Chapter one

1.1. Introduction:

Diagnostic x-ray radiology is a common diagnostic practice and there has been a substantial increase in the number of examinations recently (Bushong, 2001).

Radiation doses from diagnostic radiology are the largest contribution to the collective dose from all man-made sources of radiation (UNSCEAR, 1988).

Because most procedures causing medical exposures are clearly justified and because the procedures are usually for the direct benefit of the exposed individuals, less attention has been given to the optimization of protection in medical exposures than in most other applications of radiation sources (ICRP Publication 60) (ICRP, 1990),(ICRP, 1991). International Commission on Radiation Protection (ICRP) declared that the diagnostic reference levels (DRLs) are already being used in medical diagnosis to indicate whether the levels of patient dose from a specified imaging procedure are unusually high or low in comparison to the predefined criteria. If so, a local review should be initiated to determine appropriate protective action. This means that cooperation between national authorities and professional bodies is necessary to establish national diagnostic reference levels (NDRLs) (ICRP; 2007). Entrance Skin Air Kerma (ESAK) is recommended by the IAEA as the most appropriate patient dosimetry quantity in simple radiographic examinations, primarily due to the convenience of measurement, easy comparison with other studies in different countries or DRLs, and proportionality to patient effective dose that is used to find the probability of radiation-induced complications (IAEA; 2004).

In spite of the increasing hazard of diagnostic x-rays to human beings, Studies aimed at achieving low patient doses with sufficient image quality have continued to be of interest in research, All exposures to ionizing radiation needs to justified and optimized in terms of the benefit and risks (ICRP, 1991).

Entrance skin dose (ESD) is an important parameter in assessing the dose received by a patient in a single radiographic exposure. The European Union has identified this physical quantity as one to be monitored as a diagnostic reference level in the hopes of optimizing patient dose (Bushong, 2001); (ICRP, 1991). Patient doses in diagnostic x-ray examinations can be best estimated in terms of entrance surface dose (ESD) per radiograph or dose area product (DAP) for the complete examination (EUR ,1996).

1.2. Problem of Study:

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

International Commission on Radiation Protection (ICRP), the International Atomic Energy Agency (IAEA) have been making publications in ionizing radiation protection , Report 60 of the ICRP and the Basic Safety Standards that was published in the IAEA report have three basic principles related to the radiation protection.

Exposure of different dose values for the same clinical examination is an enough reason to draw attention to this issue.

1.3. Objectives:

1.3.1. General Objective:

The main objective of this study is Patient absorbed dose measurement in common Medical X-ray Examinations using skin estimated dose.

1.3.2. Specific Objectives:

1- To identify procedures associated with higher radiation doses..
2- To determine the effects of various parameters on patient and staff doses.
3- To estimate and calculate Entrance Surface Dose (ESD).
4- To find the correlation between entrance surface dose and weight , Kvp , mAs , body mass index.
5- Evaluate the results with the literature.

1.4. Overview of the Study:

This thesis is concerned with the Patient absorbed dose measurement in common Medical X-ray Examinations using skin estimated dose. This study falls into five chapters, Chapter one, which is an introduction, It presents the statement of the study problems, objectives of the study, 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 fours deals with results and discussions. Chapter five conclusion , recommendations and references.

Chapter two

Literature Review

2.1. Radiation:

The propagation of energy from a radiative source to another medium is termed radiation. This transmission of energy can take the form of particulate radiation or electromagnetic radiation (i.e., electromagnetic waves). The various forms of radiation originating from atoms, which include (among others) visible light, X-rays and γ-rays, are grouped together under the terms “electromagnetic radiation" or “the electromagnetic spectrum". Radio waves, which have the longest wavelengths and thus the lowest frequencies and energies of the various types of electromagnetic radiation, are located at tone end of the electromagnetic spectrum, whereas X-rays and γ-rays, which have the highest frequencies and energies, are situated at the other end of this spectrum. (Pam Cherry et al, 2009).

2.2. Classification of Radiation:

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 for ionizing an atom, ranges from a few eV for alkali elements to 24.6 eV for helium (noble gas).

• *Non-ionizing radiation* cannot ionize matter because its energy is lower than the

ionization potential of matter.

• *Ionizing radiation* can ionize matter either directly or indirectly because its energy

exceeds the ionization potential of matter. It contains two major categories:

Directly ionizing radiation (charged particles) electrons, protons, alpha particles, heavy ions, Indirectly ionizing radiation (neutral particles) photons (x rays, gamma rays), Neutrons.

2.3. 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).

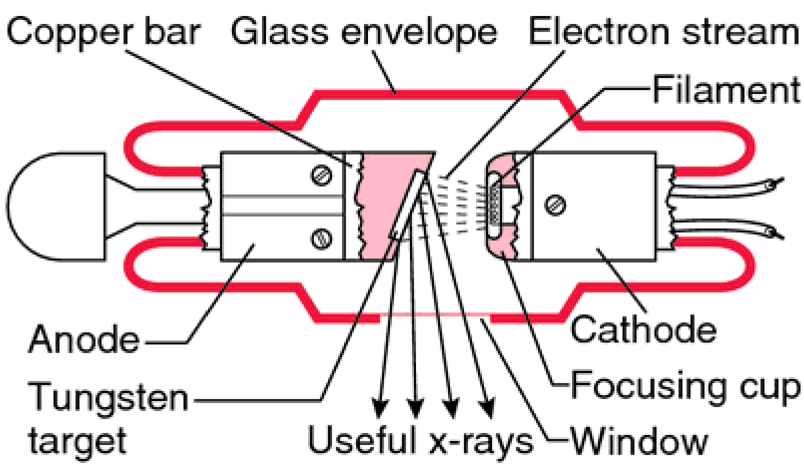


Figure (2.1) show the diagram of X-ray tube component

http://medical-dictionary.thefreedictionary.com/x-rays

2.3.1 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).

2.3.2 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).

2.4. X-ray Tubes:

2.4.1. Components of the X-ray tube:

The production of both bremsstrahlung and characteristic radiation requires energetic electrons hitting a target. Accordingly, the principal components of an X-ray tube are an electron source from a heated tungsten filament, with a focusing cup serving as the tube cathode, an anode or target, and a tube envelope to maintain an interior vacuum. The filament is heated by a current that controls the thermionic emission of electrons, which, in turn, determines the electronic current flowing from the cathode to the anode (tube or anode current).

The accelerating potential difference applied between the cathode and anode controls both X ray energy and yield. Thus, two main circuits operate within the X-ray tubes the filament circuit and the tube voltage circuit. (Bushberg JT et al , 2002).

