CHAPTER ONE

Introduction

1. Introduction:

1.1 Historical background:

X-ray imaging is the most widespread and well-known medical imaging technique. It dates back to the discovery by Wilhelm Conrad Röntgen in 1895 of a new kind of penetrating radiation coming from an evacuated glass bulb with positive and negative electrodes. Today, this radiation is known as short wavelength electromagnetic waves being called X-rays. The X-rays are generated in a special vacuum tube: the X-ray tube, which will be the subject of the first subsection. The emanating X-rays can be used to cast shadows on photographic films or radiation sensitive plates or electronic detectors for direct evaluation in the technique of planar X-ray imaging. Diagnostic x- ray examinations can support the radiologist with valuable information that can be utilized to give a patient an accurate diagnosis, and subsequently a successful treatment. However, imaging with ionizing radiation is also associated with a small risk for cancer induction or genetic detriment (ICRP, 2005).According to the linear non-threshold (LNT) hypothesis there is a linear relation between the effective dose and risk for cancer induction (ICRP, 2005) and means that the collective dose can be used as a measure of the harm to the population. Diagnostic radiology is invaluable for the health care but due to the radiation risks, radiation protection of the patient becomes an important issue. Three different principles are used for radiation protection (ICRP, 2007). The first principle is justification. Ionizing radiation should only be used in those situations where it brings more good than harm. The second principle is optimization. It means that, in those cases where the use of ionizing radiation is justified, doses should be kept as low as reasonable achievable. This is often referred to as the ALARA (As Low As Reasonably Achievable) principle. The third principle is dose

limits to the individual. However, this principle is more applicable for personnel rather than for patients in diagnostic radiology.

1.2 Planar Imaging:

X-ray planar radiography is one of the mainstays of a radiology department, providing a first 'screening' for both acute injuries and suspected chronic diseases. Planar radiography is widely used to assess the degree of bone fracture in an acute injury, the presence of masses in lung cancer/emphysema and other airway pathologies, the presence of kidney stones, and diseases of the gastrointestinal tract (GIT). Depending upon the results of an X-ray scan, the patient may be referred for a full three-dimensional X-ray computed tomography (CT) scan for more detailed diagnosis. The basis of planar radiography is the differential absorption of X-rays by various tissues. For example, bone and small calcifications absorb X-rays much more effectively than soft tissue. X-rays generated from a source are directed towards the area of interest. X-rays which pass through the patient are detected using an image receptor according to the type of radiography. In addition to being absorbed x-rays can also be scattered as they pass through the body, and this gives rise to a background signal which reduces the image contrast. Therefore, an anti-scatter grid is used to ensure that only X-rays that pass directly through the body from source-to-image receptor are recorded (Webb, 2010).

The main types of planar radiography are:-

1.2.1 Screen Film radiography (SFR)

In this type originally, the radiation was captured by a normal photographic film. In the film, the energetic X-ray photons are absorbed in the silver halide (NaB-NaI) crystals, generating very small amounts of free silver. During film processing, any grain with small amounts of free silver are completely converted to metallic, nontransparent silver, while the remaining unreduced silver

halide is removed by the fixative. To increase sensitivity and thus lower radiation dose, the photo sensitive film emulsions are often thicker and occasionally coated on both sides of the film, in contrast to normal photographic film.

