisters

Friends

And above all my teachers

Acknowledgements

First and foremost, I would like to express my deepest gratitude to

Dr. Husain Ahmed, without his help this work could not have been

accomplished

My thanks also go to Medical Modern Center.

Deep thanks to my family for their consistent mental support.

Finally, special thanks to my brother Abdalla Mohamed

Eldoma for his great support to me, and I wish him more

success and excellence.

Abstract

This study intends to assess the ED of patient undergoing brain CT in three hospitals in Khartoum state. A total of 90 patients 30 in (Alaml Hospital), 30 in (Alzaytouna Hospital) and 30 in (Army Hospital) were examined. The mean of (ED) Age, Kvp, mAs, slice thickness, Slice Number, Scan time, Scan Length, number of rotation, TF, Collimation, Pitch, CTDIw, CTDIvol, DLPw. These correlations coefficient between the Effective dose (mSv) and **(**number of slice**,** Scan length, DLPw) was obtained for all hospitals. the final result shows that there was a correlation between the ED values and **(**number of slice**,** Scan length, DLPw) for all hospitals (correlation coefficient R^2 ranged from (0.5224 to 0.8992). some result reveal that there was no correlation between ED values and scan length for patient undergoing brain CT such as in Alaml Hospital. As comparison between the three hospitals the higher effective dose obtained from this study was in Alzaytouna hospital then alaml hospital and then army hospital which was [4.64, 4.61, 3.636] respectively. In this study, large variations of radiation effective dose were observed. Different scanning protocols used among hospitals and variation in equipment design among manufacturers and models were responsible for these variations. The main contributor for this difference was the use of a larger scan length in Alzaytouna hospital than that used in alaml hospital and army hospital.

ملخص البحث:

تهدف هذه الدراسة إلى تقييم الجرعة الفعالة للمرضى خلال فحص الأشعة المقطعية للدماغ في ثلاثة مستشفيات بولاية الخرطوم. تم فحص عدد ٩٠ من المرضى ٣٠ مريض من مستشفى الأمل ، ٣٠ مريض من مستشفى الزيتونة و ٣٠ مريض من مستشفى الجيش. متوسط الجرعة الفعالة (ED) والعمر (Age) وجهد الأنبوب (KVP) وحاصل ضرب تيار الأنبوب في الزمن (mAs) وسمك الشريحة (Slice Thickness) وعدد الشريحة (Slice Number) وزمن المسح وطول المسح وعدد الدوران و TF ، الموازاة (Collimation)، Pitch ، CTDIw، CTDIvol، DLPw تم حسابها لكل الأجهزة، تم الحصول على معامل الارتباط بين الجرعة الفعالة (mSv) و (عدد الشرائح ، طول المسح ، DLPw) لجميع المستشفيات. أظهرت النتائج النهائية وجود ارتباط بين قيم الجرعة الفعالة و (عدد الشرائح وطول المسح و DLPw) لجميع المستشفيات (تراوح معامل الارتباط R2 من (٠,٥٢٢٤ إلى ٠,٨٩٩٢). بعض النتائج أظهرت أنه لا يوجد ارتباط بين قيم الجرعة الفعالة وطول المسح للمريض الذي يخضع لفحص الأشعة المقطعية للدماغ كما ظهرت في نتائج مستشفى الأمل ، وبالمقارنة بين المستشفيات الثلاث ، فإن الجرعة الفعالة الأعلى التي تم الحصول عليها من هذه الدراسة كانت في مستشفى الزيتونة ثم مستشفى الأمل ثم مستشفى الجيش الذي كان [٤,٦٤ ، ٤,٦١ ، ٣,٦٣٦] على التوالي. في هذه الدراسة لوحظت اختلافات كبيرة في الجرعة الفعالة للإشعاع. بروتوكولات المسح المختلفة المستخدمة بين المستشفيات والاختلاف في تصميم المعدات بين الشركات المصنعة والنماذج هي المسؤولة عن هذه الاختلافات وكان المساهم الرئيسي في هذا الاختلاف هو استخدام طول مسح أكبر في الزيتونة. من تلك المستخدمة في مستشفى الأمل ومستشفى الجيش.

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Abbreviations

Abbreviation	statement
CT	Computed tomography
L	The scan length
Kv	Kilo voltage
MDCT	Multi detector CT
mGy	mili Gray
CTDI	Computed tomography dose index
CTDIw	weighted Computed tomography dose index
CTDlvol	volume Computed tomography dose index
DLP	Dose Length Product
ED	The effective dose
RP	Radiation Protection
NRPB	National Radiation Protection Board
IEC	International commission
DRL	Diagnostic Reference Level
ICRP	International Commission Radiological Protection
EMR	Electromagnetic radiation

Chapter one: Introduction

1.1. Introduction:

It is well known that patient doses from CT procedures are relatively higher than doses from other imaging modalities based on ionizing radiation. For example, one CT examination of the chest delivers about 400 times the dose delivered by a conventional chest X-ray examination. Therefore, although CT represents only 5% of the total number of medical X-ray procedures worldwide, this high dose procedure contributes about 34% of the annual collective dose from all medical X-ray examinations to the population. (UNSCEAR 2000). This contribution is inevitable because it results from a combination of high dose per examination and frequent use of CT examination in diagnosis. (UNSCEAR 2000) (IAEA,2001) (ICRP, 2000).

Increased use of this high dose procedure has been of great concern globally because of the high possibility of inducing undesired health effects, such as induction of cancer, in patients. (Brenner DV et al, 2001)

Of prime concern is the significant radiation dose delivered to superficial radiosensitive organs such as the eye lens, breast, and thyroid, which are, unfortunately, irradiated during radiological procedures of the head, chest, and cervical spine. (ICRP, 2000) (Hidajat N et al, 1999) (Hopper KD, et al 2001).

The implication of some of these exposures, for example, to the breast and eyes, is the potential increase in the risk of breast cancer and cataract formation in the population. (Hopper KD, et al 2001) (Hopper KD, et al 1997).

Since radiation exposure of different organs leads to different health effects, it has been of interest in this work to determine the actual doses delivered to individual organs. The most useful way to assess organ doses is either by direct measurement (on patients using

thermoluminescent dosimeters (TLDs) or on phantom using either an ionization chamber or TLDs) or by indirect measurement through measurement of CT dose indexes (CTDI) and published conventional factors obtained from Monte Carlo simulation and mathematical phantoms. (Hidajat N et al, 1999) (Geleijns J et al 1994).

Since dose measurement using TLDs is laborious and time-consuming for a wide survey, the patient organ doses in this study were determined using measurements of CTDI and published conversion factors. With the knowledge of organ doses it would be easy to identify the organs at greatest radiation risk, which requires immediate protective measures. In addition, countries with insufficient experience in the use of this modality may have additional sources of increased dose to patients, such as lack of optimized techniques.

1.2. Problem of Study:

Due to use CT scanning patients are exposed to more doses which may result in unintended health effects, to avoid unnecessary of high dose to the patient need to estimate the effective dose.

1.3. Objective:

1.3.1. General Objective:

To estimated effective dose (E) in adult CT examination for Toshibax64 slice using CT. Exp version 2.5 software.

1.3.2. Specific Objective:

- Volume Computed Tomography Dose Index ($CTDI_{vol}$)
- Dose Length Product (DLP)

• Effective dose (E)

1.4. Overview of study:

This study falls into five chapters, Chapter one, which is an introduction, objectives of the study, Chapter two Literature review and theoretical background, Chapter three material and method, Chapter fours results and Chapter five discussions, conclusion, recommendations, then references, appendix.

Chapter two: Literature Review

2.1. Ionizing Radiation:

Ionizing (high-energy) radiation has the ability to remove electrons from atoms; i.e., to ionize the atoms. Ionizing radiation can be electromagnetic or particulate radiation (Fig. 2.1). Clinical diagnostic radiation uses photons (electromagnetic) as radiation in the diagnosis of disease and some benign conditions (Murat et al, 2010).

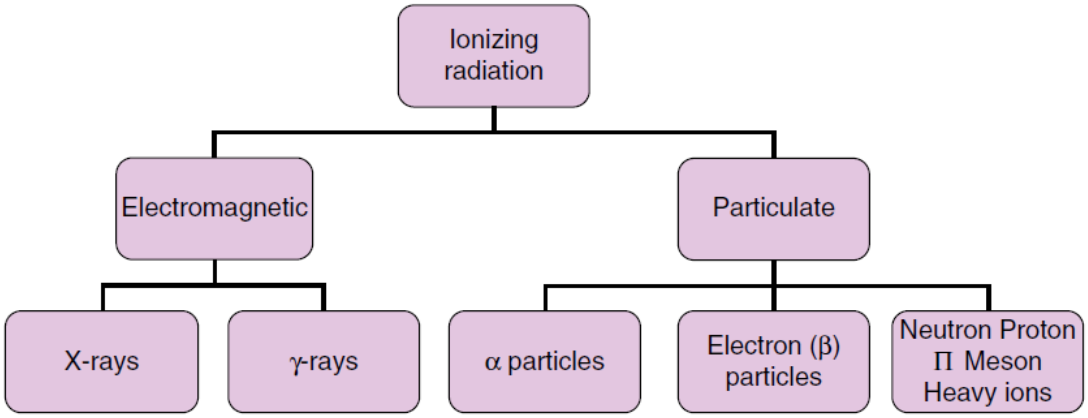


Figure (2.1) show the types of Ionizing radiation (Murat et al, 2010).

2.2. Production of X-Rays:

X-rays were discovered by Roentgen in 1895 when high-speed electrons are decelerated on collision with high atomic number material while studying cathode rays (stream of electrons) in a gas discharge tube. He observed that another type of radiation was produced (presumably by the interaction of electrons with the glass walls of the tube) that could be detected outside the tube. This radiation could penetrate opaque substances, produce fluorescence, blacken a photographic plate, and ionize a gas. He named the new radiation x-rays (ICRP, 2001).