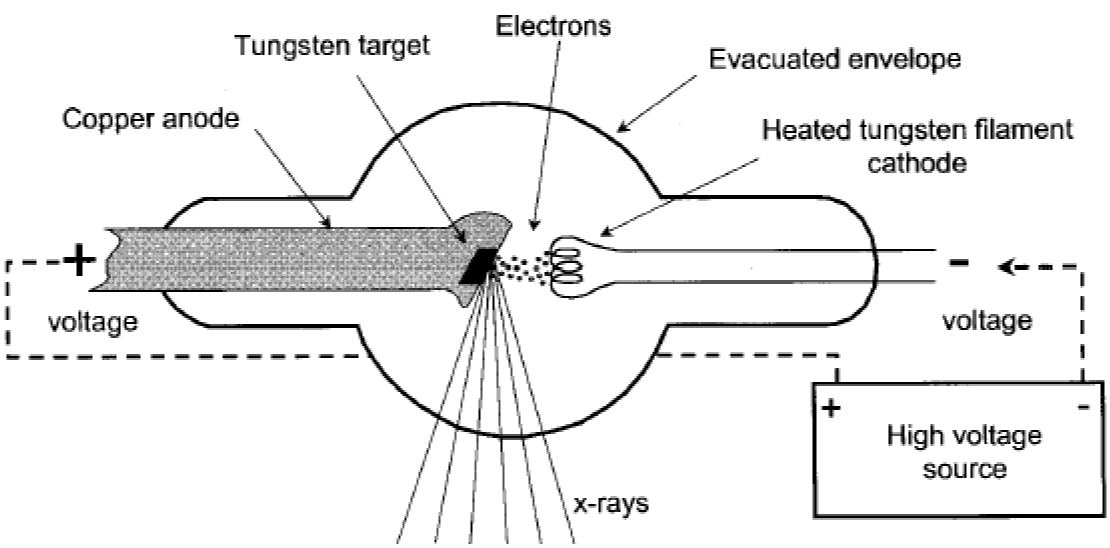


FIG. 2.2. Principal components of an X-ray tube . (Bushberg JT et al , 2002).

2.4.1.1. Cathode:

The arrangement of the filament, the focusing cup, the anode surface and the tube voltage generates an electric field accelerating the electrons towards the focal spot at the anode. X-ray tubes with two focal spots usually employ two separate filament/cup assemblies (cathode blocks).

The degree of focusing depends on the potential difference or bias voltage between the filament and focusing electrode. The focal spot will be largest if both are at the same potential. With an increasing negative bias voltage at the focusing cup, the focus size will decrease and finally the electron current will be pinched off.

This effect is sometimes used to control the focus size electronically, or for a fast switching of the anode current (grid controlled tubes) when short radiation pulses are required, as in pulsed fluoroscopy. Some bias can simply be achieved by connecting the filament and cup with a high resistance grid leak resistor. Some electrons emitted from the filament surface will hit and charge the cup. The cup is discharged via the grid leak resistor, maintaining the cup at a negative potential difference.

2.4.1.2. Anode:

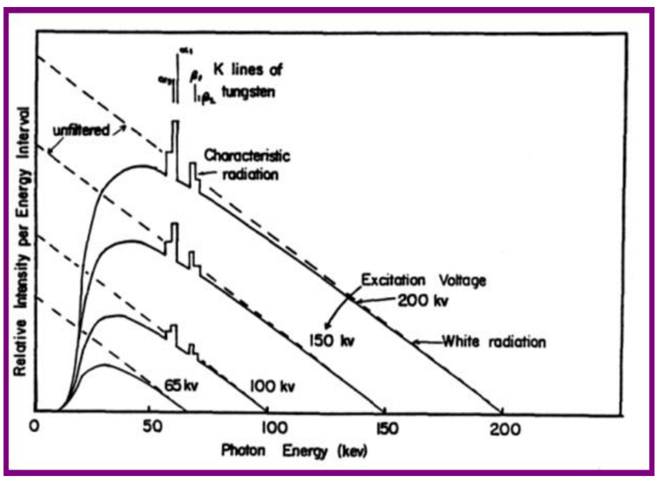
2.4.1.2.1. Choice of material:

For common radiographic applications, a high bremsstrahlung yield is mandatory, requiring materials with high atomic numbers (Z). Additionally, because of the low effectiveness of X ray production, it is also essential that the thermal properties are such that the maximum useful temperature determined by melting point, vapour pressure, heat conduction, specific heat and density is also considered. Tungsten ($Z = 74$) is the optimum choice here.

For mammography, other anode materials such as molybdenum (Z = 42) and rhodium (Z = 45) are frequently used. For such anodes, X ray spectra show less contribution by bremsstrahlung but rather dominant characteristic X rays of the anode materials. This allows a more satisfactory optimization of image quality and patient dose. In digital mammography, these advantages are less significant and some manufacturers prefer tungsten anodes.

2.5. Spectrum 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. 2.3**)** 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 (Bushberg JT et al , 2002).



The figure(2.3) show the Spectral distributions of X-rays(Bushberg JT et al , 2002)

2.6. Effects of radiation:

Ionizing radiation is known to cause damage. High radiation doses tend to kill cells, while low doses tend to damage or alter the genetic code (DNA) of irradiated cells. The biological effects of ionizing radiation are divided into two categories: Deterministic and Stochastic effects.

2.6.1 Deterministic effects:

Health effects whose severity depends on radiation dose (usually with a threshold) and dose rate is called deterministic effects. Some interventional procedures with long fluoroscopy time and multiple image acquisition (e.g. percutaneous coronary intervention, radio-frequency ablation, etc) may give rise to deterministic effects in both staff and patients. The deterministic effects include nausea, hair loss, damage to the blood and bone marrow, damage to the intestines, and damage to the central nervous system..

Table 2-1 Potential effects of x-ray exposures on reaction of skin and lens of the eye with data from ICRP population 85.

Injury	Threshold Dose to Skin (Sv)	Minutes fluoro at 0.02 Gy/min	Minutes fluoro at 0.2 Gy/min
Transient erythema	2	100	10
Permanent epilation	7	350	35
Dry desquamation	14	700	70
Dermal necrosis	18	900	90
Telangiectasia	10	500	50
Lens/Cataract	> 5	>250 to eye	>25 to eye

2.6.2. Stochastic effects:

The effects whose frequency is an increasing function of dose, usually without threshold, such effects are seen at some time after irradiation, possibly decades later. Stochastic effects include cancer and leukemia.

Table 1-2 shows the annual risk of death compared with cancer from radiation exposure.

Table 2-2 Risk of death per year from common causes [19].

Causes	Risk of death per year
Smoking 10 cigarettes/day	1 in 200
Natural causes (40 year old)	1 in 850
Accidents on road	1 in 9500
Accidents at work	1 in 43.500
Cancer from radiation exposure of 1 mSv	1 in 25.000*

* ICRP 60

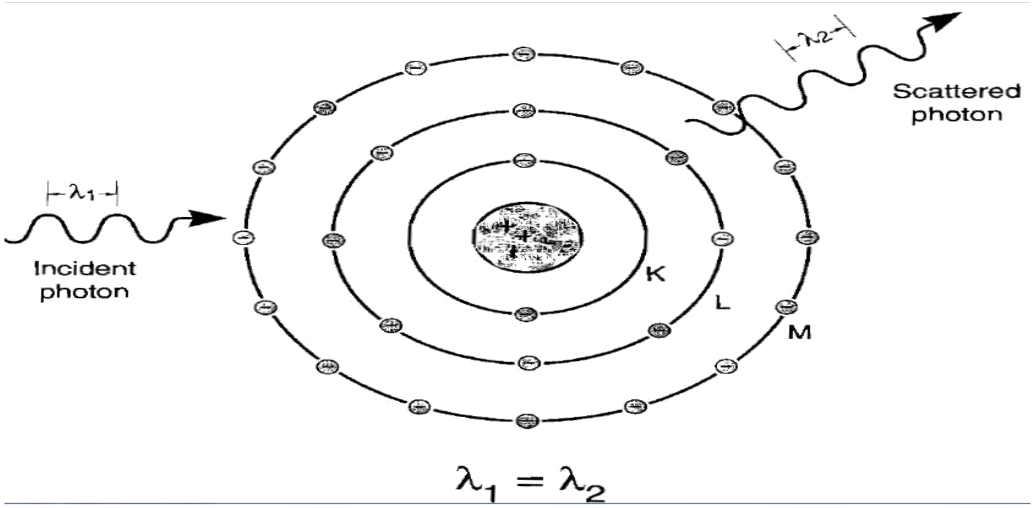
2.7. interaction of radiation with matter:

2.7.1 Rayleigh Scattering:

In Rayleigh scattering , the incident photon interact with and excites the total atom , as opposed to individual electrons as in compton scattering or the photoelectric effect , this interaction occurs mainly with very low energy diagnostic x-rays as used in mammography.

