

Chapter one

1.1. Introduction:-

X-rays are electromagnetic radiation that differentially penetrates structures within the body and creates images of these structures on photographic film or a fluorescent screen. These images are called diagnostic x rays. Diagnostic X-rays are useful in detecting abnormalities within the body. They are a painless, non-invasive way to help diagnose problems such as broken bones, tumors , dental decay and presence of foreign bodies .x-rays are form of radiation similar to light rays except that they are more energetic than the light rays and invisible to the human eye. They are created when electric current is passed through vacuum tube(Martin,2006).

X-ray were accidentally discovered in 1895 by German physicist Wilhem roentgen (1845-1923) who was later awarded the first Nobel Prize in physics for discovery Roentgen was also photographer almost immediately realized that the shadow created when x-ray passed through the body could be permanently recorded on photograph plate His first x-ray picture was his wife's hand , within few years x-ray become a valued diagnostic tool of physician worldwide (Martin ,2006).

Digital Radiography (DR) is the science of devising X-ray digital imaging detectors that may substitute the conventional radiographic screen-film combination for use in diagnostic radiology. In projection radiography, a digital imaging detector maps the two-dimensional distribution of X-ray photons transmitted by the irradiated body in discrete spatial units (pixels) and discrete signal units (bits), as opposed to the X-ray film which directly provides only an analogue recording of the two-dimensional detected photon distribution. In principle,

the digital approach has several significant benefits over the analogue film. First, it gives directly a digital image, able to be processed with computer methods as soon as it is acquired, for image storage, manipulation, archiving and network circulation within the hospital (s). This would avoid the necessity of film digitization with X-ray film scanners. This is an additional processing step after film exposure and development which would equally provide a digital X-ray image from X-ray film, but would add the cost of the film scanner which might represent a significant fraction of the cost of the entire X-ray unit. But the very true advantage of the direct X-ray digital image is related to the linearity and dynamic range of the imaging acquisition process (Guerra,2004).

Digital radiography is a form of X-ray Image, where digital X-ray sensors are used instead of traditional photographic film. Advantages include time efficiency through bypassing chemical processing and the ability to digitally transfer and enhance images. Also less radiation can be used to produce an image of similar contrast to conventional radiography (Arakawa et al ,1999).

Instead of X-ray film, digital radiography uses a digital image capture device. This gives advantages of immediate image preview and availability; elimination of costly film processing steps; a wider dynamic range, which makes it more forgiving for over- and under-exposure; as well as the ability to apply special image processing techniques that enhance overall display of the image. Also its a device that converts the X-rays to a digital signal, which is then represented on a viewing monitor for diagnosis. An image from an X-ray system that appears on a viewing monitor may have come from one of three technologies that Digital X-ray is the electronic capture of an X-ray exposure (Arnold B A1979).Arakawa et al, 2000).

1.2. Radiation Risk:

Low dose exposure to x-ray created minimal cell damage and minimal risk when x-ray are performed in an accredited facility, there is an increased risk that developing fetus will develop leukemia during childhood if exposed to x-ray radiation pregnant or potential pregnant woman should avoid x-rays there is also a slight risk of an allergic reaction to the contrast material or dye used in certain x-rays (Good Man 2010).

1.3. Problem of study:

Most clinical examination of the radiological field only take in account the image quality without taking care about patient dose so the patient receive significant dose , and use different exposure factor without found the base line of practice .

1.4. Objectives:

General Objective: To estimate the patient radiation dose During Digital Radiography Examinations for adults patients.

Specific Objectives :

- Estimate patients dose in Digital Radiography for : (i) Chest (ii) Lumber Spine .
- Calculate the Effective Dose to patient .
- To optimize technique to reduce the dose .

:Thesis outlines .1.5

This thesis is concerned with the evaluation of image quality and radiation dose to patient in digital radiography.

Accordingly, it is divided into the following chapters:

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

Chapter two contains the background material for the thesis. Specifically it discusses the dose for all absorbed dose measurements and calculations. This chapter also includes a summary of previous work performed in this field and reviewed different dosimetric techniques used in patient dose measurements.

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

Chapter four presents the results of this study.

Chapter five presents the discussion, conclusion, recommendations and references of the thesis .

Chapter two

Background

2.1.Literature review:

2.1.1.Discovery of X-ray:

Two other simple tools, photographic plates and light-emitting phosphors such as zinc sulfide and barium-platinocyanide, contributed the discovery of x-rays. These tools in combination with a highly evacuated cathode ray tube (called a Crooke's tube) and the prepared mind of Wilhelm Conrad Roentgen set the stage for this major discovery. One evening in December 1885 in an attempt to understand the glow produced in such a tube, he covered it with opaque paper. Then one of those events that triggers great minds to discovery happened: he had darkened his laboratory to better observe the glow produced in the tube, and in the dim light he noticed flashes of light on a barium-platinocyanide screen that happened to be near the apparatus. Because the tube (now covered with black paper) was obviously opaque to light emitted from the tube, he realized that the flashes on the screen must be due to emissions from the tube because they disappeared when the electric potential was disconnected. Roentgen called the emissions x-rays to denote their "unknown" nature, and in a matter of days went on to describe their major features. The most startling property was that the rays could penetrate dense objects and produce an image of the object on a photographic plate as shown in Figure 2-1, the classic picture of the bones in his wife's hand(Martin,2006).



Figure 2.1 X-ray photograph of frau Roentgent,s wife's hand.

2.1.2. Classification of radiation:

As shown in Fig.2.2, radiation is classified into two main categories, non- ionizing and ionizing, depending on its ability to ionize matter. The ionization potential of atoms (i.e. the minimum energy required to ionize an atom) ranges from a few electron volts for alkali elements to 24.5 eV for helium (noble gas).

Non-ionizing radiation (cannot ionize matter).

Ionizing radiation (can ionize matter either directly or indirectly):

Directly ionizing radiation (charged particles): electrons, protons, and alpha particles and heavy ions. Indirectly ionizing radiation (neutral particles): photons (X rays and Gamma rays), neutrons.

Directly ionizing radiation deposits energy in the medium through direct coulomb interactions between the directly ionizing charged particle and orbital electrons of atoms in the medium. Indirectly ionizing radiation (photons or neutrons). deposits energy in the medium through a two steps process in the first step a charged particle is released in the medium (photons release electrons or positrons, neutrons release protons or heavier ions). In the second step the released charged particles deposit energy to the medium through direct Coulomb interactions with orbital electrons of the atoms in the medium(IAEA,ISBN92-0-107304-6).

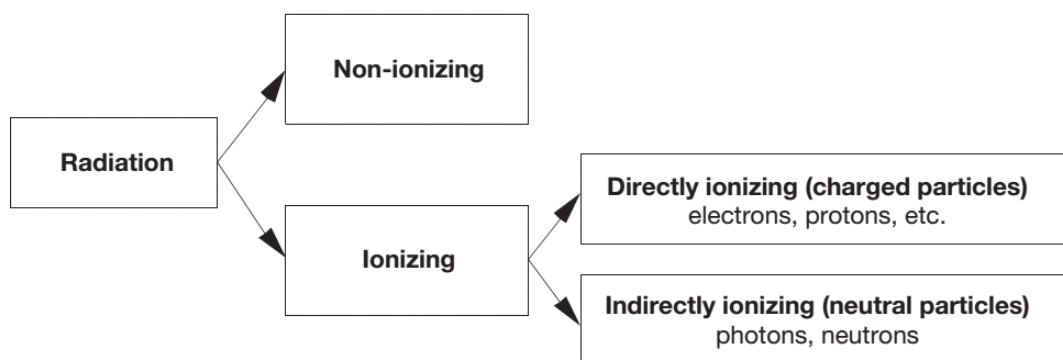


Figure 2.2 classification of radiation

2.1.3. Sources of radiation:

The nuclei of unstable atoms that eject or emit particles and high-energy waves. This process is known as radioactive decay. The major types of radiation emitted during radioactive decay are alpha particles, beta particles, and gamma rays (EPA,2007).

Alpha particles: are commonly emitted in the radioactive decay of the heaviest radioactive elements such as uranium-238, radium-226, and polonium 210, Even though they are highly energetic .The health effects of alpha particles depend heavily upon how exposure takes place.

Beta particles: are fast moving electrons emitted from the nucleus during radioactive decay more penetrating than alpha particles but are less damaging over equally traveled distance .

Gamma rays: often accompany the emission of alpha or beta particles from a nucleus. They have neither a charge nor a mass and are very penetrating One source of gamma rays in the environment is naturally-occurring potassium-40. Manmade sources include cobalt-60 and cesium-137.

X-rays: are high-energy photons produced by the interaction of charged particles with matter. X-rays and gamma rays have essentially the same properties but differ in origin. X-rays are either produced from a change in the electron structure of the atom or are machine produced (EPA, 2007).

2.2. Production of X-rays:

2.2.1. Bremsstrahlung 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 its 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).

Roentgen was able to describe most of the known characteristics of x-rays after his monumental discovery by conducting several experiments; however, it was not possible to explain how x-rays were produced until the concepts of atoms, particles, and quanta were understood. It is now known that x-ray production occurs as shown in Figure 2.3, when a negatively charged electron of kinetic energy eV enters the force field of the positively charged nucleus of a target atom. This force field, which is strongest for high-Z materials like tungsten, deflects and accelerates the electron, which causes the emission of electromagnetic radiation as it is bent near the nucleus. This is consistent with classical electromagnetic theory because the electron is not bound. Because radiation is emitted and energy is lost in the process, the electron must slow down, so that when it escapes the force field of the nucleus it has less energy. Overall, the electron experiences a net deceleration and its energy after being decelerated is $eV - h\nu$ where $h\nu$ appears as electromagnetic radiation. Roentgen named these radiations x-rays to characterize their unknown status. This process of radiation being produced by an overall net deceleration of the electrons is called Bremsstrahlung as shown in Figure 2.3 below, and its German word meaning braking radiation (Martin, 2006).

