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Estimation of Entrance skin dose (ESD) for pediatric X-ray examination for (limbs)

تقدير الجرعة الداخلة للجلد للأطفال عند التصوير الإشعاعي للأطراف

Thesis submitted for partial fulfillment for the requirements of Master degree in Medical Physics

:By

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الآيـة

قال تعالى :

"فقلت استغفروا ربكم إنه كان غفارا * يرسل السماء عليكم مدرارا*ويمددكم بأموال وبنين ويجعل لكم جنات ويجعل لكم أنهارا "

سورة نوح

Dedication

To..

My parents,

My sisters,

My brothers,

My Friends,

And my colleagues

Acknowledgements

All praise and glory to almighty Allah who gave me courage and patience to carry out this work .

I would like to express my unrestrained appreciation to my supervisor **Dr: Hussein Ahmad Hassan** for his guidance, encouragement, cooperation and supervision of this work.

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Abstract

This Study was performed to evaluate radiation Entrance skin dose ESD for pediatric patients undergoing X-ray examination for limbs imaging, in two selected centers in Khartoum state which use Computed Radiography (CR) unit. The exposure parameters (kV, mAs and FSD) were chosen for each age category of pediatric from 0-15 years , then the ESD was calculated -by using the Microsoft excel - for each category in the two hospitals and compared with the reference dose level and some previous studies.

In center A the ESD for the upper limbs at the ages ((5-10), (11-15)) years found to be(39.24,54.18)µGy and the ESD for the lower limps was (40.3,53.8)µGy and In center B the ESD for the upper limbsat the ages ((5-10), (11-15)) years was (43.7, 61.07) µGy and the ESD for the lower limbs was (45.85,57.6)µGy.

The final results showed that The ESD depends and changes with the exposure parameters (KV &mAs) and changes with age.The ESD for the lower limbs was greater than the upper limbs in each center.

The ESD in the two centers is within the reference level and lower than the previous studies, also Variations were observed in ESD values among hospitals under study. From this study we recommended that for all x-ray equipment should be regular maintenance and quality control tests and to standardize the exposure parameters in pediatric imaging.

ملخص الدراسة

أجريت هذه الدراسه لحساب الجرعه الداخلة للجلد للمرضى الاطفال اللذين يخضعون لفحص التصوير الاشعاعي للأطراف في مركزين داخل ولاية الخرطوم وقد تم اختيار عوامل التعرض (المسافه بين السطح والجهاز , ومضروب التيار ف الزمن و الجهد بالكيلو فولت) (kv,mAs FSD) لكل فئه عمريه ما بين 0-15 سنه ثم تم حساب الجرعه الداخلة للجلد عن طريق برنامج مايكروسوفت اكسيل لكل فئه عمريه في كل مستشفى , في المركز (أ) وجد أن الجرعة الداخلة للجلد للأطراف العلوية في الأعمار((5-10),(11-15))سنه (39.24,54.18)µGy ,والجرعه الداخلة للجلد للأطراف السفلية (40.3,53.8)µGy ووفي المركز (ب) وجد أن الجرعة الداخلة للجلد للأطراف العلوية في الأعمار((5-10),(11-15))سنه (43.7,61.07)µGy وللأطراف السفلية (45.85,57.6)µGy, ووجد ان الجرعه الداخلة للجلد تتناسب طرديا مع الجهد و مضروب التيار والمسافه بين السطح للجهاز وكذلك تزيد مع العمر ووجد ان الجرعه الداخلة للجلدللاطراف السفليه اقل من الجرعه للاطراف العلويه في كل من المركزين ووجد ان الجرعه الداخلة للجلد في بعض المراكز اعلى من الاخرى كما قورنت هذه النتائج ببعض الدراسات السابقه والقيم المرجعيه ووجد ان الجرعه الداخلة للجلد في هذه الدراسه اقل من الدراسات السابقه ولا تتعدى القيم المرجعيه من خلال هذه الدراسه نوصي بالقيام بالمزيد من الدراسات حول تقليل الجرعات الاشعاعيه وتوحيد عوامل التعريض و القيام باختبارات دوريه لضبط الجوده.

Chapter One

1.1. Introduction:

Pediatric projection imaging differs from imaging of the adult patient. Children are smaller, more radiosensitive, and less compliant than the adult. Their characteristics affect the way of the projection imaging is practiced and how dose is optimized. computed radiography (CR) has been embraced by pediatric practitioners in order to reduce dose and improve image quality. Unfortunately, dose optimization with CR has been hampered by a lack of definition of appropriate exposure levels, a lack of standardization in exposure factor feedback, and a lack of understanding of the fundamentals of CR technology. There for Criteria should be established for digital radiography to avoid unappropriated doses where there is no clear net benefit in the diagnosis or the image quality. An exposure factor standardization providing useful tool to establish an optimum exposure index to be used as a guideline for clinical imaging task to minimize radiation exposure for computed radiography for pediatric.

Pediatric X-ray examinations comprise approximately 10% of allradiological examinations, which may result insituations in which pediatric examinations are notwell optimized due to a lack of knowledge inchoosing the proper acquisition parameters. Many departments do not use recommended radiographic parameters for neonates and children. Furthermore, wide variations have been found in techniques, equipment performance and radiation doses among different hospitals over the world. The study first attempt to measuring ESDs for children in the area of study, the entrance skin dose ESD, in diagnostic radiologypermits the

radiation exposure of diagnostic procedures to be quantified and evaluated. Although it is nota rigorous physical quantity, it provides practicalinformation for referring doctors to clarify which modality is the most appropriate choice concerning the application of the ALARA principle for any particular clinical problem, measuring the ESD also add to the pool of data available in national records for general use it
Will 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 work, as well as provide information for comparison with patients of the same category in other countries(M.hardy et al, 2003).

1.2. Problem of the study:

Pediatric examinations are notwell optimized due to a lack of knowledge inchoosing the proper acquisition parametersthis result in high dose to the patients, estimating ESD helps in dose reduction By optimizing exposure factors for CR.

1.3 objectives:

1.3.1 General objectives:

- To estimate the entrance skin dose for pediatric.

1.3.2. Specific objectives:

- To maintain best practice in pediatric in CR projection imaging.

- Optimization of radiation dose to the limbs radiography in pediatric projection.

- Improve performance of the staff in radiography department.

-To achieve the ALARA principle in pediatric projection.

1.4. Thesis outlines:

This study falls into five chapters, Chapter one, which is an introduction, consists of general objectives of the study ,specific objectives, the problem and thesis outlines, chapter two consists of theoretical study and previous studies, Chapter three consists of material and method of data collection, Chapter four consists of the collected results . Chapter five consists of discussion of results, conclusion, recommendations and references.

Chapter Two

2.1. Introduction to radiation:

Radiation is energy in the form of waves or streams of particles. There are many kinds of radiation allaround us. When people hear the word radiation, they often think of atomic energy, nuclear power andradioactivity, but radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals (CNSC,2012).

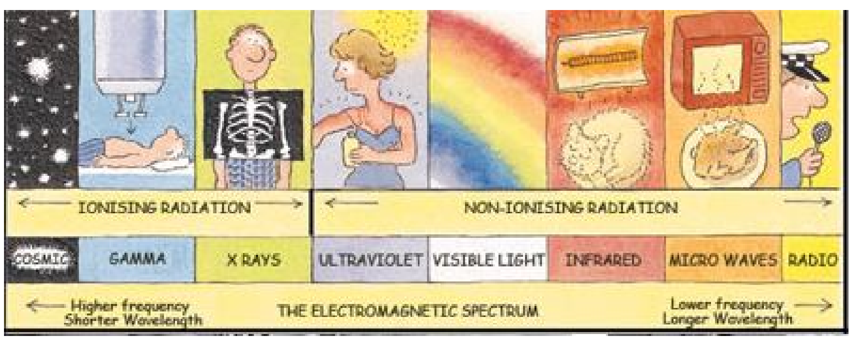

Figure2.1 presents an overview of the electromagnetic spectrum

2.2. Types and Sources of Radiation:

Radiation is energy in the form of waves of particles. There are two forms of radiation – non-ionizing and ionizing.