During the Rayleigh scattering event, the electric field of the incident photons electromagnetic wave expends energy causing all of the electrons in the scattering atom to oscillate in phase.

The atoms electron cloud immediately radiates this energy, emitting a photon of the same energy but in a slightly different direction .In this interaction, electrons are not ejected and thus ionization does not occur. In general the scattering angle increases as the x-ray energy decrease. (Murat Beyzadeoglu et al , 2010).



the figure2.4 show the Rayleigh scattering (Bushberg JT et al , 2002).

2.7.2. Photoelectric Effect

This phenomenon, which was theorized by Albert Einstein in 1905, was actually first observed by Heinrich Rudolf Hertz in 1887, and was therefore also known as the Hertz effect. To define it simply, when any electromagnetic radiation reaches a surface (generally a metallic surface), it transfers its energy to the electrons of that surface, which are then scattered. At the atomic level, the incoming radiation knocks an electron from an inner atomic orbital, propelling it from the atom (Fig. 2.5).

This is the basic interaction in diagnostic radiology. It is dominant at energies of less than 35 kV, and in atoms with high atomic numbers (*Z*). Since the atomic number of bone is higher than that of soft tissue, bone absorbs more radiation than soft tissue. This absorption difference is the basis of diagnostic radiology. This effect also explains why metals with high atomic numbers (e.g., lead) are used to absorb low-energy X-rays and gamma rays.

2.7.3 Compton Effect:

In the Compton effect, a photon collides with an electron in an outer orbital, and the photon and electron are scattered in different directions (where *q* is the angle between the directions). The energy of the incoming photon is transferred to the electron in the form of kinetic energy. The scattered electron also interacts with the outer orbital electrons of other atoms. After the interaction, the photon has a lower energy than it did beforehand. (Murat Beyzadeoglu et al, 2010).

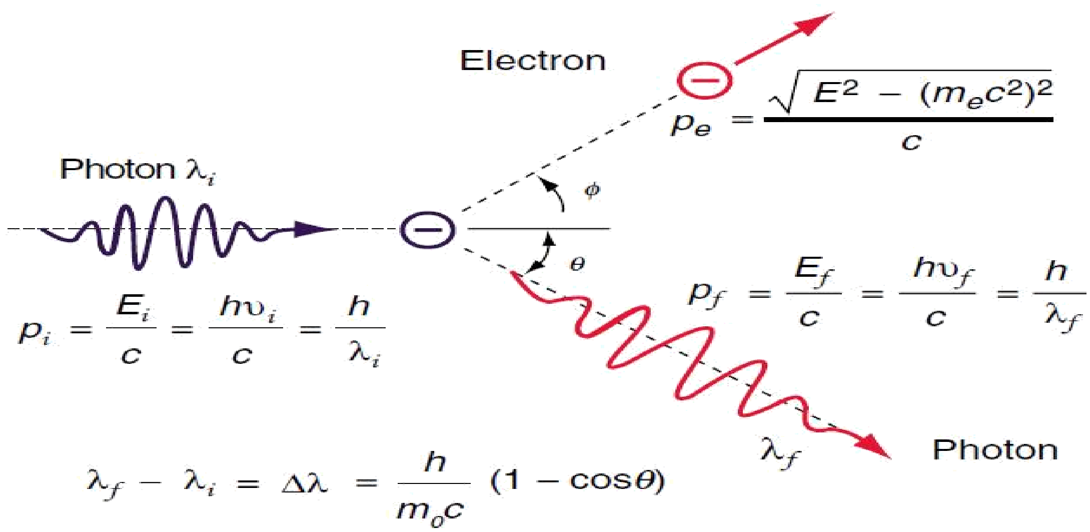


Fig. 2.5 Math associated with the Compton Effect. (Murat Beyzadeoglu et al , 2010)

This is the main mechanism for the absorption of ionizing radiation in radiotherapy. It is the dominant effect across a wide spectrum of energies, such as 35 kV–50 MV. It has no dependency on the atomic number (*Z*) of the absorbent material, but it does depend on the electron density of the material.

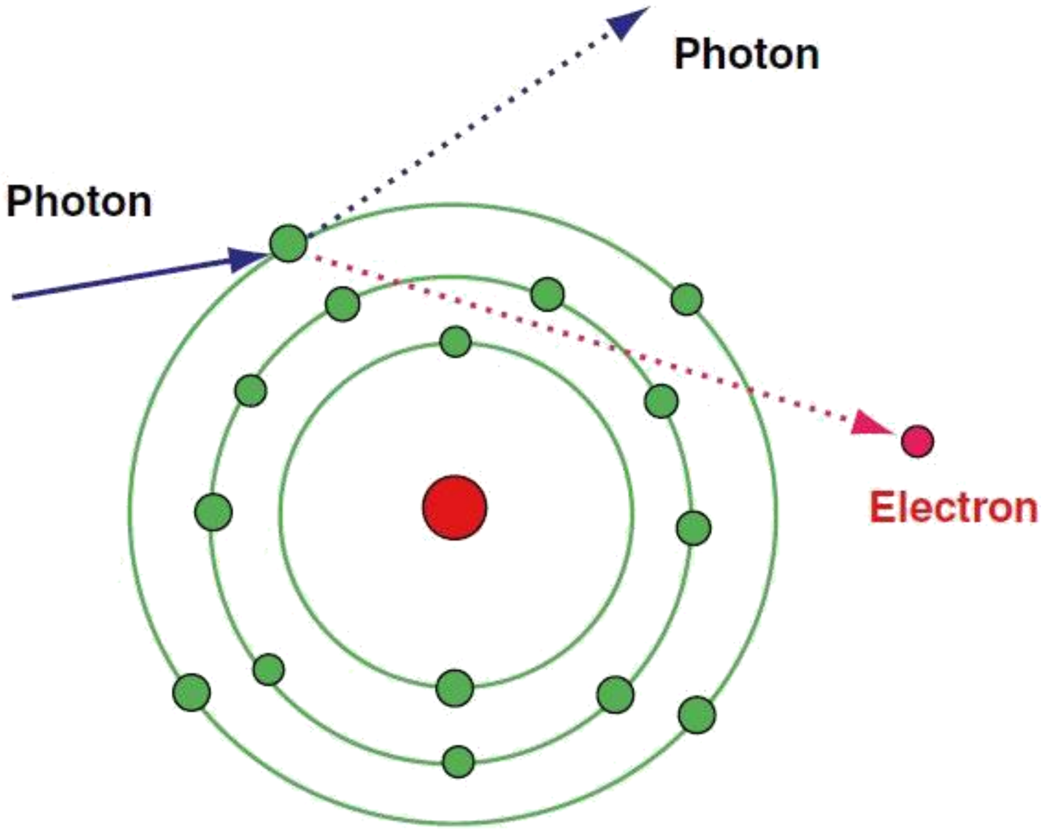


Fig. 2.6 Illustration of the Compton Effect. (Murat Beyzadeoglu et al , 2010).