Any film has a specific range of optimal sensitivity (exposure range from complete transparency to completely blacken). Although modern equipment are normally assisted by electronic exposure meters, the correct choice of film, exposure time, exposure current and high voltage is still left to the judgment of the X-ray technologist. To improve the sensitivity and thus lower radiation exposure to the patient, the film is often brought in contact with a sheet of intensifying screen. The screen contains special chemical compounds of the rare earth elements, which emit visible blue-green light when hit by X-rays or other ionizing radiation. This permits the use photographic film with thinner emulsions and more normal sensitivity to visible light. While increasing the sensitivity, the use of intensifying screen on the other hand blurs the images as the registration of X-ray radiation is no longer a direct, but an indicted process. The patients or the object is not only the source of X-ray absorption but also of X-ray scattering, mainly due to Compton Effect. Any part of the patient exposed to the primary X-ray beam will be a source of secondary, scattered, X-rays. These X-rays will have lower energy than the original ray, but as no energy discrimination is used in the registration, also the secondary scattered radiation adds to the blackening of the film. The scattered radiation carries no direct geometrical information about the object and thus only reduces the contrast by increasing the background gray level of the film. Scattered radiation can to some degree be avoided by the use of special collimators called raster. The raster can be a series of thin, closely lying bars of lead, only allowing radiation coming from the direction of the focus point to hit the film while other directions are excluded (Jensen and Wilhjelm, 2006).

1.2.2 Computed Radiography (CR)

In computed Radiography (CR) an imaging plate coated with storage phosphors is used to capture x-rays as they pass through the patient. Trace amounts of impurities are added to the phosphor materials in a process called "doping," to alter their crystalline form and physical properties. When irradiated, the enhanced phosphors absorb and store x-ray energy in gaps in their altered crystal structure. This trapped energy comprises a latent image; when stimulated by additional light energy of the proper wavelength, the trapped energy is released. In modern CR systems, storage phosphors commonly are stimulated with a low-energy laser to release visible light wherever x-rays have been absorbed. This light is captured and converted into an electrical signal, which is converted to data that can be transmitted to remote systems or locations, displayed on laser-printed films or softcopy workstations and stored digitally (Kodak, 2003).

1.2.3 Digital Radiography (DR)

Digital detectors offer a much wider dynamic range than screen-film combinations. In conventional screen-film radiography, the film has a three-fold function as the medium for image acquisition, presentation and storage which unavoidably leads to organizational problems. As a result, digital systems have a higher tolerance with respect to exposure variations, and allow for a better display of the whole signal range from minimum to maximum X-ray absorption (Prokop et al.1993).In digital radiography (DR) the image data is captured by direct electronic X-ray detection devices, this enable the benefits of rapid viewing, post processing interactive availability, and digital transmission. During the past two decades, digital radiography has supplanted screen-film radiography in many radiology departments. Today, manufacturers provide a variety of digital imaging solutions based on various detector and readout technologies. Digital detectors allow implementation of a fully digital picture archiving and communication system, in which images are stored digitally and are available anytime. Image distribution in

hospitals can now be achieved electronically by means of web-based technology with no risk of losing images. Other advantages of digital radiography include higher patient throughput, increased dose efficiency, and the greater dynamic range of digital detectors with possible reduction of radiation exposure to the patient (Körner et al. 2007).

1.3 Optimization of diagnostic radiology:

Optimization means to balance the diagnostic information (image quality) and patient dose so as to maximize the ratio between the two; either to keep the information constant and minimize the dose or to increase information at constant dose.

The dose to the patient undergoing an x-ray examination has, in digital systems, a close relation to the quantum noise in the image. The quantum noise depends on the number of photons incident on the image detector and is approximately described with a compound poison distribution, which takes the energy absorption properties of the detector into account. If we use too few photons, the image will be noisy and it will make it difficult or even impossible for the radiologist to give a correct diagnosis. It may also take longer time for the radiologist to give a diagnosis using a noisy image. Yet, above a certain dose level, the quantum noise may become negligible in comparison to the noise naturally present in the projected anatomy (Hoeschen et al 2005). There will therefore be limited benefit to increase the dose above this level. How to make the tradeoff between the dose to the patient and the image quality is a complex subject. A key aspect for the optimization of diagnostic radiology is to understand the relative importance of the quantum noise in the image and the structures in the projected anatomy that act as noise. Several authors including; (Kundel et al (1985), Samei et al (1999), Burgess et al (2001) and Håkansson et al (2005b)) have acknowledged the importance of projected anatomy in relation to quantum noise. The consensus from these studies is that at normal exposures, the projected anatomy is the

most important factor in hampering the detection of subtle nodules in chest radiographs and mammograms.