2.2.1. Non-ionizing radiation:

Non-ionizing radiation has less energy than ionizing radiation; it does not possess enough energy to produce ions. Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight.Global positioning systems, cellular telephones, television stations, earth's magnetic field, as well as magnetic field exposure from proximity to transmission lines, household wiring and electric appliances. These are defined as extremely low-frequency (ELF) waves and are not considered to pose a health risk**.**

2.2.2 Ionizing radiation:

Ionizing radiation is capable of knocking electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions. Ionizing radiation includes the radiation that comes from both natural and man-made radioactive materials(CNSC, 2012).

There are several types of ionizing radiation:

- Alpha radiation (α) consists of alpha particles that are made up of two protons and two neutrons each and that carry a double positive charge. Due to their relatively large mass and charge, they have an extremely limited ability to penetrate matter. Alpha radiation can be stopped by a piece of paper or the dead outer layer of the skin. Consequently, alpha radiation from nuclear substances outside the body does not present a radiation hazard (CNSC, 2012).
- Beta radiation **(**β**)** consists of charged particles that are ejected from an atom's nucleus and that are physically identical to electrons. Beta particles generally have a negative charge, are very small and can penetrate more deeply than alpha particles. However, most beta radiation can be stopped by small amounts of shielding, such as sheets of plastic, glass or metal. When the source of radiation is outside the body, beta radiation with sufficient energy can penetrate the body and organs. Beta-radiation-emitting nuclear substances can also be hazardous if taken into the body (CNSC, 2012).

- Photon radiation **(gamma [γ] and X-ray)** is electromagnetic radiation. There are two types of photon radiation: gamma (γ) and X-ray. Gamma radiation consists of photons that originate from within the nucleus, and X-ray radiation consists of photons that originate from outside the nucleus, and are typically lower in energy than gamma radiation .Photon radiation can penetrate very deeply and sometimes can only be reduced in intensity by materials that are quite dense, such as lead or steel. In general, photon radiation can travel much greater distances than alpha or beta radiation, and it can penetrate bodily tissues and organs when the radiation source is outside the body. Photon radiation can also be hazardous if photon-emitting nuclear substances are takeninto the body. An example of a nuclear substance that undergoes photon emission is cobalt-60, which decays to nickel-60 (CNSC, 2012).
- Neutron radiation (n)Apart from cosmic radiation, spontaneous fission is the only natural source of neutrons (n). A common source of neutrons is the nuclear reactor, in which the splitting of a uranium or plutonium nucleus is accompanied by the emission of neutrons. The neutrons emitted from one fission event can strike the nucleus of an adjacent atom and cause another fission event, inducing a chain reaction. The production of nuclear power is based upon this principle. All other sources of neutrons depend on reactions where a nucleus is bombarded with a certain type of radiation (such as photon radiation or alpha radiation), and where the resulting effect on the nucleus is the emission of a neutron. Neutrons are able to penetrate tissues and organs of the human body when the radiation source is outside the body. Neutrons can also be hazardous if neutron-emitting nuclear substances are deposited inside the body (CNSC, 2012).

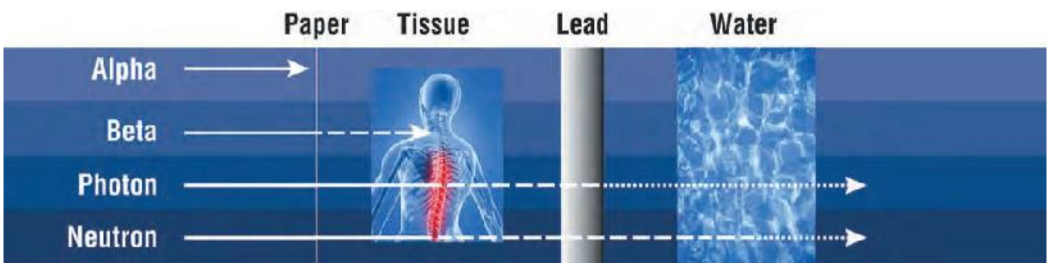

Figure 2.2: Penetration abilities of different types of ionizing radiation

2.3. Natural sources of ionizing radiation:

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) identifies four major sources of public exposure to natural radiation:

• Cosmic radiation

• Terrestrial radiation

• Inhalation

• Ingestion(CNSC, 2012).

2.4. Artificial (man-made) sources of ionizing radiation:

People are also exposed to man-made radiation from medical treatments and activities involving radioactive material. Radioisotopes are produced as a by-product of the operation of nuclear reactors, and by radioisotope generators like cyclotrons. Many man-made radioisotopes are used in the fields of nuclear medicine, biochemistry, the manufacturing industry and agriculture. The following are the most common sources:

• Medical sources: Radiation has many uses in medicine. The best-known application is in X-ray machines, which use radiation to find broken bones or to diagnose diseases. X-ray machines are regulated by Health Canada and provincial authorities(CNSC, 2012).

2.4.1. X-rays:

X-rays are produced when highly energetic electrons interact with matter and convert their kinetic energy into electromagnetic radiation. A device that accomplishes such a task consists of an electron source, an evacuated path for electron acceleration, a target electrode, and an external energy source to accelerate the electrons.

Specifically, the x-ray tube insert contains the electron source and target within an evacuated glass or metal envelope; the tube housing provides shielding and a coolant oil bath for the tube insert; collimators define the x-ray field; and the generator is the energy source that supplies the voltage to accelerate the electrons. The generator also permits control of the x-ray output through the selection of voltage, current, and exposure time. These components work in concert to create a beam of x-ray

Photons of well- defined intensity, penetrability, and spatial distribution

2.4.1.1 X-ray production:

Electrons traveling from the filament (cathode) to the target (anode) convert a small percentage (1%) of their kinetic energy into x-ray photons by the formation of bremsstrahlung and characteristic radiation.

- Bremsstrahlung interactions, the primary source of x-ray photons from an x-ray tube, are produced by the sudden stopping, breaking or slowing of high-speed electrons at the target.

When the electrons from the filament strike the tungsten target, x-ray photons are created if they either hit a target nucleus directly (rare) or their path takes them close to the nucleus. If a high speed electron hits the nucleus of a target atom, all its kinetic energy is transformed into a single x-ray photon. (Total absorption has occurred). Thus, the energy of the resultant photon (keV) is numerically equal to the energy of the electron. This in turn is equal to the kilo voltage applied across the x-ray tube at the instant of its passage. This happens rarely.

Most high-speed electrons have near or wide misses with the nuclei. In these interactions, a negatively charged high-speed electron is attracted toward the positively charged nucleus and loses some of its velocity. This deceleration causes the electron to lose some kinetic energy, which is given off the form of a photon. The closer the high-speed electron approaches the nuclei, the greater is the electrostatic attraction on the electron, the braking effect, and the greater the energy of the resulting Bremsstrahlung photon (Neill .2001)

Bremsstrahlung interactions generate x-ray photons with a continuous spectrum of energy. i.e. different energies. The energy of an x-ray beam may be described by identifying the peak operating voltage (in kVp).A dental x-ray machine operating at a peak voltage of 70,000 volts (70 kVp) for example, apples to a fluctuating voltage of as much as 70 kVp across the tube.

This tube therefore produces x-ray photons with energies ranging to a maximum of 70,000 keV(70 keV). The reasons for this continuous spectrum are as follow:

- The continuously varying voltage difference between the target and the filament, which is characteristic of half wave rectification, causes the electrons striking the target to have varying levels of kinetic energy.
- Most electrons participate in many interactions before all their kinetic energy is expended.

As a consequence, an electron carries differing amounts of energy at the time of each interaction with a tungsten atom that results in the generation of an x-ray photon.

- The bombarding electrons pass at varying distances around tungsten nuclei and are thus deflected to varying extents. As a result, they give up varying amounts of energy in the form of Bremsstrahlung photons.
- Depth of generation of photons in the target(Neill .2001).

-Characteristic radiation occurs when an electron from the filament displaces an electron from an inner-shell of the tungsten target atom, thereby ionizing the atom. When this happens, another electron in an outer-shell of the tungsten atom is quickly attracted into the void in the deficient inner-shell. When the displaced electron is replaced by the outer-shell electron, a photon is emitted with an energy equivalent to the difference in the two orbital binding energies.