2.7.4. 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)**

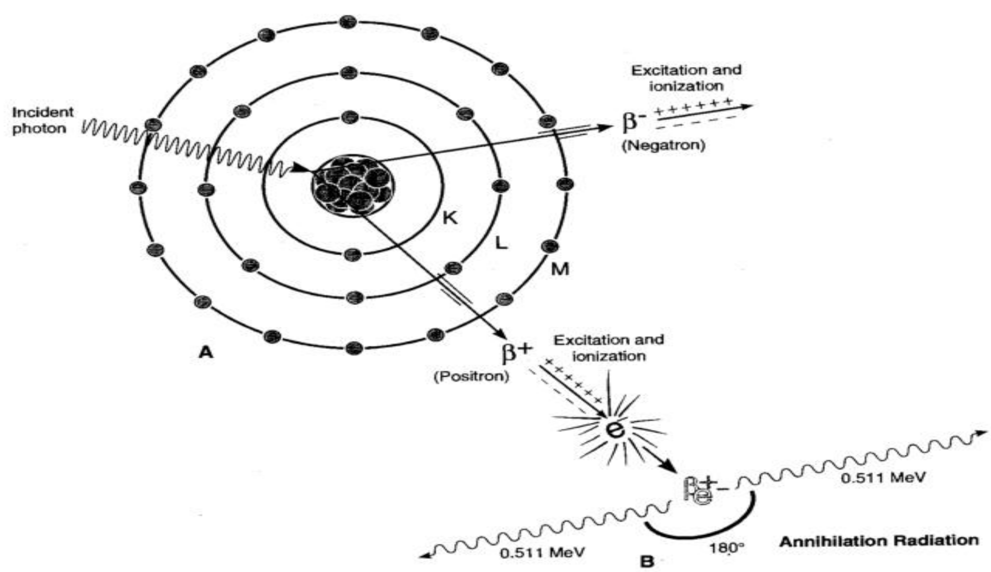


figure (2.7) show Pair Production(Bushberg et al.,2002)

2.7.5 Photodisintegration (PD):

is the process by which the x-ray photon is captured by the nucleus of the atom with the ejection of a particle from the nucleus when all the energy of the x-ray is given to the nucleus. Because of the enormously high energies involved, this process may be neglected for the energies of x-rays used in radiography.

2.8. 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.

2.8.1 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.

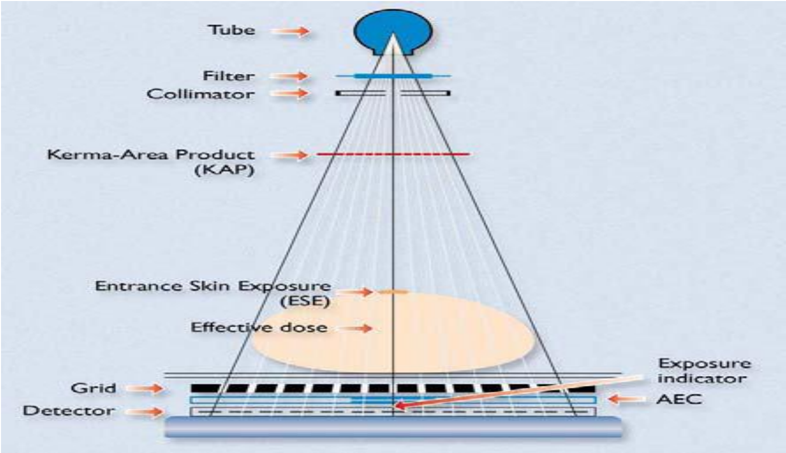


Figure (2.8) Typical examination beam geometry and related radiation dose quantities(IAEA, 2005)

2.8.1.1 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).

2.8.1.2. 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).

2.8.1.3. 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).

2.8.1.4. 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).

2.8.1. 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).

2.8.1.6. Equivalent dose H_T :

Accounts for biological effect per unit dose

$$H_T = W_R x D$$

Table 2.3 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

2.7.1.7. Effective dose : E :

Risk related parameter, taking relative *radio sensitivity* of each organ and tissue into account :

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

W_T : tissue weighting factor for organ T

H_T: eequivalent dose received by organ or tissue T

Table 2.4 Tissue and organ weighting factors (UNSCEAR 2008) :

weighting factors for different organs			
Tissue	Tissue weighting factors		
	ICRP 30(136) 1979	ICRP 60(13) 1991	ICRP 103(16) 2008
Gonads	0.25	0.20	0.08
Red bone marrow	0.12	0.12	0.12
Colon	-	0.12	0.12
Lung	0.12	0.12	0.12
Breast	0.15	0.05	0.12
Esophagus	-	0.05	0.04
Thyroid	0.03	0.05	0.04
Skin	-	0.01	0.01
Bone surfaces	0.03	0.01	0.01
Salivary glands	-	-	0.01
Brain	-	-	0.01
Remainder	0.30	0.05	0.12

2.9. Radiation Units:

2.9.1. 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).

2.9.2. 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).

2.9.3. 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.

2.9.4. 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.

2.9.5. 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).

2.9.6. Calculation of ESD from Exposure Factors:

ESD may be calculated in practice by means of knowledge of the tube output (Toivonen, 2001). The relationship between x-ray unit current time product (mAs) and the air kerma free in air is established at a reference point in the x-ray field at 80 kVp tube potential. Subsequent estimates of the ESD can be done by recording the relevant parameters (tube potential, filtration, mAs and FSD) and correcting for distances and back scattered radiation according to the following equation (Toivonen, 2001).

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

where OP is the tube output per mAs measured at a distance of 100 cm from the tube focus along the beam axis at 80 kVp, kV is peak tube voltage (kVp) recorded for any given examination (in many cases the output is measured at 80 kVp, and therefore this appears in the equation as a quotient to convert the output into an estimate of that which would be expected at the operational kVp. The value of 80 kVp should be substituted with whatever kVp the actual output is recorded at in any given instance).

mAs is the tube current-time product which is used in any given instant. FSD is the focus-to-patient entrance surface distance and BSF is the backscatter factor.

2.10. Radiation measurements:

With respect to measurement, three separate features of an X-ray beam must be identified .The first consideration is the flux of photons travelling through air from the anode towards the patient .The ionization produced by this flux is a measure of the Radiation exposure. If expressed per unit area per second it is the intensity of more fundamental importance as far as the biological risk is concerned is the absorbed dose of radiation. This is a measure of the amount of energy deposited as a result of ionization processes.