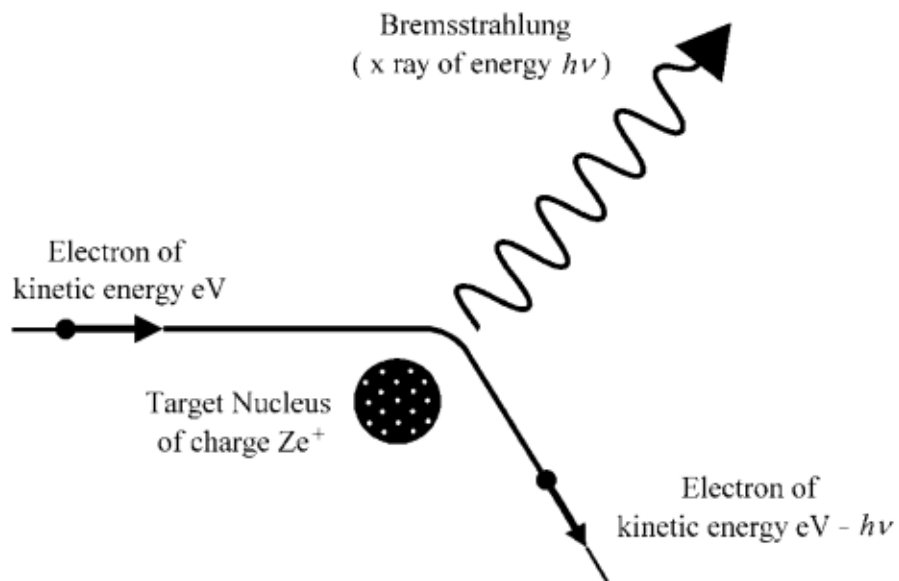


Figure 2.3 Production of x-rays in which accelerated electrons emit bremsstrahlung.

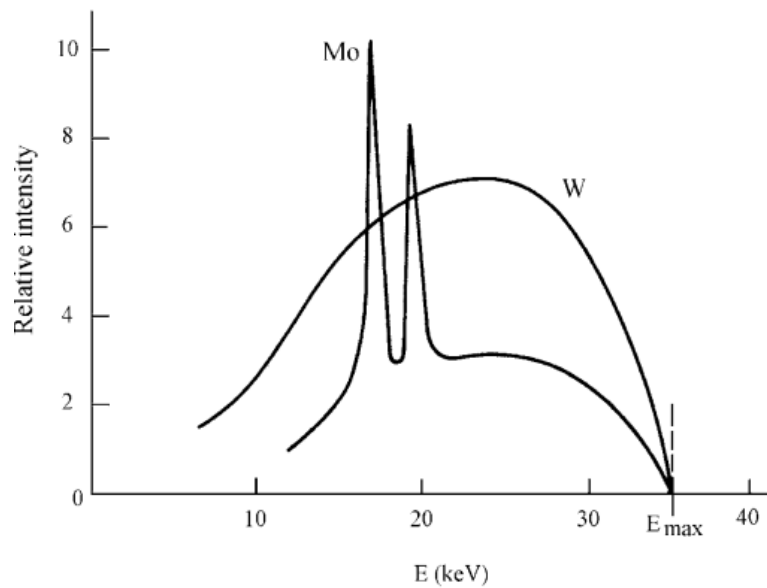


Fig. 2.4 X-ray spectra of intensity $I(\nu)$ versus electron energy E for tungsten (W) and molybdenum (Mo) targets, each of which is operated at 35 kV (Martin,2006).

X-ray production is a probabilistic process because any given electron may take any path past a target nucleus including one in which all of its energy is lost. Bremsstrahlung photons are thus emitted at all energies up to the accelerating energy eV and in all directions, including absorption in the target.

As shown in Figure 2.3 for tungsten (W) and molybdenum (Mo), x-ray spectra have a continuous distribution of energies up to the maximum energy E_{\max} of the incoming electron. The value of E_{\max} does not depend on the target material, but is directly proportional to the maximum voltage. About 98% of the kinetic energy of the accelerated electrons is lost as heat because most of the impinging electrons expend their energy in ionizing target atoms (Martin,2006) .

2.2.2. Characteristic x-rays:

Figure 2.4 shows discrete lines superimposed on the continuous x-ray spectrum for a molybdenum target because the 35 keV electrons can overcome the 20 keV binding energy of inner shell electrons in the molybdenum target. However, this does not occur for the tungsten target spectrum because the inner shell electrons of tungsten are tightly bound at 69.5 keV. The vacancy created by a dislodged orbital electron can be filled by an outer shell (or free) electron changing its energy state, or, as Bohr described it, jumping to a lower potential energy state with the emission of electromagnetic radiation; the emitted energy is just the difference between the binding energy of the shell being filled and that of the shell from whence it came. And since the electrons in each element have unique energy states, these emissions of electromagnetic radiation are “characteristic” of the element, hence the term “characteristic x-rays” as show in Figure 2.5 They uniquely identify each element (Martin,2006).

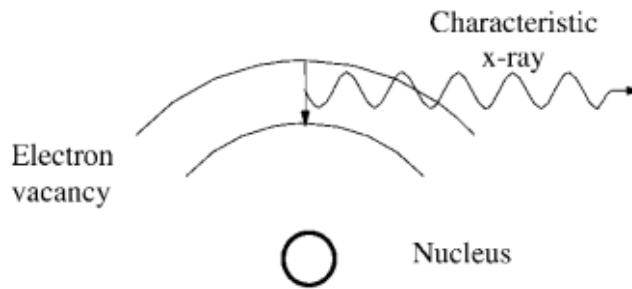
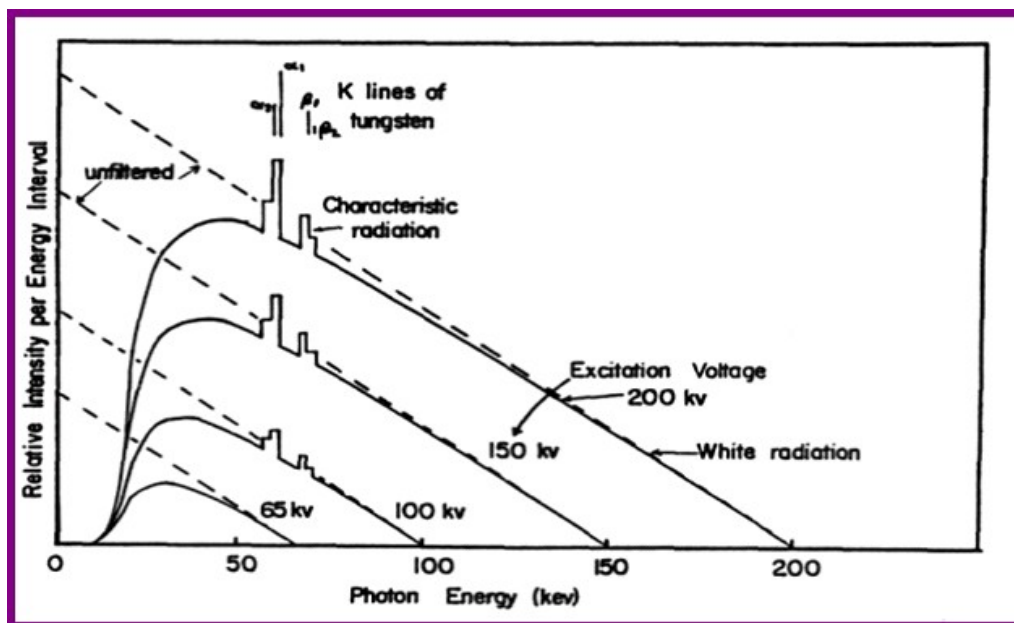


Figure 2.5. production of Characteristic X-ray

2.2.3. Spectra of X-ray:

X-ray photons produced by an X-ray machine are heterogeneous in energy. The energy spectrum shows a continuous distribution of energies for the bremsstrahlung photons superimposed by characteristic radiation of discrete energies. A typical spectral distribution is shown in Fig. The inherent filtration in conventional X-ray tubes is usually equivalent to about 0.5- to 1.0-mm aluminum. Added filtration, placed externally to the tube, further modifies the spectrum. It should be noted that the filtration affects primarily the initial low-energy part of the spectrum and does not affect significantly the high energy photon distribution. The purpose of the added filtration is to enrich the beam with higher-energy photons by absorbing the lower energy components of the spectrum. As the filtration is increased, the transmitted beam hardens, i.e., it achieves higher average energy and therefore greater penetrating power. Thus the addition of filtration is one way of improving the penetrating power of the beam. The other method, of course, is by increasing the voltage across the tube. Since the total intensity of the beam (area under the curves in Fig. 2.6) decreases with increasing filtration and increases with voltage, a proper combination of voltage and filtration is required to achieve desired hardening of the beam as well as acceptable intensity. The shape of the X-ray energy spectrum is the result of the alternating voltage applied to the tube, multiple bremsstrahlung interactions within the target and

Filtration in the beam. However, even if the X-ray tube were to be energized with a constant potential, the X-ray beam would still be heterogeneous in energy because of the multiple bremsstrahlung processes that result in different energy photons. Because of the X-ray beam having a spectral distribution of energies, which depends on voltage as well as filtration, it is difficult to characterize the beam quality in terms of energy, penetrating power, or degree of beam hardening. A rule of thumb is often used which states that the average X-ray energy is approximately one-third of the maximum energy or KVp. of course, the one-third rule is a rough approximation since filtration significantly alters the average energy. Another quantity, known as half value layer, has been defined to describe the quality of an X-ray beam (Bush berg JT et al , 2002).



The figure (2.6) show the Spectral distributions of X-rays(Bush berg JT et al , 2002).