Characteristic radiation from the K-shell occurs only above 70kVp with tungsten target and occurs as discrete increments compared with Bremsstrahlung radiation. The energies of characteristic photons are a function of the energy levels of various electron orbital levels and hence are characteristic of the target atoms. Characteristic radiation has a higher intensity, is preferred but is only a minor source of radiation from an x-ray tube(neill .2001).

2.5. Interactions of X -rays 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.three mechanisms exist where these interactions take place:

2.5.1Coherent scattering:

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 (neill .2001)

2.5.2. 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. 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.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.

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(Neill .2001)

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2.5.3. Photoelectric absorption:

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. 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.

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 replacement electron, The recoil electrons ejected during photoelectric absorptions travel only a short distance in the absorber before they give up their 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

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 (Neill .2001).

2.5.4. Secondary electrons:

In both Photoelectric absorption and Compton scattering, electrons are ejected from their orbits in the absorbing material after interaction with x-ray photons. These secondary electrons give up their energy in the absorber by either of two processes:

(1) Collisional interaction with other electrons, resulting in ionization or excitation of the affected atom, and

(2) Radiative interactions, which produce bremsstrahlung radiation resulting in the emission of low-energy x-ray photons. Secondary electrons eventually dissipate all their energy, mostly as heat by collisional interaction, and come to rest(hyperphysics.com).

2.5.5. Beam attenuation:

The reduction of beam intensity is predictable because it depends on physical characteristics of the beam and absorber. A monochromatic beam of photons, a beam in which all the photons have the same energy provides a good example. When primary (not scattered) photons are considered, a constant fraction of the beam in attenuated as the beam moves through each unit thickness of an absorber. HVL describes the amount of an absorber that reduces the beam intensity by half The absorption of the beam depends primarily on the thickness and mass of the absorber and the energy of the beam.

The spectrum of photon energies (as illustrated by the kVp setting) in an x-ray beam is wide (hyperphysics.com).

In such a heterogeneous beam the probability of absorption of individual photons depends on their energy. Low-energy photons are much more likely than high-energy photons to be absorbed. As a consequence the superficial layers of an absorber tend to remove the low energy photons and transmit the higher energy photons. Therefore as an x-ray beam passes through matter, the intensity of the beam decreases but the mean energy of the resultant beam increases. In contrast to the absorption of a monochromatic beam, an x-ray beam is absorbed less and less by each succeeding unit of absorber thickness (hyperphysics.com).

2.6. X-ray tube:

Consists of: Cathode (tungsten filament): heated filament which is the source of the electron beam directed towards the Anode (stationary or rotating): impacted by electrons, emits X Rays Metal tube housing surrounding glass (or metal) X Ray tube (electrons are travelling in vacuum) Shielding material (protection against scattered radiation)

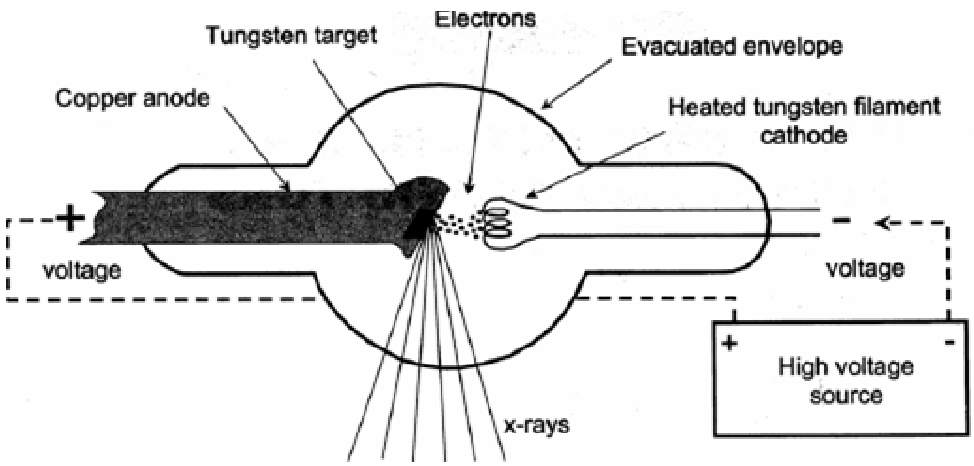

Figure 2.3 x-ray tube components

2.6.1. Cathode structure:

Cathode includes filament(s) and associated circuitry. The filament usually made of tungsten material because: Its high melting point (3370°C) Slow filament evaporation .Modern tubes have two filaments a long one : higher current/lower resolution a short one : lower current/higher resolution (hyperphysics.com).

2.6.2. Anode mechanical constraints:

There are two kind of anode stationary and rotator anode.

Made of one of: tungsten, rhenium, molybdenum, graphite Focal spot : surface of anode impacted by electrons (hyperphysics.com).

2.7 Radiation Quantities and units:

Determining the quantity of radiation exposure or dose is termed dosimetry. The term dose is used to describe the amount of energy absorbed per unit mass at a site of interest.

2.7.1. Exposure:

Exposure is a measure of radiation quantity, the capacity of radiation to ionize air. The roentgen is the traditional unit of radiation exposure measured in air, 1 R is that amount of x-radiation of gamma radiation that produces 2.08 x 109 ion pairs in 1 cc of air (STP). It measure the intensity of radiation to which an object is exposed. No specific SI unit is equivalent to the R, but in terms of other SI units it is equal to coulombs per kilogram (C/kg);

1 R = 2.58 x 104 C/kg equals 3.88 x 103 R. The roentgen applies only for x-rays and gamma rays (IAEA, 2007).

2.7.2. Absorbed dose:

Absorbed dose is a measure of the energy absorbed by any type of ionizing radiation per unit mass of any type of matter. The SI unit is the gray (Gy) – 1 Gy equals 1 joule/kg. The traditional unit of absorbed dose is the Rad (radiation absorbed dose), where 1 rad is equivalent to 100 ergs/g of absorber.

One gray equals 100 rad(IAEA, 2007).

2.7.3. Equivalent dose:

The equivalent dose is used to compare the biologic effects of different types of radiation on a tissue or organ.

It is expressed as a sum to allow for the time possibility that the tissue or organ has been exposed to more than one type of radiation. The radiation weighting factor is chosen for the type and energy of the radiation involved. Therefore high – LET radiations (which are more damaging to tissue than low LET radiations) have a correspondingly higher WR. The unit of equivalent dose is the sievert (Sv). For diagnostic x-ray examinations, 1 Sv equals 1 Gy.

The tradition unit of equivalent dose is the rem (roentgen equivalent man).

One Sievert equals 100 rems

2.7.4. Effective dose:

The effective dose (E) is used to estimate the risk in humans.

The unit of effective dose is the Sievert (Sv)(IAEA, 2007).

2.8. Specific dosimetric quantities:

2.8.1. Entrance skin dose:

The entrance surface dose,ESD, is the Dose to air measured on the central beam axis at the position of the patient or phantom surface .

$$ESD = op_x(kv/80)^2 \times mAs \times (100/fsd)^2 \times BSF$$

Where (OP) is the output in mGy/ (mA s) of the X-ray tube ,(kV) is the the tube potential,(mA s) is the product of the tube current (in mA) and the exposure time(in seconds), (FSD) the focus-to-skin distance (in cm) and (BSF) the backscatter factor

Unit is gray (Gy) (IAEA, 2007).

2.8.2. Incident air kerma:

is the kerma to air from an incident X ray beam measured on the central beam axis at the position of the patient or phantom surface

Unit: J/kg. The name for the unit of kerma is gray (Gy)(IAEA, 2007).

2.8.3. Entrance surface air kerma:

The entrance surface air kerma, Ke, is the kerma to air measured on the central beam axis at the position of the patient or phantom surface.

The radiation incident on the patient or phantom and the backscattered radiation are included (IAEA, 2007).

