قال تعالي

(وَيَسْأَلُونَكَ عَنِ الرُّوحِ ۖ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُم

مِّنَ الْعِلْمِ إِلَّا قَلِيلًا)

صدق الله العظيم

الاسراء(85)

Dedication

To my Father soul

To my mother for her moral support and all the work she did to get me where I am today.

To my lovely sisters and brothers for their kind support.

To my friends who stood beside me and supported me.

To my supervisor and teachers.

Thanks for all

ACKNOLODEGMENT

I thank almighty God for giving me the strength, courage and determination in conducting this study, despite all difficulties.

I would like to thank gratefully my supervisor

Dr. Ahmed Mostafa Abukonna

Phrases may not cover what I mean to show, but a word must be penned to those who helped me and guided me through the way and to those who intended to help me accomplish this work, it's because of their patience and splendid character

I reached this far.

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Abstract

Pediatric radiography is a challenging procedure from the perspective of radiation dosage. Children are approximately ten times more sensitive to radiation-induced cancer than middle-aged adults and three times more sensitive than the population average.

A total of 100 patients were enrolled in this study. ESDs were evaluated for the chest postero-anterior (PA) projection and abdomen antero-posterior (AP) projection. For each studied examination, the patient anthropometrical data (sex, age, weight and height) and technical parameters used (kVp, mAs and FSD) were collected at the time of the examination on a self-designed data collection sheet. The ESD was assessed by indirect method, with the data on the radiation output of the X-ray tube and exposure factors (kVp, mAs and FSD). The image quality for each examination was also assessed using quantitative technique.

The result of the study revealed that the (mean ± SD) for ESDs were found to be (0.11 ± 0.03 mGy), (0.41 ± 0.15 mGy) for PA chest and abdomen consequently. The maximum ESD for abdomen (0.723 mGy) observed at maximum kV_p (62 kV_p) which emphases the significant correlation between kVp and ESD, no correlation was found between patient age or weight and ESD. Image resolution in term of information entropy was optimum and correlated with selected Kvp and mAs.

The study is considered as an attempt to evaluate the ESDs received by digital radiographic x-ray machine for children aged between 1 - 8 years old, taking into considerations number of other variables. The mean ESD values obtained are found to be within the standard reference. It may provide guidance on where efforts on dose reduction will need to be directed to fulfill the requirements of the optimization process and serve as a reference for future researches.

الملخص

التصوير الاشعاعي للاطفال من التحديات المشاهده في تقدير الجرعات الاشعاعية واعطاؤها .الاطفال لهم حساسيه عشره مرات تقربيا من البالغين وثلاث مرات تقربيا من معدل التعداد. مائه مريض هو العدد الكلي الذي سجل في هذه الدراسه، والجرعه الممتصة التي قيمت بالنسبة للصدر والبطن في الفحص الروتيني مع تسجيل بيانات المرض (نوع المريض - والعمر- والوزن – والطول) وعوامل تقنية التصوير الاشعاعي (فرق الجهد – والتيار – ومسافه المريض من مصدر الاشعه) . تم جمع هذه البيانات في نفس وقت الفحص في أستمارة البيانات ، وتم حساب الجرعة الممتصة بطريقه غير مباشره مع معرفة كميه الاشعة الخارجة من انبوب الاشعة وعوامل التعريض (فرق الجهد – والتيار - ومسافة المريض من مصدر الاشعة).نتيجة الدراسة اظهرت ان متوسط الحد الادني والاعلي للجرعة الممتصة وجدناه يساوي (0.11+_ mcy0.03) و(mGY+_0.410.15) بنسبةلفحص الصدر والبطن علي التوالي . والحد الاعلي للجرعه الممتصة بنسبة للبطن كان(mGy0.723) عندما لوحظه الحد الاعلي لكيلو فولت كان (kvp62) وهذا اكد لنا ان هنالك ارتباط مميزه بين الجرعه الممتصة وفرق الجهد وليس هنالك ارتباط بين الجرعة وعمر وزون المريض

والدراسة هي تجربه مميزه والتي حصلنا فيها علي الجرعة الممتصة بواسطة جهاز رقمي عند استعمال جهاز الاشعه بنسبة للاطفال الذين تتروا ح اعمارهم بين 1- 8 سنوات اخذين اعتبارات معينه ومتغيرات مختلفة .

متوسط قيم الجرعات الممتصة والتحصل عليها وجدناه في الحد المناسب للجرعة ، والبيانات المتحصل عليها اضافت معلومات يمكن ان نجدها في السجلات القوميه بالنسبة للاستخدام العام. وهي تعد طرق نحاول من خلالها تقليل الجرعة التي نحناج اليها لكي ننجز متطلبات العمليه المثالية وتزويد المراجع بالنسبة للباحثين في المستقبل.

Chapter one

Introduction

1.1 Introduction:

Pediatric radiography is a challenging procedure from the perspective of radiation dosage. Because, it is well-known that the dose of radiation is an extremely important issue in children, who are significantly more radiosensitive and more likely to manifest radiation-induced changes over their lifetimes (Guo et al., 2013). Children are approximately ten times more sensitive to radiation-induced cancer than middle-aged adults and three times more sensitive than the population average (Brenner et al., 2001). More people are exposed to ionizing radiation for medical practice than any other human activity, and in many cases, individual doses are highest. Exposure to radiation in medicine involve people undergo diagnostic radiographic, interventional procedures or radiation therapy. Diagnostic radiology examinations lead to higher risks per unit dose of radiation to cancer in infants and children compared with adults.

The International Commission on Radiological Protection (ICRP) asserted that the use of effective dose is actually not recommended for assessing the risks of stochastic effects in retrospective situations for exposures in patients, however this quantity can be of value for comparing the use of similar technologies and procedures in different hospitals and countries as well as the use of different technologies for the same medical examination (2007).

The Entrance Skin Dose (ESD) is defined as the absorbed dose to air where the X-ray beam intersects the skin surface of the patient including the backscatter (Alm-Carlsson et al., 2007). The reasons for evaluating ESD is that; the physical parameter recommended for monitoring the Diagnostic Reference Levels (DRLs) in conventional radiography was the ESD and the dose is greatest at the surface where radiation enters the body of the patient therefore the skin is the main organ for which there is a possibility of deterministic effect i.e., skin burn (Sharifat and Oyeleke, 2009) another reason the organs equivalent dose can be estimate from the ESD and that very important especial in case where the part of the body undergoing to be imaged contain sensitive organ to the effect of radiation.

DR has been shown to provide good resolution with no significant difference in diagnostic quality at reduced radiation doses. Volk’s study suggested that dose reduction of approximately 50-75% had no significant impact on image quality. However, a more efficient detector on its own is not sufficient to ensure a consistent low-dose operation in routine clinical practice (Völk et al., 2004).

The knowledge of the relationship that links image quality and radiation dose is a prerequisite to any optimization of medical diagnostic radiology, because – according to the ALARA concept – the dose received by the patient during a radiological examination should be kept ‘as low as reasonably achievable’. The image quality and dose required for a successful and reliable diagnosis depends on physical parameters such as contrast, resolution and noise, the constitution of the patient, the viewing conditions and also on the characteristics of the observer that assesses the image (Al-Kinani and Mohsen, 2014).

This study was aimed to estimate the ESD for pediatric patients undergoing diagnostic X-ray examinations of the chest and abdomen in pediatric hospital in Khartoum, Sudan to help in applying optimization of radiation protection of the patients.

1.2 Problem of study:

Children increased mitotic activity and longer life expectancy, are more radiosensitive than a middle-aged adult by a factor of up to 10.

1.3 Objectives of study:

1.3.1General:

The main objective of this study was to estimate the radiation dose for pediatric patients undergoing X-ray examinations of the Chest and Abdomen.

1.3.2 Specific:

- To measure absorption dose for pediatrics during chest and abdomen imaging.
- To optimize the exposure factors those give good image quality and don't exceed the radiation dose.
- To measure effective dose for pediatrics during chest and abdomen.
- To compare the estimated dose with published works and internationally established diagnostic reference levels.

1.4 Thesis layouts:

This study fells into fives chapters where; chapter one deals with introduction, problem of the study, objectives, definition of Entrance Skin Dose and thesis layout. chapter two will high light about a theoretical background and literature review, chapter three includes Methodology, chapter four about results , chapter five present discussion, conclusion and recommendation.

Chapter two

Literature Review

2. 1 X -ray beam quantity:

The X-ray beam quantity is the X-ray intensity (number of photons per unit area per unit time) or the radiation exposure; and is affected by the change in any of the following factors: Milliampere seconds, kVps and distance and filtration.

Milliamper seconds: (mAs) is the product of X-ray tube current by the time of exposure, it controls the number of electrons accelerated towards the anode. If the current is doubled, twice as many electrons will flow from the cathode to the target, and hence twice as much X-ray photons will be produced. Thus, X-ray quantity is directly proportional to the mAs Thus:

$$\frac{I_1}{I_2} = \frac{mAs_1}{mAs_2}$$

Where I_1 is the X-ray intensity that is produced when a current mAs_1, is applied on the tube, and I_2 is the X-ray intensity that is produced when current mAs_2 is applied on the X-ray tube. Thus increasing X-ray tube current will also increase X-ray quantity with the same ratio (see figure 2.1).

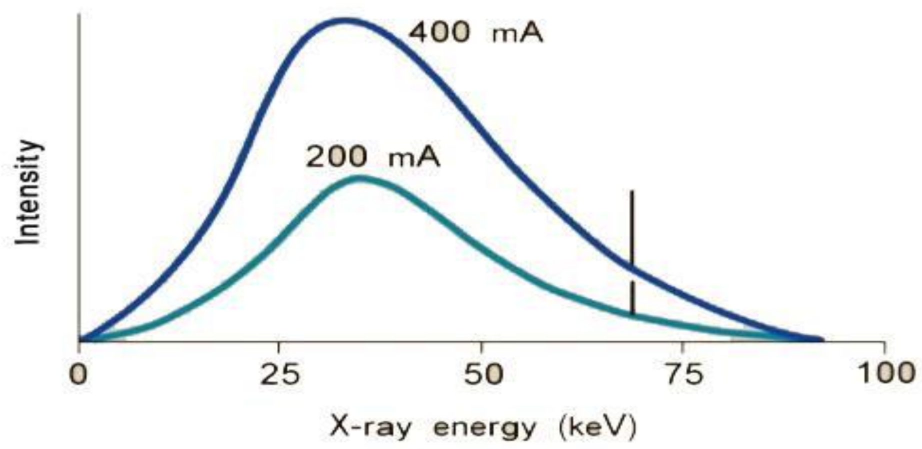

Figure 2.1: Effect of Tube current on X-ray spectrum (Hanan 2007)

Applied voltage (kVp): The increase in the applied voltage will increase the probability of bremstruhlung interaction and hence more X-ray Photons will be produced. It was found that X-ray quantity is approximately proportional to the square ratio of the applied voltage, thus:

$$\frac{I_1}{I_2} = \left(\frac{kVp_1}{kVp_2}\right)^2$$

Where I_1 is the intensity of the beam produced when kVp_1 voltage is applied on the tube and $I_2$is the intensity of the beam when kVp_2voltage is applied on the tube. Any change in the potential will affect both the amplitude and the position of the X-ray spectrum. The area under the curve increases with the square of the factor by which kVp is increased and the relative distribution of emitted X-ray photons shifts to the right (higher energies). Thus for the same mAs increasing the applied voltage will increase X-ray beam quantity (Bushong, 2013).