2.10.1 Dose measurement:

There are several ways of measuring doses from ionizing radiation. Workers who come in contact with radioactive substances or may be exposed to radiation routinely carry personal dosimeters. In the United States, these dosimeters usually contain materials that can be used in thermo luminescent dosimeter (TLD) or optically stimulated luminescence (OSL). Outside the United States, the most widely used type of personal dosimeter is the film badge dosimeter, which uses photographic emulsions that are sensitive to ionizing radiation. The equipment used in radiotherapy (linear particle accelerator in external beam therapy) is routinely calibrated using ionization chambers or the new and more accurate diode technology (EPA, 2006).

2.10.1.1. Ionization chamber:

In medical x-ray imaging the Free-in-air air kerma measurements are best made with suitably designed ionization chambers of typically between 0.6 and 180 cm3 volume. The chambers should have 'air equivalent' walls so that their energy response in terms of air kerma is substantially uniform for all relevant x-ray spectra. The leakage current should be very small compared with the ionization current produced by the minimum dose rate to be measured and the response should not be affected appreciably by ion recombination at high dose rates. Dosimeters should be calibrated in a manner traceable to a national primary standard of air kerma as described; there are special requirements for ionization chambers used for air-kerma measurements in mammography: these are a thin entrance wall to reduce attenuation at low photon energies, and ideally a structure that does not appreciably disturb the primary radiation field. Thin entrance window chambers with small volumes generally have a rather massive construction on the exit side, which implies that the charge produced in the cavity contains a significant contribution from scattered radiation (HALL, 2002).

2.10.1.2 Dose -area product meters:

Dose area product is defined as the absorbed dose to air averaged over the area of the X-ray beam in a plane perpendicular to the beam axis multiplied by the area of the beam in the same plane. It is usually measured on Gy cm2 and radiation backscattered from the patient is excluded Provided that the cross sectional area of the beam lies completely within the detector, it may be shown by simple application of the inverse square law that the reading will not vary with the distance from the tube focus.

Thus the dose area product can be measured at any point between the diaphragm housing on the X-raytube and the patient, but not so close to the patient that there is significant backscattered radiation.

Dose area product meters consist of flat, large area parallel plate ionization chambers connected to suitable electrometers which respond to total charge collected over the whole area of the chamber .The meter is mounted close to the tube focus where the area of the X-ray beam is relatively small and dose rates are high. It is normally mounted on the diaphragm housing whereit does not interfere with the examination and is usually transparent so that when fitted to an over –couch X-ray tube the light beam diaphragm device can still be used (Avenue, 2002).

2.10.1.3. Thermo Luminescent Dosimetry:

Many crystalline materials exhibit phenomena of thermo luminescence .When such a crystal is irradiated, a very minute fraction of the absorbed energy is stored in crystal lattice. Some of this energy can be recovered latter as visible light if the material is heated. This phenomena of release of visible photon by thermal means is known as thermoluminescence.(Thayland, 2001).

2.10.2. Direct measurement of entrance surface dose:

ESD is defined as the absorbed dose to air at intersection point of the X-ray beam axis with the entrance surface of the patient, including backscatter radiation. This does is expressed in mGy. The most straight forward method for skin dose determination is to put TLDs or other detectors on the patients' skin. However, the choice of the methods and dosimeters are not yet clearly established. In this section an overview is given of the measurement of the maximum skin dose D skin, local during radiological examinations. Although most of the measurements were actually performed with TLDs, scintillation dosimeters and film dosimeters have also been used. Semiconductor dosimeters [diodes or metal oxide semiconductor field effect transistors (MOSFETs)] have been used only for phantom. The ESD is estimated in order to assess the possibility of skin dose exceeding the threshold for deterministic effects. The total values of imparted radiation dose from all fluoroscopic and radiographic exposures involved in the specific examination .ESD depends on the exposure parameters (Tube voltage, Total filtration, mAs andFFD), and patient's conditions (patient positioning, field size, and film screen system (Thayalan,2001).

2.11. Previous studies:

Mhamadain K. E. M et al 2004 estimated the entrance skin dose (ESD), the body organ dose (BOD) and the effective dose (E) for chest x-ray exposure of pediatric patients in five large units, three in Sudan and two in Brazil, and to compare the results obtained in both countries with each other and with other values obtained by some European countries. Two examination projections have been investigated, namely, postero-anterior (PA) and antero-posterior (AP). The age intervals considered were: 0-1 year, 1-5 years, 5-10 years and 10-15 years. The results have been obtained with the use of a software called DoseCal. Results of mean ESD for the age interval 1-5 years and AP projection are: 66 μGy IPPMG Hospital), 41, 86 and 68 μGy (IFF Hospital), 161 μGy (Omdurman Hospital), 395 μGy (Khartoum Hospital) and 23 μGy (Ahmed Gasim Hospital). In the case of the IFF Hospital, the results refer, respectively, to rooms 1, 2 and for the six mobile equipments. The mean E for the same age interval was 11 μSv in the IPPMG, 6, 15 and 11 μSv in the IFF, respectively for rooms 1, 2 and the 6 mobiles, 25 μSv in the Omdurman Hospital, 45 μSv in the Khartoum Hospital and 3 μSv in the Ahmed Gasim Hospital.

Suliman1, et al 2006 evaluated the entrance surface doses (ESDs) to patients undergoing selected diagnostic X-ray examinations in major Sudanese hospitals. ESD per examination was estimated from X-ray tube output parameters in four hospitals comprising eight X-ray units and a sample of 346 radiographs. Hospital mean ESDs estimated range from 0.17 to 0.27 mGy for chest AP, 1.04–2.26mGy for Skull AP/PA, 0.83–1.32 mGy for Skull LAT, 1.31–1.89 mGy for Pelvis AP, 1.46–3.33 mGy for Lumbar Spine AP and 2.9–9.9 mGy for Lumbar Spine LAT. With exception of chest PA examination at two hospitals, mean ESDs were found to be within the established international reference doses. The results are useful to national and professional organisations and can be used as a baseline upon which future dose measurements may be compared.

Brennan et al 2000 the study was to establish a reference doses for paediatric radiology as a function of patient size. Five standard sizes of patient have been chosen at ages 0 (newborn), 1, 5, 10 and 15 years. Standard AP and lateral thickness for the head and trunk for the reference ages were derived from published measurements on children. Normalization factors for entrance surface dose and dose-area product measurements were calculated which depend on the 26

thickness of the real patient, the thickness of the nearest standard 'patient', and an effective linear attenuation coefficient (μ). These normalization factors were applied to European data to derive some preliminary reference doses.

Chapter Three

Materials and Methods

3.1Materials:

3.1.1. Equipments:

In the present study, different modalities X-ray machines, from different manufacture were used.

3.2. Methods:

3.2.1. Study place:

This study conducted in biggest two hospitals in Sudan Alshab Teaching Hospital and Ibrahim Malik Teaching Hospital.

3.2.2. Method of data collection

A total of 220 patients will examined in biggest tow hospitals in Sudan. The data were collected using a sheet for all patients in order to maintain consistency of the information. The following parameters will recorded age, weight, height, body mass index (BMI) derived from weight (kg)/ (height (m)) and exposure parameters were recorded. The dose will measures for common x-rays examinations. The examinations will collect according to the availability.