Unit: J/kg. The name for the unit of kerma is gray (Gy)

2.9. Factors affecting x-ray emission:

The output of an x-ray tube is often described by the terms quality, quantity, and exposure. Quality describes the penetrability of an x-ray beam, with higher energy x-ray photons having a larger HVL and higher "quality." Quantity refers to the number of photons comprising the beam. Exposure is nearly proportional to the energy flounce of the x-ray beam and therefore has quality and quantity associated characteristics. X-ray production efficiency, exposure, quality, and quantity are determined by six major factors: x-ray tube target material, voltage, current, exposure time, beam filtration, and generator waveform.

1. The target (anode) material affects the efficiency of bremsstrahlung radiation production, with output exposure roughly proportional to atomic number. Incident electrons are more likely to have radiative interactions in higher-Z materials.

The energies of characteristic x-rays produced in the target depend on the target material. Therefore, the target material affects the quantity of bremsstrahlung photons and the quality of the characteristic radiation.

2. Tube voltage (kVp) determines the maximum energy in the bremsstrahlung spectrum and affects the quality of the output spectrum. In addition, the efficiency of x-ray production is directly related to tube voltage. Exposure is approximately proportional to the square of the kVp in the diagnostic energy range:

Exposure α Kv p^2

An increase in k Vp increases the efficiency of x-ray production and the quantity and quality of the x-ray beam.

3. The tube current (mA) is equal to the number of electrons flowing from the cathode to the anode per unit time. The exposure of the beam for a given kVpand filtration is proportional to the tube current.

4. The exposure time is the duration of x-ray production. The quantity of x-rays is directly proportional to the product of tube current and exposure time (mAs).

5. The beam filtration modifies the quantity and quality of the x-ray beam by selectively removing the low-energy photons in the spectrum. This reduces the photon number (quantity) and shifts the average energy to higher values, increasing the quality.

6. The generator waveform affects the quality of the emitted x-ray spectrum. For the same kVp, a single-phase generator provides a lower average potential difference than does a three-phase or high-frequency generator. Both the quality and quantity of the x-ray spectrum are affected.

In summary, the x-ray quantity is approximately proportional to Ztarget × kVp^2×mAs. The x-ray quality depends on the kVp, the generator waveform, and the tube filtration. Exposure depends on both the quantity and quality of the x-ray beam. Compensation for changes in kVp with radiographic techniques requires adjustments of mAs on the order of the fifth power of the kVp ratio, because kVp determines quantity, quality, and transmission through the object, whereas mAs determines quantity only.(Jerrold et.al 2001)

2.10. Computed radiography:

CR is a technique that captures a radiographicimage on phosphor imaging plates in conventionalfilm and saves it in an electronic formatfor further examination. Unlike “prompt-emitting”phosphors used in conventional phosphor-intensifyingscreens, the CR image plates retain the latentimage that remains stable until it is cleared by thewhite light in the unit after the image has beenscanned and stored. This process makes the platesreusable for many shots. Depending on how muchradiation they are exposed to, one could potentiallyget thousands of exposures on one plate.The image is scanned with a laser to stimulate the phosphor, causing it to release its stored energy in the form of visible light. This phenomenon is known as photostimulable luminescence. Like conventional intensifying screens, the intensity of stimulated luminescence is directly proportional to the number of

X-ray photons absorbed by the storage phosphor) qualityimage.com).

Figure 2.3 the CR unit

2.10.1 Benefits of computed radiography:

- Image quality comparable with to conventional screen- film systems

- Wide dynamic range- ability to image structures of different attenuation values (thorax and abd)

-Reduction of repeat exposuresCR is compatible with most conventional x-ray systems.

- Increased savings: no film , chemicals , dark room and storage room required.

- Computer processing of imagebrightness contrast sharpness enhancement , zooming , measurements(qualityimage.com).

2.10.2 Dose management during limbs exposure:

Pediatriclimbs exposure is the event in the imaging chain during which the most significant impact on patient dose is possible, regardless of the acquisition system. However, with few exceptions, CR systems do not communicate directly with the exposure equipment (user console, generator, automatic exposure control (AEC)). Therefore, information about the exposure parameters for any image (kVp, mA, s, filtration, source-image distance (SID), grid, etc.) must generally be entered into the CR acquisition system manually by the radiographer. This is an infrequent event in normal clinical practice. A complicating issue is that there is a much broader spectrum of body habitus in pediatric imaging than is found in adults (from sub-kg infants to 70+-kg adolescents). As a result, the definition of ‘‘standard’’ exposure techniques is difficult, since these are highly dependent on patient age and weight. While Agfa and other manufacturers can and often do offer guidelines on appropriate CR exposure techniques for specific (age/ weight) patient groups, have little control over the actual technique used for a particular patient. Given the large pediatric patient variability, this is probably good. (M.Hardy, 2003)

Figure 2.4 pediatric limbs during exposure

2.11. Previous studies:

Suliman et al. (2008) was published study on radiation doses from some common pediatrics X-ray examinations in Sudan.

doses was obtained.neonates falls in the range of 52–100, 115–169, 145–183, 204–242 μGy, respectively. For a 1-y-old infant, mean ESD range was 80–114, 153–202, 204–209, and 181–264 μGy, respectively. Some doses for neonates and infants were exceeding the reference doses by >20%.

(W.E. Muhogora et al, 2010) on Typical Radiation Doses to Patients from Some Common X Ray Examinations in Tanzania.

The mean entrance dose per X ray examination at each hospital ranged from 0.1 to 0.9 mGy for chest AP, 3.5-13.9 mGy for abdomen AP, 1.6-13.1 mGy for pelvis AP, 3.6-12.7 mGy for lumbar spine AP and 10.0-

29.6 mGy for lumbar spine LAT. Inter-hospital and intra-hospital dose variations up to a factor of 5 were observed for the same type of X ray examination.

Elisa Rizzi's study was to optimizing exposure parameters Dose levels for each configuration have been compared with RDLs suggested by European Guidelines and enforced by current Italian law, and radiation-induced risk has been evaluated and compared in terms of Entrance Skin Dose (ESD) to the patient and related risk factors, but also in terms of image quality.This study have been performed with Computed Radiography CR. the selection of 60 kV, 1 mAs and 6 ms, leads to an ESD of approximately 30 μGy, which is way lower than the 80 μGy suggested by EUR16261, the 50 μGy suggested by NRPB and the ESD which was imparted before the optimization. It can be concluded that the delivered dose was reduced by a factor varying from a minimum of 37% to a maximum of 67%, depending on the operating mode which employed the Technologists before the present study (E.Rizzi etal, 2014)

Sahar Othman the study was in pediatric To estimate entrance surface air kerma(ESAK), the radiographer in charge of the facility was asked to provide typical exposure parameters (kV, mAs and FSD) for each age category (newborn(1-30 days), 1, 5. 10 and 15 years). ESAK was estimated using the X-ray tube output measurements and the recorded exposure parameters. The obtained mean ESAK range from /27 to 57/ μGy, /25 - 103/ μGy, /45 – 128/ μGy, /47-139/ μGy and from /68- 299/ μGy for newborn, 1,5,10, and 15 years patients, respectively. The estimated ESAK were within the established international reference dose values and also the values obtained in previous studies (S. Othman (2011)

Chapter Three

Materials and Method

3.1. Materials:

3.1.1. Equipments:

In the present study, two different models of X-ray machines, from two centers were used as described in (Table 3.1)

Table (3.1) Shows X-rays equipment's specifications:-

Center	Manufacturer	Type	Focal Spot (mm)	Filtration (mmAl)	Max KVp	Max mAs	Max time	Installation year
A	Toshiba	Fixed	0.5	1	150	500	2.2	2010
B	Shimadzu	Fixed	0.5	1.5	150	500	2.2	2005

3.1.2. CR units:

The both centers are using Fujifilm CR unit

3.1.3. Patients:

A total of 50 patients were examined in two radiology centers in Khartoum state. The data were collected using a sheet for all patients in order to maintain consistency of the information. The following parameters age, weight, thickness and exposure parameters were recorded (kv,mAs). The dose was measured for limps X-rays examination. The examinations were collected according to the availability.