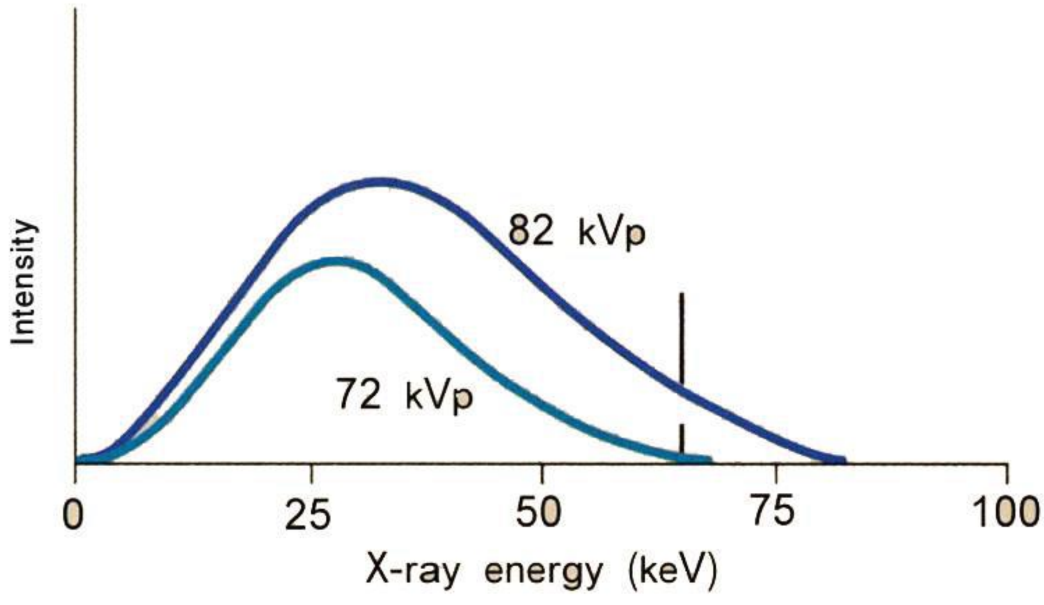

Figure 2.2: Effect of Tube potential on X-ray spectrum (Hanan 2007)

Distance: The intensity of X-rays is inversely proportional to the square distance from the target ,thus:

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

Where I_1 is the intensity of the beam when a distance $d_1$is used and I_2 is the intensity of the beam when a distance $d_2$is used Filtration: Any material that lies in the path of the X-ray beam is called filtration. There are two types of filtration; inherent and added filtration. The X-ray tube housing for example is an inherent filter material. Any added material to the beam is called added filtration. Filtration reduces the X-ray quantity by selectively removing low energy X-ray photons that do not add any information to the diagnosing image and hence improving the X-ray beam quality (Bushong 1993). Thus the total effect of filtration on the X-ray beams depend on change in the X-ray spectrum shape, the peak of the spectrum shifts towards higher energies, the maximum energy remains unchanged and the minimum energy shifts towards higher energies (Bushong, 2013).

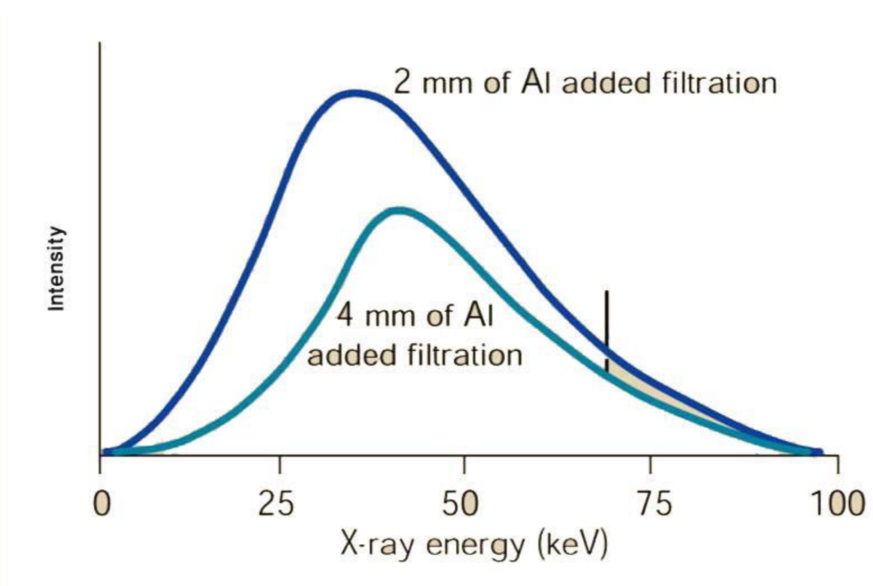

Figure 2.3 Effect of filtration on X-ray spectrum

2.2 X-ray beam quality:

The X-ray quality is a measure of the penetrating ability of the X-ray beam and it is measured by the half value layer (HVL) of the beam. HVL is the thickness of a substance needed to reduce the intensity of the beam into half of its original value. The larger the HVL, the higher the beam quality. The factors that affect the X-ray beam quality are the applied voltage (Kvp) which controls the speed of the accelerated electrons and therefore controls the energy of the produced X-rays and the half value layer, the target material, the atomic number of the target material affects both the number and the effective energy of the X-rays. When the atomic number of the target is increased, the spectrum is shifted to the right. Finally, the filtration, the increase of total filtration will increase the beam quality by removing low energy photons (Bushong, 2013).

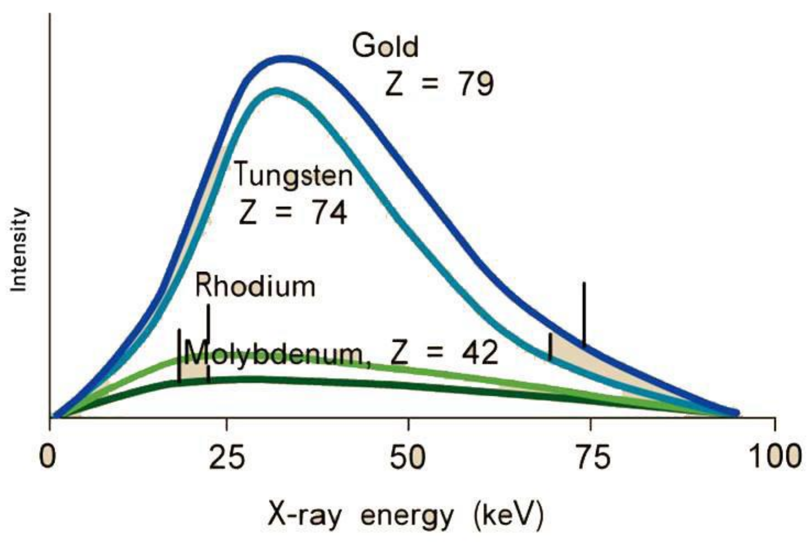

Figure 2.4: Effect of atomic number of target material on X-ray spectrum (Tungsten atomic number = 74, Molybdenum atomic number = 42

2.3 Interaction of radiation with matter:

The intensity of an x-ray beam is reduced by interaction with the matter it encounters. This attenuation results from interactions of individual photons in the beam with atoms in the absorber (patient). The x -ray photons are either absorbed or scattered out of the beam. In scattering, photons are ejected out of the primary beam as a result of interactions with the orbital electrons of absorber atoms. Four mechanisms exist where these interactions take place: Coherent scattering, Compton scattering and photoelectric absorption and pair production. In addition, about 9% of the primary photons pass through the patient without interaction to produce the image (Curry et al., 1990).

2.3.1 Coherent Scattering:

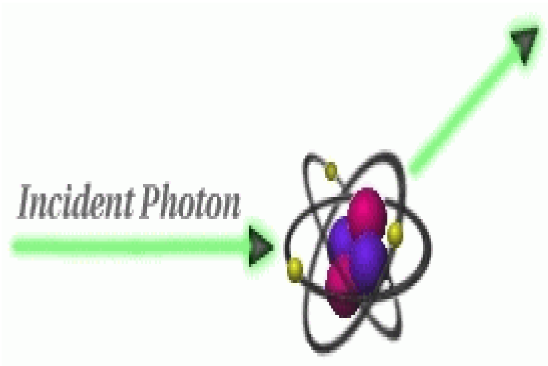

Figure 2.5: Effect Schematic diagram of classical scattering (Curry et al., 1990)

Coherent Scattering (also known as classical scattering and Thompson Scattering) may occur when a low-energy incident photon passes near an outer electron of an atom (which has a low binding energy). The incident photon interacts with the electron in the outer-shell by causing it to vibrate momentarily at the same frequency as the incoming photon. The incident photon then ceases to exist. The vibration causes the electron to radiate energy in the form of another x-ray photon with the same frequency and energy as in the incident photon effect. Coherent scattering contributes very little to film fog because the total quantity of scattered photons is small and its energy level is too low for much of it to reach the film (Curry et al., 1990).

2.3.2 Compton scattering:

Occurs when a photon interacts with an outer orbital electron, which receives kinetic energy and recoils from the point of impact. The incident photon is then deflected by its interaction and is scattered from the site of the collision.