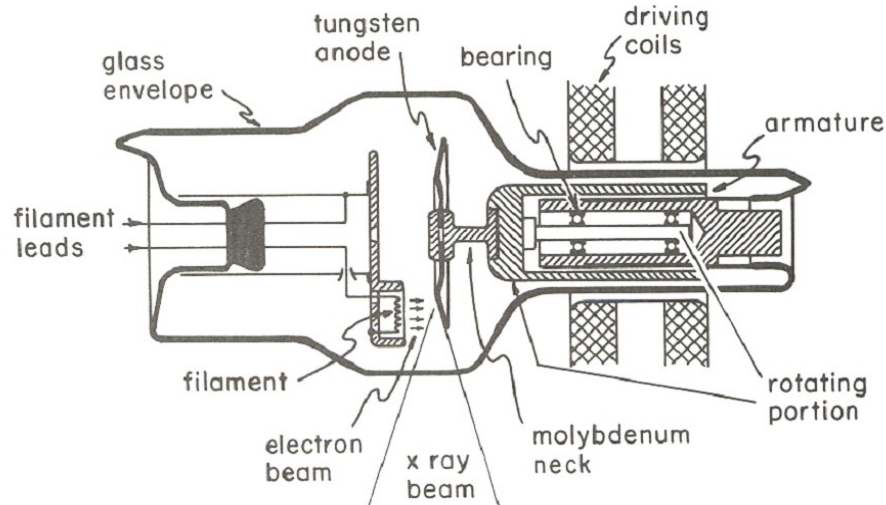


Figure 2.7: X-rays tube structure ([http:// medical dictionary.thefreedictionary.com/x-rays](http://medical.dictionary.thefreedictionary.com/x-rays)).

Anode: target material=high atomic number and high melting point, Tungsten Copper anode: conduction of heat striking the walls or other non-target. Anode hood: prevents stray electrons from non-target. Cathode: wire filament for thermionic emission of electrons, circuit to provide. Filament current and a negatively charged focusing cup.

Cathode cup: direct the electrons toward the anode.

2.3. Interaction of Photons with Matter:

A beam of photons passes through material until each undergoes a collision, at Random, and is removed from the beam. Thus, the intensity of the beam will Continuously drop as the beam propagates through the medium but the energy of the photons will remain constant. This degradation of the beam follows the Beer-Lambert exponential attenuation law.

$$I = I_0 e^{-\mu x} \quad \mu = 1/\lambda_{(2)}$$

μ Attenuation coefficient; λ mean free-path.

2.3.1. Compton scattering:

Scattering of a photon by a (free) electron that leads to moving electron and a lower energy photon. The two-body scattering leads to a correlation between angle and electron kinetic energy. The total cross -section for the scattering is given by the Klein-Nishina formula (DJ Morrissey, 2009).

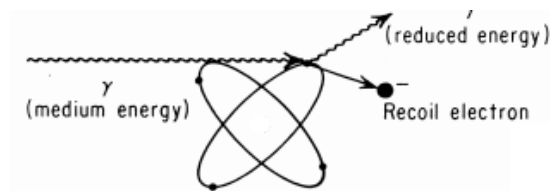


Figure 2.8 show the Compton scatter process.

Pair production:

$E_\gamma > 1.02\text{MeV}$, the conversion of a photon into a Matter/antimatter pair of electrons in the presence of a nucleus (or an Electron). The process generally depends on the Z of the medium and grows with photon energy. The two moving electrons share the remainder of the initial photon energy. Eventually the positron annihilates at the end of its range giving two 511 keV photons as show in figure 2.9(Morrissey.2009).

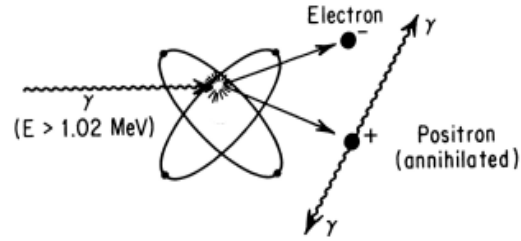


Fig 2.9:pair production process.

2.3.3.Photoelectric Effect: The process originally described by Einstein, most efficient conversion of photon into a moving electron to ionize the medium as atomic scale (square angstrom) cross sections that decrease sharply with photon energy with steps at the electron shell energies.

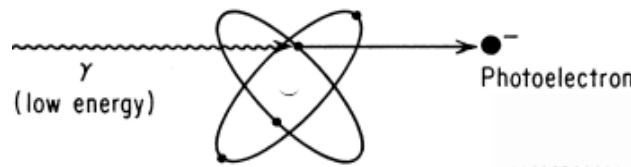


Figure 2.10:photoelectric process

.Photoelectric effect generates one electron with $E_e = h\nu - BE_e$ (Morrissey.2009)

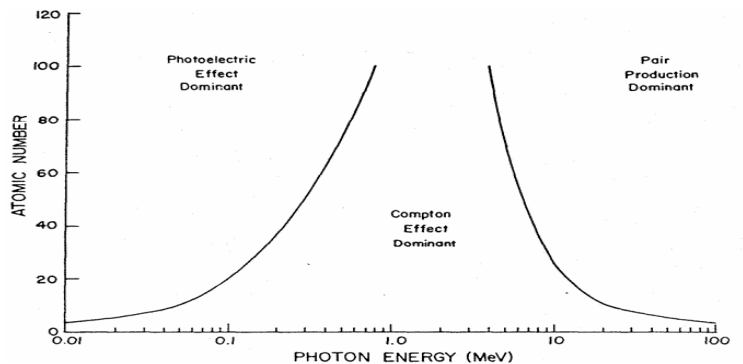


Figure: 2.11 Effects of photon energy and atomic mass number of absorbing medium on dominant type of photon attenuation processes.

2.11. Detection of ionizing radiation:

The dominant modern methods by which ionizing radiation is sensed are largely based on materials that were developed, in the form of single crystal scintillators (such as sodium iodide NaI(Tl)) or semiconductors (silicon (Si) or high purity germanium (HPGe principally), and gas-filled counters. These legacy materials have survived and flourished because they have delivered adequate performance for many medical imaging, military, and plant-monitoring applications, and there was no low-cost replacement materials that delivered equivalent or superior performance. Thus, most of the research effort throughout the latter half of the 20th century was focused on the implementation of single-crystal solid and gas-filled detectors into various radiation detection niches. The dominant sensing technologies of ionizing radiation depend on its namesake; that is they sense the non-equilibrium charge states induced in the interaction media. Thus, either charges, in the form of electron-ion or electron-hole pairs, can be sensed by their effects on the electric field created by the surrounding device architecture, or the light that accompanies the radiative-recombination of that charge is monitored using scintillation photon detectors (Mitsuru Neno, 2012).

2.4.1. X-ray detectors for digital radiography:

receptors simplifies the task of correction for non-uniformities of the receptors. A reusable cassette system may be advantageous where a high degree of portability or flexibility is required, such as in intensive care situations or operating theatres, and has the advantage of being compatible with existing radiographic units (Quantum efficiency).

2.4.2. Gas field detector:

Radiation passing through a gas can ionize the gas molecules, provided the energy delivered by it is higher than the ionization potential of the gas. The charge pairs thus produced can be made to move in opposite directions by the application of an external electric field. The result is an electric pulse that can be measured by an associated measuring device. This process has been used to construct the so called gas filled detectors. A typical gas filled detector would consist of a gas enclosure and positive and negative electrodes. The electrodes are raised to a high potential difference that can range from less than 100 volts to a few thousand volts depending on the design and mode of operation of the detector.

2.4.2.1. Production of Electron-Ion Pairs:

Whenever radiation interacts with particles in a gas, it may excite the molecules ionize them, or do nothing at all. The quantity that is extremely important, at least for radiation detectors, is the average energy needed to create an electron-ion pair in a gas. This energy is referred to as the W-value. It would be natural to think that if the underlying radiation interaction processes are so complicated and dependent on energy and types of particles involved then the W-value would be different at each energy, for each radiation type, and for each type of gas. This is certainly true but only to a certain extent, the W-value depends only weakly on these parameters and lies within 25-45eV per charge pair for most of the gases and types of radiation. For a particle that deposits energy ΔE inside a detector, the W-value can be used to determine the total number of electron-ion pairs produced by

$$(3) \dots\dots\dots N = \frac{\Delta E}{W}.$$

If the incident particle deposits all of its energy inside the detector gas, then of course ΔE would simply be the energy E of the particle. However in case of partial energy loss, we must use some other means to estimate ΔE . An obvious parameter that can be used is the stopping power dE/dx , the above relation can be written as

$$N = \frac{1}{W} \frac{dE}{dx} \Delta x \dots\dots\dots(4)$$

Where Δx is the path covered by the particle, to calculate the number of electron-ion pairs produced per unit length of the particle track

$$n = \frac{1}{W} \frac{dE}{dx} \dots\dots\dots 5(\dots\dots\dots \text{jj})$$

2.4.3. Computed Radiography (CR):

Is a term for photo stimulable phosphor detector (PSP) systems. Phosphor used in screen-film radiography, when x-ray are absorbed by photo stimulable phosphors, some light is emitted, but much of the absorbed x-ray energy is trapped in the PSP screen and can be read out later. For this reason, PSP screens are also called storage phosphors or imaging plates. CR was introduced in the 1970. After exposing the CR cassette is brought to CR reader. In the CR reader the imaging plate is scanned by laser beam. The laser light stimulates the emission of trapped energy in the imaging plate, and visible light is released from the plate. To form the image, the light released from the plate is collected by photomultiplier tube (PMT)(HALL, E.J, 2002).

2.4.4 The modern film-screen :

System used for general radiography consists of cassette, one or two intensify screens, and a sheet of film. The film itself is a sheet of thin plastic with photosensitive emulsion coated on to

one or both sides. Film can be used to detect x-rays but it is relatively insensitive and therefore a lot of x-ray energy is required to produce a properly exposed x-ray film. To reduce the radiation dose to the patient, x-ray screens are used in all modern medical diagnostic radiography. Screens are made of a scintillation material, which is called a phosphor. When x-rays interact in phosphor, visible or ultraviolet (UV) light is emitted. This light given off by the screens that principally causes the film darkening; only about 5% of the darkening of the film is a result of direct x-ray interaction with the film emulsion. Therefore film-screen detectors are considered an indirect detector. The emulsion of an exposed sheet of x-ray film is altered by the exposure to light and the latent image is recorded as altered chemical bonds in the emulsion, which are not visible. However this latent image is visible during film processing (HALL, E.J, 2002).