3.2. Method:

This study was carried out Tow centers in Khartoum state; included several CR machines. questionnaires were distributed to radiographers in charge of the diagnostic facilities. Each radiographer was asked to provide information with respect to his computed radiography unit, to calculate the ESD the radiographer was asked to provide the typical exposure parameters used for patients aged between 1 month and 15 years. The parameters were: peak tube voltage (kVp), exposure current-time product (mAs), focus-to-film distance (FSD).

3.2.1.Study duration:

The duration of study was 3 months according to the patient rate in the radiology centers from December 2015 up to February 2016.

3.2.2 Study place:

This study was carried out two hospitals in Khartoum state

3.2.3 Dose calculation:

The kV and mAs was changed according to the patient size, age and weight ESD was calculated by using micro soft excel to calculate By determining the tube output data and exposure factors. Using the equation below (Suliman2008)

$$ESD = op_x(kv/80)^2 \times mAs \times (100/fsd)^2 \times BSF$$

Where (OP) is the output in mGy/ (mA s) of the X-ray tube ,(kV) is thethe tube potential,(mA s) is the product of the tube current (in mA) and the exposure time(in seconds), (FSD) the focus-to-skin distance (in cm) and (BSF) the backscatter factor. The tube output, the patient anthropometrical data and the radiographic parameters (kVp, mA s, FSD and filtration) are initially inserted in the Microsoft excel.

Chapter Four

Results

Table (4.1) Radiographic parameters used in limbs X-ray examinations of pediatrics patients aged from 0 to 15 years old at center A.

Age years	Number of population	Thickness cm	exam	Kv	mAs	FSD cm	ESD µGy
5-10	5	3-5	UPPER	42±2	3±1.5	100	39.24
10.5-15	8	3-6	UPPER	44±2	3±1.5	100	54.18
6-10	9	3-6	LOWER	43±2	3±1.5	100	40.3
10.5-15	7	4-10	LOWER	45±	3±1.5	100	53.8

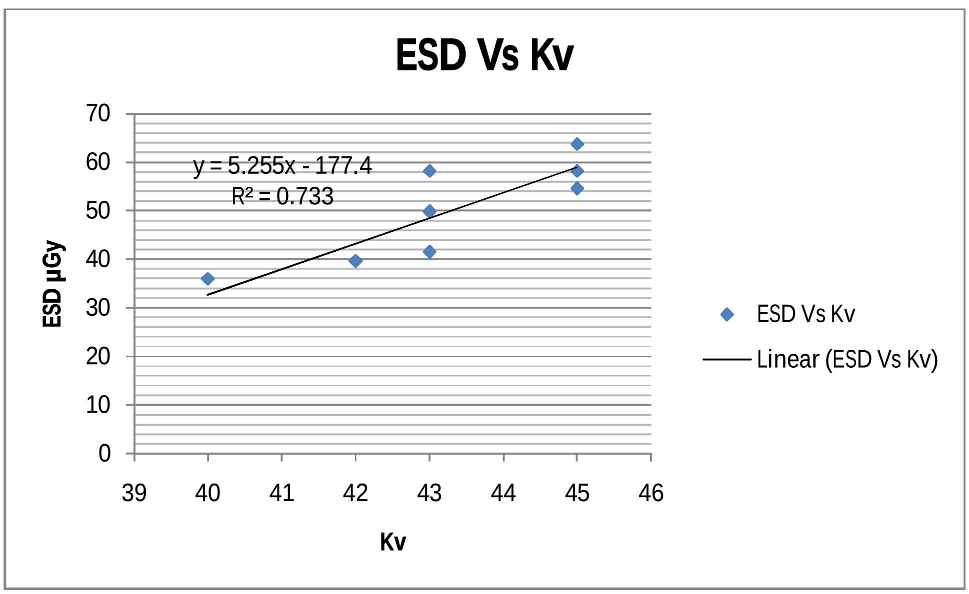

Figure 4.1 showed the correlation between Kv and ESD for upper limbs in center A.

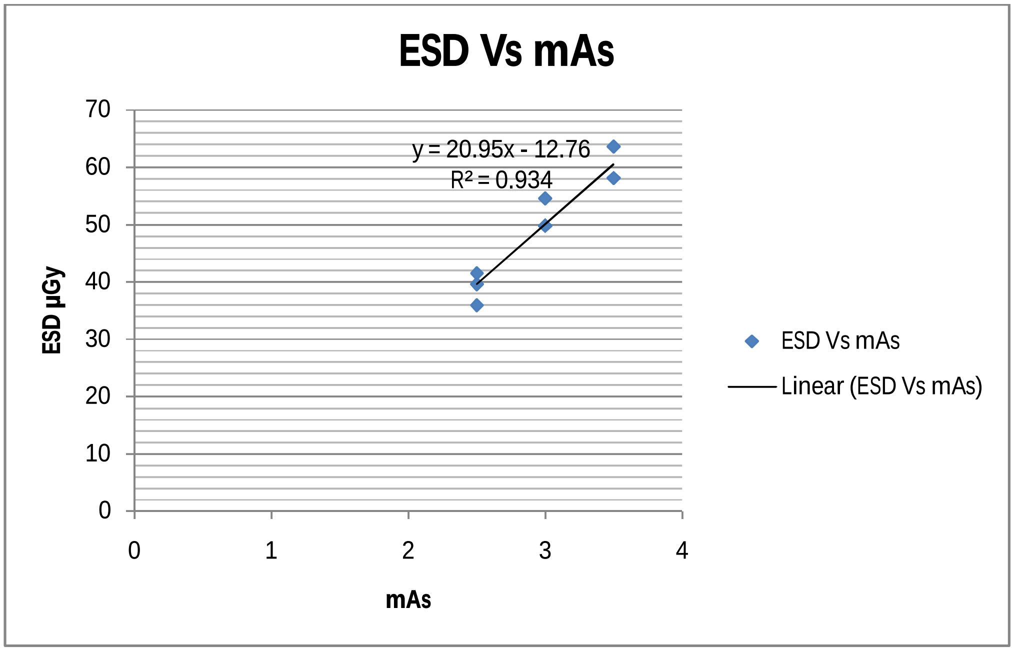

Figure 4.2 Showed the correlation between mAs and ESD for upper limbs in center A.

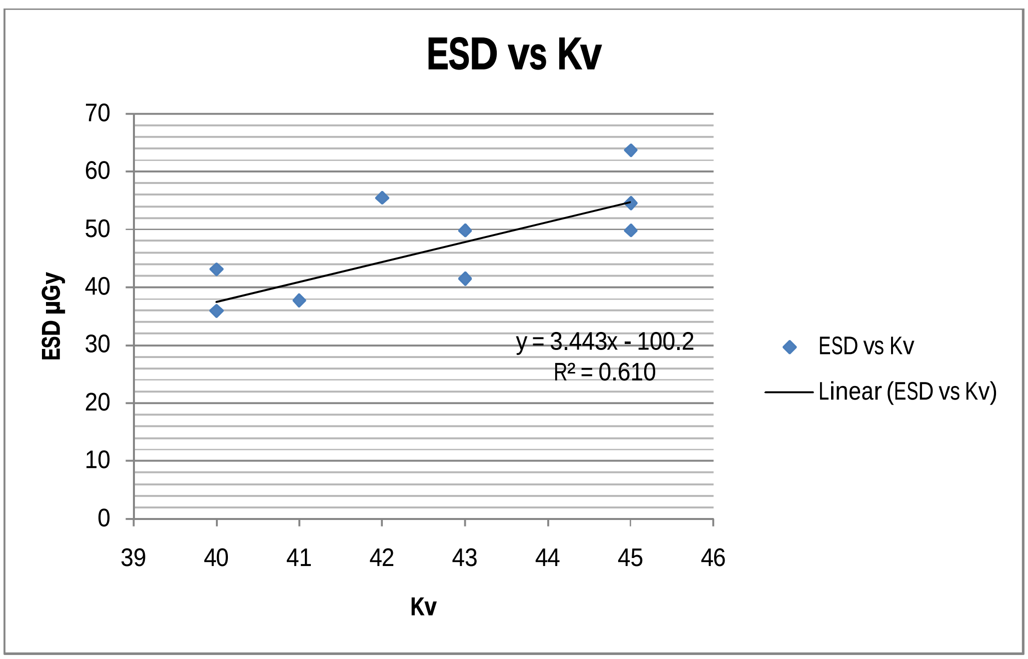

Figure 4.3 showed the correlation between Kv and ESD for lower limbs in center A.