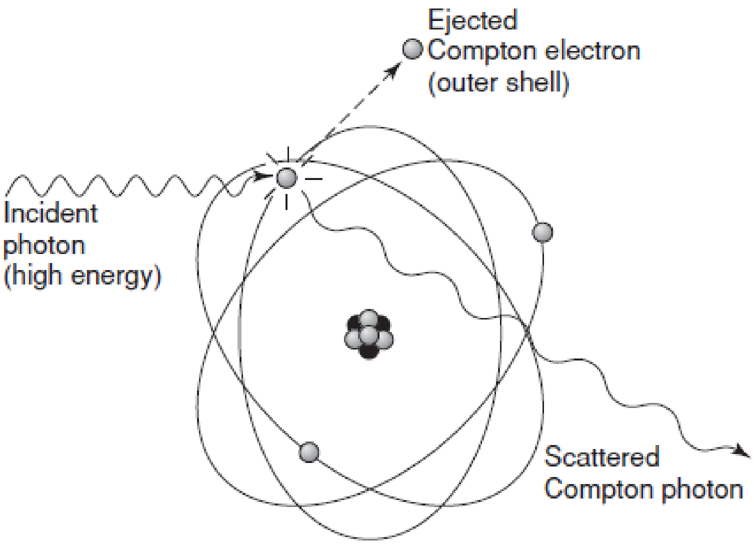

Figure 2.6: Schematic diagram of Compton scattering

The energy of the scattered photon equals the energy of the incident photon minus the kinetic energy gained by the recoil electron plus its bonding energy. As with photoelectric absorption, Compton scattering results in the loss of an electron and ionization of the absorbing atom. Scattered photons travel in all directions. The higher the energy of the incident photon, however, the greater the probability that the angle of scatter of the secondary photon will be small and its direction will be forward. This is advantageous to the patient because some of the energy of the incident x -ray beam escapes the tissue, but it is disadvantageous because it causes nonspecific film darkening (or fogging of the film). Scattered photons darken the film while carrying no useful information to it because their path is altered. (Curry et al., 1984) The probability of Compton scattering is directly proportional to the electron density. The number of electrons in bone is greater than in water, therefore the probability of Compton scattering is correspondingly greater in bone than in tissue. In a dental x -ray beam, approximately 62% of the photons undergo Compton scattering (Curry et al., 1990).

The importance of photoelectric absorption and Compton scattering in diagnostic radiography relates to differences in the way photons are absorbed by various anatomic structures. The number of photoelectric and Compton interactions is greater in hard tissues than in soft tissues. As a consequence, more photons in the beam exit the patient after passing through soft tissue than through hard tissue. This allows a radiograph to provide a clear image of enamel, dentine and bone and also soft tissue (Curry et al., 1990).

2.3.3 Photoelectric absorption:

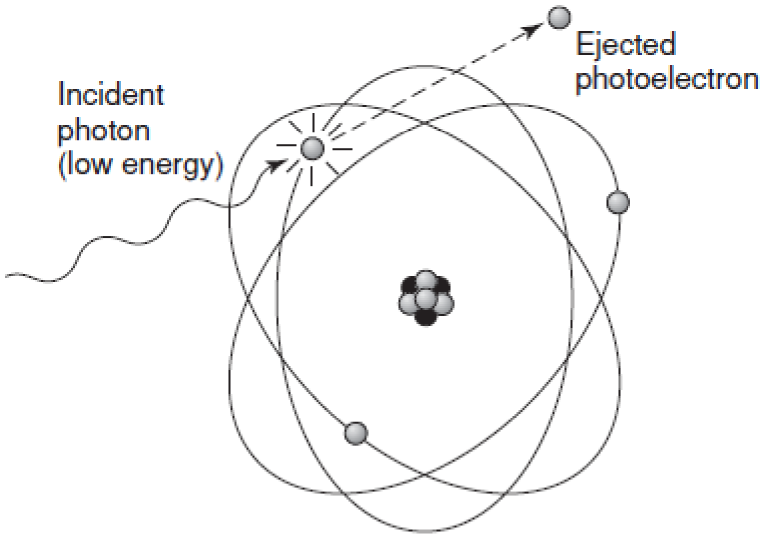

Figure 2.7: Schematic diagram of photoelectric effect

Photoelectric absorption occurs when an incident photon collides with an inner-shell electron in an atom of the absorbing medium resulting in total absorption and the incident photon ceases to exist. The electron is ejected from its shell, resulting in ionization and becomes a recoil electron (photoelectron). The kinetic energy imparted to the recoil electron is equal to the energy of the incident photon minus that used to overcome the binding energy of the electron. In the case of atoms with low atomic numbers (e.g. those in most biologic energy of the incident photon. Most Photoelectric interactions occur in the K shell because the density of the electron cloud is greater in this region and a higher probability of interaction exists (Curry et al., 1990).

An atom that has participated in photoelectric interaction is ionized. This electron deficiency (usually in the K shell) is instantly filled, usually by an L-or M -shell electron, with the release of characteristic radiation. Whatever the orbit of the .energy that they are absorbed within the patient and do not fog the film (Curry et al., 1990).

The recoil electrons ejected during photoelectric absorptions travel only a short distance in the absorber before they give up t heir energy. As a consequence, all the energy of incident photons that undergo photoelectric interaction is deposited in the patient. This is beneficial in producing high quality radiographs, because no scattered radiation fogs the film, but potentially deleterious for patients because of increased radiation absorption (Curry et al., 1990).

The frequency of photoelectric interaction varies directly with the third power of the atomic number of the absorber. For example, because the effective atomic number of compact bone (Z = 7,4), the probability that a photon will be absorbed by a photoelectric interaction in bone is approximately 6.5 times greater than in an equal distance of water. This difference is readily seen on dental radiographs. It is this difference in the absorption that makes that production of a radiographic image possible (Curry et al., 1990).

2.4 Biological Damage:

Only a short time elapsed between the discovery of X-rays and reported cases of radiation damage from their use. The workers themselves (clinicians and technicians), who held the film cassettes in the X-ray beam, noticed damage to their hands that was slow to heal. Radiation workers were also suffering from general radiation exposure which sometimes led to cancers and early death. Relatively little radiation biology was done prior to 1940. Fundamental research in this area stemmed from the development of nuclear weapons, and the present strict guidelines and controls on the use of radiation originate from that time. Of the various forms of radiation damage the most important is that to the DNA structure. Damage to DNA can prevent survival or reproduction of the cell but there is a repair mechanism. If sufficient cells are killed or damaged there will be loss of organ function; an event that the ICRP calls deterministic. Somatic or hereditary effects which may start from a single modified or transformed cell are called stochastic effects (Van Dyk, 2013)

2.5 Direct and indirect damage:

Alpha and beta particles, being charged, lose energy by electrical interactions with the outer electrons of atoms in tissue. Electromagnetic radiation (gamma and X-rays), being uncharged, can behave differently but both produce ionizing events. Other radiosensitive biological molecules are RNA, enzymes and the molecular structure of the cell wall.

2.5.1 Direct Damage:

DNA may be directly damaged by radiation, causing a break in a chain. It can also damage the nuclear cell membrane. Indirect damage is caused by free radicals produced by irradiation of water molecules some distance from the target. Free radicals attack the structure of DNA and other important biological complexes by forming unstable and very reactive compounds (Van Dyk, 2013).

2.5.2 Indirect Damage:

This occurs when a charged particle passes through atoms in the tissue transferring some of its energy to atomic electrons in the medium (mostly water) without causing direct effects on radiosensitive targets. Water molecules, the most common constituent of tissue, enter a state of excitation, forming free radicals (H and OH). These are highly reactive and are responsible for indirect protein damage (stages 8 and 9). Simple ionization of the water can also occur (H2O→ H# # OH#). The main reactions with water are shown in stages 4 to 7. Both indirect and direct reactions can lead to self-perpetuating chain reactions (Steineck et al., 2017)

2.6 Organ response to radiation:

A cell modified by radiation damage may transmit flawed genetic information via its DNA to other cell generations. This can cause both somatic and hereditary effects which may start from a single modified cell; this is the stochastic effect where radiation causes potential harm even at low doses. If enough cells in an organ or tissue are killed or prevented from functioning normally there will be a loss of organ function; this is the deterministic effect where there is a threshold dose below which these effects are not seen (e.g. cataracts and erythemas); a linear response region may still exist.. These effects are a valuable guide to personnel radiation protection recommendations indicating maximum permissible radiation doses. Radiation protection measures aim to prevent deterministic (nonstochastic) effects and reduce the probability of stochastic effects to acceptable levels. Deterministic effects are shown where a loss of tissue function is seen at doses of a few hundred mSv (100mSv # 10 rem). These are characterized by a dose–frequency relationship for which a dose threshold exists (Oktaria et al., 2017).

2.7 Somatic and genetic effects:

Radiation can damage body tissues causing somatic effects, seen mainly as carcinogenesis in individuals or populations, or affect their offspring causing genetic effects which are hereditary defects seen in populations.

2.7.1 Somatic Cell Damage:

This is the damage that is apparent during the lifetime of the organism, exclusive of effects on the reproductive system. Somatic cells include all cells except gametes. A great variety of changes can be seen, some temporary and others permanent, the latter often leading to cell death. Somatic cells most commonly survive low radiation dose rates since the damage at molecular and sub-cellular levels is mostly repaired. Somatic damage could result in leukemia, breast cancer and other adult carcinomas in individuals and populations. Noncarcinoma damage, for instance cataract or pulmonary fibrosis, is seen in people exposed to local high radiation levels. Somatic effects occur mainly as a result of acute (short time-span) doses from atomic weapons or therapy. Chronic radiation exposure data from large populations in the USA and China have failed to show any unequivocal evidence that high natural background radiation levels increase the incidence of somatic or genetic effects. Prior to 1921 radiologists exposed continuously to quite high levels of soft (low energy) radiation had an increased cancer mortality. This is not seen in present-day radiologists owing to safer equipment and decreased radiation exposures; indeed they may illustrate a 'healthy worker syndrome' as they have a lower incidence of cancer than the general population. Somatic changes are seen in radiation sensitive adult tissues having high proliferation rates, for instance bone marrow, breast and gastrointestinal mucosa. Less damage is done to slowly proliferating (Oktaria et al., 2017). Cells as in the adult central nervous system. Somatic damage is most dangerous at the embryo and fetus stages where cells have multiple descendants. Inhibition of cell division by radiation mostly leads to cell death but some radiation damage causes cell transformation where normal cell functions are altered and carcinogenesis initiated. Soft radiation (UV, electrons), or soft (low energy) X-rays give a high surface dose and these would promote skin cancer. The small incidence of radiogenic cancer that may be present in a population is indistinguishable from naturally occurring cancers (leukemia, breast, sarcoma, lung) and since the natural cancer rate is about 16% per 100000 (16000 deaths) the effect of low level radiation on the population (cancer incidence) is almost impossible to detect with statistical confidence (Oktaria et al., 2017).