2.2.1 Bremsstralung X-rays:

The process of bremsstrahlung is the result of radiative interaction between a high-speed electron and a nucleus. The electron while passing near a nucleus may be deflected from in path by the action of Coulomb forces of attraction and loses energy as bremsstrahlung, a phenomenon predicted by Maxwell's general theory of electromagnetic radiation. According to this theory, energy is propagated through space by electromagnetic fields. As the electron, with its associated electromagnetic field, passes in the vicinity of a nucleus; it suffers a sudden deflection and acceleration. As a result, a part or all of its energy is dissociated from it and propagates in space as electromagnetic radiation. Since an electron may have one or more bremsstrahlung interactions in the material and an interaction may result in partial or complete loss of electron energy, the resulting bremsstrahlung photon may have any energy up to the initial energy of the electron. Also, the direction of emission of bremsstrahlung photons depends on the energy of the incident electrons. At electron energies below about 100 KeV, X-rays are emitted more or less equally in all directions (Bushberg JT et al , 2002).

2.2.2 Characteristics X-rays:

Electrons incident on the target also produce characteristic X-rays. An electron with kinetic energy E_0, may interact with the atoms of the target by ejecting an orbital electron, such as a K, L, or M electron, leaving the atom ionized.The original electron will recede from the collision with energy when a vacancy is created in an orbit, an outer orbital electron will fall down to fill that vacancy. In doing so, the energy is radiated in the form of electromagnetic radiation. This is called characteristic radiation, i.e., characteristic of the atoms in the target and of the shells between which the transitions took place. With higher

atomic number targets and the transitions involving inner shells such as K, L, M, and N, the characteristic radiations emitted are of high enough energies to be considered in the X-ray part of the electromagnetic spectrum (Bushberg JT et al , 2002).

2.3 Interactions of Ionizing Radiation:

When an x- ray beam passes through a medium, interaction between photons and matter can take place with the result that energy is transferred to the medium. The initial step in the energy transfer involves the ejection of electrons from the atoms of the absorbing medium. These high-speed electrons transfer their energy by producing ionization and excitation of the atoms along their paths. If the absorbing medium consists of body tissues, sufficient energy may be deposited within the cells, destroying their reproductive capacity. However, most of the absorbed energy is converted into heat, producing no biologic effect(Bushberg et al.,2002).

2.3.1 Interaction of photon with matter:

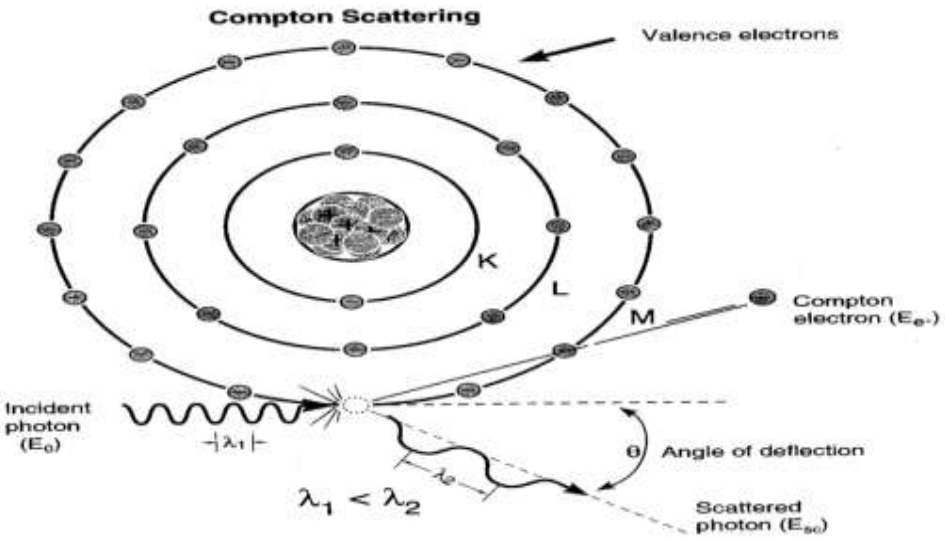
When traversing matter, photons will penetrate, scatter, or be absorbed. There are four major types of interactions of x- and gamma-ray photons with matter, the first three of which play arole in diagnostic radiology an: (a) Compton scattering, (b) photoelectric absorption, and (c) pair production(Bushberg et al.,2002).

2.3.1.1 Compton scatters:

Compton scattering (also called inelastic or nonclassical scattering) is the predominant interaction of x-ray and gamma-ray photons in the diagnostic energy range with soft tissue. In fact, Compton scattering not only predominates in the diagnostic energy range above 26 kev in soft tissue, but continues to predominate well beyond diagnostic energies to approximately 30 Mev. This interaction is most likely to occur between photons and outer ("valence") shell electrons (Fig. 2.4). The electron is ejected from the atom, and the photon

is scattered with some reduction in energy. As with all types of interactions, both energy and momentum must be conserved.

Thus the energy of the incident photon (Eo) is equal to the sum of the energy of the scattered photon (Ese) and the kinetic energy of the ejected electron (Ee-), as shown in Equation . The binding energy of the electron that was ejected is comparatively small and can be ignored (Bushberg et al.,2002).



$$E_o = E_{sc} + E_{e-}$$

Figure (2.2) show Compton scatters (Bushberg et al.,2002)

Compton scattering results in the ionization of the atom and a division of the incident photon energy between the scattered photon and ejected electron. The ejected electron will lose its kinetic energy via excitation and ionization of atoms in the surrounding material. The Compton scattered photon may traverse the medium without interaction or may undergo subsequent interactions such as Compton scattering, photoelectric absorption (to be discussed shortly) (Bushberg et al.,2002).

The energy of the scattered photon can be calculated from the energy of the incident photon and the angle of the scattered photon (with respect to the incident trajectory):

$$E_{sc} = \frac{E_o}{1 + \frac{E_o}{511\ keV}(1 - \cos\theta)}$$

where E_{sc} = the energy of the scattered photon,
E_o = the incident photon energy, and
θ = the angle of the scattered photon.

2.3.1.2. Photoelectric effect:

In the photoelectric effect, all of the incident photon energy is transferred to an electron, which is ejected from the atom. The kinetic energy of the ejected photo- electron (Ee) is equal to the incident photon energy (Eo) minus the binding energy of the orbital electron (Eb) .

$$E_e = E_o - E_b$$

In order for photoelectric absorption to occur, the incident photon energy must be greater than or equal to the binding energy of the electron that is ejected.

The ejected electron is most likely one whose binding energy is closest to, but less than, the incident photon energy. For example, for photons whose energies exceed the K-shell binding energy, photoelectric interactions with K-shell electrons are most probable. Following a photoelectric interaction, the atom is ionized, with an inner shell electron vacancy. This vacancy will be filled by an electron from a shell with a lower binding energy. This creates another vacancy, which, in turn, is filled by an electron from an even lower binding energy shell.

(Bushberg et al.,2002).

2.3.1.3 Pair production:

Pair production can only occur when the energies of x- and gamma rays exceed 1.02 MeV

In pair production, an x-ray or gamma ray interacts with the electric field of the nucleus of

an atom. The photon's energy is transformed into an electron-positron pair . The rest mass energy equivalent of each electron is 0.511 MeV and this is why the energy threshold for this reaction is 1.02 MeV. Photon energy in excess of this threshold is imparted to the electrons as kinetic energy. The electron and positron lose their kinetic energy via excitation and ionization. As discussed previously, when the positron comes to rest, it interacts with a negatively charged electron, resulting in the formation of two oppositely directed 0.511 MeV annihilation photons.

Pair production is of no consequence in diagnostic x-ray imaging because of the extremely high energies required for it to occur.

In fact, pair production does not become significant unless the photon energies greatly exceed the 1.02 MeV energy threshold **(Bushberg et al.,2002)**

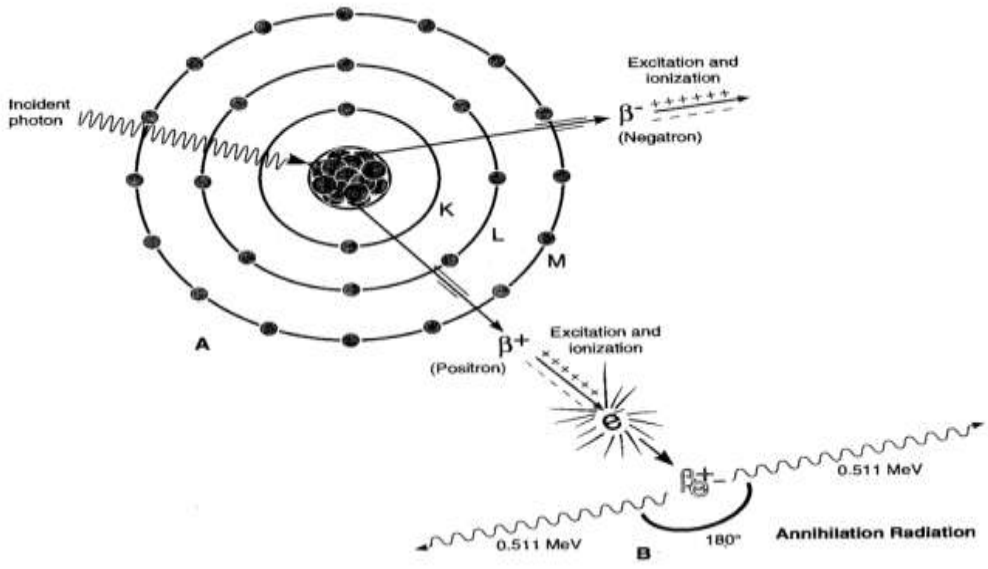


figure (2.3) show Pair Production (Bushberg et al.,2002)

2.4. Biological Effect of Ionizing Radiation:

The collective to the population resulting from medical exposure has been estimated to represent the largest single man-made contribution to both the somatic and the genetically

significant dose equivalent in European countries. A similar distribution was found in other developed countries. The largest contribution being from Diagnostic Radiology, which estimated at ten times the sum of contributions from nuclear medicine and radiotherapy. It is desirable to reduce the patient dose in diagnostic radiology to minimum with good image quality to keep the dose as low as reasonably achievable (ALARA principle).(BUSHONG, et al, 2002).

Biological effects may occur in the exposed individual as somatic radiation damage to the cell or alternatively this genetic damage could be passed on to individual's descendants. The effects are classified into stochastic and deterministic effects.