2.5. Characteristics of X-Ray Imaging Systems:

2.5.1. Figure of merit for image quality:

The assessment of quality in image science requires the evaluation of many different parameters and image features, like detection efficiency spatial resolution and image noise. In comparing the different detector systems for digital X-ray imaging, a main figure of merit will be used namely, the detective quantum efficiency, or DQE, and its generally accepted as a quantitative measure of the overall image especially in comparing different digital systems. Knowledge of other image quality parameters is necessary, related to efficiency and resolution and noise quality, At a preliminary stage, the DQE of an imaging system can be defined as the squared ratio of the output and input signal-to-noise ratio (SNR):

$$DQE = \frac{SNR_{out}^2}{SNR_{in}^2}$$

(6).....

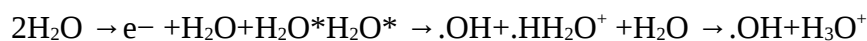
In other terms, the DQE gives an indication of how the SNR of an input image signal is transferred to the output image field. Ideal imaging systems have a DQE of 1. both the input and the output image fields contain spatial variations in the number of incident photons, that can be described by the spatial frequency variable f (often expressed in line pairs per mm, lp/mm). This implies that the DQE as defined in (Eq) corresponds exactly only to the zero spatial frequency detective quantum efficiency $DQE(0)$.

$$DQE(0) = \frac{SNR_{out}^2(0)}{SNR_{in}^2(0)} \dots\dots\dots (7)$$

Here, $SNR(0)_{out}$ and $SNR(0)_{in}$ represent the zero spatial frequency signal-to-noise ratios of the output and input of the imaging system respectively (HALL, E.J, 2002).

2.6. Biological effects of ionizing radiation:

Ionizing radiation (IR) is a stream of high energy particles (such as electrons, protons or α -particles) or any of the short wavelength electromagnetic radiation (such as X-rays, γ -rays or ultraviolet rays) that is capable of removing an electron from an atom or a molecule in the substance through which it passes. The most common biological effect of IR is ejection of an electron from water molecule, resulting in the formation of highly reactive species:



In the reaction above, the dot before a radical indicates unpaired electron and * indicates an excited species. These free radicals are highly reactive and can alter other molecules in the cell. DNA is one such important target which can also be directly ionized by IR. Cells experiencing IR-induced DNA damage respond in different ways, depending on the extent of

damage. In cases where the extent of DNA damage is minimal, the cells successfully repair the damaged DNA and as a result, there is no recognizable biological effect. At the other extreme is when the damage is severe, leading to a failure in the cells' ability to repair the DNA and as a result, the cells undergo programmed cell death or apoptosis so that a potential damage from the entire tissue is prevented. In the middle of these two extremes are detectable DNA mutations that occur when repair results in a non-lethal DNA mutation that can be transmitted to the daughter cells produced during successive cell divisions and these mutations may induce cancer subsequently. A fourth possible consequence of exposure to IR is when cells experience irreparable DNA damage leading to replication and transcriptional errors that predispose their daughter cells to premature aging and cancer (Mitsuru Neno,2012).

2.6.1. Radiation and DNA

Radiation is simply a mechanism whereby energy passes through space. It takes the form of an electromagnetic wave, with the frequency of the electromagnetic wave determining its position in the electromagnetic spectrum. Low-frequency waves such as radio waves and high-energy, high-frequency X-rays/Gamma rays. These high-frequency, high-energy waves are termed "ionizing" radiation because they contain sufficient energy to displace an electron from its orbit around nucleus. The most important consequence of this displaced electron on human tissue is the potential damage it can inflict on DNA, which may occur directly or indirectly. Direct damage occurs when the displaced electron hits and breaks a DNA strand. Indirect damage occurs when the electron reacts with a water molecule, creating a powerful hydroxyl radical which then damages the cell's DNA. The deleterious effect ionizing radiation has on human

tissue can be divided into two types: non-stochastic (deterministic) or stochastic effects (T.R.Good man,2010).

2.6.1.1. Deterministic (Non-Stochastic) Effects

Only occur once a threshold of exposure has been exceeded. The severity of deterministic effects increases as the dose of exposure increases because of an identifiable threshold level.

Mechanisms: Deterministic effects are caused by significant cell damage or death. The physical effects will occur when the cell death burden is large enough to cause obvious functional impairment of a tissue or organ, such as; Erythema occurs 1 to 24 hours after 2 Sv have been received, Cataract occurs after 2 to 10 Gy have been received, Sterility; this effect decreases with age, radiation exposure to the testes can result in temporary or permanent. Permanent sterility occurs after 2.5 to 3.5 Gy have been received by the gonads, Radiation sickness involves nausea, vomiting, and diarrhea developing within hours or minutes of a radiation exposure.

2.4.1.2. Stochastic Effects:

Current thinking is that stochastic effect occurrence follows a linear no-threshold hypothesis. This means that although there is no threshold level for these effects, the risk of an effect occurring increases linearly as the dose increases.

Mechanism of Stochastic effects occur due to the ionizing radiation effect of symmetrical translocations taking place during cell division such as: Cancer, Hereditary Defects (Goodman,2010).

2.7. Radiation quantities:

2.7.1. Radiation Exposure:

The term exposure is used to describe the quantity of ionization produced when x-rays or gamma rays interact in air because it can be conveniently measured directly by collecting the electric charge, whereas that which occurs in a person cannot be. The roentgen (R) is the unit of radiation exposure; it is defined only for air and applies only to x-rays and gamma rays up to energies of about 3MeV. The roentgen is not included in the SI system of units; the SI unit for exposure is the X unit, defined as the production of 1 C coulomb of charge in 1 kg of air, or $X = 1 \text{ C/kg}$ of air. The X unit corresponds to deposition of 33.97 J in 1 kg of air, and is equal to 3876R (Martin, 2006).

2.7.2. Radiation Absorbed Dose (RAD):

The absorbed dose is defined as the amount of energy deposited per unit mass. The conventional unit for absorbed dose is the rad (radiation absorbed dose), and is equal to the absorption of 100 erg of energy in 1 g of absorbing medium, typically tissue $\text{rad} = 100 \text{ erg/g}$ of medium. The SI unit of absorbed dose is the gray (Gy) and is defined as the absorption of 1J of energy per kilogram of medium $1\text{Gy}=1\text{J/kg}$, A milligray (mGy) is 100 m rads, which is about the amount of radiation one receives in a year from natural background, excluding radon. The rate at which an absorbed dose is received is quite often of interest. Common dose rates are rad/s, mrad/h, etc. In SI units, dose rates may be expressed as Gy/s, mGy/h, etc., and because the Gy is such a large unit compared to many common circumstances, the unit lGy/h is often used (Martin, 2006).

(8)
$$D_T = \frac{\bar{\epsilon}_T}{m_T}$$

2.7.3. Radiation Equivalent Dose (H):

The definition of dose equivalent is necessary because different radiations produce different amounts of biological damage even though the deposited energy may be the same. If the biological effects of radiation were directly proportional to the energy deposited by radiation in an organism, the radiation absorbed dose would be a suitable measure of biological injury, but this is not the case. Biological effects depend not only on the total energy deposited, but also on the way in which it is distributed along the path of the radiation. Radiation damage increases with the linear energy transfer (LET) of the radiation; thus, for the same absorbed dose, the biological damage from high-LET radiation (alpha particles, neutrons, etc.) is much greater than from low-LET radiation (beta particles, gamma rays, x-rays). The dose equivalent, denoted by H, is defined as the product of the absorbed dose and a factor W_R , Radiation weighting factor, that characterizes the damage associated with each type of radiation

$H(\text{dose equivalent}) = D(\text{absorbed dose}) W_R(\text{weighting factor})$. In the conventional system of units, the unit of dose equivalent is the rem which is calculated from the absorbed dose as $\text{rem} = \text{rad } W_R$. The value of W_R arise with the type of radiation , $W_R = 1.0$ for x-rays, gamma rays and electrons, $W_R = 20$ for alpha particles and fission fragments, and $W_R = 2-10$ for neutrons of different energies.

The SI unit of dose equivalent is the Sievert (Sv) or Sieverts = $\text{Gy } W_R$ (Martin,2006).

Table 2.1. Radiation weighting factor (ICRP, 2007)

Radiation weighting factor(W_R)	Radiation type and energy
1	Photons all energies
1	Electrons myons all energies
5	Neutron < 10 keV
10	10 to 100keV
20	> 100keV to 2MeV
10	>2MeV to 20MeV
5	> 20MeV
5	Protons > 2MeV
20	α particle, fission fragment, heavy nuclei

2.7.4. Effective dose (E):

The effective dose E is a measure of the combined detriment from stochastic effects for all organs and tissues for the reference man. It is the sum over all of the organs and tissues of the body of the product of the equivalent dose H_T to the organ or tissue and the tissue weighting factor W_T for that organ or tissue.

$$E = \sum_T w_T H_T$$

Table 2.2 Tissue weighting factors for reminder tissues is applied to the arithmetic mean of the doses to 14 organs\tissues (ICRP, 33(

ΣW_T	Tissue weighting factor(ΣW_T)	Tissue or organ
--------------	---	-----------------

0.72	0.12	Bone marrow, colon, lung, stomach, breast, reminder tissues
0.08	0.08	Gonads
0.16	0.04	Urinary bladder, esophagus, liver, thyroid
0.04	0.01	Bone surface, brain, salivary glands, skin

Tables 2.3, 2.4: Tissue weighting factor (ICRP, 2007) publication 26, 60 Respectively:

W_T	Organ
0.03	Thyroid, bone surface
0.12	Lung, bone marrow
0.15	Breast
0.3	Remainder
0.25	Gonads

2.7.5.

W_T	Organ
0.01	Skin, bone surface
0.05	Bladder, breast, liver, esophagus, thyroid, remainder
0.12	Bone marrow, lung, stomach
0.2	Gonads

Medical exposure:

Exposure incurred by patients for the purposes of medical or dental diagnosis or treatment; by careers and comforters; and by volunteers subject to exposure as part of a program of biomedical research.