2.7.2 Tissue Damage:

At the tissue level, disruption to the nervous system ،to the bone marrow and to the digestive tract ،for example, can occur as well as the induction of cancer . Additionally, such changes can lead to genetic damage and to the death of the irradiated person. At the population level, such changes could ultimately lead to changes in the gene pool. Furthermore, the risk of cancer induction from diagnostic X-ray exposures although small is nevertheless estimated to represent ~1% of cancers which arise spontaneously among the population.

It should be noted that this *target theory* used widely in Radiation Biology does not completely explain specific cellular responses observed at low doses, such as the Radio-Adaptive Response and the Radiation-Induced Bystander Response. The adaptive response is also referred to as Radiation Hormes is and assumes that cells can adapt to low levels of exposure by the stimulation of repair mechanisms. The bystander response, in contrast, assumes that radiation damage occurs by affecting cells which are not directly exposed to the radiation beam. Communication between the irradiated cells and nearby un irradiated cells is considered to be the cause (Oktaria et al., 2017).

2.8 A stochastic effect:

Is one in which the probability of the effect occurring, (rather than its severity), increases with dose. Radiation-induced cancer and hereditary effects are stochastic in nature. For example, the probability of radiation-induced leukemia is substantially greater after an exposure to 1 Gy than to 10 mGy, but there will be no difference in the severity of the disease if it occurs.

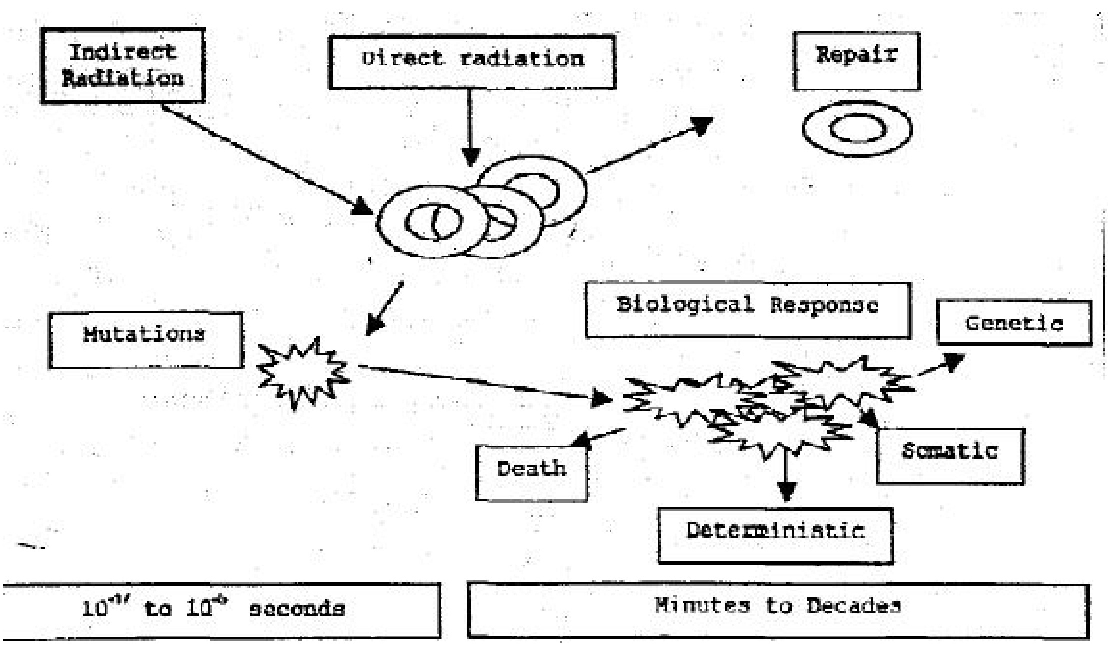

Figure 2.8 show the process of cell damage from the time of irradiation (Bushberg et al.,1997)

2.9 Radiation quantities:

2.9.1 Absorbed Dose:

Since exposure applies only to quantifying X-ray and gamma radiation in air, a different unit is needed to quantify the radiation energy absorbed in materials, particularly. Furthermore, the energy absorbed by different materials may differ, even if they when considering other types of radiation, such as alpha or beta particles. Dose is a measure of the amount of energy deposited per unit amount of matter. It is more important than counting the number of X-rays, because the amount of energy deposited depends on the energy and type of radiation, not just the number of photons receive exactly the same exposure The SI unit measuring dose is the gray (Csillag and Lengyel). One gray is equal to 1 J deposited per kilogram of material (1 Gy= 1 J/kg). The older (ergs) unit, still common in the literature, is the rad. One rad is equal to 100 ergs deposited per gram of material. The conversion from rad to gray is 100 rad = 1 Gy.

2.9.2 Kerma:

Kerma (K) is an acronym for *k*inetic *e*nergy *r*eleased in *ma*tter. Kerma is defined at the kinetic energy transferred to charged particles by indirectly ionizing radiation per unit mass, as described in Step 1 above.

The SI unit of Kerma is the joule per kilogram with the special name of the *gray* (Csillag and Lengyel) or milligray (mGy), where1 Gy5 1 J kg21. For x-rays and gamma rays, kerma can be calculated from the mass energy transfer coefficient of the material and the energy fluence (Gerber et al., 2009).

2.9.3 Equivalent Dose:

The biological consequences of radiation exposure depend not just on the amount of energy deposited but also the type of radiation the subject is exposed to. Some types of radiation produce more significant biological effects than others for the same absorbed dose. The equivalent dose accounts for factors that modify the biological effects of the absorbed radiation energy. The equivalent dose relates the amount of a particular type of radiation (e.g., alpha particles) to the same amount of a standard radiation

To obtain the equivalent dose, the absorbed dose (in gray) of a given type of radiation is multiplied by a weighting factor, *wR*, which is related to the relative biological effectiveness of different types of radiation. The unit for the equivalent dose is the Sievert (Gerber et al., 2009).

$$HT = wR.Dt$$

•*T* is some tissue (or organ.(

•*R* is the radiation type.

•*HT* is the equivalent dose to tissue *T* (Sv)

•*DT,R* is absorbed dose to tissue *T* from radiation *R*.

•*wR*is radiation weighting factor for radiation of type *R*.

The old unit of equivalent dose is the rem (roentgen equivalent man), and the old name for the quantity “equivalent dose” is “dose equivalent.”.

2.9.4 Effective Dose:

The effective dose relates the biological harm of a partial body exposure to the harm of total body irradiation. The effective dose is equal to the dose to the entire body that would produce the same level of harm as a dose to the part of the body actually exposed. The effective dose is obtained by first multiplying the equivalent dose to each critical organ by the tissue weighting factor, *wT*, and then adding up all the weighted doses.

$$HE = Wt.HT$$

•*HE* is the effective dose.

•*HT* is the equivalent dose to tissue *T*.

•*wT*is the tissue weighting factor.

2.9.5 Interaction of Radiation with Tissue:

gamma-ray photon interactions in tissue, as well as radiations emitted during radionuclide decay, result in the production of energetic electrons .These electrons transfer their kinetic energy to their environment via excitation, ionization, and thermal heating. Energy is deposited randomly and rapidly(in less than 10−8 seconds) and the secondary ionizations set many more low-energy electrons in motion causing additional excitation and ionization along the path of the initial energetic electron.

Observable effects such as chromosome breakage, cell death, oncogenic transformation, and acute radiation sickness, all have their origin in radiation-induced chemical changes in important bimolecular.

2.9.6 Scattering:

Scattering refers to an interaction that deflects a particle or photon from its original trajectory. A scattering event in which the total kinetic energy of the colliding particles is unchanged is called *elastic*. When scattering occurs with a loss of kinetic energy (i.e., the total kinetic energy of the scattered particles is less than that of the particles before the interaction), the interaction is said to be *Inelastic (Armpilia et al., 2002).*

2.10 Radiation Units and Measurements:

The International System of units (SI) provides a common system of units for science and technology. The system consists of seven base units: meter (m) for length, kilogram(kg) for mass, second (s) for time, ampere (A) for electric current, kelvin (K) for temperature, candela (Thomas et al.) for luminous intensity, and mole (mol) for the amount of substance.

In addition to the seven base units, there are *derived units* defined as combinations of the base units.

Examples of derived units are speed (m/s) and density (kg/m3). Details regarding derived units used in the measurement and calculation of radiation dose for specific applications can be found in the documents of the International Commission on Radiation Units and Measurements (ICRU) and the International Commission on Radiological Protection (Clement, 2014).

2.10.1 Rem:

Unit of radiation dosage (such as from X rays) applied to humans. Derived from the phrase *Roentgen equivalent man*, the rem is now defined as the dosage in rads that will cause the same amount of biological injury as one rad of X rays or gamma rays. Formerly poorly defined, the rem was redefined in 1962 to clarify the usage of the term *relative biological effectiveness* (Gerber et al.) in both radiobiology and radiation protection. A rem is equal to 0.01 sievert in the International System of Units) SI

2.10.2 Sievert (Sv):

Unit of radiation absorption in the International System of Units) SI).The sievert takes into account the relative biological effectiveness (Gerber et al.) of ionizing radiation, since each form of such radiation—e.g., X-rays ‹gamma rays ‹neutrons—has a slightly different effect on living tissue. Accordingly, one sievert is generally defined as the amount of radiation roughly equivalent in biological effectiveness to one gray) or 100 rads) of gamma radiation. The sievert is inconveniently large for various applications, and so the millisievert (mSv), which equals 1/1,000 sievert, is frequently used instead. One millisievert corresponds to 10 ergs of energy of gamma radiation transferred to one gram of living tissue. The sievert was recommended in 1977 by the International Commission on Radiation Units and Measurements (ICRU) as a substitute for the rem ‹the long-standing special unit for measuring biological absorption of radiation (Clement, 2014).

2.10.4 Gray

Unit of absorbed dose of ionizing radiation ‹defined in the 1980s by the International Commission on Radiation Units and Measurements. One gray is equal approximately to the absorbed dose delivered when the energy per unit mass imparted to matter by ionizing radiation is one joule per kilogram. As a unit of measure, the gray is coherent with the units of measure in the International System of Units) SI). The gray replaced the rad ‹which was not coherent with the SI system. One gray equals 100 rads (Clement, 2014)

2.10.5 Rad:

The unit of absorbed dose of ionizing radiation, defined in 1962 by the International Commission on Radiological Units and Measurements as equal to the amount of radiation that releases an energy of 100 ergs per gram of matter . One rad is equal approximately to the absorbed dose delivered when soft tissue is exposed to one roentgen of medium-voltage radiation. "Rad" is derived from "radiation absorbed dose." In 1975 it was replaced by the gray) Csillag and Lengyel(, equal to 100 rads, in the International System of Units (SI). The rad is used now only in the United States (Clement, 2014).