2.4.1. Stochastic Effects:

Short-term effects may arise soon after exposed to radiation. The effect may subside quickly. These effects generally manifest many years, even decades, after the radiation exposure (and were once called “late effects”). Their major characteristics, in direct contrast with those for non stochastic effects, are:

1. A threshold may not be observed.

2. The probability of the effect increases with dose.

3. You cannot definitively associate the effect with the radiation exposure (Van Rooyen et aI., 1995).

2.4.2. Deterministic effects:

In deterministic effect there is a threshold dose of radiation below, which the effect does not occur. Doses significantly above the threshold will produce effects which severity is proportional to the absorbed dose received. Short-term effects are: radiation erythema, gastro-intestinal syndrome where the cell renewal system is damaged (Van Rooyen et al., 1995).

The major identifying characteristics of non stochastic Effects are:

1. There is a threshold of dose below which the effects will not be observed.

2. Above this threshold, the magnitude of the effect increases with dose.

3. The effect is clearly associated with the radiation exposure.

2.5. Radiation dosimetry:

Radiation dosimetry is the calculation of the absorbed dose in matter and tissue resulting from the exposure to indirectly and directly ionizing radiation. It is a scientific subspecialty in the fields of health physics and medical physics that is focused on the calculation of internal and external doses from ionizing radiation.

2.5.1 Radiation quantities:

There are many different physical quantities that can be used to express the amount of radiation delivered to a human body. Generally, there are advantages and applications as well as disadvantages and limitations for each of the quantities. There are two types of radiation quantities: those that express the concentration of radiation at some point, or to a specific tissue or organ, and there are also quantities that express the total radiation delivered to a body. We will be considering each of these quantities in much more detail(IAEA, 2005). The general relationship between the concentration and total radiation quantities are illustrated below.

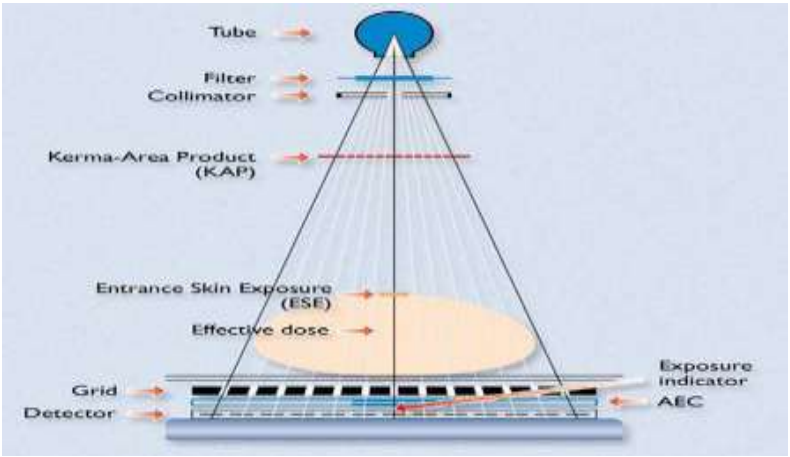


Figure (2.4) Typical examination beam geometry and related radiation dose quantities (IAEA, 2005)

2.5.1.1 Exposure:

Exposure is a radiation quantity that expresses the concentration of radiation delivered to a specific point, such as the surface of the human body. There are two units for expressing Exposure. The conventional unit is the roentgen (R) and the SI unit is the coulomb/kg of air (C/kg of air). The unit, the roentgen, is officially defined in terms of the amount of ionization produced in a specific quantity of air. The ionization process produces an electrical charge that is expressed in the unit of coulombs. So, by measuring the amount of ionization (in coulombs) in a known quantity of air the exposure in roentgens can be determined (IAEA, 2005).

2.5.1.2. Air kerma:

Air kerma is a radiation quantity that is used to express the radiation concentration delivered to a point, such as the entrance surface of a patient's body. It is a quantity that fits into the SI scheme. The quantity, kerma, originated from the acronym, KERMA, for Kinetic Energy Released per unit Mass (of air). It is a measure of the amount of radiation energy, in the unit of joules (J), actually deposited in or absorbed in a unit mass (kg) of air. Therefore, the quantity, kerma, is expressed in the units of J/kg which is also the radiation unit, the gray (Gy) (IAEA, 2005).

2.5.1.3. Absorbed Dose:

Absorbed Dose is the radiation quantity used to express the concentration of radiation energy actually absorbed in a specific tissue. This is the quantity that is most directly related to biological effects. Dose values can be in the traditional unit of the rad or the SI

unit of the gray (Gy). The rad is equivalent to 100 ergs of energy absorbed in a gram of tissue and the gray is one joule of energy absorbed per kilogram of tissue(IAEA, 2005).

2.5.1.4. Entrance Surface dose:

Entrance skin exposure is defined as the exposure in roentgens at the skin surface of the patient without the backscatter contribution from the patient. This measurement is popular because entrance skin exposure is easy to measure, but unfortunately the entrance skin exposure is poorly suited for specifying the radiation received by patients undergoing radiographic examination. The entrance skin exposure does not take into account the radio sensitivity of individual organs or tissues, the area of an x-ray beam, or the beam's penetrating power, therefore, entrance skin exposure is poor indicator of the total energy imparted to the patient (NRPB, 1999).

2.5.1. 5. Entrance surface air kerma (ESAK):

The entrance surface air kerma (ESAK) is defined as the kerma in air at the point where the central radiation beam axis enters the hypothetical object, i.e. patient or phantom, in the absence of the specified object.

The entrance surface dose, or alternatively the entrance skin dose (ESD) is defined as the absorbed dose to air on the x-ray beam axis at the point where x-ray beam enters the patient or a phantom, including the contribution of the backscatter (NRPB, 1992). The ESD is to be expressed in mGy. Some confusion exists in the literature with regard to the definition of the ESD. That is, whether the definition should refer to the absorbed dose to the air as defined above or absorbed dose to tissue (NRPB, 1999).

2.5.1.6. Equivalent dose H_T :

Accounts for biological effect per unit dose

$$H_T = W_R x D$$

Table 2.1 Radiation weighting factors (W_R):

Radiation type and energy range	weighting factors (W_R):
Photons (X-rays and gamma-rays) all Energies	1
Electron all Energies Neutrons	1
<10 keV	5
10-100 keV	10
>100 kev to 2 MeV	20
2-20 MeV	10
>20 MeV	5
Protons >20MeV	5
Alpha particles , Fission fragments	20

2.5.1.7. Effective dose : E :

Risk related parameter, takingrelative *radiosensitivity* ofeach organ and tissue into account

$E(Sv) = \Sigma_T W_T \times H_T$

W_T : tissue weighting factor for organ T

H_T: equivalent dose received by organ or tissue T

2.6. Radiation Units:

2.6.1. Roentgen:

The roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and X-rays, and only in air. One roentgen is equal to depositing in dry air enough energy to cause 2.58 x 10-4 coulombs per kg. It is a measure

of the ionizations of the molecules in a mass of air. The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and x-rays(Avenue, 2002).

2.6.2. Radiation absorbed dose (Rad):

The rad is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One rad is defined as the absorption of 100 ergs per gram of material. The unit rad can be used for any type of radiation, but it does not describe the biological effects of the different radiations(Avenue, 2002).

2.6.3. Rem (roentgen equivalent man):

The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem. To determine equivalent dose (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the type of incident radiation.

2.6.4. Gray (Gy):

The gray is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 rads.

2.6.5. Sievert (Sv):

The sievert is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a sievert, or micro-sievert. To determine equivalent dose (Sv), you multiply absorbed dose (Gy) by a quality factor (Q) that is unique to the type of incident radiation. One sievert is equivalent to 100 rem (Thayalan,2001).

2.7 Principles of Computed Tomography:

The CT scanner is a device using an X-ray source which can be used to give precise information on the attenuation properties of a thin sectional volume of the body. The basic elements of the CT scanner include the X-ray tube and the detector or detector array located in the gantry and known as the data acquisition system, the image processing system, and the image display system. The X-ray tube rotates around the patient producing a tightly collimated X-ray radiation photon beam. Once attenuated by the patient the attenuated beam strikes the detectors which convert the photon intensity to a digital signal. Multiple profiles of patient attenuation are collected (Brenner,2001).

2.8. Historical Development of CT System:

Each change in the fundamental CT tube-detector structure is known as a CT generation. The CT generation has changed from the first introduced in 1972 up to the fifth in more recent years. The generation development has improved acquisition time and image quality (Website: http://www.state.nj.us/dep/rpp).

2.8.1. 1the first and second generation scanners:

The first generation scanner was based on parallel beam geometry and the translate-rotate scanning motion. It used a single highly collimated X-ray beam (pencil beam) and one or two detectors which first translated across the patient collecting transmission readings This was done for 180° around the patient. This first generation scanner took 4.5 to 5.5 minutes to produce a complete scan. The major problem for this generation is patient throughput, motion artifacts caused by the patient, and poor image quality. Second-generation scanners are based, on a small fan beam geometry and translate- rotate motion This method is referred to as rectilinear multiple pencil beam scanning and the path traced by the X-ray tube during the scanning is same as first generation that is 180°. The scan motion and increasing detector numbers reduced the scanning time to 20 to 60 seconds. The first and second generation scanners are no longer in use. They have been replaced by third and fourth generation scanners (Fowlkes 1995).

2.8.2 Third and fourth generation scanners:

Third generation scanners employ rotate-rotate configuration based on a fan beam geometry with no translation and complete rotation of the X-ray tube and detectors. The X-ray tube is coupled to a curved detector array that subtends an arc of about 30° to 40° from the apex of the fan located at the X-ray tube. The fan beam geometry rotates continuously around the patient for 360°. The minimum scan time is 1 to 4 seconds. The fourth generation scanners are based on fan beam geometry and complete rotation of the X-ray tube around a stationary 360° ring of detectors. The number of detectors in such a scanner varies from about 300 to 4000. The scan time ranges from 2 to 8 seconds.

2.9. Applications of CT Imaging:

CT is a radiologic, anatomical imaging technique that provides valuable clinical information for the detection and differentiation of several diseases. In fact, CT is the primary diagnostic tool for a wide range of clinical indications, being also used as a complement for other imaging modalities. A CT system produces cross-sectional images of selected regions of the body, which can be used for different diagnostic and therapeutic purposes. The images obtained can help diagnose or rule out different diseases and abnormalities, also being often used as a reference for therapy planning and monitoring (FDA. 2010).