3.2.3. Dose measurement:

ESD which is defined as the absorbed dose to air at the center of the beam including backscattered radiation, measured for all patients using mathematical equation in addition to output factor and patient exposure factors. The exposure to the skin of the patient during standard radiographic examination or fluoroscopy can be measured directly or estimated by a calculation to exposure factors used and the equipment specifications from formula below:

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

Where:

(OP) is the output in mGy/ (mA) of the X-ray tube at 80 kV at a focus distance of 1 m normalized to 10 mA s, (kV) the tube potential,(mA) the product of the tube current (mA) and the exposure time(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) will initially insert in the software. The kinds of examination and projection will select afterwards.

3.2.4. Method of data analysis:

The data were analyzed with excel program to find the correlation between ESD and BMI, weight, KVP, mAs.

3.2.5. Method of data storage:

The data stored securely in password personal computer (PC)

3.2.6. Ethical issue:-

Permission from radiology department.

Chapter Four:

The Results

Table (4.1) shows the mean values of ESD and ED obtained in this study for study samples.

ESD (*m*Gy)	Ibrahim Malik Hospital	Alshab Hospital
Mean	4.39	.125
SD	1.23	.04
Min	1.16	.046
Max	7.41	.288
Variance	1.51	.0016

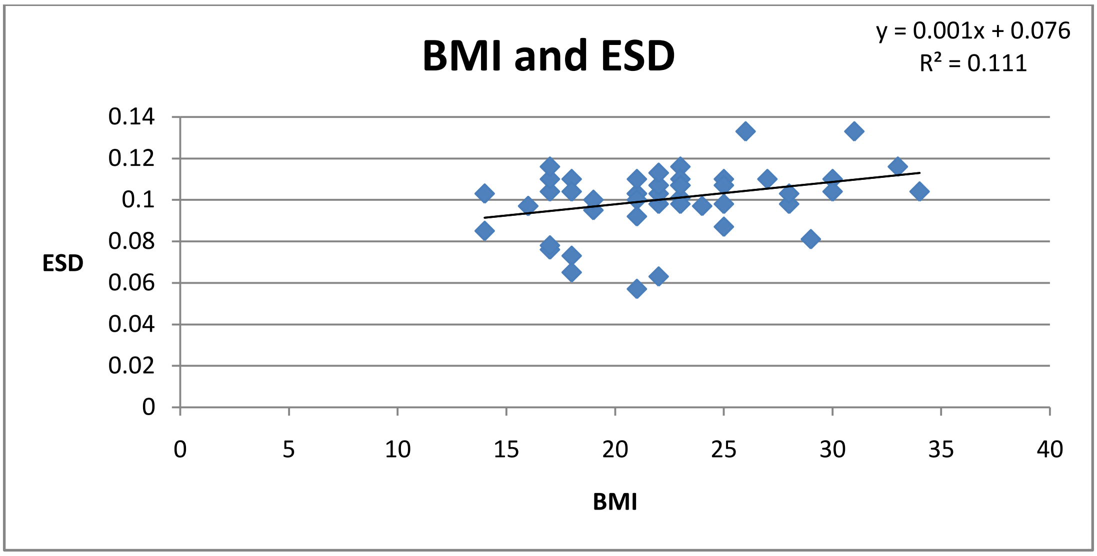


Figure 4-1. Correlation between entrance skin dose ESD (mGy) and body mass index BMI (Kg/m2) of patients undergoing Chest X-ray in Alshab Teaching Hospital.

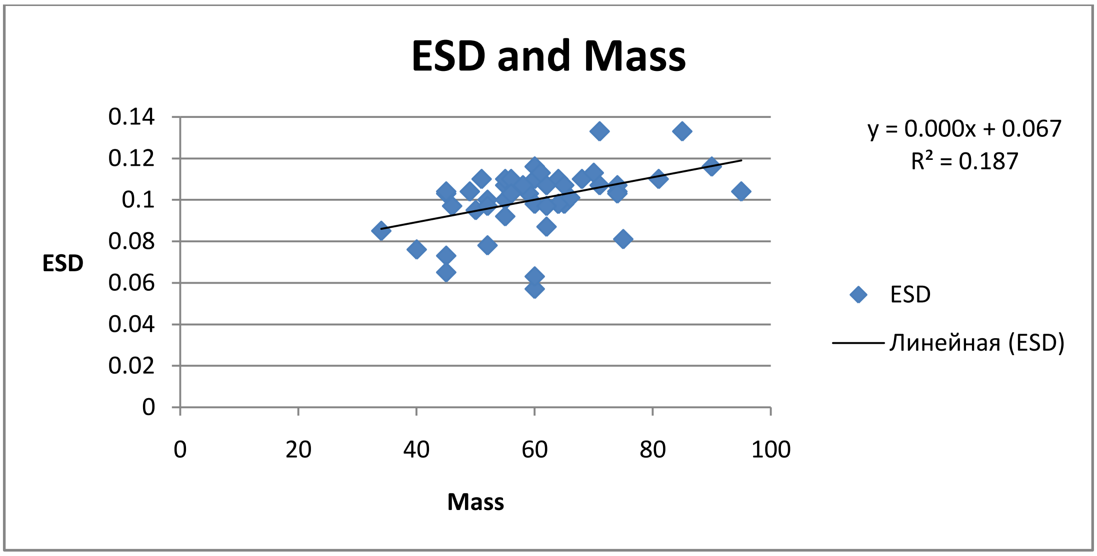


Figure 4-2: correlation between entrance skin dose ESD (mGy) and weight (mass) of the body (Kg) of patients undergoing chest X-ray in Alshab Teaching Hospital.

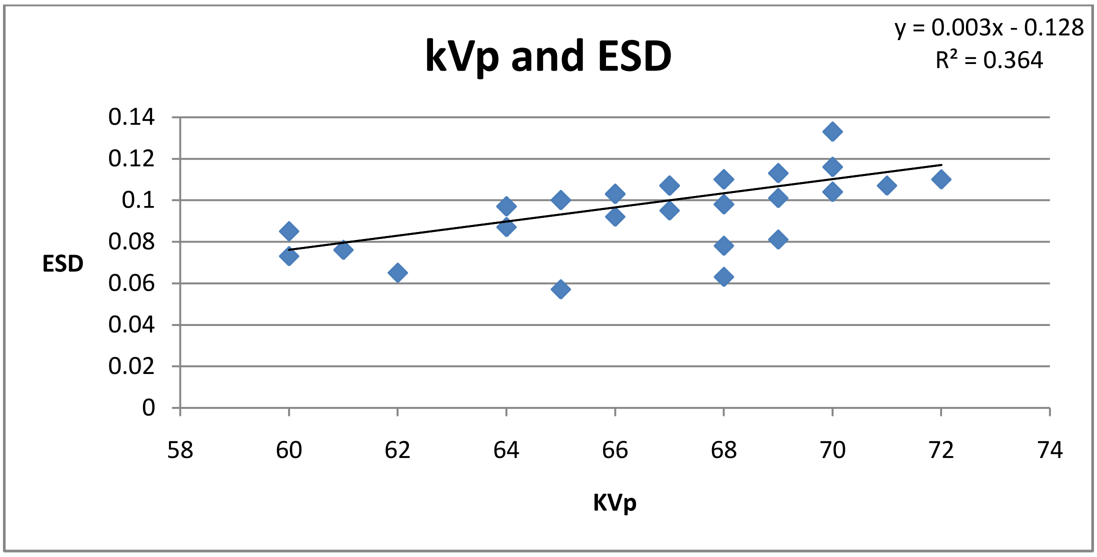


Figure 4-3: correlation between entrance skin dose ESD (mGy) and tube potential kVp to patients undergoing chest X-ray in Alshab Teaching Hospital.