1.4 Quality Assurance (QA) and Quality Control (QC):

Quality Assurance (QA) program, which includes quality control tests, helps to ensure that high quality diagnostic images are consistently produced while minimizing radiation exposure. The QA program covers the entire x-ray system from machine, to processor, to view box. This program will enable the facility to recognize when parameters are out of limits, which could result in poor quality images and can increase the radiation exposure to patients. Simply performing the quality control tests is not sufficient. When quality control test results exceed established operating parameters, appropriate corrective action must be taken immediately and documented.

The quality criteria concept has proved to be an effective method for optimizing the use of ionizing radiation for x-ray examinations. The purpose of quality criteria for x-ray examinations is to provide an operational framework for radiation protection initiatives for radiography in which technical parameters required for image quality are considered in relation to patient dose. The two basic principles of radiation protection of the patient as recommended by ICRP 60 (1991) are justification of practice and optimization of protection, including the consideration of dose reference levels. Justification is the first step in radiation protection. It is accepted that no diagnostic exposure is justifiable without a valid clinical indication, no matter how good the imaging performance may be. Every examination must result in a net benefit for the patient. This only applies when it can be anticipated that the examination will influence the efficacy of the decision of the physician with respect to diagnosis, patient management and therapy, and final outcome for the patient. Practitioners may not have all the possible diagnostic information and this may lead to an incorrect diagnosis, and if the quality of the radiograph is so poor that it

cannot be used, then the patient shall be exposed again, causing unnecessary radiation exposure with increase in the cost of diagnosis. For that it is very important to control these factors in order to perform radiographic examinations with lower radiation dose and accurate diagnostic information (EUR, 1996).

1.5 Problem of the Study:

X-rays are known to cause malignancies, skin damage and other side effects and they are thus potentially dangerous. Therefore, it is essential and in fact mandatory to reduce the radiation dose in diagnostic radiology as far as possible. However, the dose is linked to image quality and the image quality may not be lowered so far that it affects the diagnostic outcome.

Although the task is important, to our knowledge, no study was performed regarding radiation dose and image quality for planar diagnostic radiology in Sudan. Therefore, it is mandatory to evaluate the image quality and radiation dose during planar diagnostic radiology and recommend the optimization measures as needed.

1.6 Objectives of the study:

1.6.1 General Objective

The main objective of this study is to optimize the patient radiation dose and image quality in planar diagnostic radiology in selected x-ray departments in Khartoum state hospitals, to delineate a national quality standards and diagnostic reference levels (DRLs).

1.6.2 Specific Objective

The specific objectives of this study are to:

i. Measure the physical parameters and acceptability limits of the radiation generators and imaging devices as base line for optimizing image quality and radiation dose.

ii. Assess the radiation dose for patients during common radiographic examinations, and estimate the effective dose for the patients.

iii. Investigate the demographic data that may affect the patient radiation dose and image quality

iv. Evaluate the radiographic image quality following the international standards based on the European guidelines on Quality Criteria for Diagnostic Radiographic Images.

v. Determine the main factors affecting patient's radiation dose and image quality and recommend on how to optimize it practically.

1.7 Thesis outlines

This thesis traces the progress in image quality and radiation dose optimization for planar imaging from applied research in the field of diagnostic radiology through reviewing and implementing the current theories and practices with emphasis on applying a practical work in ten major Khartoum hospitals to rule out the main factors that affect image quality and patient radiation dose in common radiographic procedures. Chapter one of this thesis introduces planar imaging and its development as well as identifying thesis objectives. Chapter two provides the thesis context by describing the general principles of image quality and radiation dose optimization in planar diagnostic radiology through reviewing the applied research in the field for the last twenty years. This chapter also provides an overview about the importance of planar imaging with emphasis on the practical methods and techniques for image quality and radiation dose optimization as well as reviewing the local and international previous studies. Chapter three describes materials and methods used in this study. It also involves the practical work and data collection procedures. Chapter four presents the results of the data collected and its related experiments. Finally, chapter five presents the discussion, conclusions, recommendations and the suggestions for future work.