For instance, one of the fields where CT is most widely used is Neuroradiology. It is highly useful in the examination of the brain, being frequently indicated for neurologic examinations such as the evaluation of acute head trauma, suspected intracranial hemorrhage, and vascular lesions. Also in Neurology, CT might be a suitable alternative when MRI is deemed contraindicated. Other advanced applications of CT imaging include the visualization of specific anatomical structures and tissues using CT perfusion, volumetry, angiography, and venography (FDA. 2010).

2.10. Basic Principles of CT Imaging:

In CT imaging, anatomic cross-sectional (or “slice”) images of body tissues and organs are produced. These images represent the x-ray attenuation properties of the different tissues: the x-ray photons, generated within an x-ray tube, are attenuated in the patient’s tissues and organs. The interaction between x-ray and matter depends on the x -ray photons energy, and matter’s thickness and electron density. Thicker and denser materials, such as bone, attenuate more X-rays photons than less dense, thinner tissues like muscle or fat, and these

differences in attenuation will result in correspondent contrast variations, in the final image (Suetens,2009).

Thin x-ray beams scan the desired anatomical region, and this process is repeated for different angle directions. The actual attenuation at each particular location inside the body is then reconstructed from all those attenuation measurements, through sophisticated mathematical algorithms, which reconstruct data information of the x-ray attenuation coefficients determined for the different anatomical structures (Suetens,2009).

The intensity of the x-ray beam before it reaches the body is measured by an x-ray detector, as well as its final intensity, in order to compute the μ values of the different tissues the x-ray beam interacts with . The x-ray detector area is constituted by a radiation-sensitive material (such as cadmium tungstate or gadolinium-oxide), which converts x-rays into visible light. This light interacts with a silicon photodiode and is converted into an electrical current, which is later amplified and converted into a digital signal . The data from the detector array is then reconstructed to obtain images of the internal structures of the body region scanned (Suetens,2009).

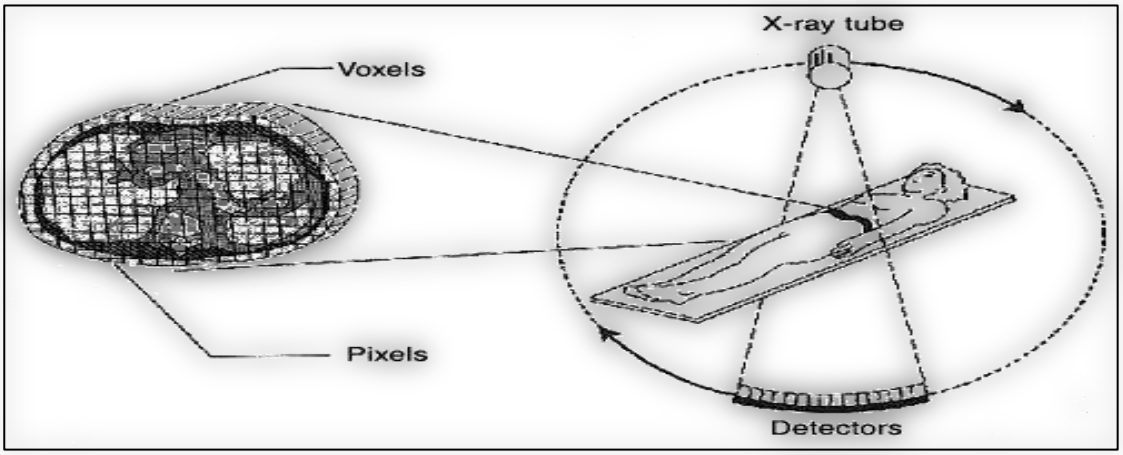


Figure (2.5) Anatomical structures within the patient's body is reconstructed from the x-ray transmission data. Adopted from (Lima,2010)

2.11. The CT scanner Components:

The general structure of a CT equipment can be divided in four principal elements:

The Data Acquisition and Transfer System, which encompasses the gantry, the patient's table, the PDU and a data transfer unit: The gantry is a central opening where the patient is moved into during the examination, in which are assembled the x-ray tube source, where electrons are generated in a cathode and accelerated towards an anode (the target) producing x-ray photons; the detector area, diametrically opposed to the x-ray source in the gantry; a collimation system, which determines the slice width; a filtering system to remove the low energy component of the x-ray beam; a refrigerating system and a power source for the x-ray tube and detectors rotation (Lima,2010).

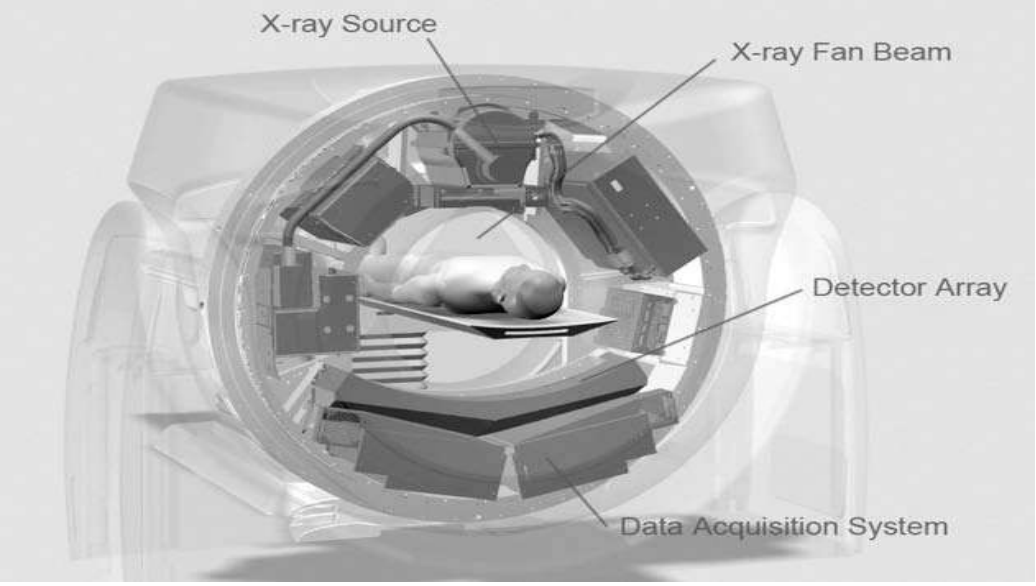


Figure (2.6) The x-ray tube and the detector array are oppositely placed, inside the gantry. Adopted (Thorsten,1965)

2.12. Types of machines:

Spinning tube, commonly called spiral CT, or helical CT in which an entire X-ray tube is spun around the central axis of the area being scanned. These are the dominant type of scanners on the market because they have been manufactured longer and offer lower cost

of production and purchase. The main limitation of this type is the bulk and inertia of the equipment (X-ray tube assembly and detector array on the opposite side of the circle) which limits the speed at which the equipment can spin. Some designs use two X-ray sources and detector arrays offset by an angle, as technique to improve temporal resolution. (Herman,2009)

Electron beam tomography (EBT) is a specific form of CT in which a large enough X-ray tube is constructed so that only the path of the electrons, travelling between the cathode and anode of the X-ray tube, are spun using deflection coils. This type had a major advantage since sweep speeds can be much faster, allowing for less blurry imaging of moving structures, such as the heart and arteries. Fewer scanners of this design have been produced when compared with spinning tube types, mainly due to the higher cost associated with building a much larger X-ray tube and detector array and limited anatomical coverage. Only one manufacturer (I matron, later acquired by General electric) ever produced scanners of this design. Production ceased in early 2006.In multislice computed tomography (MSCT), a higher number of tomographic slices allow for higher-resolution imaging.

2.13. Contrast media in CT examination:

The contrast media used in a CT examination can be either positive or negative (Baert & Sartor 2001). Positive contrast media can be iodinated or a diluted barium suspension, and may be administered orally, rectally or intravenously. Negative contrast media, such as gas or water, may also be used in the examination. Both kinds of contrast nmay be used together to optimize the detection of abnormalities. CT examinations can be carried out with or without contrast enhancement based on the clinical situation (Slone 2000).

Pre-contrast series (without contrast enhancement) are carried out to demonstrate the presence of stone, or calcification, or as a standard baseline before contrast enhancement. Contrast series are preferred in most cases to demonstrate different phases of blood intake in any organ or abnormal structures. Administration of contrast media is contra indicated however, for patient allergies to contrast media such as iodine. The timing of image acquisition after contrast administration is crucial to achieve the examination objectives. If arterial and venous phases are carried out, it is known as a biphasic series. Further, if delay

series are taken after those two series, it is known as a triphasic series. With current CT technology, scanning after contrast media injection can be initiated automatically once the appropriate density, for example around 50 Hounsfield Unit (HU) (Siemens 2000). Is selected. A Hounsfield unit is a quantitative scale for describing radiopacity of image area or image density. For example, liver enhances about 40 HU within 30 seconds with 2.5 ml/seconds rate and volume 125 ml bolus. Although, the use of contrast media has many advantages in demonstrating abnormalities, it also increases the number of scan series, thus increasing scan volume, which directly increases the patient radiation dose (Seeram 2000).

2.14. CT examination protocols:

Current CT scanners have preset protocols installed in their system, These protocols allow the user to automatically select appropriate parameters to be used for CT examinations. Scan parameters include kV, mAs, slice thickness and table speed, and can also be manipulated manually after consideration of patient size, the organ involved, and patient condition. Occasionally the user may choose specific organs to be examined which require different parameters to the original preset parameters, eg: routine abdominal CT examinations include the upper abdomen and pelvis and is normally scanned with the patient requested to suspend end-expiration to reduce internal pressure and motion. X-ray tube potentials normally range from 120 to 140 kV while, mAs can typically vary from 210

to 330. These two scan parameters are vital for dose optimization with patient size. The selection of slice collimation may be from 5 to 8 mm with a pitch of 1 to 1.6. For individual organs such as the pancreas or kidneys, slice thickness may range from 2 to 5 mm to allow detection of small lesions (Seeram 2000).

The applied protocols from different centres affect the dose measured amongst scanners. To provide best practice the American College of Radiologists and the European Commission (European Commission 1998) have provided guidelines on CT protocols .The information includes appropriate protocols for parameters, image interpretation and quality assurances ((ACR 2001).