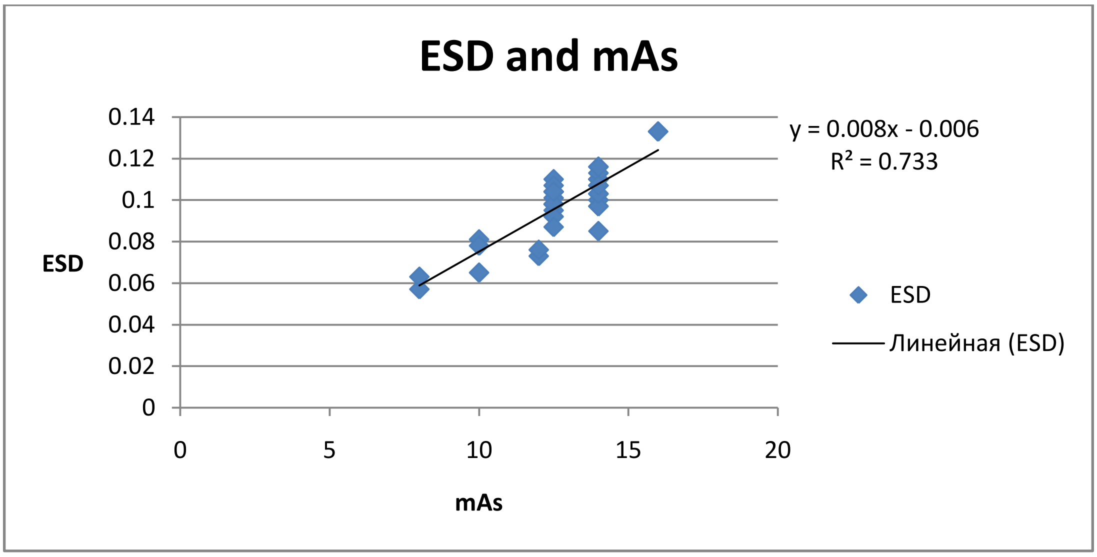


Figure 4-4: correlation between entrance skin dose ESD (mGy) and time current product of patients undergoing chest X-ray in Alshab Teaching Hospital.

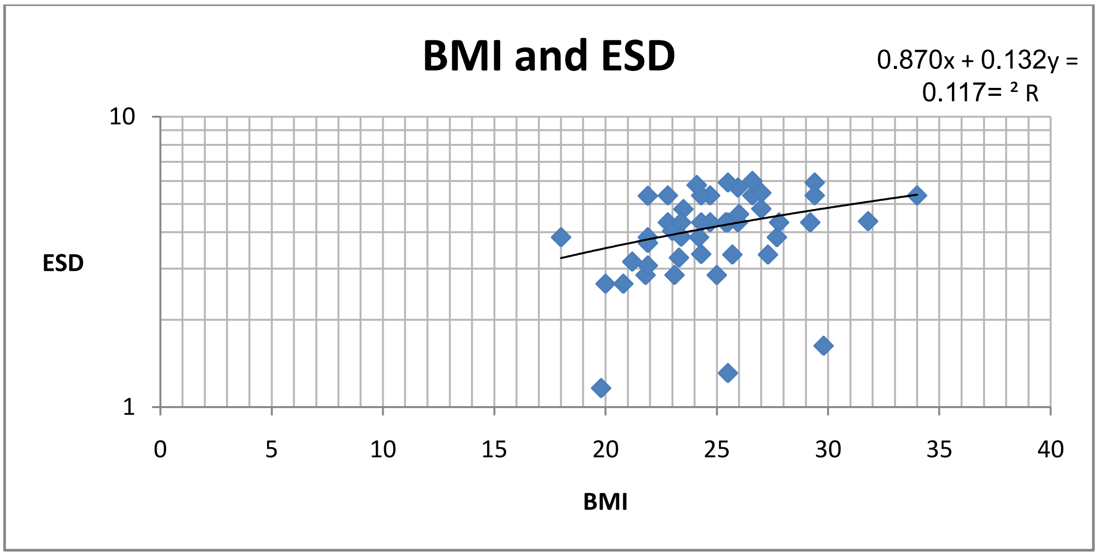


Figure 4-5. Correlation between entrance skin dose ESD (mGy) and body mass index BMI (Kg/m2) of patients undergoing Lumbar Spine X-ray in Ibrahim Malik Teaching Hospital.

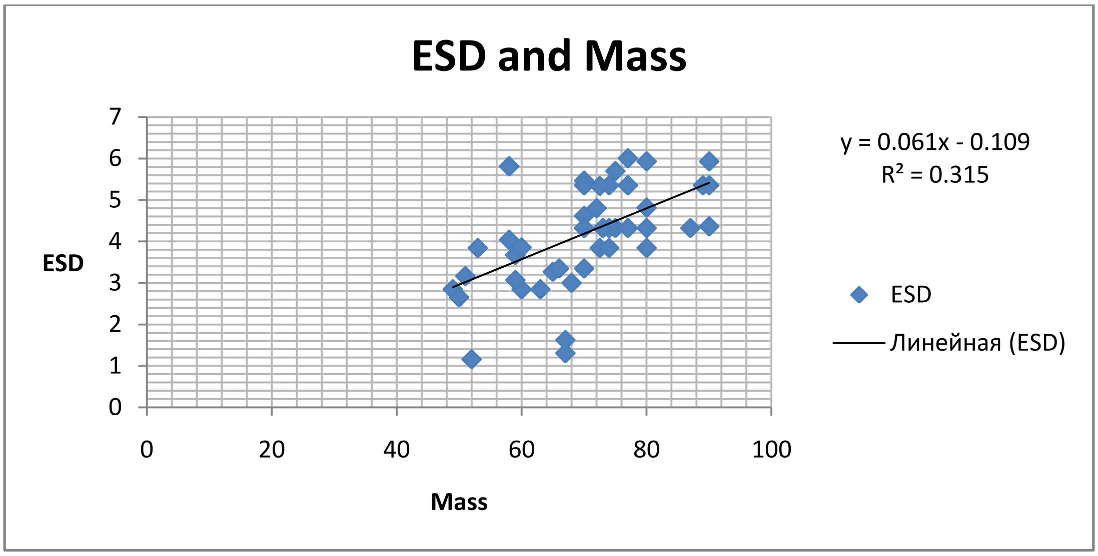


Figure 4-6. Correlation between entrance skin dose ESD (mGy) and weight (mass) of the body (Kg) of patients undergoing Lumbar Spine X-ray in Ibrahim Malik Teaching Hospital.