CHAPTER TWO

Theoretical Background and Previous Studies

2.1 Theoretical Background

2.1.1 X-ray Nature and Production

X-rays are a form of ionizing electromagnetic radiation which has a very high frequency and a very short wavelength. The wavelengths x-rays range between 0.001 to 10 nm.

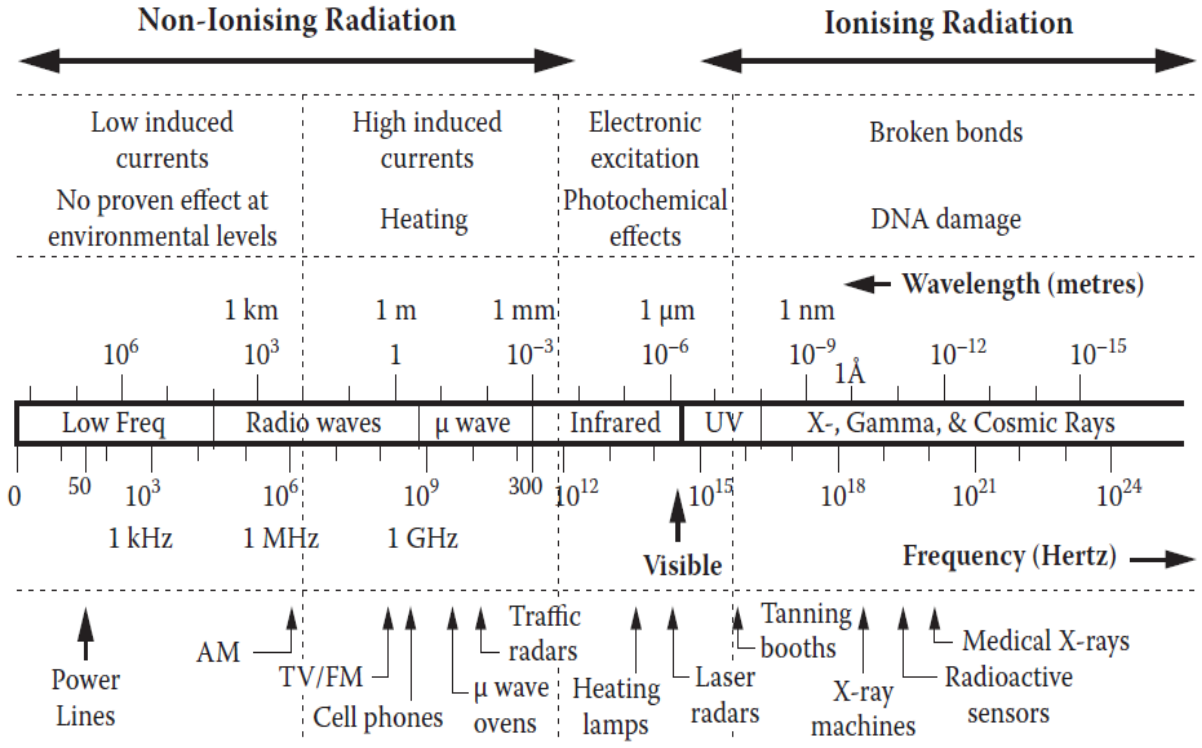

Figure 2.1: The electromagnetic Spectrum (Holmeset al 2013)