2.15. General definitions of exposure and dose:

Radiation dose to a patient is better appreciated by an understanding of the relationships between radiation exposure and dose. Many dosimetry definitions had been described in international publications by the International Commission on Radiological Protection (ICRP 1991). Thus in this section a review of the terms, radiation exposure.

absorbed dose and effective dose and their relationships is discussed.

Dosimetry is the process of determining radiation dose. It includes the description of the type of radiation and the amount of energy it may deposit in some medium. Radiation from an X-ray generator consists of a beam of photons with a variety of energies; however, it can be manipulated to produce a more monoenergetic beam by filtration. The two distinct terms generally used in dosimetry are exposure and absorbed dose.

2.16. Previous studies:

GU J et al 2009 (The development, validation and application of a multi detector CT (MDCT) scanner model for assessing organ doses to the pregnant patient and the fetus using Monte Carlo simulations) developed and validated an MDCT scanner using the Monte Carlo method, and meanwhile the pregnant patient phantoms were integrated into the MDCT scanner model for assessment of the dose to the fetus as well as doses to the organs or tissues of the pregnant patient phantom. The scanner model was validated by comparing simulated results against measured CTDI values and dose profiles reported in the literature. The source movement along the helical trajectory was simulated using the pitch of 0.9375 and 1.375, respectively. The validated scanner model was then integrated with phantoms of a pregnant patient in three different gestational periods to calculate organ doses. It was found that the dose to the fetus of the 3 month pregnant patient phantom was 0.13 mGy/100 mAs and 0.57 mGy/100 mAs from the chest and kidney scan, respectively. For the chest scan of the 6 month patient phantom and the 9 month patient phantom, the fetal doses were 0.21 mGy/100 mAs and 0.26 mGy/100 mAs, respectively. The paper also discusses how these fetal dose values can be used to evaluate imaging procedures and to assess risk using recommendations of the report from AAPM Task Group 36. This work demonstrates the ability of modeling and validating an MDCT scanner by the Monte Carlo method, as well as assessing fetal and organ doses by combining the MDCT scanner model and the pregnant patient phantom.

Walter Huda, et al 2006 (Patient Radiation Doses from Adult and Pediatric CT) determined typical organ doses, and the corresponding effective doses, to adult and pediatric patients undergoing a single CT examination. The organs were 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. Relative to CT scanners from the early 1990s, present-day MDCT scanners result in doses that are 1.5 and 1.7 higher per unit mAs in head and body phantoms, respectively. Organ absorbed doses in head CT scans increase from 30 mGy in newborns to 40 mGy in adults. Patients weighing less than 20 kg receive body organ absorbed doses of 7 mGy, which is a factor of 2 less than for normal-sized (70-kg) adults. Adult head CT effective doses are 0.9 mSv, four times less than those for the neonate. Effective doses for neonates undergoing body CT are 2.5 mSv, whereas those for normal-sized adults are 3.5 mSv. 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.

Jolanta Hansen & Anne Grethe Jurik in their study (Survival and radiation risk in patients obtaining more than six CT examinations during one year) observed 300 patients with more than six CT examinations during one year. They comprised 8% of the patients and accounted for 27% of all examinations. These patients needed further analysis. The 300 patients were analyzed concerning age, type of diseases indicating multiple CTs and the CT protocols used. The e ffective dose and risk of low dose radiation was estimated and survival of the patients after 1.5 year was analyzed. A total of 289 patients had malignancies, the most frequent being lung cancer, bladder cancer and colon cancer. A total of 4.3% of the patients with malignancies were 54 year old, 13.3% were 41_50 years old and 62.7% 5170 years old. The highest average number of CT examinations was observed in patients with sarcomas (11.2 examinations per patient). Eleven patients (aged

15_77 years) had traumatic lesions. Their number of examinations varied from 7 to 20. The total radiation dose for all 300 patients was 21.42 Sv, which may imply induction of a fatal cancer in one of the patients. However, only 102 patients survived their disease. A total of 198 patients had serious disease and were not alive 1.5 years after the examinations. The multiple CT examinations were necessary to monitor their treatment. For the surviving 102 patients the use of CT contributed to an optimal therapy, but the examinations implied a risk for radiation induced malignancies.

Jumaa Yousif et al 2014 (Measurement of adult and pediatric Patient doses during head CT scan) the aim of this research was to study the trend of CT dose from brain examinations in Khartoum State, and its relationship to patient weight. The result of the research could be used to establish a Diagnostic Reference Level (DRL) to assist in optimizing radiation dose for CT brain examination in Sudan. The use of NRPB software dose calculator for this study has also been used by other researchers therefore the results from this study are comparable to related previous studies. Finally, an evaluation in the relationship between image quality, exposure factor selection and dose is also useful for professional benchmarking in maintaining lower dose level.

Chapter Three

Materials and Methods

3.1. Materials:

3.1.1. CT scanner:

Different Ct scanner Modalities were used from different three hospitals in Khartoum state.

3.2. Methods:

3.2.1. Area of the study:

The data used in this study was collected from three hospitals in the Khartoum state, Alaml Hospital, Alzaytouna Hospital, Army Hospital.

3.2.2. Population of study:

A total of 90 patients (male and female). Underwent CT study for Brain for different clinical problems was selected and recorded their Anthropometrical data (Age, sex,) with CT protocol technical data (kv, mAs ,DlP ,CTDI) and slice thickness.

3.2.3. Techniques used:

Data were collected using a sheet for all patients in order to maintain consistency of the information from display. A data collection sheet was designed to evaluate the patient doses and the radiation related factor. The collected data included patient sex, age, tube voltage and tube current–time product settings; section thickness. Clinical indications are important factor in patient dose during CT. In addition, we also recorded all scanning parameters, as well as the CT dose descriptors CT dose index volume (in milligrays) and dose-length product (in milligray-centimeters). All these factors that have a direct influence on radiation dose. The entire hospitals were passed successfully the extensive quality control tests performed by Sudan atomic energy commission and met the criteria of this study.

3.2.4. Dosimetric calculations

CT Expo software will used to calculate common CT dose descriptors:

(i) CT weighted dose index ($CTDI_W$) and volume dose index ($CTDI_{vol}$) provides an indicationof 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

(iii) effective dose (E): a method for comparing patient doses from different diagnostic procedures (Effective dose)

CTDI was obtained from a measurement of dose, D(z), along the z-axis made in air using a special pencil-shaped ionization chamber connected to an electrometer. The calibration of the ion chamber is traceable to the standards of the German National Laboratory and was calibrated according to the International Electrical Commission standards. The overall accuracy of ionization chamber measurements was estimated to be ±5%. Measurements of CTDI in air ($CTDI_{100}$, air) were made as recommended by the EUR 16262EN based on each combination of typical scanning parameters obtained from the machine. The required organ doses for this study were estimated using normalized CTDI values published by the Impact group, calculate $CTDI_{vol}$ and DL.

Found the effective dose by the equation:

ED= DLP * coefficient K

3.2.5. Data analysis:

The data was analyzed using excel Microsoft office.

Chapter Four:

The Results

4.1. Results:

Table 4.1. the mean value of effective dose and effective dose measurement parameters.

Hospital	Alaml Hospital	Alzaytouna Hospital	Army Hospital
Age	61.4	55.7	55.966
Kvp	120	120	120
mAs	225	225	225
Slice Thick	0.5	0.5	0.5
Slice No	671.5	664.2666	664.266
Scan Time	12.2	13.66	13.815
Scan Length	16.45	16.571	16.49
No of rotation	10.492	10.379	10.379
TF	15.707	15.96	15.892
Collimation	32	32	32
Pitch	0.491	0.50	0.497
CTDIw [mGy]	44.6	44.6	58.85
CTDIvol [mGy]	79.2	79.2	79.45
DLPw* [mGy*cm]	1502.9	1518.63	1369.13
E* [mSv]	4.61	4.64	3.636

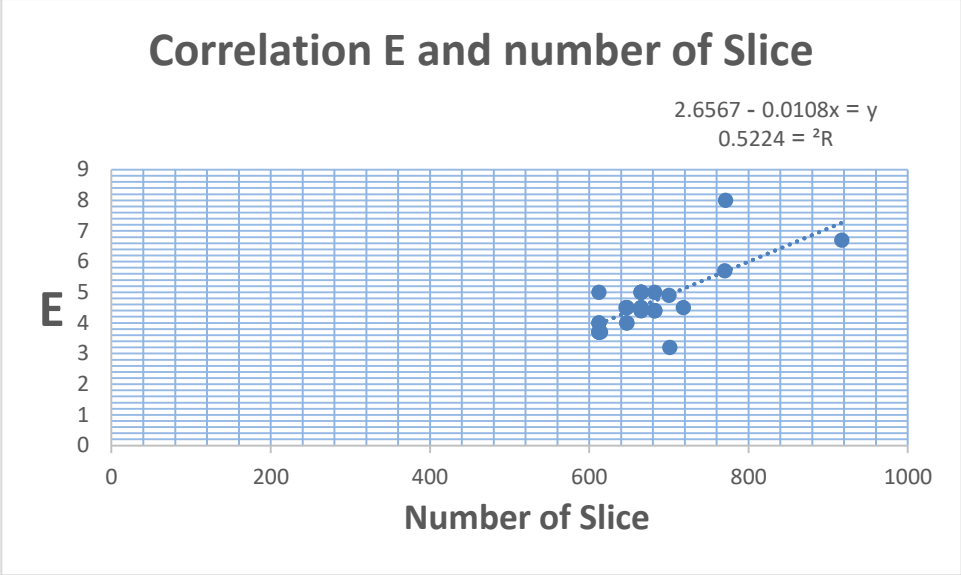


Figure 4-1. Correlation between effective dose E (mSv) and number of slice for patient undergoing brain CT in Alaml Hospital.