Note: A patient is an individual who is a recipient of services of health care professionals and/or their agents that are directed at: (i) health promotion ; ii) prevention of illness and injury; (iii) monitoring health; (iv) maintaining health; and (v) medical treatment of diseases, disorders and injuries in order to achieve a cure or, failing that, optimum comfort and function(IAEA, 2013).

2.7.6. Entrance surface air kerma.

The air kerma at a point in a plane corresponding to the entrance surface of a specified object, e.g. a patient's breast or a standard phantom. The radiation incident on the object and the backscatter radiation are included.(IAEA, 2013).

2.7.7. Entrance surface dose:

Absorbed dose in air, including the contribution from backscatter. This is assessed at a point on the entrance surface of a specified object. exposure parameters. The settings of X ray tube voltage (kV), tube current (mA), exposure time (s), source to image distance and use of a grid(IAEA, 2013).

2.7.8. Inverse Square Law (ISL):

The number of radiation pulses that enter and/or traverse a medium is governed by source strength and the geometry between the source and the medium of interest, a relationship that can often be conveniently expressed as (number/cm²) or a fluence rate or flux (number/cm²s). A radioactive point source of activity $S(\text{t/s})$ emits radiation uniformly in all directions, and at a distance r will pass through an area equal to that of a sphere of radius r . Therefore, the flux is

$$\phi(\text{number/cm}^2 \text{ s}) = \frac{S(\text{t/s})f_i}{4\pi r^2}$$

Where f_i is the fractional yield per transformation of each emitted radiation. This relationship is the “inverse square law” which states that the flux of radiation emitted from a point source is inversely proportional to r^2 (Martin,2006).

2.7.9. 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).

2.8. Previous studies:

E. M. Mohamadain march 2015 estimated the entrance skin doses ESD for patients undergoing X-ray examination, the study for chest, skull and lumbar spine examinations in adults has been carried out at two hospitals. The aim of the study was the assessment of adult patient's dose for chest PA, chest LAT, skull AP and lumbar spine AP examinations. The Entrance Surface Dose (ESD) and the Effective Dose (ED) for each examination were obtained using Dose Cal software. For each examination different results were obtained at the two hospitals. At hospital A (IFF Hospital), the total number of patients studied was 140. The mean ESD values obtained for chest PA, chest LAT, skull AP and lumbar spine AP were 0.20 mGy, 0.47 mGy, 1.25 mGy, and 1.61 mGy, respectively. At hospital B HGB Hospital), the total number of patients studied was 369 for similar examinations and projections. The ESD values were 0.10 mGy, 0.28 mGy, 0.66 mGy and 2.47 mGy, respectively. The mean ED values at hospital A and B were 0.02 mSv and 0.01 mSv for chest PA, 0.04 mSv and 0.03 mSv for chest LAT, 0.1 mSv and 0.06 mSv for skull AP, and 0.15 mSv and 0.26 mSv for lumbar spine AP, respectively. The results were compared with the European Community Reference Levels. Although the doses were low, there was still a need for personnel training and national guidance on good practice for optimization of patients' doses.

M. A. Halato et al ,Nov 2008 ; estimated the entrance skin doses ESDs for patients undergoing selected diagnostic X-ray examinations in two large public hospitals in Khartoum state, Sudan. The study included the examinations of the chest postero-anterior (PA) , skull antero-posterior(AP), skull Lateral (LAT) , Lumbar spine AP/LAT, abdomen Intravenous urogram (IVU) and Pelvis AP. Totally, 241 patients were included in this study. ESDs were estimated from patients' specific exposure parameters using established relation between output ($\mu\text{Gy/mAs}$) and tube voltage (kVp). The estimated ESDs ranged from 0.18 - 1.05 mGy for chest

PA, 0.98 - 3.48 mGy for Skull(AP), 0.66 - 2.75 mGy for skull (LAT), 1.22 - 4.35 mGy for abdomen (IVU) 1.18-5.75 mGy for Pelvis, 1.52 - 5.01 mGy Lumbar spine AP and 2.48 - 10.41mGy for Lumbar spine (LAT). These values compare well with the international reference dose levels. This study provides additional data that can help the regulatory authority to establish reference dose level for diagnostic radiology in Sudan.

R. Torres Cabrera evaluate and compare the image quality and patients' entrance surface dose(ESD) in PA and LAT chest X-ray by several digital flat panel X-ray units. Four hospitals are involved: H. C. U. Lozano Blesa of Zaragoza, H. U. de la Princesa of Madrid, H. U. Ramón y Cajal of Madrid and H. Clínico Universitario of Valladolid. ESD received by 50 standard patients has been estimated, both for PA and LAT projections, by using the tube output and the radiographic technique (selected kVp, mAs, patient thickness and focus-to-detector distance), assuming a standard backscattering factor ($bf= 1.35$). Average values for ESD in PA chest and in LAT chest are much lower than reference values (PA:0,3 mGy; LAT: 1,5 mGy) although a wider range can be seen in the mean values, partly due to the use of additional filtration. Image quality has been evaluated with an anthropomorphic phantom (QC Phantom for digital and conventional chest radiography, Nuclear Associates 07-646) and a contrast-detail test pattern (CDRAD type 2.0, Instrumental Dienst). There is a direct relation between dose and image quality.

Osman 2010, measured patient dose in routine X-ray examinations in Omdurman teaching hospital Sudan. A total of 110 patients were examined and 134 radiographs were obtained in two X-ray rooms. Entrance surface doses (ESDs) were calculated from patient exposure parameters using Dos Cal software. The mean ESD for the chest, lateral lumbo-sacral spine , anterior posterior lumbar spine, were; $231\pm44 \mu\text{Gy}$, $716\pm39 \mu\text{Gy}$, $611\pm55\mu\text{Gy}$, respectively. Also he has shown his data results comparable with previous study in Sudan and Brazil . Osman, 2010 found

that the ESD for chest radiographs are comparable to those reported in previous studies Performed by Olivera Ciraj et al and Henner Anja respectively. And for lumbo-sacral spine AP and lateral it is also reduced by factor of 59%, 90%, 132%, 93% for study of Olivera Ciraj et al and Kepler .K et al respectively.

Chapter three

Material and Method

3.1. Materials

3.1.1 Equipment:

The study has been carried out with two Digital X-ray Machine used for routine x-ray examination from different manufactures with following characteristics in table 3.1 below:

Table 3.1: Digital systems characteristics

	M1	M2
Generator	PHILIPS	FUJIFILM
Tube	PHILIPS 9890	FUJIFILM
Total filtration	2.5 mm AL	2mmAL\75
Detector	Trixell	
Size	35*43	
Matrix	1920*2367	
Anti-scatter grid	Removable	Removable
Scintillator plate		
SN		13F666

M1 refere to Radiation and Isotopes Center of Khartoum, M2 refer to Modern Medical

3.1.2 Patients:

Total of 82 patients s examined 42 chest, 40 lumbar spine in two radiology department" Radiation and Isotopes Center of Khartoum (RICK) , Modern Medical Center". This study will be conducted in Khartoum state - Sudan. The data were collected used sheet for all patients in order to maintain consistency of information, the patient parameter age, weight(kg) and height(m) were recorded then used for deriving the body mass index(BMI)kg\m².

3.2. Methods:

3.2.1 Study Design:

This is an analytical study where the patient selected conventionally.

3.2.2 Duration of study:

This study started on October 2015 and end on May 2016

3.2.3 ESD Calculation :

Calculate the Entrance Surface Dose (ESD) and Effective Dose (ED) used following Equations .

Dose Calculation:

$$ESD = OP \left(\frac{kV}{80} \right)^2 mAs \left(\frac{100}{FSD} \right)^2 BSF$$

Where:

(OP) is the output in (mGy/ mA s) of the X-ray tube at 80 kV at a focus distance of 1 m normalized to 10(mAs, kV) the tube potential,(mA s) is the tube current in (mA) and the exposure time in (s), (FSD) the focus-to-skin distance (in cm) ,(BSF) the backscatter factor, the normalization at 80 kV and 10 mAs was used as the potentials across the X-ray tube and the tube current are highly stabilized at this point. BSF is calculated automatically by the Dose Cal software after all input data are entered manually in the software. The tube output, the patient

anthropometrical data and the radiographic parameters (kVp, mA s, FSD and filtration) are initially inserted in the software. The kinds of examination and projection are selected afterwards.

Chapter four

Results:

The collected data is presented in following tables and graphs:

Table 4.1. Show the age distribution for both gender among the study samples for chest exam.

Female	Male	Age group(year)
14.3%	14.3%	20--39
31%	11.9%	40--59
11.9%	16.7%	60--80

Table4.2. The mean and stander deviation of Body Mass Index (BMI) for both gender in chest examination:

Body mass index (BMI) ratio		Age group(years)
Female	Male	
24.617 ± 8.287	23.98 ± 4.715	20-39
24.085 ± 5.681	23.12 ± 5.852	40-59
24.9 ± 7.166	22.414 ± 2.4477	60-80

Table 4.3. show the mean and stander deviation of exposure factor (kv,mAs) for both gender in x-ray chest examination:

Mean ± stander deviation		Age groups(year)
mAs	kV	
6.769± 4.92	89.25± 25.612	20-39
13.217 ± 6.176	70.28 ± 12.938	40-59
12.292 ± 4.9393	70.67 ± 16.593	60-80

Table4.4. Show the exposure factors, mean dose values(mGy) and effective dose (mSv) for study group of x-ray chest examination:

Exam	kVp	mAs	ESD(mean+sd)	ED(mean)
Chest	68.9±6.45	13.288±2.169	0.216±0.0372(0.166)	0.036