2.11 Radiation protection in radiography:

Radiography is still the most commonly performed imaging procedure in children. While there is still some older screen film radiography performed, the technology is evolving toward computed radiography (CR) and digital radiography (DR) exclusively, and discussion of digital technologies will be emphasized. There are multiple strategies for radiation protection which can be used for radiography in infants and children, including establishment of optimal technique, minimization of unnecessary additional exposures, and appropriate collimation. Technical exposure factors can vary substantially in adults and children (Kehoe, 2007).

The range of exposure factors for diagnostic examinations and interventional procedures has been reported to vary up to 88 fold. This type of variation potentially could be modulated using diagnostic reference levels, although these have not been established nationally in the United States. Pediatric protocols for CR and DR have greater demands on the range of techniques than with adult imaging, given the wide ranges of sizes in children (e.g. weights of 1.0 kg to more than 100 kg). Pediatric protocols are best established with the initial assistance of the application specialist with the particular vendor. It is important to review image quality shortly after the installation of new equipment to assure that image quality and dose estimates are within acceptable standards (Valentin, 2005).

This type of quality review is important with any imaging modality. With radiography, for example, it is possible to manually collimate the image to look as if the exposure was limited to the appropriate region. This was not possible with screen film radiography, where the exposure served as quality control. This type of exposure outside the field is important to monitor, but is not readily evident on daily clinical viewing of digital radiographic images. There is a small amount of scatter radiation that occurs from radiography. The importance of the scatter is nominal and will not be reduced by shielding. With appropriate collimation, shielding is not a requisite for radiography. However, as with fluoroscopy and angiography and computed tomography, placement of shields beyond the level of exposure assures the child and the family that all measures are taken for radioprotection. However, the routine use of shields will have to be based on individual practice standards. Placing shields on areas of increased radiation vulnerability/sensitivity, such as the gonads for pelvic radiography, will depend on shielding during radiography is not predictable given the variable location of the ovaries the clinical indication (Valentin, 2005).

2.11.1 Methods of Exposure Control:

There are four principal methods by which radiation exposures to persons can be minimized: (1) reducing time of exposure, (2) increasing distance, (3) using shielding, and (4) controlling contamination by radioactive material. Although these methods are widely used in radiation protection programs.

2.11.1.1 Collimators:

Collimators are the best restrictors, they consist of attenuating shutters that can be moved inwards and outwards to shape X-ray beam. With the use of collimation the X-ray beam can be restricted to the scanning site, and limit radiation dose to other parts of the body. Without the use of the collimator, the whole body of the patient may be exposed to X-ray beam (Wrixon, 2008).

2.11.1.2 Time:

Although it is obvious that reducing the time spent near a radiation source will reduce one's radiation exposure, techniques to minimize time in a radiation field are not always recognized or practiced. First, not all sources of radiation produce constant exposure rates. Diagnostic x-ray machines typically produce high exposure rates during brief time intervals (Wrixon, 2008).

2.11.1.3 Distance:

The exposure rate from a source of radiation decreases with increasing distance from the source, even in the absence of an attenuating material. In the case of a point source of radiation (i.e., a source whose physical dimensions are much less than the distance from which it is being measured), the exposure rate decreases as the distance from the source is squared.

2.11.1.4 Shielding:

Shielding is used in diagnostic radiology and nuclear medicine to reduce exposures of patients, staff, and the public. The decision to utilize shielding, and its type, thickness, and location for a particular application, are functions of the photon energy, intensity and geometry of the radiation sources, exposure rate goals at various locations, and other factors.

Radiation protection in radiography:

There is a small amount of scatter radiation that occurs from radiography. The importance of the scatter is nominal and will not be reduced by shielding. Placing shields on areas of increased radiation vulnerability/sensitivity, such as the gonads for pelvic radiography, will depend on the clinical indication. For females, the benefit of gonadal shielding during radiography is not predictable given the variable location of the ovaries.

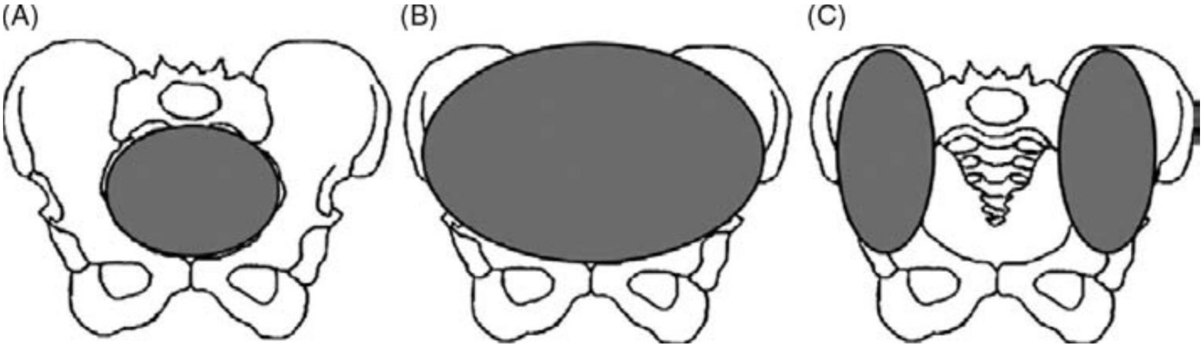

Figure 2.9 shielding of the pelvic area

2.11.2 Protection of the Patient in Medical X-ray Imaging:

The two main methods for limiting the radiation doses to patients in medical imaging are to avoid unnecessary examinations and to ensure the doses from examinations are no larger than necessary. The goal of a radiological examination should be to produce images of adequate quality for the clinical task, not images of unnecessarily high quality if that increases the radiation dose to the patient. On the other hand, using too low a dose can also be harmful, if it results in images that cause a clinical error or must be repeated.

2.11.2.1 Tube Voltage and Beam Filtration:

An important goal in diagnostic imaging is to achieve an optimal balance between image quality and dose to the patient. *Increasing the kV* will result in a greater transmission (and therefore less absorption) of x-rays through the patient. Even though the air kerma (or exposure) per mAs increases as the kV is increased, an accompanying reduction in the mAs to produce a similar signal to the image receptor will decrease the incident exposure to the patient. Unfortunately, there is a concomitant reduction in image contrast due to the higher effective energy of the x-ray beam. Within limits, this compromise is acceptable. Therefore, the patient exposure can be reduced by using a higher kV and lower mAs. Filtration of the polychromatic x-ray energy spectrum can significantly reduce exposure by selectively attenuating the low-energy x-rays in the beam that would otherwise be absorbed in the patient with little or no contribution to image formation. These low-energy x-rays mainly impart dose to the skin and shallow tissues where the beam enters the patient. As the beam filtration is increased, the beam becomes “hardened” (the average photon energy increases) and the dose to the patient *decreases* because fewer low-energy photons are in the incident beam. The amount of filtration that can be added is limited by the increased x-ray tube loading necessary to offset the reduction in tube output and the decreased contrast that occurs with excessive beam Hardening (Holm, 2004).

2.11.2.2 Field Area, Organ Shielding, and Geometry:

Restriction of the field size by collimation to just the necessary volume of interest is an important dose reduction technique. While it does not significantly reduce the entrance dose to the area in the primary beam, it reduces the volume of tissue in the primary beam and thus the energy imparted to the patient. It also reduces the amount of scatter and thus the radiation doses to adjacent organs. From an image quality perspective, the scattered radiation incident on the detector is also reduced, thereby improving image contrast and the signal-to-noise ratio. When possible, particularly radiosensitive organs of patients undergoing radiographic examinations should be shielded. For instance, when imaging a limb (such as a hand), a lap apron should be provided to the patient. When the gonads are in the primary beam, *gonad shielding* should be used to protect the gonads when the shadow of the shield does not interfere with the anatomy under investigation because the gonad shield must attenuate primary radiation, its thickness must be equivalent to at least 0.5 mm of lead. In any situation, the use of patient protection must not interfere with the examination.

Increasing the distance from the x-ray source to the patient (source-to-object distance [SOD]) helps reduce dose. As this distance is increased, a reduced beam divergence limits the volume of the patient being irradiated, thereby reducing the integral dose. Increasing this distance also reduces entrance dose due to the inverse square law (Holm, 2004).

2.11.2.3 X-ray Image Receptors:

For film-screen image receptors, the speed of the image receptor determines the number of x-ray photons and thus the patient dose necessary to achieve an appropriate film darkening. Relative speed values are based on a par speed screen-film system, assigned a speed of 100; a higher speed system requires less exposure to produce the same optical density (e.g., a 400-speed screen-film receptor requires four times less exposure than a 100-speed system.

2.11.3Technique Factors in Radiography:

The principal x-ray technique factors used for radiography include the tube voltage (the kV), the tube current (mA), the exposure time, and the x-ray source-to-image distance, SID. The SID is standardized to 100 cm typically , and 183 cm for upright chest radiography. In general, lower kV settings will increase the dose to the patient compared to higher kV settings for the same imaging procedure and same body part, but the trade-off is that subject contrast is reduced with higher kV (Ofori et al., 2012).

2.11.4 Scattered Radiation in Projection Radiographic Imaging:

The basic principle of projection x-ray imaging is that x-rays travel in straight lines. However, when x-ray scattering events occur in the patient, the resulting scattered x-rays are not aligned with the trajectory of the original primary x-ray, and thus the straight-line assumption is violated. Scattered radiation that does not strike the detector has no effect on the image; however, scattered radiation emanating from the patient is of concern for surrounding personnel due to the associated radiation dose (Ofori et al., 2012).

2.11.4.1Moving Grids:

Grids are located between the patient and the detector, and for high-resolution detector systems such as screen-film receptors, the grid bars will be seen on the image if the grid is stationary. Stationary grids were common in upright screen film chest radiography systems, and the success of this approach suggests that the radiologist is quite adroit at "looking through" the very regularly spaced grid lines on the image (Cho et al., 2008).