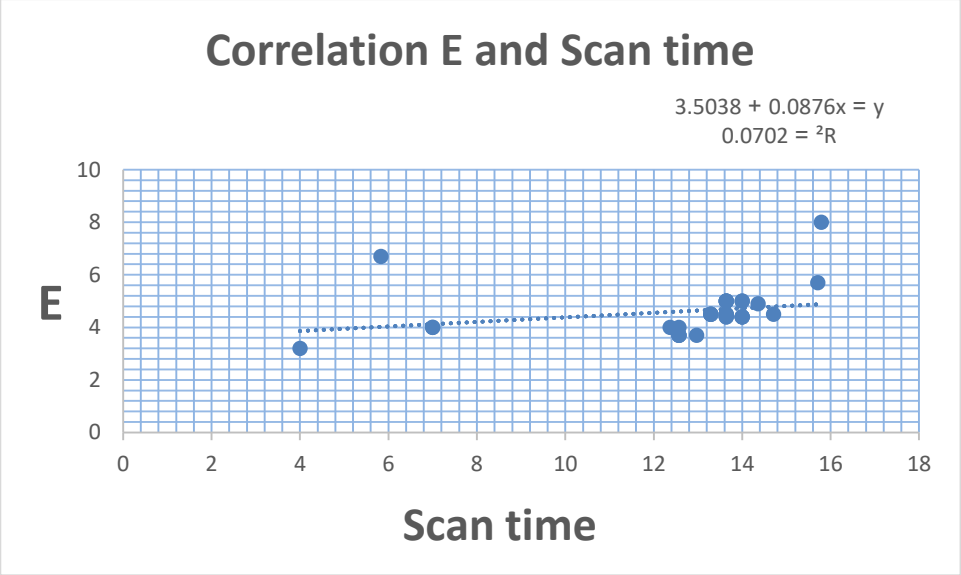


Figure 4-2. Correlation between effective dose E (mSv) and Scan time for patient undergoing brain CT in Alaml Hospital.

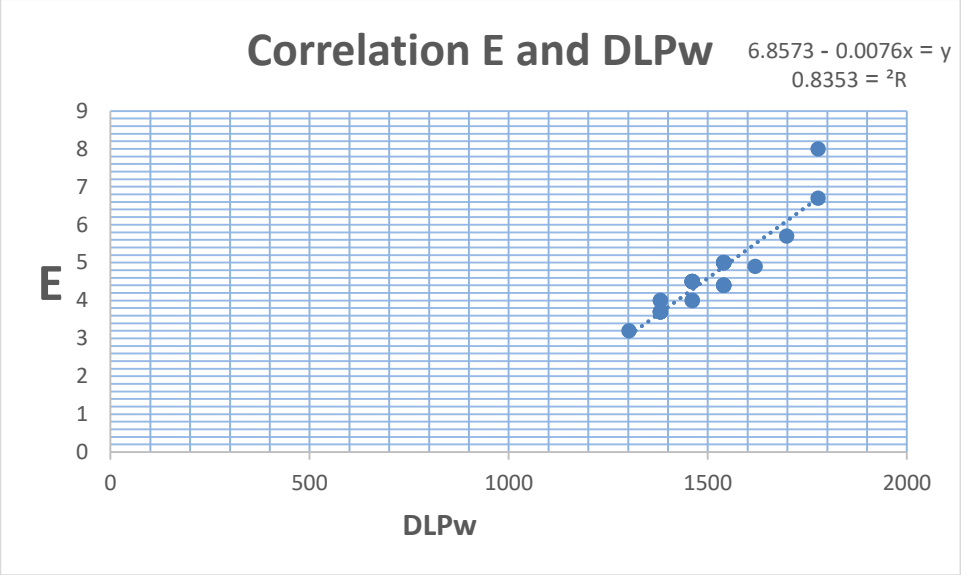


Figure 4-3. Correlation between effective dose E (mSv) and DLPw [mGy*cm] for patient undergoing brain CT in Alaml Hospital.

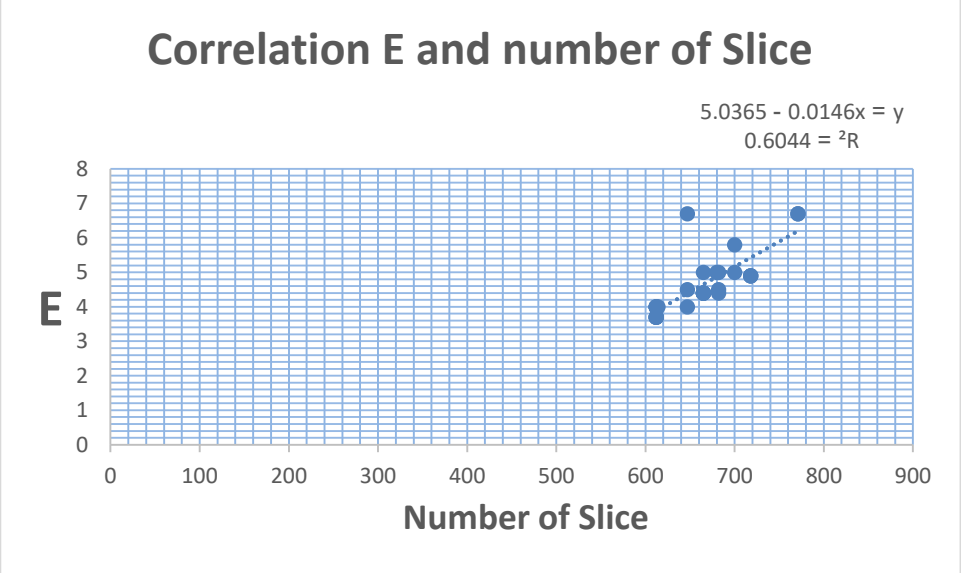


Figure 4-4. Correlation between effective dose E (mSv) and number of slice for patient undergoing brain CT in Alzaytouna Hospital.

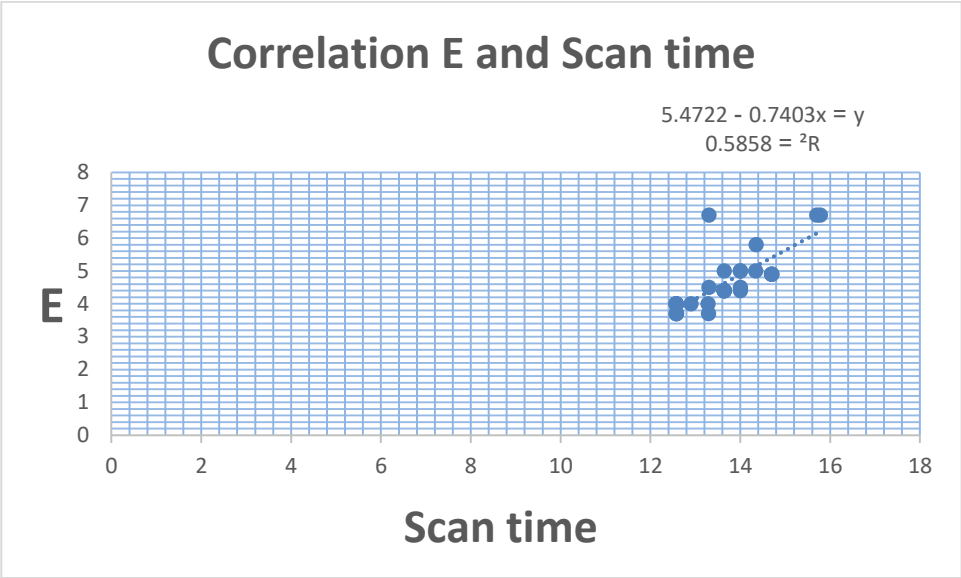


Figure 4-5. Correlation between effective dose E (mSv) and Scan time for patient undergoing brain CT in Alzaytouna Hospital.

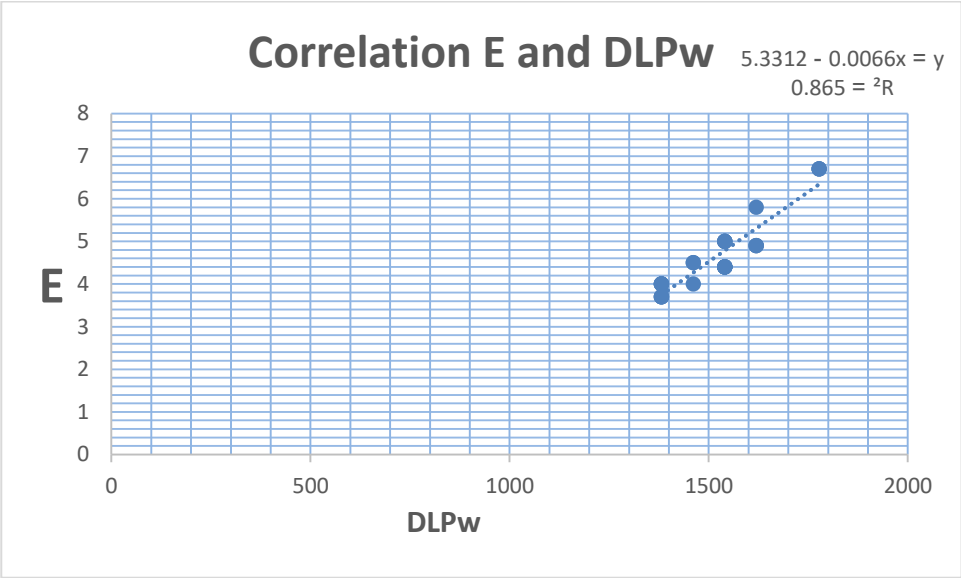


Figure 4-6. Correlation between effective dose E (mSv) and DLPw [mGy*cm] for patient undergoing brain CT in Alzaytouna Hospital.

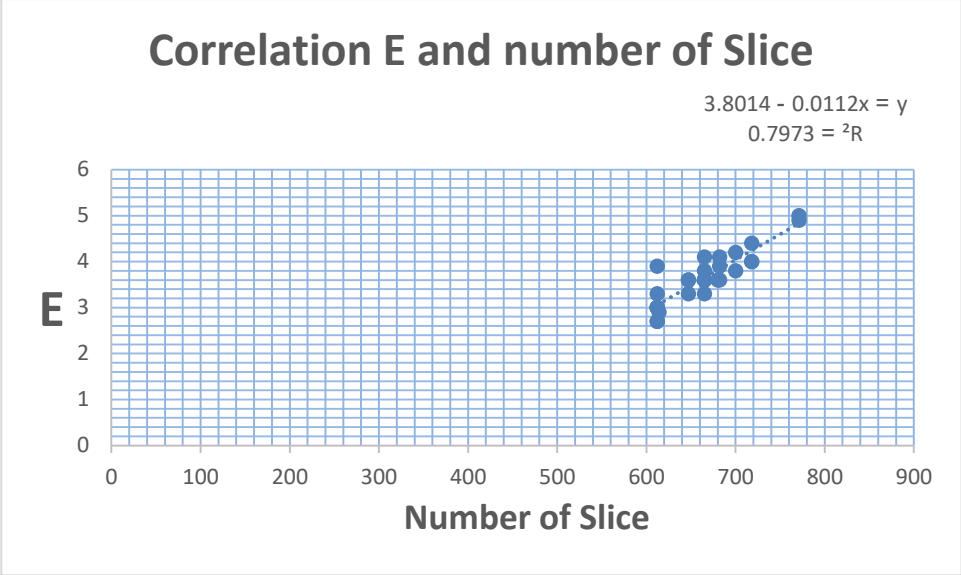


Figure 4-7. Correlation between effective dose E (mSv) and number of slice for patient undergoing brain CT in Army Hospital.