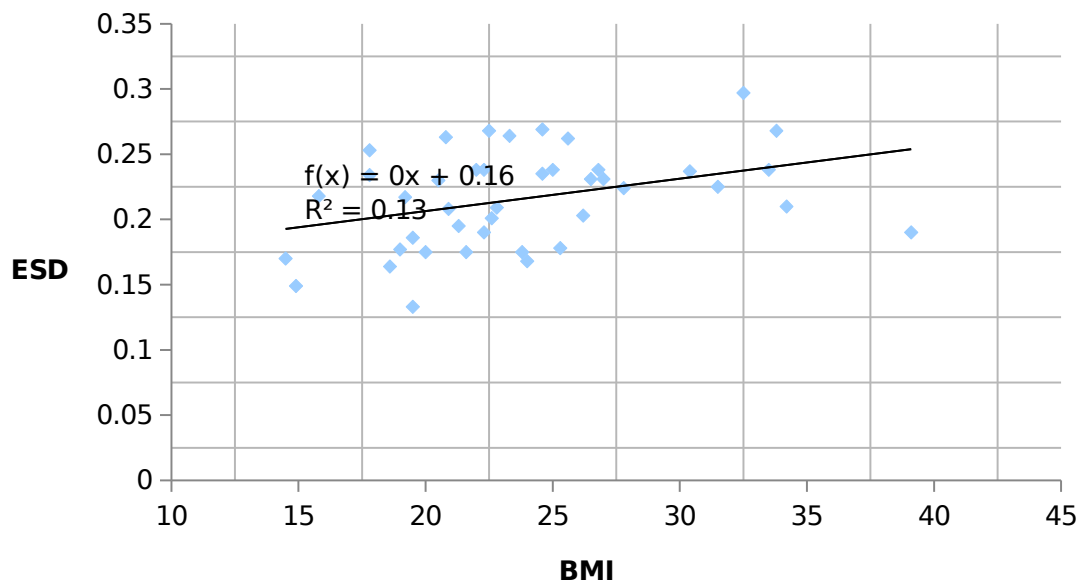


Figure 4.1: correlation between Entrance Skin Dose(ESD) and Body Mass Index (BMI) for x-ray chest examination

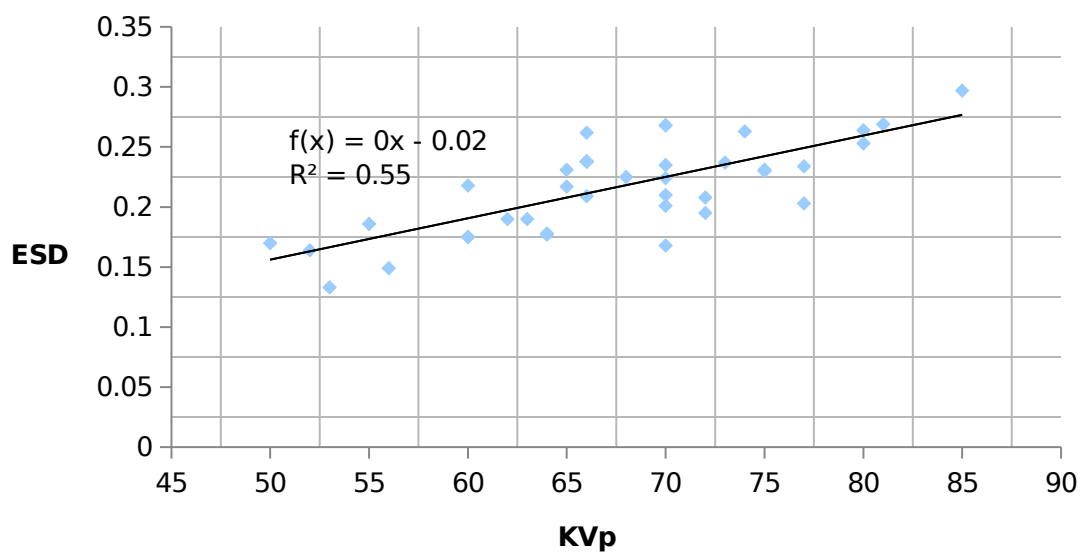
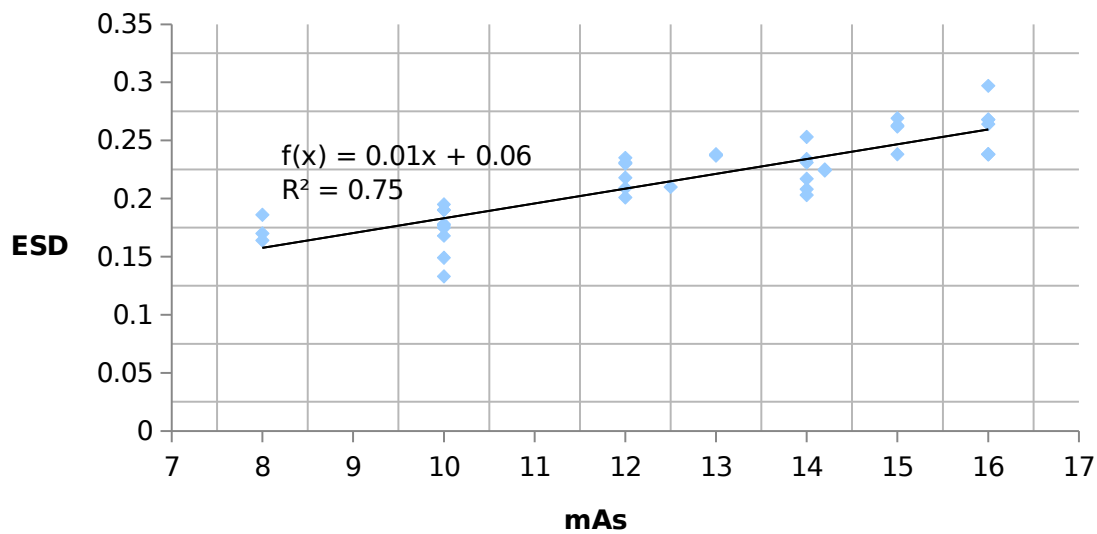
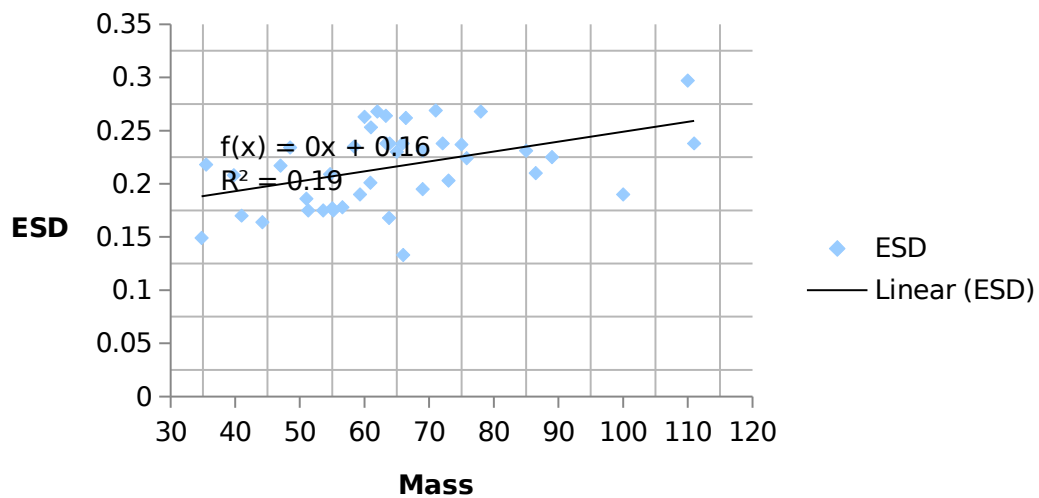


Figure 4.2: correlation between Entrance Skin Dose ESD(mGy) and tube voltage kVp for x-ray chest examination.



Figure(4.3): correlation between Entrance Skin Dose ESD(mGy) and tube current time product (mAs) for chest examination



Figure(4.4): correlation between Entrance Skin Dose (ESD)(mGy) and body weight (kg) for X-ray chest examination.

Table 4.5 show the age distribution for both gender among the study samples for x-ray lumbar spine examination.

Female	Male	Age group(year)
12.5%	15%	20--39
25%	15%	40--59
25%	7.5%	60--80

Table 4.6. the mean and stander deviation of Body Mass Index BMI(kg\m²) for both gender in lumbar spine examination

Body mass index (BMI) ratio		Age group(years)
Female	Male	
24.617 ± 8.287	23.98 ± 4.715	20-39
24.085 ± 5.681	23.12 ± 5.852	40-59
24.9 ± 7.166	22.414 ± 2.4477	60-80

Table 4.7. show the mean and stander deviation of exposure factor (kv,mAs) for both gender in X-ray lumbar spine (AP) examination

Mean ± stander deviation		Age groups(year)
mAs	kV	
6.769± 4.92	89.25± 25.612	20-39
13.217 ± 6.176	70.28 ± 12.938	40-59
12.292 ± 4.9393	70.67 ± 16.593	60-80

Table4.8:Show the mean and stander deviation of exposure factor (kv,mAs) for both gender in x-ray lumbar spine(LAT) examination:

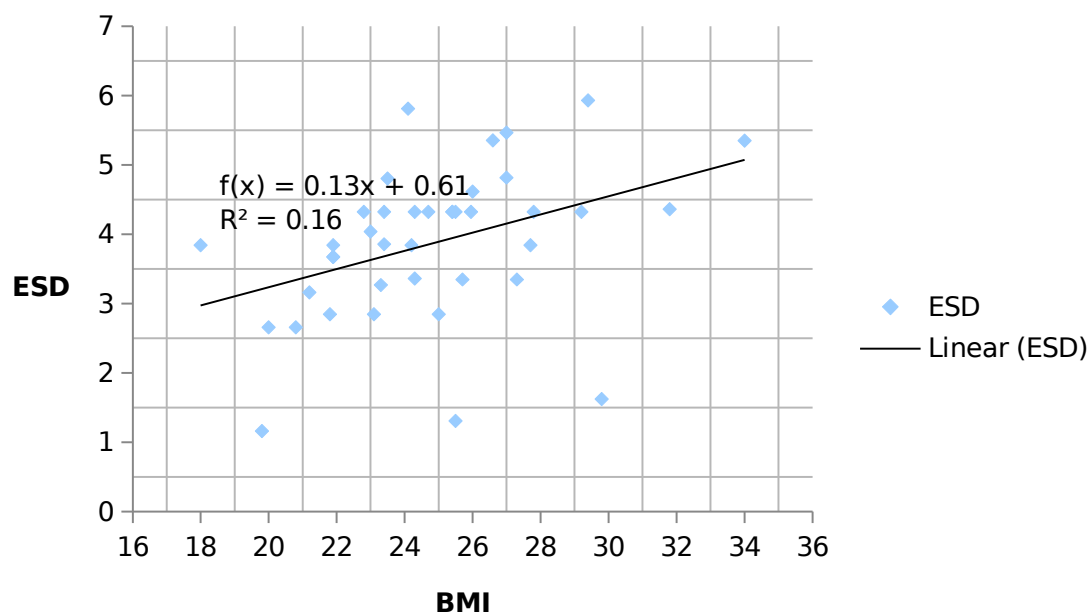
Mean ± stander deviation		Age groups(year)
mAs	kV	
37.4 ± 5.168	91.2 ± 4.662	20-39
34.075± 6.39	88.588 ± 5.197	40-59
29.846 ± 6.135	82.615 ± 6.225	60-80