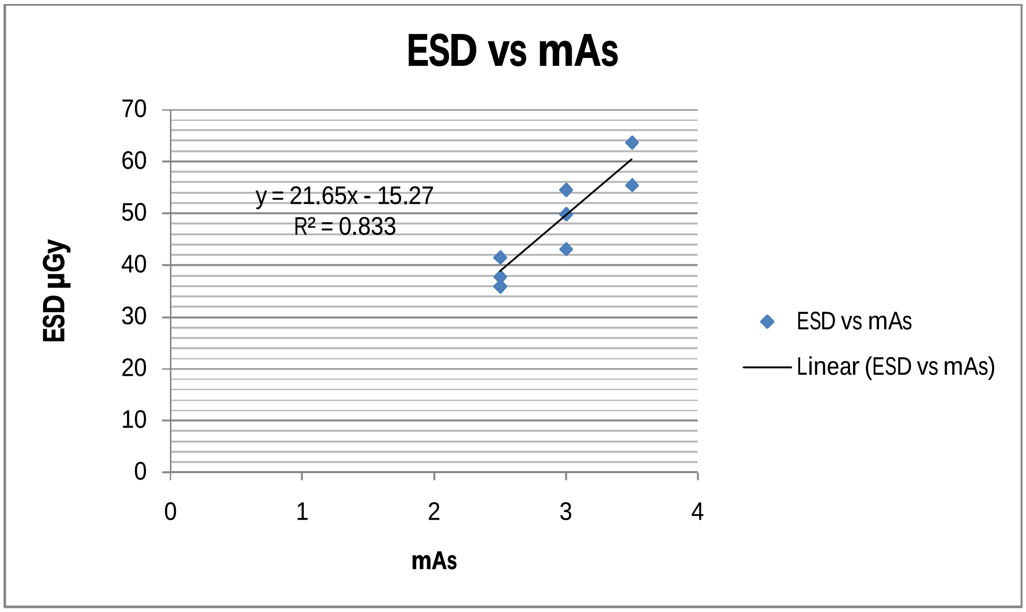

Figure 4.4 Showed the correlation between mAs and ESD for lower limbs in center A.

Table 4.2 Radiographic parameters used in limps X-ray examinations of pediatrics patients aged from 0 to 15 years old incenter B.

Age years	Number of patients	Thickness cm	exam	Kv	mAs	FSD cm	ESD µGy
5-10	7	2-6	UPPER	40±1	3±1.5	100	43.7
10.5-15	4	5-11	UPPER	45	3±1.5	100	61.07
6-10	6	3-7	LOWER	45±2	3±1.5	100	45.85
10.5-15	5	4-10	LOWER	47±1	3±1.5	100	57.6

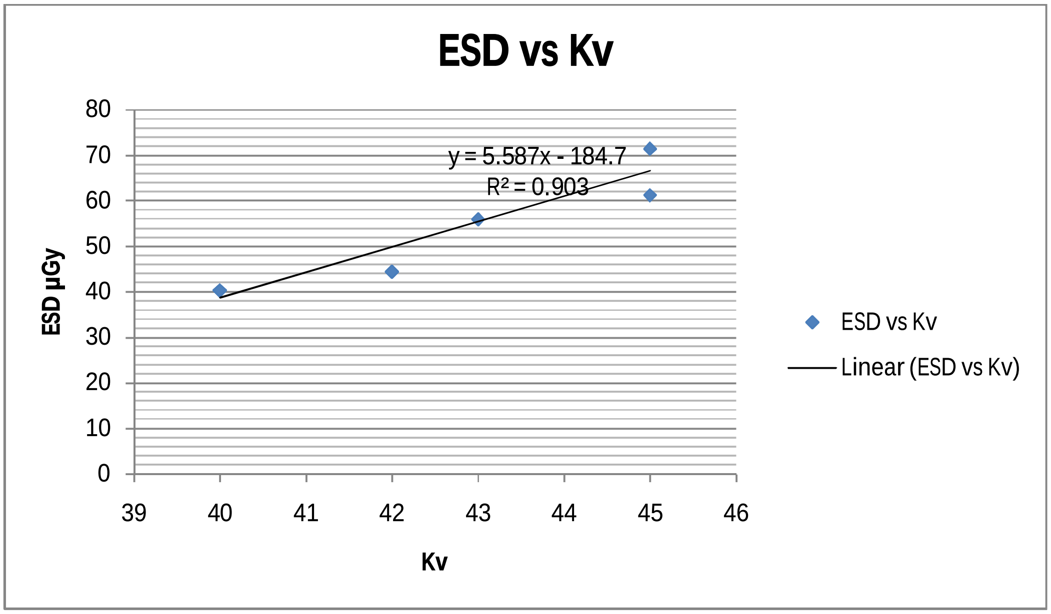

Figure 4.5 showed the correlation between Kv and ESD for upper limbs in center B.

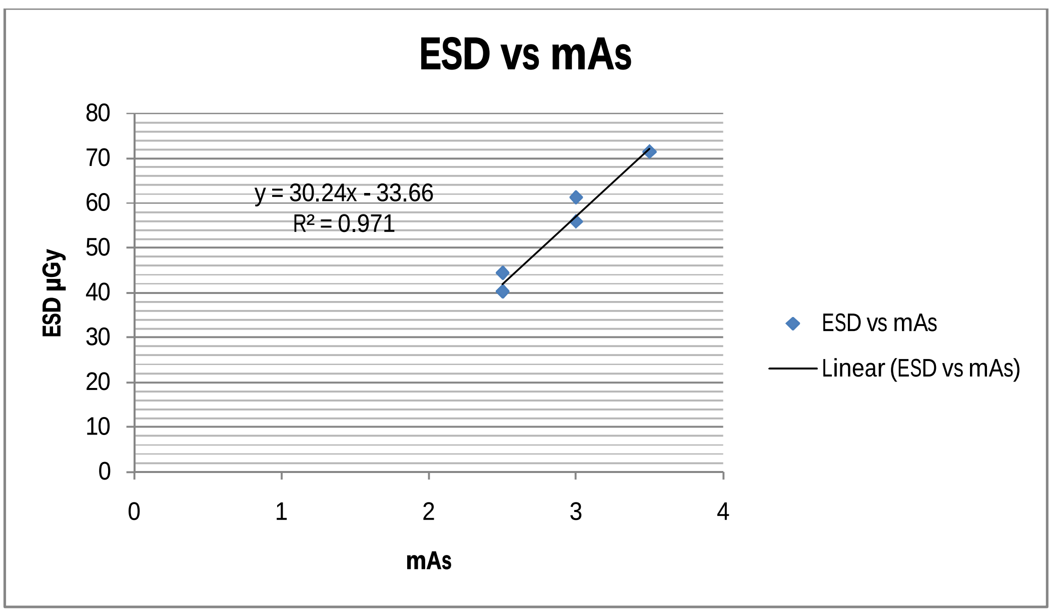

Figure 4.6 showed the correlation between mAs and ESD for upper limbs in center B.