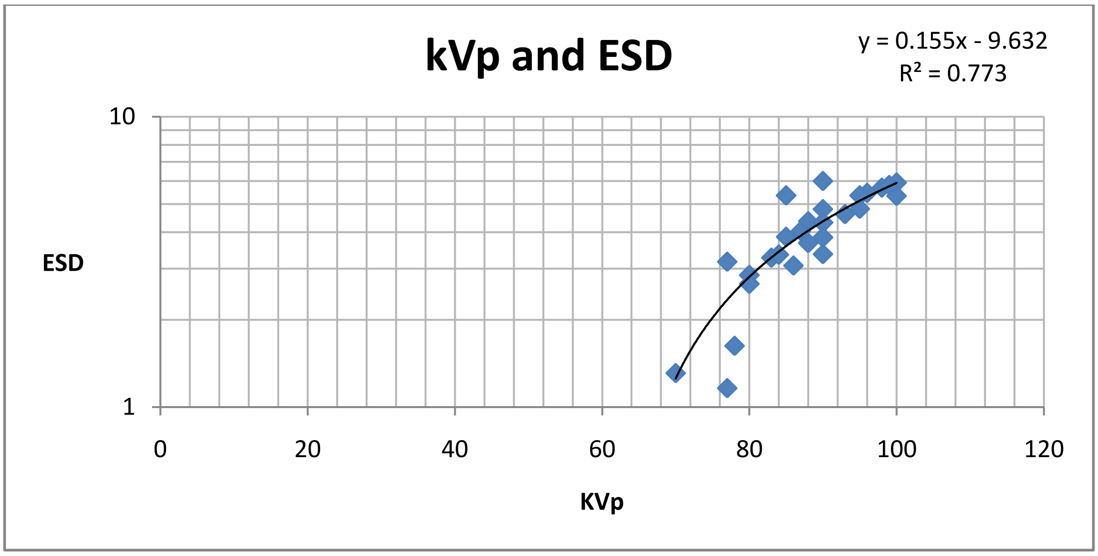


Figure 4-7. Correlation between entrance skin dose ESD (mGy) and tube potential kVp of patients undergoing Lumbar Spine X-ray in Ibrahim Malik Teaching Hospital.

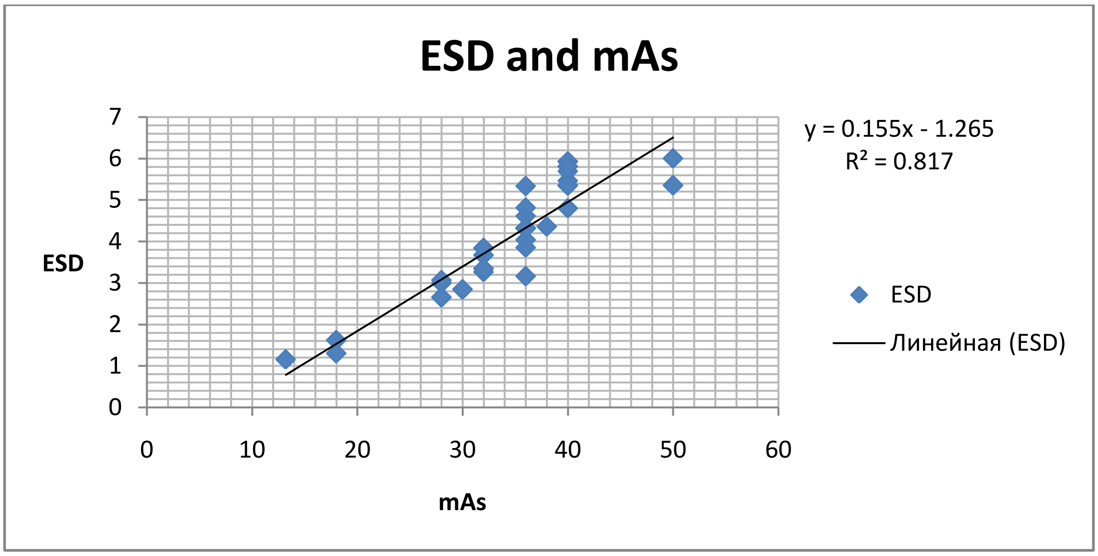


Figure 4-8. Correlation between entrance skin dose ESD (mGy) and time current product (mAs) of patients undergoing Lumbar Spine X-ray in Ibrahim Malik Teaching Hospital.

Chapter Five

Discussion, Conclusion and Recommendation

5.1 Discussions:

This study aimed to estimate the patient Entrance Skin Dose in chest x-ray examination in Alshab Teaching Hospital and Lumbar spine examination in Ibrahim Malik Teaching Hospital. A total of 220 patients 140 chest x-ray examination in Alshab Teaching Hospital and 80 Lumbar spine examination in Ibrahim Malik Teaching Hospital were examined in the two hospitals. the data sheet of X-ray unit current time product (mAs) , kVp, weight, height was recorded and the ESDs was measured from exposure factors and output factor of x-ray machine using mathematical equation. The X-ray tube outputs, in mGy (mAs), was measured using Kv meter. mean and standard deviation of exposure factors (kV, mAs) for two hospitals were recorded and body mass index (BMI) of patient data (age, weight, height) for two hospitals were recorded. The Entrance skin dose in mGy for the two hospitals were recorded , The correlation coefficient which is defined as a measure of the degree of linear relationship between two variables, usually labeled X and Y used in this study to describe the relation. These correlations coefficient between the patient dose ESD (mGy) against BMI, weight of the patients tube current time product (mAs) and tube voltage (kV) were obtained. Positive correlation coefficients were obtained between ESD and mAs for two hospitals and Positive correlation coefficients were obtained between ESD and KVP for Ibrahim Malik Hospital , negative correlation coefficients were obtained between ESD and BMI for two hospitals and negative correlation coefficients were obtained between ESD and weight (mass) of the patient for two hospitals , negative correlation were obtained between ESD and KVP for Alshab Teaching Hospital. The figures (4.1, 4.2, 4.3) shows that there were no correlation found between the ESDs values and the BMI ,weight, KVP respectively in Alshab Teaching Hospital. The figure (4.4) shows that there were correlation found between the ESDs values and the mAs in Alshab Teaching Hospital. The figures (4.5, 4.6,) shows that there were no correlation found between the ESDs values and the BMI ,weight, respectively in Ibrahim Malik Teaching Hospital. The figure (4.7, 4.8) shows that there were correlation found between the ESDs values and the KVP, mAs in Ibrahim Malik Teaching Hospital. The reason for the lack of correlation between ESD and patient weight, BMI is that patient dose depend on exposures factors and output factor of the x-ray machine. The mean ESDs and standard deviation was measured (4.39 ± 1.23) and (.125 ± .04) mGy in (Ibrahim Malik) and (Alshab) respectively, Generally there were 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 Patient absorbed dose measurement in common Medical X-ray Examinations using skin estimated dose. 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. The patient dose was measured in two hospitals was (4.39 $\pm$ 1.23) and (.125 $\pm$ .04) mGy in (Ibrahim Malik) and (Alshab) respectively.

5.3 Recommendation:

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 skilful 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 and reduce the number of films repeated. More studies should be carried out especially in hospitals using old diagnostic facilities.

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Appendix:

Table of results.

NO. of patients	Name	sex	Age	height	weight	BMI	O/P	Kvp	mAs	ESD