2.11.4.2 Bucky Factor:

The Bucky factor, not to be confused with the moving Bucky grid, describes the relative increase in x-ray intensity or equivalently, mAs, needed when a grid is used, compared to when a grid is not used. The Bucky factor essentially describes the radiation dose penalty of using the grid—and typical values of the Bucky factor for abdominal radiography range from 3 to 8. The Bucky factor is relevant in screen-film radiography, but less so with digital imaging systems. In screen-film radiography, the use of the grid slightly reduces the amount of detected primary radiation and substantially reduces the amount of scattered radiation detected, and both of these effects reduce the OD of the resulting film (Sprawls, 1987).

2.11.5 Optimization:

An implication of the principle of optimization is that all exposures should be kept as low as reasonably achievable (ALARA .(This should be applied with both economic and societal factors taken into account which implies that the level of protection should be the best available given the circumstances. The fundamental tenets of radiation protection are:

Time - exposure periods to be kept as short as possible؛

Distance - exploit the inverse square law; and

Shielding - use materials of high atomic number such as lead.

In diagnostic radiography, the optimization principle is applied in specific designs for X-ray facilities and equipment, and in that equipment's appropriate application. For the moment, we can conclude that a patient's exposure should be sufficient for the medical purpose and that any unnecessary exposure should be avoided. It should be appreciated however that use of too low an exposure may affect the diagnostic quality of radiographs. For this reason, exam-specific Reference Levels have been introduced which provides values of the typical dose for an average patient - see the following table for examples:

Table 2.1 Diagnostic Reference (Guidance) Levels for Common X-Ray Examinations

Reference Level (mGy/radiograph)	Examination
0.2	Chest, PA
5	Abdomen, AP
5	Pelvis, AP
3.5	Thoracic Spine, AP
5	Lumbar Spine, AP
15	Lumbar Spine, LAT

Note that reference levels generally refer to the Entrance Skin Dose (ESD). This quantity can be measured directly using TLDs, for instance, or indirectly by repeating the radiographic exposure using a radiation detector and correcting for backscatter and other factors. Dose-Area Product can also be used to express reference levels. A comprehensive survey in the United Kingdom was used as the basis for establishing national reference levels. Reference levels were based on the third quartile values of dose distributions for over 30 types of diagnostic X-ray examination generated by over a quarter of a million measurements at 316 hospitals over a 5-year period to the end of 2005, and are ~15-30% lower than those listed in the table above. It is important to appreciate that the reference level concept was developed by the ICRP for dose management purposes in regional, national or local environments and was not designed to be used for comparisons with individual patient doses (Sprawls, 1987).

2.12 Dose Limits:

The dose limits principle does not apply to medical exposures since such limits may interfere with a patient's medical treatment. Different dose limits are nevertheless applied to members of the general public than to those who are exposed occupationally, e.g. X-ray personnel. For example, annual effective dose limits of 20 mSv for occupationally-exposed people (averaged over 5 years, with an annual limit of 50 mSv in any single year) and of 1 mSv for the public are recommended by the ICRP - along with additional limits for the skin, the hands and feet, and the lens of the eye and for pregnant workers. Personal dose monitors are therefore worn by radiation workers to ensure that doses are below the annual limits and to assess their radiation safety practices. Annual staff doses are of the order of 0.25 mSv for radiographers, 0.75 mSv for radiologists and 2.5 mSv for interventionists. It is important to realize that the dose limits should not be considered as acceptable levels, but rather as maximum values which should not be exceeded (Aichinger et al., 2011).

The requirement to have two sets of limits, one for workers and one for the public, arises because the general population, including children, may be more radiosensitive than the limited population of radiation workers. Children in particular have a longer time following exposure for any deleterious effects to develop. In addition, radiation workers are generally more aware of the sources of risk and can take precautions to minimize them. The public is generally unaware of radiation hazards. Furthermore, people need protection in the form of suitable shielding should they, for instance, walk nearby or sit in the waiting room of an X-ray facility. On this basis, the provision of dose limits for members of the public has to be taken into account when designing new X-ray rooms (Aichinger et al., 2011).

2.13 Dose Reduction:

The referral of a patient for diagnostic radiography is generally the initial occasion for optimization issues to arise. The benefit of the examination to the patient's health management and the availability of other forms of imaging which use non-ionizing radiation (e.g. ultrasound and MRI (should be considered. Since there is always a small but finite health risk from X-ray examinations, dose reduction strategies should always be considered. It is also reasonable to assume that when patient radiation doses are kept to a minimum, then staff radiation doses are also reduced to a minimum (Brauer-Krisch et al., 2015).

Strategies for patient dose reduction in General Radiography include: Limiting the area of the patient which is exposed to the primary X-ray beam - this should also improve contrast through the reduction in scattered radiation. Filtering the primary beam appropriately - generally such filtration should equivalent to 2.5 mm Al or greater for exposures greater than 70 kV. Applying the maximum kV that is compatible with adequate image contrast. Using a source-to-skin distance generally no less than 30 cm for mobile radiography and 45 cm for fixed radiography (Meghzifene, 2017).

Using fixed X-ray equipment as opposed to mobile radiography, when appropriate - radiography rooms generally offer a wider choice of exposure factors and patient positioning options while also providing automatic exposure control (AEC) and better protection for radiation workers and other patients.Using X-ray grids only in appropriate examinations, i.e. when improved subject contrast is warranted.Using image receptor cassettes and patient tables with low attenuating properties, e.g. carbon-fiber.Shielding the patient's gonads when applicable, particularly when children are exposed. Compressing the body part, if appropriate, e.g. in intravenous pyelography and mammography.Establishing a quality assurance system for the radiographic equipment which ensures optimization, minimizes retake and repeat examinations and maintains image quality. Note that there are additional strategies to be applied in fluoroscopy and angiography which we will consider in the next chapter .Note also that numerous additional considerations are required for radiography of children and pregnant patients (Meghzifene, 2017).

2.14 X-Ray Detectors:

2.14.1 Computed Radiography:

Computed radiography (CR) refers to photostimulable phosphor detector (PSP) systems, which are historically housed in a cassette similar to a screen-film cassette. Traditional scintillators, such as Gd2O2S and cesium iodide (Csillag and Lengyel), emit light promptly(nearly instantaneously) when irradiated by an x-ray beam.

When x-rays are absorbed by photostimulable phosphors, some light is also promptly emitted, but a fraction of the absorbed x-ray energy is trapped in the PSP screen and can be read out later using laser light. For this reason, PSP screens are also called *storage* phosphors (Meghzifene, 2017).

2.14.2 Flat Panel Thin-Film-Transistor Array Detectors:

Flat panel Thin-Film-Transistor (TFT) array detectors make use of technology similar to that used in flat panel displays, and much of this has to do with the wiring requirements of a huge number of individual display elements.

Instead of producing individual electrical connections to each one of the elements in a flat panel display, a series of horizontal and vertical electrical lines is used which, when combined with appropriate readout logic, can address each individual display This signal modulates light transmittance from a backlit liquid crystal display Element in the flat panel Display (Meghzifene, 2017).

2.14.3 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 (Gress et al., 2017).

2.15 Image Quality:

In medical imaging, image quality is determined by at least five factors: contrast, resolution, noise, artifacts, and distortion. Of these factors, resolution and noise are the most commonly used physical characteristics. As is well known, they are described by the modulation transfer function (MTF) and noise power spectrum (NPS), respectively. The MTF describes the ability of an imaging system to reproduce the frequency information contained in the incident X-ray signal. The NPS describes the frequency content of the noise of an imaging system. However, one of the dilemmas in medical radiography is the extent to which these metrics affect image quality. In comparison of two imaging systems, for example, an imaging system may only be superior in one metric while being inferior to another in the other metric. To deal with this issue, the noise equivalent quanta or detective quantum efficiency, which can be calculated if the MTF, NPS, and the input signal-to-noise ratio of the X-ray beam used to measure the NPS are known, is used as a single parameter to describe the general quality of the system.

2.15.1 Optical density:

Optical density (OD), often called image density or simply density, describes the degree of darkness or blackening of the x-ray image. OD is the logarithm of the ratio of the incident light intensity on the film to the light intensity transmitted through the film. Figure 2.10 illustrates the incident light intensity on and transmitted through the film. The formula for the OD is:

$$OD = \log_{10} (I_0/I_1)$$

Where I_0 is the incident light intensity and I_I is the transmitted light intensity. In the example shown in Figure 10.1, the incident light is 100% and only 1% of the light is transmitted through the film. The OD of the film is equal to 2 because log 100 = 2. OD is measured using an optical densitometer. This instrument is shown in Figure 2.11. OD is defined as a logarithm because the eye has a logarithmic response to changes in brightness, and so an image with twice the OD will appear twice as dark .Images in diagnostic radiology have ODs that range from 0.2 to 3.0, with most of the useful information in the 0.5 to 1.5 range. It is just possible to read a newspaper through a film with a density of 1.0.

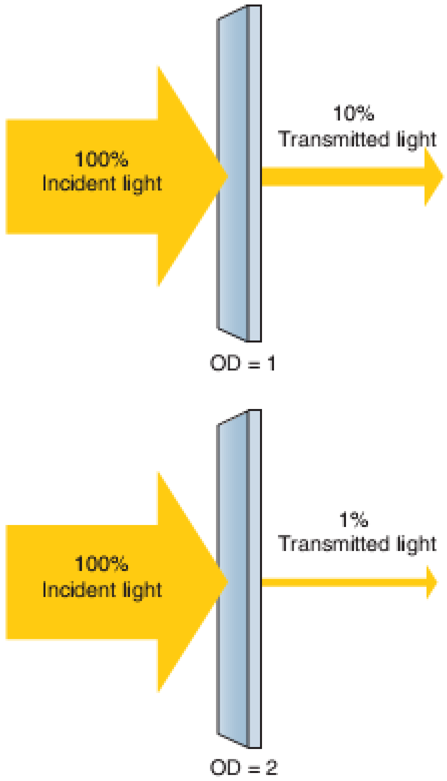

Figure 2.10: OD is the logarithm of the ratio of incident light intensity to transmitted light intensity. Films that transmit 10% and 1% of the incident light have OD of 1 and 2, respectively.

Figure 2.11: Optical densitometer used to measure density on a film.

2.15.2 Image contrast:

Contrast is the difference in density between two areas on the image. Contrast is the radiographic quality that allows the radiographer to identify different areas of anatomy. When there is no difference in contrast within an image, the human eye will not be able to visualize the image; likewise if there are minimal differences in contrast, very little information will be available. Contrast is the result of differences in attenuation of the x-ray pho-tons with various tissues in the body; the density of the tissue will affect the amount of attenuation. Contrast is one of the most important factors in producing a quality diagnostic image (Fosbinder and Orth, 2011).