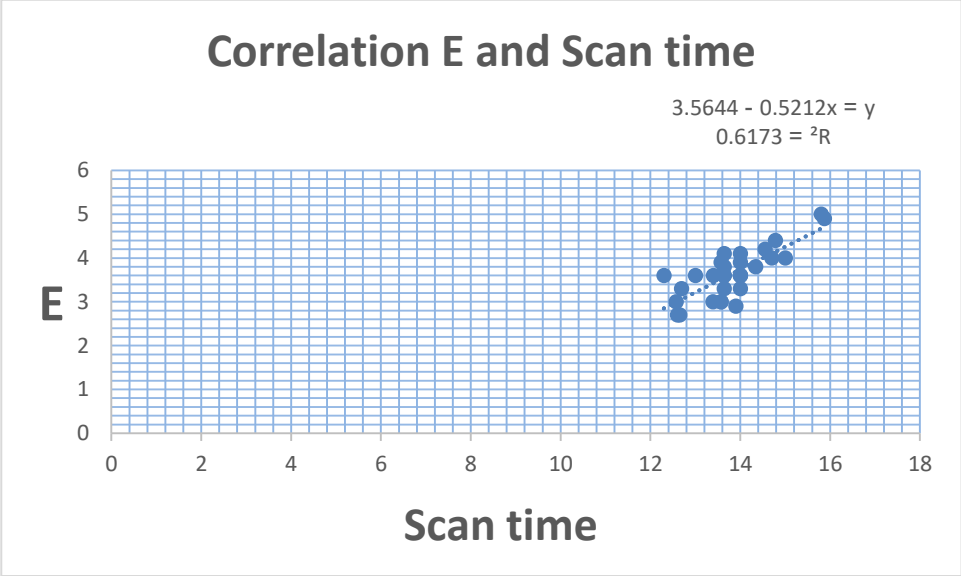


Figure 4-8. Correlation between effective dose E (mSv) and Scan time for patient undergoing brain CT in Army Hospital.

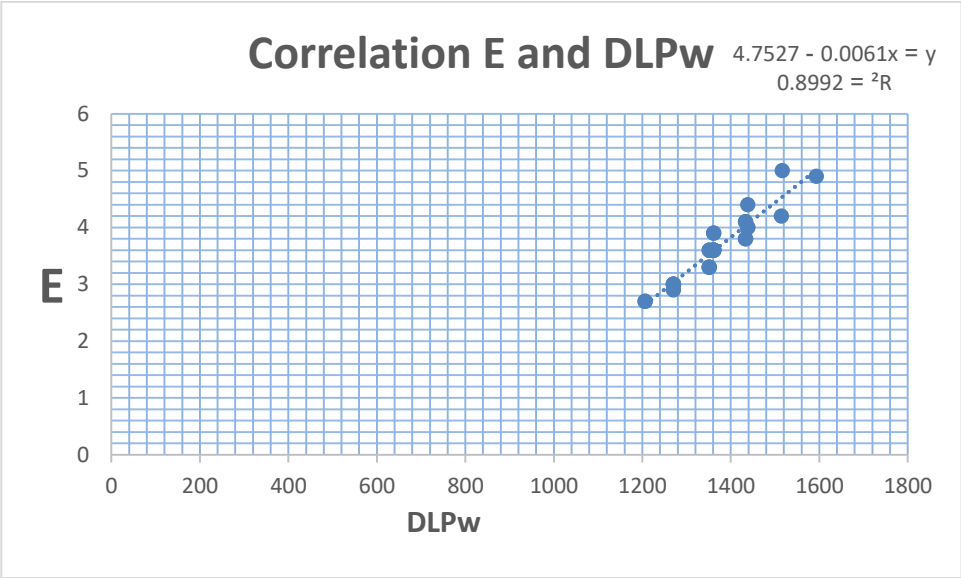


Figure 4-9. Correlation between effective dose E (mSv) and DLPw [mGy*cm] for patient undergoing brain CT in Army Hospital.

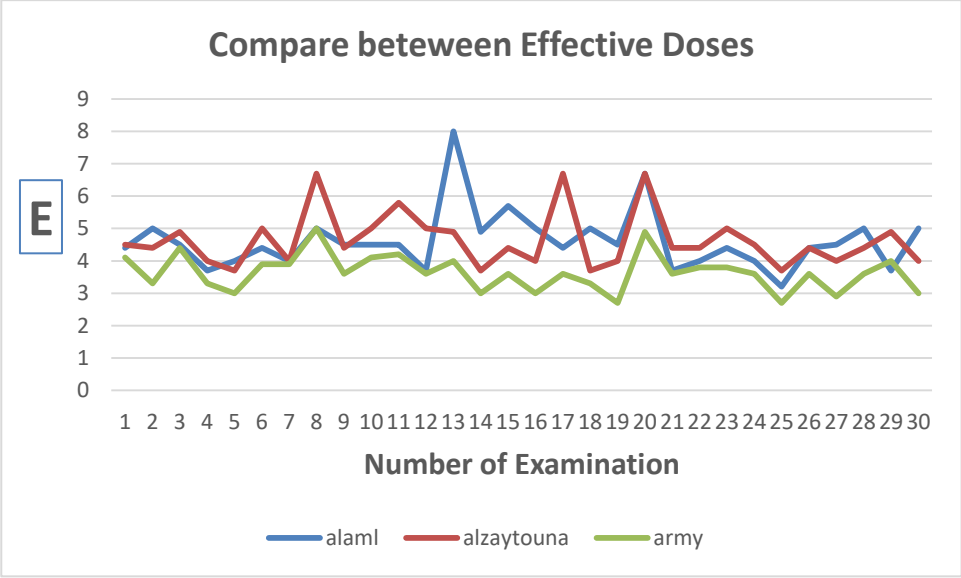


Figure 4-10. Compare between effective doses E (mSv) between Alaml Hospital, Alzaytouna Hospital and Army Hospital.

Chapter Five

Discussion, Conclusion and Recommendation

5.1 Discussions:

This study intends to assess the ED of patient undergoing brain CT in three hospitals in Khartoum state. A total of 90 patients 30 in (Alaml Hospital), 30 in (Alzaytouna Hospital) and 30 in (Army Hospital) were examined. The mean of (ED) Age, Kvp, mAs, slice thickness, Slice Number, Scan time, Scan Length, number of rotation, TF, Collimation, Pitch, CTDIw, CTDIvol, DLPw recorded in table [4.1]. The correlation coefficient which is defined as a measure of the degree of linear relationship between two variables was found out. These correlations coefficient between the Effective dose (mSv) and **(**number of slice**,** Scan length, DLPw) was obtained for all hospitals. The figures (4.1, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9) shows that there was a correlation found between the ED values and **(**number of slice**,** Scan length, DLPw) (correlation coefficient R^2 ranged from (0.5224 to 0.8992). the figure 4.2 shows there was no correlation between ED values and scan length for patient undergoing brain CT in Alaml Hospital. The figure 4.10 shows the comparison between three hospitals in ED values, the mean values of effective dose obtained from this study was higher in Alzaytouna hospital then alaml hospital and then army hospital which was [4.64, 4.61, 3.636] respectively. In this study, large variations of radiation effective dose were observed. Different scanning protocols used among hospitals and variation in equipment design among manufacturers and models were responsible for these variations. The main contributor for this difference was the use of a larger scan length in Alzaytouna hospital than that used in alaml hospital and army hospital.

5.2 Conclusion:

Radiation dose from CT procedures varies from patient to patient. A particular radiation dose will depend on the size of the body part examined, the type of procedure, the weight of patient and the type of CT equipment and its operation. Typical values cited for radiation dose should be considered as estimates that cannot be precisely associated with any individual patient, examination, or type of CT system. 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.

5.3 Recommendation:

The large observed variations of radiation effective doses among hospitals and relatively high organ doses in hospitals call for the need to optimize CT scanning protocols. This can be achieved through optimal selection of scanning parameters based on indication of study, body region of interest being scanned, and patient size. In addition, further studies should be done to investigate the potential for using radio protective materials to protect superficial radiosensitive organ.

Further studies should be done in order to optimize the radiation dose to establish national diagnostic reference level in Sudan.

An increase focusing on that there should be a medical physicist staff within each department of radioactivity in hospitals and diagnostics centre coached at high levels.