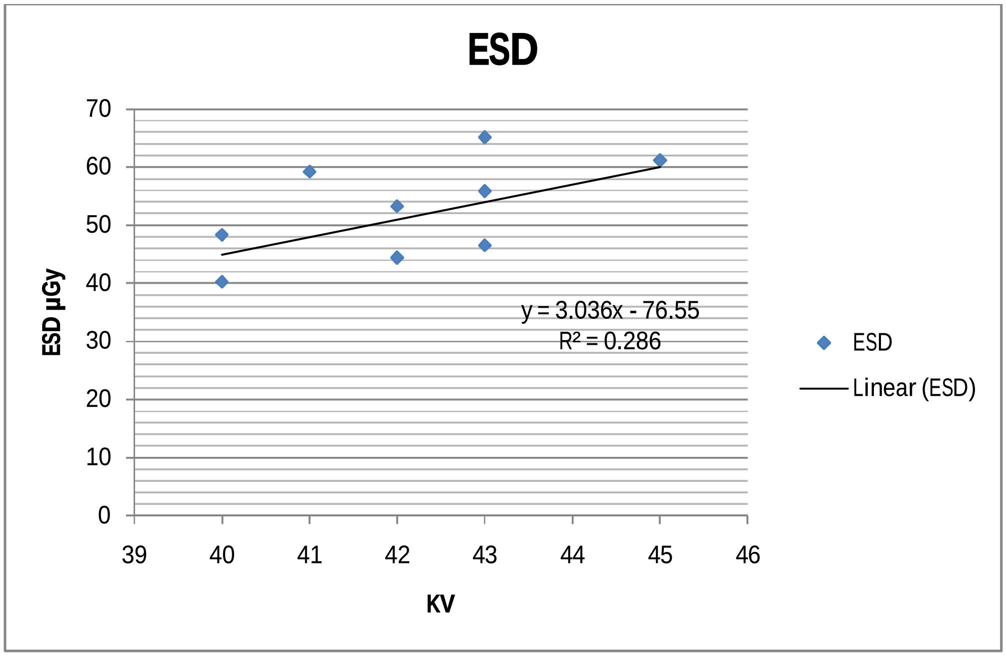

Figure 4.7 showed the correlation between Kv and ESD for lower limbs in center B.

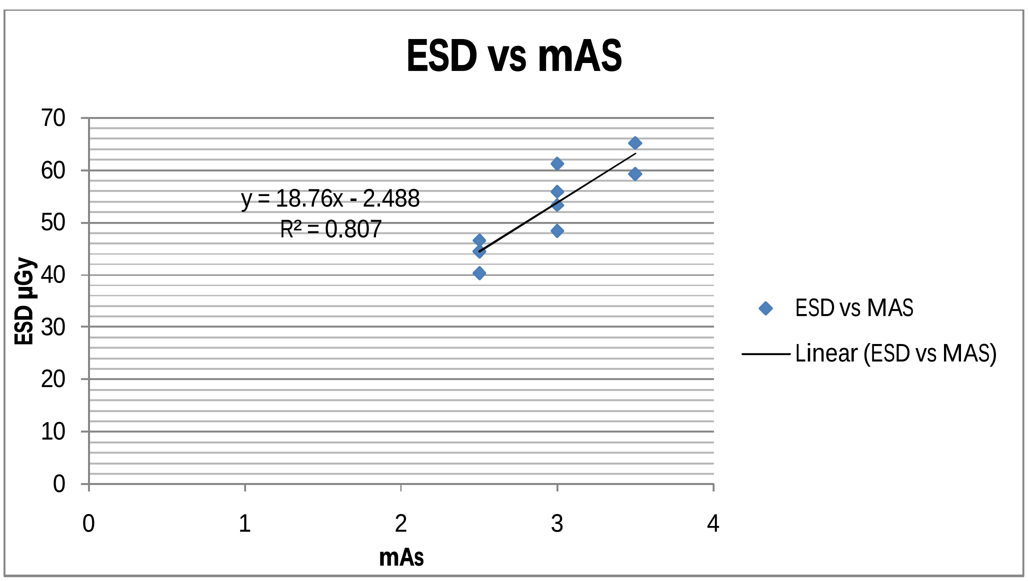

Figure 4.8 Showed the correlation between mAs and ESD for lower limbs in center B.

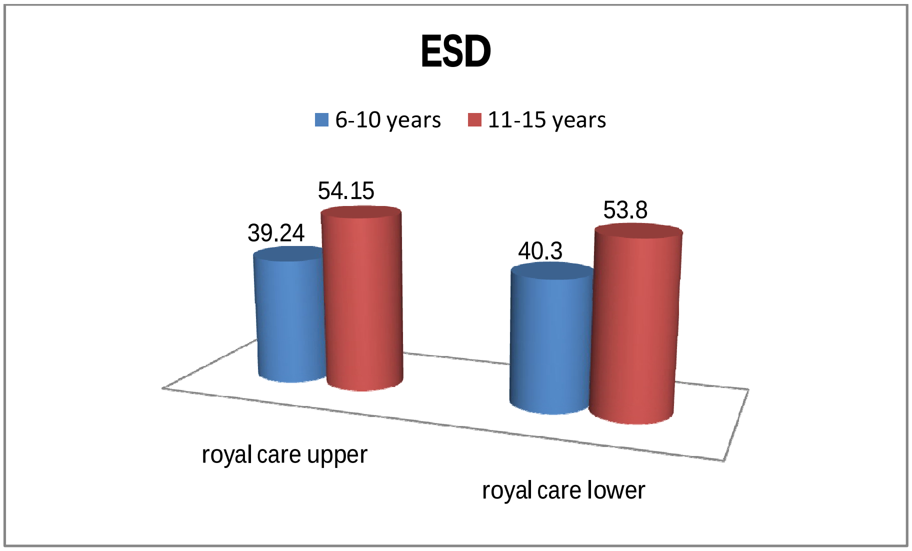

Figure 4.9 shows the ESD comparison of the upper limbs and the lower limbs in center A.

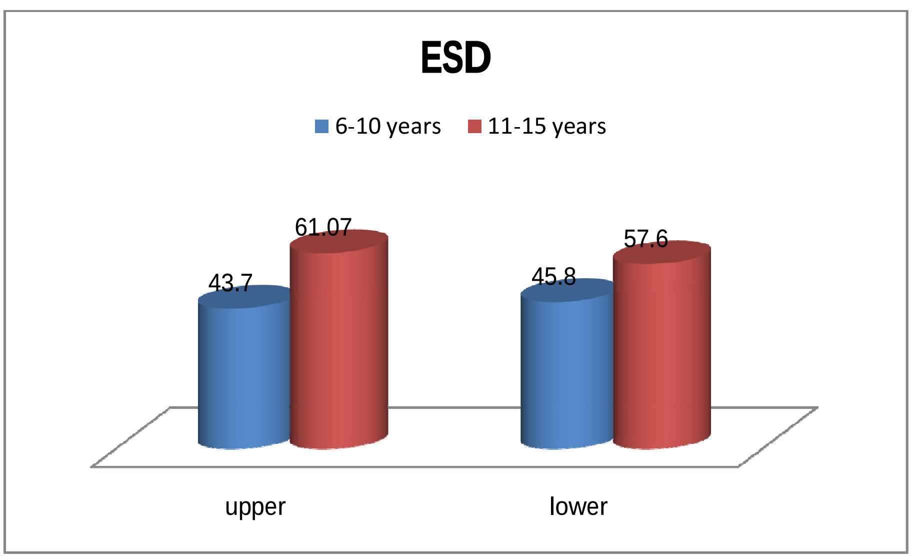

Figure 4.10 shows the ESD comparison of the upper limbs and the lower limbs center B.

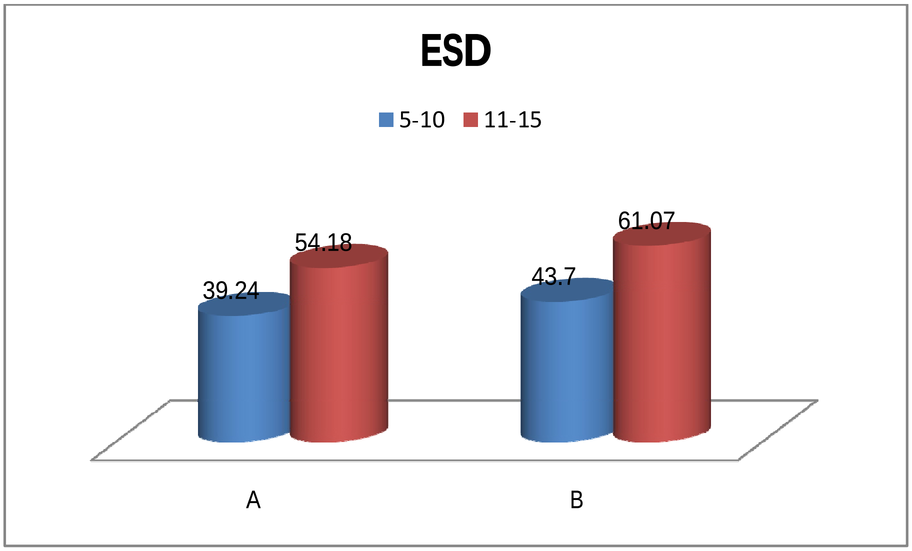

Figure 4.11 shows the ESD comparison of the upper limbs between the two centers at different ages