Table 4.9.show the mean and stander deviation of exposure factors(kV,mAs) dose values(mG) and effective dose(mSv) for patients underwent x-ray lumbar spine(AP) examination:

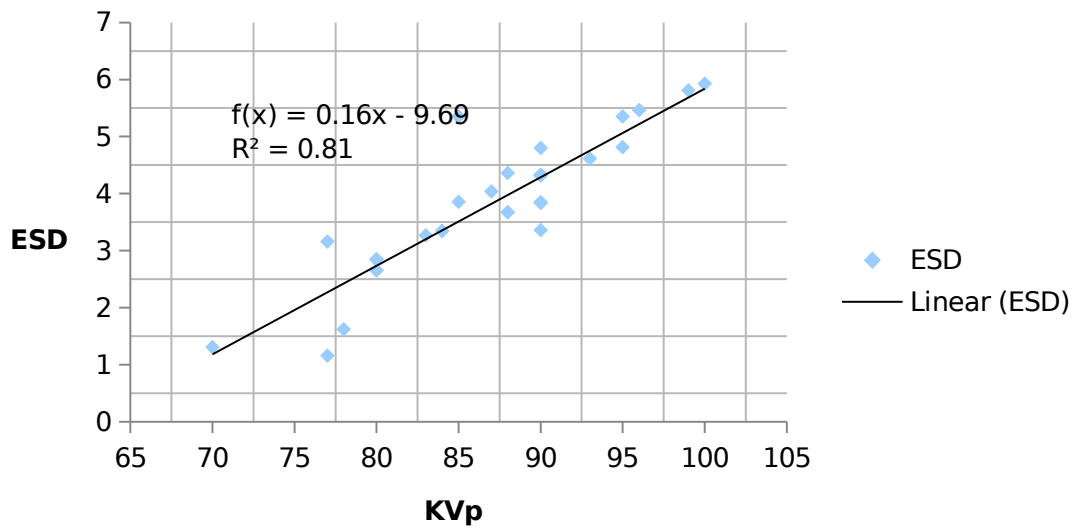
Exam	kVp	mAs	ESD(mean+sd)	ED
Lumbar(AP)	6.321±87.3	33.48±6.48	(0.173)3.869±1.09	0.53

Table 4.10. show the mean and stander deviation of exposure factors(kV,mAS) , dose values(mGy) and effective dose(mSv) for x-ray lumbar spine (LAT) examination.

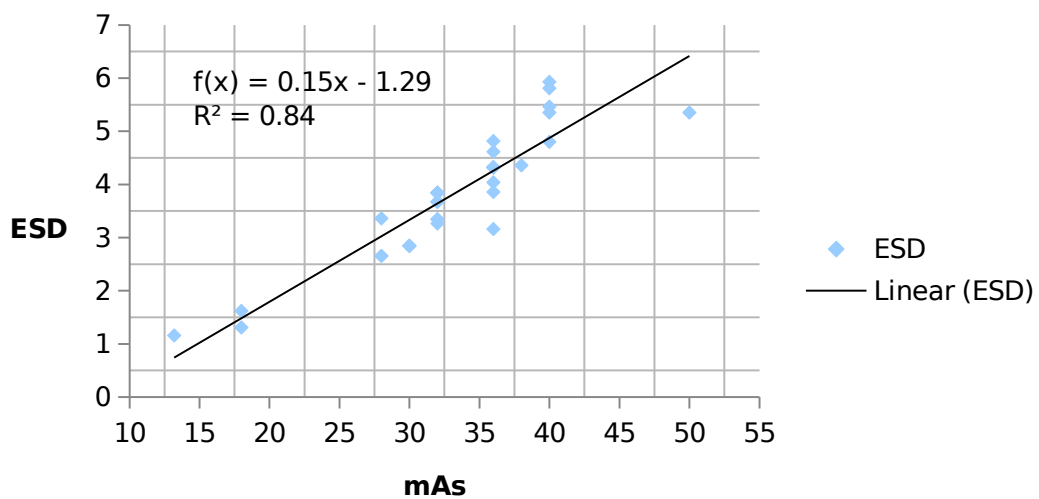
Exam	kVp	mAs	ESD(mean+sd)	ED
Lumbar(LAT)	92.825±6.547	38.45±5.291	(0.039)4.965±1.07	0.194



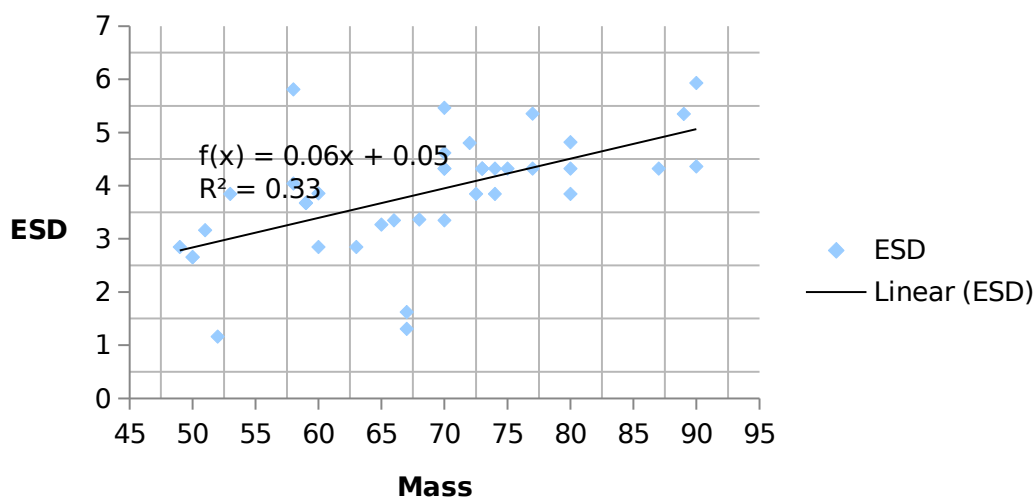
Figure(4.5): correlation between Entrance Skin Dose(ESD)(mGy) and Body Mass Index (BMI) (kg\m²) for Lumbar (AP) examination.



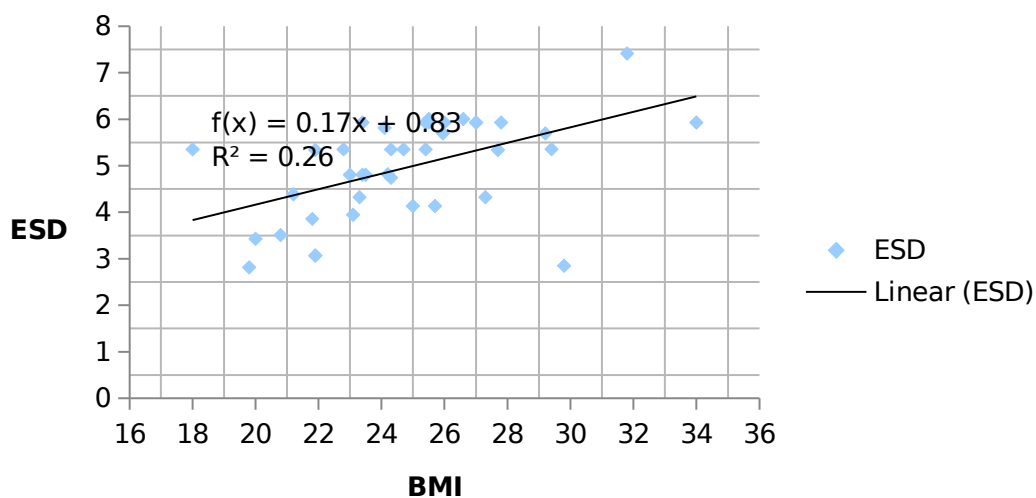
Figure(4.6): correlation between Entrance Skin Dose (ESD)(mGy) and kVp for Lumbar (AP) examination



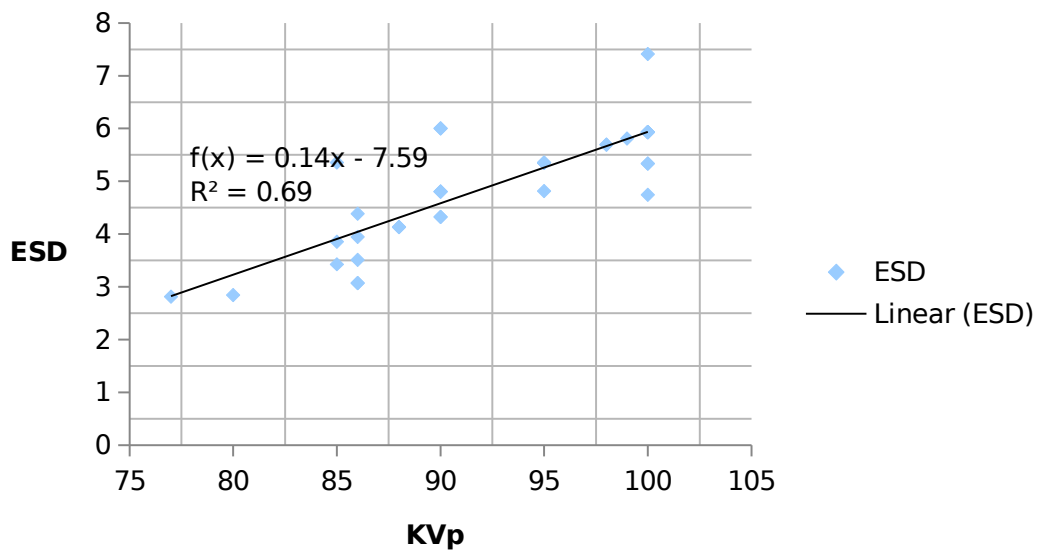
Figure(4.7): correlation between Entrance Skin Dose (ESD) (mGy) and mAs for Lumbar (AP) examination