A diagnostic image is produced when the x-ray beam has sufficiently penetrated the tissue. The penetrability of the primary x-ray beam is controlled by kilovoltage; therefore kVp is the controlling factor for contrast on an image. When considering the amount of contrast on an image, the radiographer must determine if a short or long scale of gray is most appropriate for the anatomy to be imaged. The number of densities from black to white on a radiographic image is an indication of the range of the scale of contrast. The terms long-scale and short-scale describe the number of different densities between black and white on the image. The choice of mAs or SID will not affect radiographic contrast. Figure 10.7 shows a step wedge of graduated thickness to illustrate how higher kVp examinations penetrate greater thicknesses and pro-duce long-scale contrast images. Low-kVp examinations penetrate fewer thicknesses and have only a few steps between black and white, and so produce short-scale contrast images.

When the primary beam penetrates through tissue with adjacent densities which have great differences in contrast, the image is described as high contrast. The image will have few shades of gray. A short-scale contrast image has fewer steps between black and white and is a high-contrast image. Low-kVp examinations produce short-scale contrast images. This is the preferred scale of contrast when imaging bone anatomy as this demonstrates the fine trabecular markings and fractures the best .A zebra is a great example of high contrast because it has black and white stripes.

Imaging the abdomen requires a long scale of gray because the anatomy of the abdomen is comprised of soft tissue and vital organs with minor density differences. These images will have few differences in contrast because the differences between adjacent densities are small; this is referred to as a long-scale contrast image which has many steps between black and white and is a low-contrast image. Using higher kVp will produce more shades of gray which will allow for better visualization of abdomen anatomy. A herd of elephants is an excel-lent example of a long gray scale; each elephant will have a slightly different color than other elephants; however, they are all some shade of gray (Fosbinder and Orth, 2011).

2.16 Previous Studies:

Guo studied the optimization of radiation dose and image quality in Pediatric chest radiography, in his study the quality and radiation dose of different tube voltage sets for chest digital radiography (DR) were compared in a series of pediatric age groups. Forty-five hundred children aged 0-14 years (yrs.) were randomly divided into four groups according to the tube voltage protocols for chest DR: lower kilovoltage potential (kVp) (A), intermediate kVp (B), and higher kVp (C) groups, and the fixed high kVp group (controls). The results were analyzed among five different age groups (0-1 yrs., 1-3 yrs., 3-7 yrs., 7-11 yrs. and 11-14 yrs.). The dose area product (DAP) and visual grading analysis score (VGAS) were determined and compared by using one-way analysis of variance. The mean DAP of protocol C was significantly lower as compared with protocols A, B and controls ($p < 0.05$). DAP was higher in protocol A than the controls ($p < 0.001$), but it was not statistically significantly different between B and the controls ($p = 0.976$). Mean VGAS was lower in the controls than all three protocols ($p < 0.001$ for all). Mean VGAS did not differ between protocols A and B ($p = 0.334$), but was lower in protocol C than A ($p = 0.008$) and B ($p = 0.049$) (Guo et al., 2013).

Stephen et.al review pediatric exposures at RCH which also contained scientific tests. An overview of outcomes from the optimization process showed that the mean DAP was reduced for AP/PA chest, AP abdomen, AP pelvis, and AP/lateral skull projections in all age/size groups. These dose reductions were due to manipulating multiple-exposure variables. In the case of AP abdomen, the mean DAP was reduced by up to 83% compared to pre-optimization levels. The mean DAP is below the three-quarter percentile for German and Austrian DRLs. The relatively high detective quantum efficiency of the installed digital X-ray equipment has typically allowed for reductions in target detector exposure (and thus mAs) of about 20%, resulting in reductions to patient dose while maintaining or in many cases improving image quality (SNR and CNR) (Knight, 2014).

O. Iacob et.al in their studies revealed that the annual effective doses from all medical examinations for the average pediatric patient are as follows: 1.05 mSv for 0year old, 1.08 mSv for 1 year old, 0.53 mSv for 5 year old, 0.69 mSv for 10 year old and 0.71mSv for 15 year old. The resulting annual collective effective dose was evaluated at 625 manSv and the annual effective dose of average pediatric patient (within 0-15 age range) due to diagnostic radiological exposures was estimated at 0.74 mSv (Iacob et al., 2002).

Chapter Three

Materials and Methods

3.1 Material:

3.1.1 Machine used:

In the present study, X-ray machine with the following specification was used

Manufacturer	Shimadzu Corporation
Model	P18DE-85
Focal spot size	0.6/1.2
Total filtration	2.5 mm AL at 75 kV_P
Generator Manufacturer	Shimadzu Corporation
CR reader	Fujifilm FCR PRIMA 35×43cm

3.1.2 Subjects:

A total of 100 patients were enrolled in this study. Their age ranged (1- 8) years, they patients were randomly selected from pediatric patients of both sexes attending medical investigations at Jaafar Ibn Auf Hospital for children. Children parents were verbally informed that the data will be used for scientific research.

3.2 Method:

3.2.1 Technique used:

The examination performed were chest posterio-anterior (PA) projection and abdomen anterio-posterior (AP) projection. For each studied examination, the patient anthropometrical data (sex, age, weight and height) and technical parameters used (kVp, mAs and FSD) were collected at the time of the examination on a self-designed data collection sheet. The standard FFD of 180 cm for the chest PA and 100 cm for the abdomen AP were used as routine.

3.2.2 Dose measurement:

The ESD was assessed by indirect method, with the data on the radiation output of the X-ray tube and exposure factors (kVp, mAs and FSD) using the following Equation, which used by (Ofori et al., 2012)

$$\mathrm{ESD} = \mathrm{Tube\ ouput} \times \mathrm{mAs} \times (\frac{100}{\mathrm{FSD}})^2 \times \mathrm{BSF}$$

Where Tube output in (mGy/mAs), mAs is the product of the tube current (mA) and the exposure time in seconds, FSD is the focus-to-skin distance, BSF is the backscatter factor, the backscatter factor was 1.35 suggested in European guidelines (EC, 1996) and used by (Sharifat and Oyeleke, 2009) and (A.Alkreem and Abukonna, 2017).

$\mathrm{FSD} = \mathrm{FFD} - \mathrm{T}$ Where FFD is the focus film distance, T is AP chest separation

Generator output air kerma values (in mGy/mAs) at different kVp settings from (40 to 80) kVp and constant mAs were first measured using the DIAVOLT universal (Model T43014-01292). The detector was placed on top of the table at one meter focus detector distance. The relationship between X-ray Air Kerma X-ray tube and applied tube voltages kVp was plotted using Microsoft Excel Worksheet as shown in figure 1 and expressed by the fitting Equation

$$\mathrm{y} = 0.0224\mathrm{x} - 0.7938$$

Where Y-axis: X-ray Air Kerma in mGy/mAs and X-axis: applied tube voltage in kV

3.2.3 Image quality assessment:

Image resolution was measured in term of information entropy which has been proposed and used by (Tsai et al., 2008), the obtained value of entropy has been plotted against exposure factors.

Chapter Four

Results

4.1 Results:

Table 4 -1: The patient anthropometrical data

		Sex		Age	Weight	Height	FSD
		Male	Female	(year)	(Kg)	(cm)	(cm)
Chest	Minimum			1	8	62	168
	Maximum			8	27	121	178
	Mean	47	26	3.5	14.3	83.5	172.4
	Std. Deviation			2	4.7	12	2.88
Abdomen	Minimum			1	8	48	88
	Maximum			10	28	134	93
	Mean	10	17	3.5	13	77	90.8
	Std. Deviation			2.4	5.9	18.8	1.8

Table 4 -2: Exposure parameters

		Minimum	Maximum	Mean	Std. Deviation
Chest	Kv	48	62	53.9	3.7
	mAs	2	7	4.7	1.01
Abdomen	Kv	46	62	52.7	5.1
	mAs	3	6	4.5	1.19

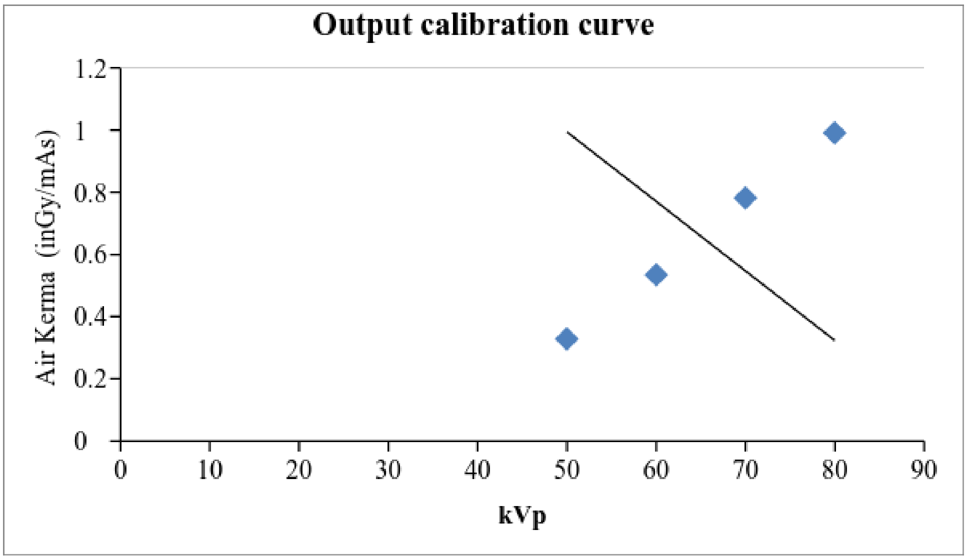

Figure 4 - 1: The relationship between X-ray Air Kerma X-ray tube and applied tube voltages kV_p

Table 4-3: the ESD (in mGy)

ESD (mGy)	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Chest	0.049	0.202	0.11	0.03
Abdomen	0.215	0.723	0.414	0.15

Table 4-4: Comparison with previous studies

	This study	**)(Eljak et al., 2015**	**(European Commission 1999)**
Chest	0.12	0.16	0.1
Abdomen	0.37	0.46	1