X-radiation is created by taking energy from electrons and converting it into photons with appropriate energies. This energy conversion (Fig 2.1), takes place within the x-ray tube. The quantity (exposure) and quality (spectrum) of the x-radiation produced can be controlled by adjusting the electrical quantities (kVp, MA) and exposure time, S, applied to the tube. (Holmes et al 2013)

2.1.2 The x ray Machine

2.1.2.1 The x ray Tube

The major components of an X-ray machine are the tube, the high voltage generator, the control console, and the cooling system. X-rays are generated by directing a stream of high speed electrons at a target material such as tungsten, which has a high atomic number. When the electrons are slowed or stopped by the interaction with the atomic particles of the target, X-radiation is produced. This is accomplished in the X-ray tube. An x-ray tube (Fig 2.2) is an energy converter. It receives electrical energy and converts it into two other forms: x-radiation and heat. The heat is an undesirable byproduct. X-ray tubes are designed and constructed to maximize x-ray production and to dissipate heat as rapidly as possible. The x-ray tube is a relatively simple electrical device typically containing two principle elements: a cathode and an anode. As the electrical current flows through the tube from cathode to anode, the electrons undergo an energy loss, which results in the generation of x-radiation.

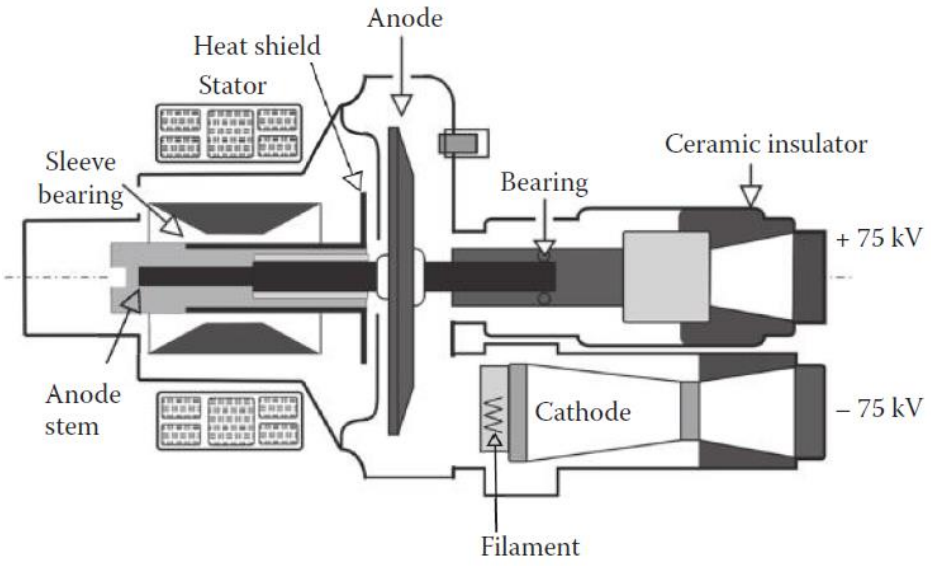

Figure 2.2: The X-ray Tube [Holmes et al 2013]

2.1.2.2 The Anode

The anode is the component in which the x-radiation is produced. It is a relatively large piece of metal that connects to the positive side of the electrical circuit. The anode has two primary functions: (1) To convert electronic energy into x-radiation, and, (2) To dissipate the heat created in the process. The material for the anode is selected to enhance these functions.