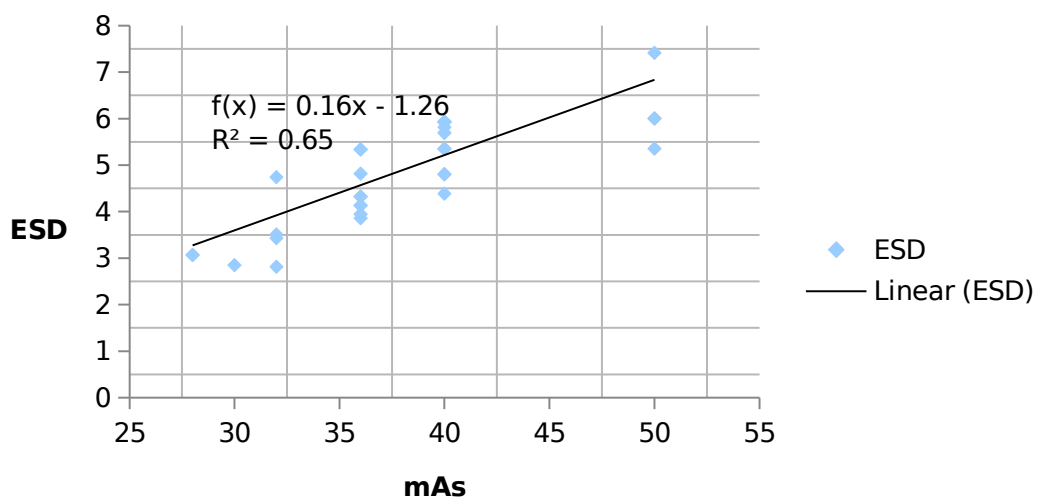
Figure(4.8): correlation between Entrance Skin Dose (ESD)(mGy) and body weight (kg) for Lumbar (AP) examination.



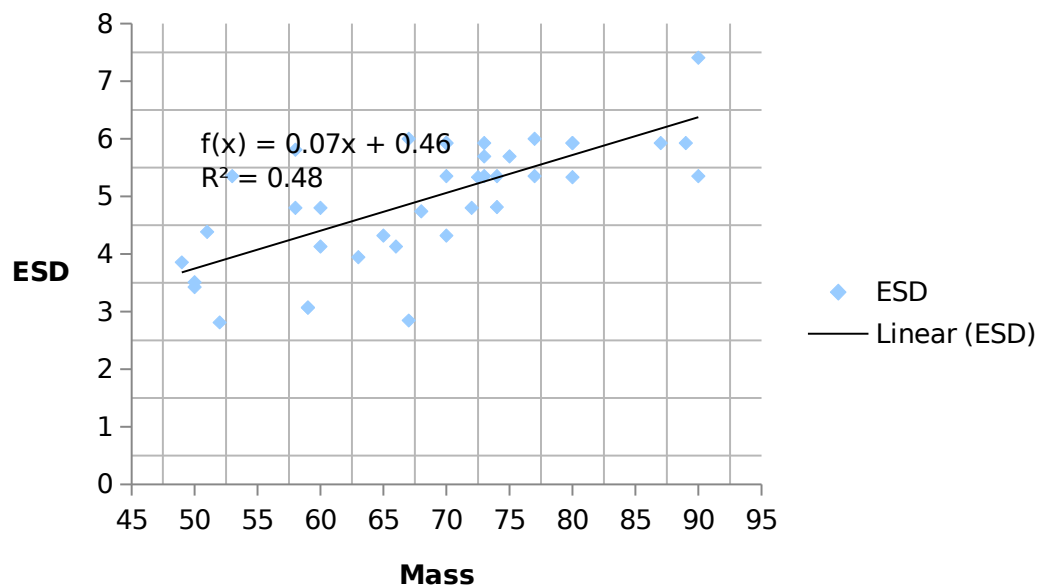
Figure(4.9): correlation between Entrance Skin Dose (ESD) (mGy) and Body Mass Index (BMI) (kg\m²) for Lumbar (LAT) examination.



Figure(4.10): correlation between Entrance Skin Dose(ESD) (mGy) and tube voltage (kVp) for x-ray Lumbar (LAT)examination



Figure(4.11): correlation between Entrance Skin Dose(ESD) (mGy) and tube current product(mAs) for Lumbar (LAT) examination



Figure(4.12): correlation between Entrance Skin Dose (ESD) (mGy) and body weight (kg) for Lumbar (LAT) examination.

Chapter five

Discussion, Conclusion and Recommendation

5.1. Discussion:

The purpose of these study was to estimate the entrance skin dose(ESD) and effective dose (ED) for adult patient undergoing x-ray examinations of the chest(PA) lumbar spine (AP,LAT) in two public hospitals in Khartoum state, total 82 patients selected in RICK and MMC with approximately 57.2% and 62.5% being female respectively with rest male. Tables 4.2 , 4.3,4.6,4.7 and 4.8 shows the technical parameters and patient's characteristic, the mean and stander deviation of exposure factors, entrance skin dose and effective dose shows in table 4.4 , 4.9 and 4.10 For both examination and all projection. The entrance skin dose ranged from a minimum 0.133 mGy to the maximum of 7.411mGy with respective mean ESD and ED were range from 0.216 to 4.965mGy and 0.036 to 0.53mSv. The correlation coefficient which is define as a measure of the degree of relationship between two variable X and Y used in this study to describe the relation between ESD(mGy) against BMI(kg\m²),mass (kg) ,kV, mAs, positive correlation coefficients were obtained between values of kV , mAs and the calculated ESDs values. The figures (4.1, 4.4,4.5, 4.8, 4.9,4.12) shows that were no correlation found between the ESDs values and the weight and BMI in both hospitals (correlation coefficient R² ranged from (0.1349 to 0.4796).The reason for the lack of correlation between ESD and patient weight, BMI is the subjective manual selection of the tube voltage values and other exposure parameters for most of the patients. The mean ESD obtained in this study compared with other published workers elsewhere and internationally established Diagnostic Reference Levels

(E.M.Mohamadain 2015, M.A. Halato 2008 R. Torres Cabrera , Osama 2010) and the values obtained in DRLs reported in European guidelines on quality criteria for diagnostic radiographic images Report EUR 16260EN which is the range mGy are in comparable with the values obtained. The values of ESD recorded in MMC and RICK were lower than the values of ESD recorded by other published workers. These results indicate that a high degree of patient dose optimization was achieved in this study.

These results indicate that a high degree of patient dose optimization was achieved in this study. The ESDs per chest radiographic image ranged between (0.034) and (0.493) mGy in (MMC) ,and ESDs per lumbar spine (AP,LAT) radiographic image ranged between (1.16 to 7.411) mGy which is slightly lower than the corresponding values reported in the DRLs reported in European guidelines on quality criteria for diagnostic radiographic images EUR 16260EN. Generally there are no significant different in the values of ESDs recorded in this survey and other previous studies.

However, lower ESDs were recorded for the chest examinations in this study was lower than which recorded in the previous study. The obtaining of differences in ESDs is attributed to the use of low kilovolts. The difference also could be due to imaging Protocols and the state of some of the equipment used in the two hospitals is a source of concern.

5.2. Conclusion:

This study was intended to evaluate the radiation doses for patients underwent diagnostic x-ray examinations in different two hospitals in Khartoum to help in applying radiation protection procedure of the patient. The most of the estimated ESDs values were within the range of reference level and below the range at some previous studies. The ESD depend on the exposure parameters and the machine wave form and filtration, Patient radiation dose is a very important parameter to control the quality of the X-ray services within the hospital. Dose monitoring helps to ensure the best possible protection of the patient and provides an immediate indication of incorrect use of technical parameters or equipment malfunction. Chest and lumbar spine radiographs are the most commonly performed radiological exam. The patient dose was measured in two hospitals in different computed radiography modalities, the radiation dose was found lower than Dose Reference Level. The findings from the present study showed that optimization of technical and clinical factors may lead to a substantial patient dose reduction. The results of this study allow a better understanding of how different working habits and examination technology influence the patient doses and make medical staff aware of their responsibility for optimization of daily radiological practice.

5.3. Recommendations:

- X-ray Radiography operator must optimize the patient dose by use the best strategies available for reducing radiation dose, the mAs reduction radiation dose and it have relation to patients size and weight and adapt the current based on patient size.

-X-ray Radiography must be used with high level of training for medical staff due to the high dose.

-Each radiology department should implement a patient dose measurement quality assurance program.

- Practical guidelines for better image quality in X-ray radiography is mainly concerned with the professional skills of the users and the establishment of an efficient quality control program specifically designed to produce the best quality of clinical images.

- Radiologists should support and encourage staff in the radiology department to appreciate the importance of an effective quality control program.

In addition, radiographers who utilize the technology should also receive proper training on developing professional skills. A successful digital radiology enterprise will undoubtedly earn immeasurable benefits from an effective quality control program and skillful radiographers who correctly utilize the technology.

-Reference dose levels for diagnostic radiology must be established on the national scale, in order to reduce the patient exposure and to maintain a good diagnostic image. -Filtration and collimation of the x-ray beam are very important safety measures keep doses As Low as Reasonably Achievable (ALARA) principle in diagnostic radiology to reducing the radiation dose for patients. Short exposure times can improve image quality. More studies should be carried out especially in hospitals using old diagnostic facilities.

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