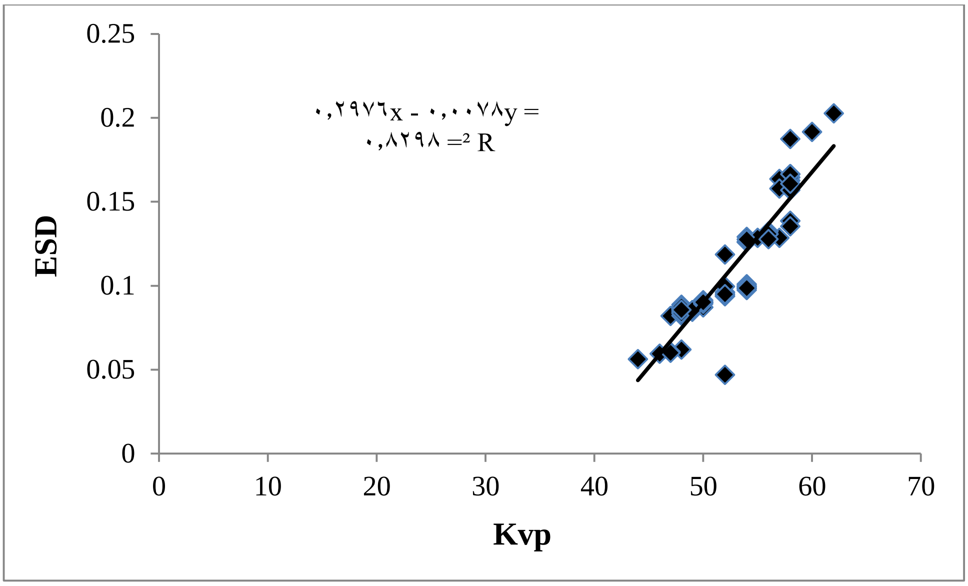

Figure 4-2: The correlation between kVp and ESD

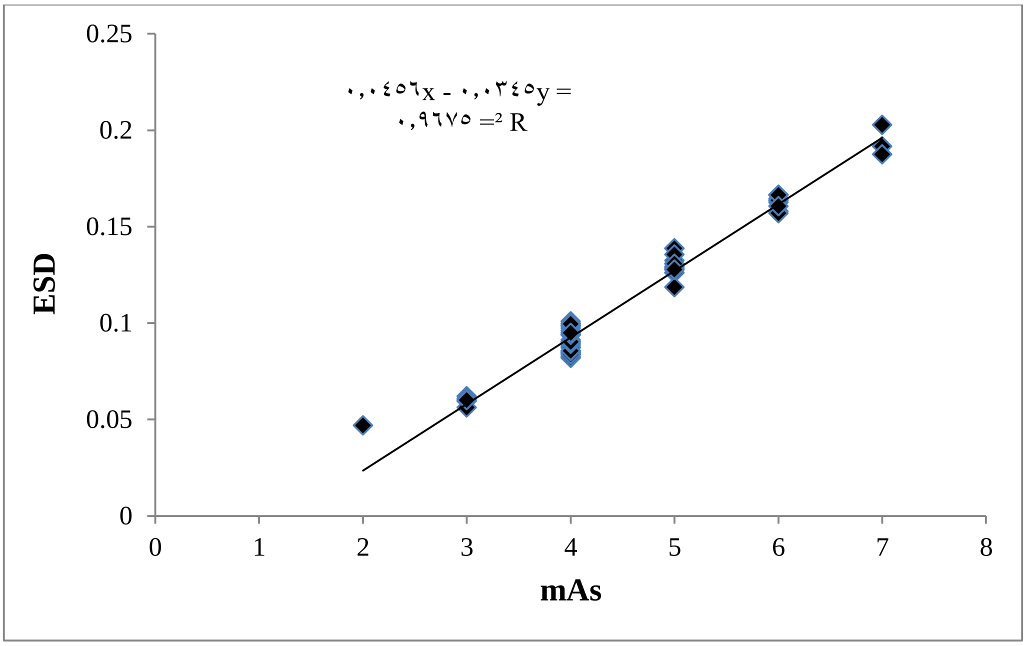

Figure 4-3: The correlation between mAs and ESD

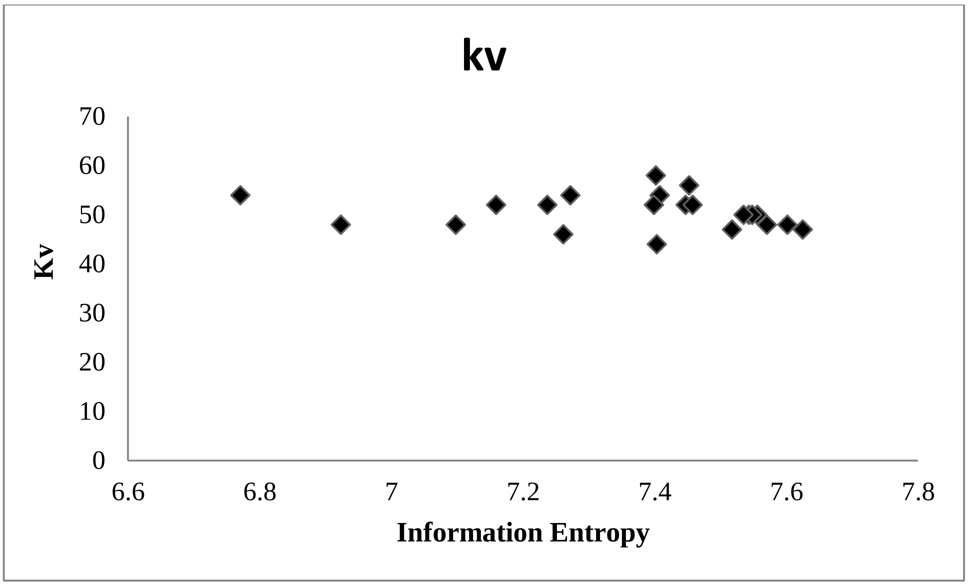

Figure 4-4: The correlation between kVp and entropy

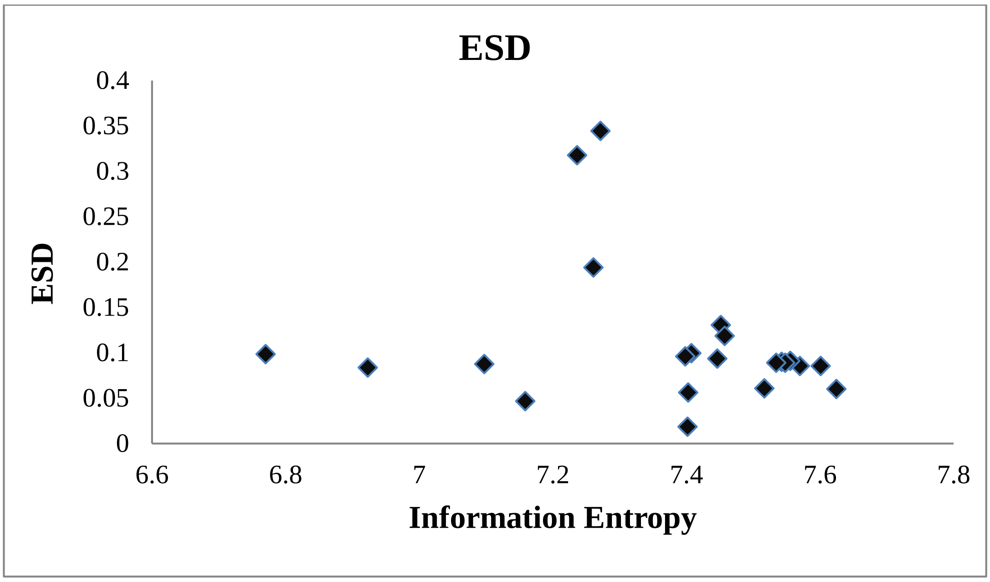

Figure 4-5: The correlation between ESD and entropy

Chapter Five

Discussion, Conclusion and Recommendation

5.1 Discussion:

Pediatric imaging techniques vary greatly due to the extremely large differences in patient size and weight. Therefore, different parameter settings may be necessary to gain optimal results for the same anatomical regions, according to the child's age. The result of this study showed that, for chest PA the age rang (1-8) years with mean age 3.5 years and weight range (8-27) kg with mean 14.3 kg and for abdomen AP the age rang (1-10) years with mean age 3.5 year and weight range (8-28) kg with mean 13 kg.

Table 4 showed that, the maximum ESD (0.202 mGy) for chest PA observed for the maximum kV_p (62 kV_p) and the maximum ESD for abdomen (0.723 mGy) also observed for maximum kV_p (62 kV_p) that emphases the significant correlation coefficient between kVp and ESD and no correlation coefficient was found between patient age or weight and ESD as shown in figure 3, this result was in line with the previous study (Suliman et al., 2007). The ESDs values compared with the (Rosenstein, 2008) and other studies in the Sudan (Suliman et al., 2007) and other countries (Eljak et al., 2015), the results showed that; all estimated ESDs values lower than the values of (Protection, 1999) and some previous studies .

Correlations between Entrance Skin Dose (ESD) and exposure parameters was performed and showed significant correlation (figure 2). Many authors stated that the absorbed dose in skin is directly proportional to tube current; the length of exposure, and the square of peak kilovoltage (Parry et al., 1999). The justification was that the digital imaging X-ray machine may allow for use of a lower tube current or a shorter exposure, thus reducing the dose to the patient as mentioned previously (Parry et al., 1999) and where the image quality controlled automatically because the using of automatic exposure control as well as the presence of aluminum filter of 2.0 mm.

Figure 4-5 shows the relation between the relative exposure dose and information entropy. The results illustrate that the information entropy increases with the increase of exposure dose. The rise of information entropy is considered due to the decrease of noise resulting from the increase of radiation dose, the value of the information entropy decreases when exposure dose increases. A previous study reported by Uchida and Fujita indicated that the is closely related to the noise of an imaging system (Uchida and Fujita, 1980).

The data obtained may add to the available information in national records for general use. It will provide guidance on where efforts on dose reduction need to be directed to fulfill the requirements of the optimization process and serve as a reference for future researches in pediatrics radiography.

5.2 Conclusion:

This study de sign to assessment of patient dose during x-ray examination in Jaafar ibn Auf hospital for chest and abdomen examination 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 abdomen radiographs are the most commonly performed radiological exam

The mean ESD values obtained are found to be within the standard reference. The data obtained may add to the available information in national records for general use.

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.

5.3 **Recommendation**:

- X-ray Radiography operator must optimize the patient dose by use the best strategies available for reducing radiation dose.
- 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.
- Quality control program specifically should be 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.
- Radiologic technologists who utilize the technology should also receive proper training on developing professional skills.
- 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.

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