The ideal situation would be if most of the electrons created x-ray photons rather than heat. The fraction of the total electronic energy that is converted into x-radiation (efficiency) depends on two factors: the atomic number (Z) of the anode material and the energy of the electrons. Most x-ray tubes use tungsten, which has an atomic number of 74, as the anode material. In addition to a high atomic number, tungsten has several other characteristics that make it suited for this purpose. Tungsten is almost unique in its ability to maintain its strength at high temperatures, and it has a high melting point and a relatively low rate of evaporation. For many years, pure tungsten was used as the anode material. In recent years an alloy of tungsten and rhenium has been used as the target material but only for the surface of some anodes. The anode body under the tungsten-rhenium surface on many tubes is manufactured from a material that is relatively light and has good heat storage capability. Two such materials are molybdenum and graphite. The use of molybdenum as an anode base material should not be confused with its use as an anode surface material. Most x-ray tubes used for mammography have molybdenum-surface anodes. This material has an intermediate atomic number (Z = 42), which produces characteristic x-ray photons with energies well suited to this particular application. Some mammography tubes also have a second anode made of rhodium, which has an atomic number of 45. This produces a higher energy and more penetrating radiation, which can be used to image dense breast. The use of a rhenium-tungsten alloy improves the long-term radiation output of

tubes. With x-ray tubes with pure tungsten anodes, radiation output is reduced with usage because of thermal damage to the surface.

Most anodes are shaped as beveled disks and attached to the shaft of an electric motor that rotates them at relatively high speeds during the x-ray production process. The purpose of anode rotation is to dissipate heat. The radiation is produced in a very small area on the surface of the anode known as the focal spot. The dimensions of the focal spot are determined by the dimensions of the electron beam arriving from the cathode. In most x-ray tubes, the focal spot is approximately rectangular. The dimensions of focal spots usually range from 0.1 mm to 2 mm. X-ray tubes are designed to have specific focal spot sizes; small focal spots produce less blurring and better visibility of detail, and large focal spots have a greater heat-dissipating capacity. Focal spot size is one factor that must be considered when selecting an x-ray tube for a specific application. Tubes with small focal spots are used when high image visibility of detail is essential and the amount of radiation needed is relatively low because of small and thin body regions as in mammography. Most x-ray tubes have two focal spot sizes (small and large), which can be selected by the operator according to the imaging procedure (Sprawls, 2005).

2.2.2.3 The Cathode

The basic function of the cathode is to expel the electrons from the electrical circuit and focus them into a well-defined beam aimed at the anode. The typical cathode consists of a small coil of wire (a filament) recessed within a cup-shaped region (Fig 2.3). Electrons that flow through electrical circuits cannot generally escape from the conductor material and move into free space. They can, however, if they are given sufficient energy. In a process known as thermionic emission, thermal energy is used to expel the electrons from the cathode. The filament of the cathode is heated in the same way as a light bulb filament by passing a current through it. This heating current is not the same as the current flowing through the x-ray tube (the mA) that

produces the x-radiation. During tube operation, the cathode is heated to a glowing temperature, and the heat energy expels some of the electrons from the cathode.

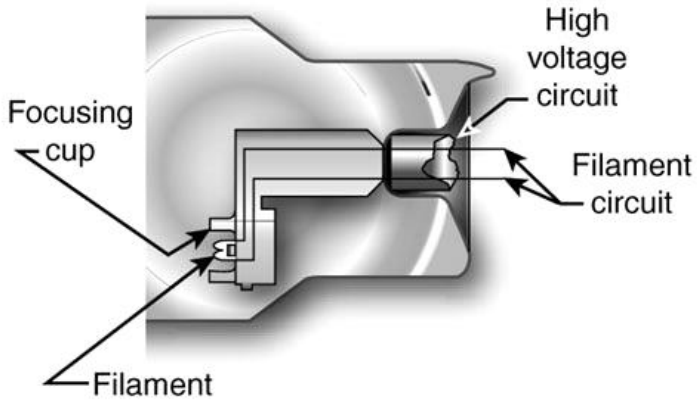

Figure 2.3: The Cathode Assembly (Sprawls, 2005)

2.1.2.4 The Envelop and Tube Housing

The anode and cathode are contained in an airtight enclosure, or envelope. The envelope and its contents are often referred to as the tube insert, which is the part of the tube that has a limited lifetime and can be replaced within the housing (Fig 2.4). The majority of x-ray tubes have glass envelopes, although tubes for some applications have metal and ceramic envelopes. The primary functions of the envelope are to provide support and electrical insulation for the anode and cathode assemblies and to maintain a vacuum in the tube. The presence of gases in the x-ray tube would allow electricity to flow through the tube freely, rather than only in the electron beam. This would interfere with x-ray production and possibly damage the circuit.