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5.5. Appendix:

5.5.1. Alaml Hospital data sheet:

NO	Sex	Age	Kvp	mAs	Slice Thick	Slice NO	Scan Time	Scan Length	No of rotation	TF	Collimation	Pitch
1	M	87	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
2	F	70	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
3	F	85	120	225	0.5	647	13.29	15.99	10.11	15.81	32	0.49
4	M	37	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
5	F	25	120	225	0.5	612	12.37	15	9.56	15.69	32	0.49
6	M	85	120	225	0.5	682	14	16.98	10.66	15.93	32	0.50
7	M	78	120	225	0.5	647	7	15.99	10.11	15.82	32	0.49
8	F	32	120	225	0.5	682	14	16.98	10.66	15.93	32	0.50
9	F	47	120	225	0.5	665	13.64	16	10.39	15.40	32	0.48
10	F	46	120	225	0.5	665	13.64	16	10.39	15.40	32	0.48
11	F	50	120	225	0.5	718	14.71	18	11.22	16.04	32	0.50
12	M	95	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
13	F	22	120	225	0.5	771	15.79	19.5	12.05	16.19	32	0.51
14	M	41	120	225	0.5	700	14.36	17.49	10.94	15.99	32	0.50
15	M	75	120	225	0.5	770	15.71	18.99	12.03	15.78	32	0.49
16	F	84	120	225	0.5	612	14	16.99	9.56	17.77	32	0.56
17	M	87	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
18	F	70	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
19	F	85	120	225	0.5	647	13.29	15.99	10.11	15.81	32	0.49
20	M	28	120	225	0.5	917	5.83	19.5	14.33	13.61	32	0.43
21	M	37	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
22	F	25	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
23	M	85	120	225	0.5	682	14	16.98	10.66	15.93	32	0.50
24	M	78	120	225	0.5	647	7	15.99	10.11	15.82	32	0.49
25	M	50	120	225	0.5	701	4	14.1	10.95	12.87	32	0.40
26	M	73	120	225	0.5	682	14	16.98	10.66	15.93	32	0.50
27	F	85	120	225	0.5	646	13.29	15.97	10.09	15.82	32	0.49
28	F	43	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
29	M	90	120	225	0.5	614	12.97	15	9.59	15.64	32	0.49
30	F	47	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50

NO	**$CTDI_w$** [mGy]	**$CTDI_{vol}$** [mGy]	**DLP_w^*** [mGy*cm]	**E^*** [mSv]
1	44.6	79.2	1540	4.4
2	44.6	79.2	1540	5.0
3	44.6	79.2	1461	4.5
4	44.6	79.2	1381	3.7
5	44.6	79.2	1381	4.0
6	44.6	79.2	1540	4.4
7	44.6	79.2	1461	4.0
8	44.6	79.2	1540	5.0
9	44.6	79.2	1461	4.5
10	44.6	79.2	1461	4.5
11	44.6	79.2	1461	4.5
12	44.6	79.2	1381	3.7
13	44.6	79.2	1777	8.0
14	44.6	79.2	1619	4.9
15	44.6	79.2	1698	5.7
16	44.6	79.2	1540	5.0
17	44.6	79.2	1540	4.4
18	44.6	79.2	1540	5.0
19	44.6	79.2	1461	4.5
20	44.6	79.2	1777	6.7
21	44.6	79.2	1381	3.7
22	44.6	79.2	1381	4.0
23	44.6	79.2	1540	4.4
24	44.6	79.2	1461	4.0
25	44.6	79.2	1302	3.2
26	44.6	79.2	1540	4.4
27	44.6	79.2	1461	4.5
28	44.6	79.2	1540	5.0
29	44.6	79.2	1381	3.7
30	44.6	79.2	1540	5.0

5.5.2. Alzaytouna Hospital Data Sheet:

NO	Sex	Age	Kvp	mAs	Slice Thick	Slice NO	Scan Time	Scan Length	No of rotation	TF	Collimation	Pitch
1	F	31	120	225	0.5	682	14	15.99	10.66	15.01	32	0.47
2	M	45	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
3	M	50	120	225	0.5	718	14.69	18	11.22	16.04	32	0.50
4	M	85	120	225	0.5	647	13.28	16	10.11	15.83	32	0.49
5	M	24	120	225	0.5	612	13.29	15	9.56	15.69	32	0.49
6	F	85	120	225	0.5	682	14	16.96	10.66	15.92	32	0.50
7	F	37	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
8	M	20	120	225	0.5	771	15.7	19.5	12.05	16.19	32	0.51
9	M	87	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
10	F	71	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
11	F	41	120	225	0.5	700	14.35	17.5	10.94	16	32	0.5
12	F	73	120	225	0.5	680	14	17	10.63	16	32	0.5
13	M	50	120	225	0.5	718	14.7	17.99	11.22	16.04	32	0.50
14	M	25	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
15	M	87	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
16	F	29	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
17	M	84	120	225	0.5	647	13.3	19.99	10.11	19.77	32	0.62
18	M	25	120	225	0.5	612	12.58	15	9.56	15.69	32	0.49
19	F	36	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
20	M	21	120	225	0.5	771	15.78	19.5	12.05	16.19	32	0.51
21	M	88	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
22	M	69	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
23	F	40	120	225	0.5	700	14.34	17.4	10.94	15.91	32	0.50
24	F	84	120	225	0.5	647	13.3	16	10.11	15.83	32	0.50
25	M	27	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49
26	M	77	120	225	0.5	682	14	16.9	10.66	15.86	32	0.50
27	F	89	120	225	0.5	614	12.9	15	9.59	15.64	32	0.49
28	M	46	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
29	M	50	120	225	0.5	718	14.7	17.9	11.22	15.96	32	0.50
30	F	95	120	225	0.5	612	12.57	15	9.56	15.69	32	0.49

NO	**$CTDI_w$** [mGy]	**$CTDI_{vol}$** [mGy]	**DLP_w^*** [mGy*cm]	**E^*** [mSv]
1	44.6	79.2	1461	4.5
2	44.6	79.2	1540	4.4
3	44.6	79.2	1619	4.9
4	44.6	79.2	1461	4.0
5	44.6	79.2	1381	3.7
6	44.6	79.2	1540	5.0
7	44.6	79.2	1381	4.0
8	44.6	79.2	1777	6.7
9	44.6	79.2	1540	4.4
10	44.6	79.2	1540	5.0
11	44.6	79.2	1619	5.8
12	44.6	79.2	1540	5.0
13	44.6	79.2	1619	4.9
14	44.6	79.2	1381	3.7
15	44.6	79.2	1540	4.4
16	44.6	79.2	1381	4.0
17	44.6	79.2	1777	6.7
18	44.6	79.2	1381	3.7
19	44.6	79.2	1381	4.0
20	44.6	79.2	1777	6.7
21	44.6	79.2	1540	4.4
22	44.6	79.2	1540	4.4
23	44.6	79.2	1540	5.0
24	44.6	79.2	1461	4.5
25	44.6	79.2	1381	3.7
26	44.6	79.2	1540	4.4
27	44.6	79.2	1381	4.0
28	44.6	79.2	1540	4.4
29	44.6	79.2	1619	4.9
30	44.6	79.2	1381	4.0

5.5.3. Army Hospital Data Sheet (AH):

NO	Sex	Age	Kvp	mAs	Slice Thick	Slice NO	Scan Time	Scan Length Cm	No of rotation	TF	Collimation	Pitch
1	F	33	120	225	0.5	682	14	17	10.66	15.95	32	0.50
2	M	48	120	225	0.5	665	13.64	16	10.39	15.40	32	0.48
3	F	50	120	225	0.5	718	14.78	18	11.22	16.04	32	0.50
4	M	90	120	225	0.5	647	14	16	10.11	15.83	32	0.49
5	F	26	120	225	0.5	612	13.39	15	9.56	15.69	32	0.49
6	F	81	120	225	0.5	682	14	16.56	10.66	15.54	32	0.49
7	F	34	120	225	0.5	612	13.57	16.5	9.56	17.25	32	0.54
8	F	21	120	225	0.5	771	15.8	19.0	12.05	15.77	32	0.49
9	M	88	120	225	0.5	665	13	16.5	10.39	15.88	32	0.50
10	F	69	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
11	M	44	120	225	0.5	700	14.55	17.5	10.94	16	32	0.5
12	M	75	120	225	0.5	680	14	17.0	10.63	16	32	0.5
13	M	53	120	225	0.5	718	15	17.99	11.22	16.04	32	0.50
14	F	22	120	225	0.5	612	13.57	15.0	9.56	15.69	32	0.49
15	M	84	120	225	0.5	665	13.64	16.55	10.39	15.93	32	0.50
16	F	33	120	225	0.5	612	13.57	15.0	9.56	15.69	32	0.49
17	F	88	120	225	0.5	647	12.3	15.99	10.11	15.82	32	0.49
18	M	26	120	225	0.5	612	12.69	15.5	9.56	16.21	32	0.51
19	M	31	120	225	0.5	612	12.65	15.0	9.56	15.69	32	0.49
20	M	25	120	225	0.5	771	15.87	19.5	12.05	16.19	32	0.51
21	M	82	120	225	0.5	665	14	16.5	10.39	15.88	32	0.50
22	M	66	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
23	M	46	120	225	0.5	700	14.34	17.4	10.94	15.91	32	0.50
24	F	86	120	225	0.5	647	13.4	16.0	10.11	15.83	32	0.49
25	M	28	120	225	0.5	612	12.6	15.0	9.56	15.69	32	0.49
26	M	72	120	225	0.5	682	14	16.95	10.66	15.91	32	0.50
27	M	89	120	225	0.5	614	13.9	15.0	9.59	15.64	32	0.50
28	M	44	120	225	0.5	665	13.64	16.5	10.39	15.88	32	0.50
29	M	54	120	225	0.5	718	14.7	17.9	11.22	15.96	32	0.50
30	F	91	120	225	0.5	612	12.57	15.0	9.56	15.69	32	0.49

NO	**$CTDI_w$** [mGy]	**$CTDI_{vol}$** [mGy]	**DLP_w^*** [mGy*cm]	**E^*** [mSv]
1	58.2	81.5	1433	4.1
2	58.2	81.5	1351	3.3
3	59.5	77.4	1438	4.4
4	58.2	81.5	1351	3.3
5	58.2	81.5	1270	3.0
6	59.5	77.4	1361	3.9
7	59.5	77.4	1361	3.9
8	59.5	77.4	1516	5.0
9	59.5	77.4	1361	3.6
10	58.2	81.5	1433	4.1
11	58.2	81.5	1514	4.2
12	59.5	77.4	1361	3.6
13	59.5	77.4	1438	4.0
14	58.2	81.5	1270	3.0
15	59.5	77.4	1361	3.6
16	58.2	81.5	1270	3.0
17	58.2	81.5	1351	3.6
18	58.2	81.5	1351	3.3
19	59.5	77.4	1206	2.7
20	59.5	77.4	1593	4.9
21	59.5	77.4	1361	3.6
22	58.2	81.5	1433	3.8
23	58.2	81.5	1433	3.8
24	58.2	81.5	1351	3.6
25	59.5	77.4	1206	2.7
26	59.5	77.4	1361	3.6
27	58.2	81.5	1270	2.9
28	59.5	77.4	1361	3.6
29	59.5	77.4	1438	4.0
30	58.2	81.5	1270	3.0