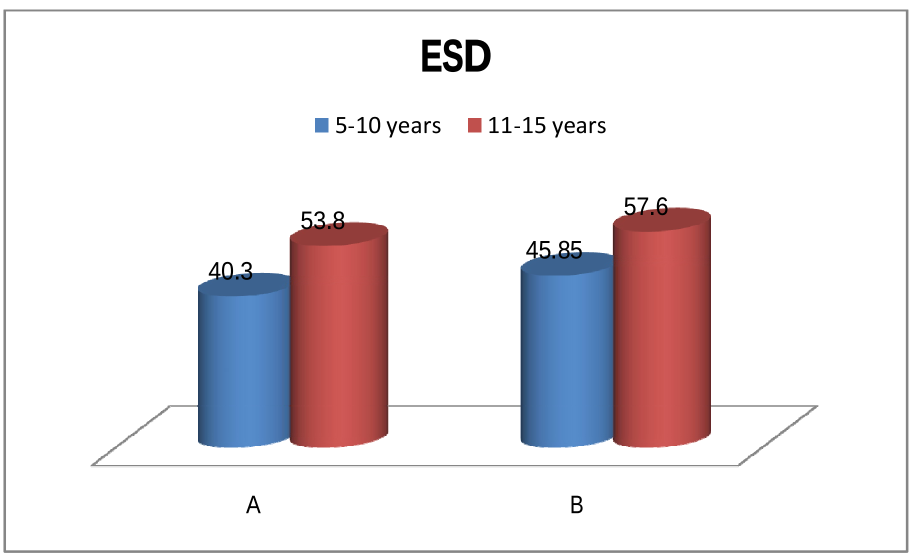

Figure 4.12 shows the ESD comparison of the lower limbs between the two centers at different ages

Chapter Five

Discussion, Conclusion and Recommendations

5.1. Discussion:

The ESD which calculated at certain Exposure parameters (kV, mAs, FSD) collected at each age in the specified centers, In center A the ESD for the upper limbs at the ages((5-10),(11-15)) years was (39.24 , 54.18)µGy and the ESD for the lower limps was (40.3 , 53.8) µGy as showed in table (4.1) . In center B the ESD for the upper limbs at the ages ((5-10), (6-11)) years found to be (43.7, 61.07) µGy and the ESD for the lower limbs was (45.85, 57.6) µGy as showed in table (4.2). the above figures from (4-1)to (4-8) showed that the ESD increases with the age & the exposure parameters (Kv,mAs). The comparison between the upper limbs and lower limbs in center Ashowed that the ESD for the lower limbs is higher than the upper as shown in figure (4.9). The same thing in center Bas shown in figure (4.10). the comparison between the two centers showed that the ESD in center Bwas greater than center Aas showed in figures ((4-11) and (4-12)) that may be due to the different in parameter selection , the ESD for the two centers compared with previous study which done in other centers in Sudan(S. Othman (2011)), (W.E. Muhogora et al(2010)) and (M.A. Halato1et al (2004)). the result showed that the ESD are higher than the resent study for all age ranges probably due to the fact that the two centers in this study are modern hospital with new equipments .and also could be due to the few data population in this study or due to the difference in dose calculation method and differences in exposure parameters used. The comparison between this study with the DRL we found that the results were within the Dose reference level, It is somewhat difficult to compare these reference values with the present results because of wide range of population study and the large parameters which considered when the reference level was creating.

5.2. Conclusion:

The ESD was higher in center B than center A.The ESD depends and changes with the exposure parameters (KV &mAs) and changes with age, the most of the estimated ESD values were within the range of reference level and lower than some previous studies.

5.3. Recommendations:

Special training in dealing with kids and the pediatric positioning (immobilizing) technique in imaging procedure

More studies must done about standardize the exposure parameter for dose optimization to achieve the ALARA principle

Quality control for the equipment must be done routinely in pediatric radiology.

References:

- Canadian Nuclear Safety Commission (CNSC), Introduction to Radiation,2012
- El.Rizzi1, S. Emanuelli, S. Amerio1, D. Fagan, F. Mastrogiacomo, P. Gianino, ,Optimization of Exposure Conditions for Computed Radiology Exams in Neonatal Intensive Care, 2014.
- H. F.Akhdar ,Assessment of Entrance Skin Dose and Effective Dose of Some Routine X-ray Examinations,2007
- http://hyperphysics.phy-astr.gsu.edu/hbase/mod1.html#c5
- IAEA ,Radiation oncology physics: A Handbook for Teachers and Students, 2002

- J.T.Bushberg , J.A.seiberg,E.M.leitholdt ,the essential physics for medical imaging,2002
- -Maryann Hardy & Stephen Boynes ,pediatric radiology,2003
- N. Serman, Goaz and Pharoah, Production of X-rays and Interactions of X-rays with Matter,2001

- T.KILJUNEN, A.TIETA ¨,A. VIITALA &M. KORTESNIEMI , Organ Doses and Effective Doses in Pediatric Radiography: Patient-Dose Survey in Finland, Helsinki,2009

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Appendix

No	Age	weight	exam	Kv	mAs	FSD
1	7.5	19	Lat (upper)	42	2.5	100
2	9	20	Lat (upper)	43	2.5	100
3	12	32	PA (upper)	43	3	100
4	12	32	PA (upper)	43	3	100
5	12	36	PA (upper)	43	3	100
6	7	20	Lat (upper)	42	2.5	100
7	13	45	Lat (upper)	45	3	100
8	8	22	Lat (upper)	42	2.5	100
9	5	12	PA(upper)	40	2.5	100
10	15	50	PA (upper)	45	2.5	100
11	15	45	PA (upper)	45	3.5	100
12	13	45	Lat (upper)	43	3	100
13	14	42	Lat (upper)	43	3.5	100
14	9.5	22	AP (lower)	40	3	100
15	14.5	40	AP (lower)	45	3.5	100
16	10.5	21	AP (lower)	45	3	100
17	13	35	AP (lower)	42	3.5	100
18	7	19	AP (lower)	41	2.5	100
19	11.5	25	Lat (lower)	43	3	100
20	8	20	AP (lower)	43	2.5	100
21	6.5	14	AP (lower)	40	2.5	100
22	9	20	AP (lower)	43	2.5	100
23	12	27	Lat (lower)	45	3	100
24	10	19	Lat (lower)	45	3	100
25	7.5	16	AP (lower)	43	2.5	100
26	5	14	Lat (lower)	40	2.5	100
27	11	24	Lat (lower)	43	3	100
28	8.5	22	Lat (lower)	40	2.5	100
29	12.5	27	Lat (lower)	43	3	

The data collected from center A

No	Age	weight	Exam	Kv	mAs	FSD
1	12	30	Lat (upper)	45	3	100
2	10	20	Lat (upper)	43	3	100
3	6.5	12	PA (upper)	40	2.5	100
4	6	12	PA (upper)	40	2.5	100
5	14	45	Lat (upper)	45	3.5	100
6	8	19	PA (upper)	42	2.5	100
7	7	17	PA (upper)	42	2.5	100
8	5	14	Lat (upper)	40	2.5	100
9	5.4	14	PA (upper)	40	2.5	100
10	15	4.7	Lat (upper)	45	3.5	100
11	10	23	Lat (lower)	42	2.5	100
12	7.5	20	Lat (lower)	42	2.5	100
13	9	18	Lat (lower)	42	2.5	100
14	11	25	AP(lower)	43	3	100
15	6	14	Lat (lower)	40	2.5	100
16	11.5	26	AP(lower)	43	3	100
17	14	38	AP(lower)	45	3.5	100
18	8.5	22	AP(lower)	42	2.5	100
19	5	15	AP(lower)	40	2.5	100
20	11	24	AP(lower)	41	3	100
21	12	29	AP(lower)	43	3	100

Data collected from center B