The x-ray tube housing provides several functions in addition to enclosing and supporting the other components. It functions as a shield and absorbs radiation, except for the radiation that passes through the window as the useful x-ray beam. Its relatively large exterior surface dissipates most of the heat created within the tube. The space between the housing and insert is

filled with oil, which provides electrical insulation and transfers heat from the insert to the housing surface (AAPM, 2014).

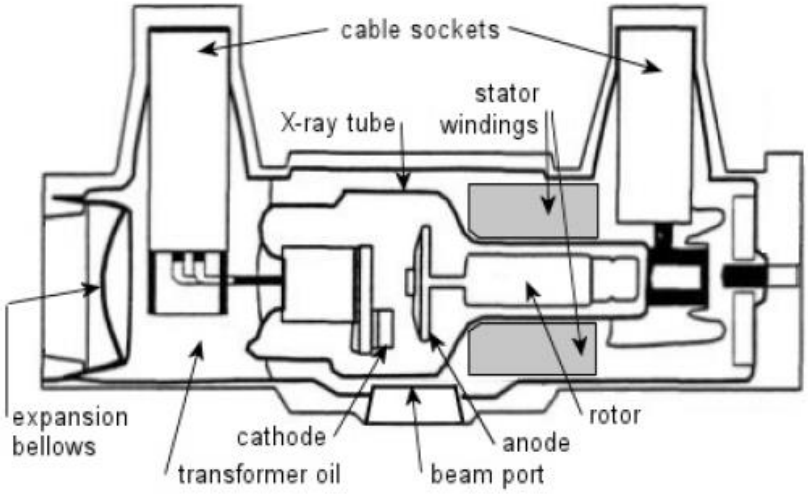

Figure 2.4: Typical housing assembly for a general purpose x ray tube (AAPM, 2014)

2.1.2.5 The x-ray Circuit

The energy used by the x-ray tube to produce x-radiation is supplied by an electrical circuit (Figure 2.5).

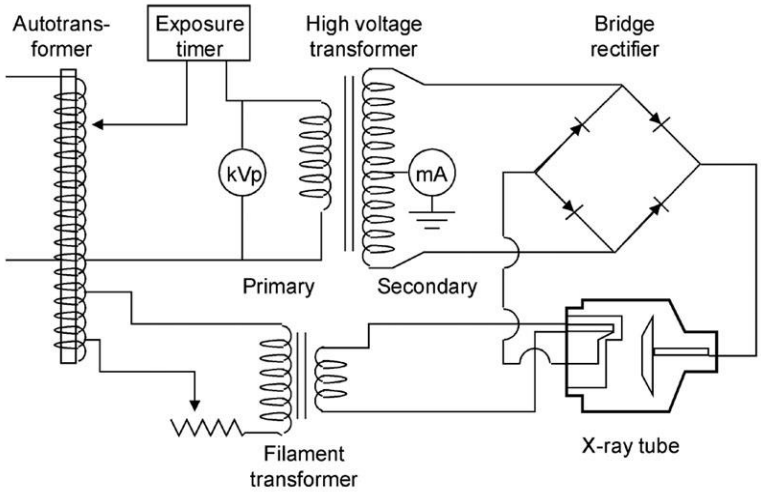

Figure 2.5: The X-ray Circuit (Sprawls, 2005)

The circuit connects the tube to the source of electrical energy that in the x-ray room is often referred to as the generator which receives the electrical energy from the electrical power system and converts it into the appropriate form (DC, direct current) to apply to the x-ray tube. The generator also provides the ability to adjust certain electrical quantities that control the x-ray production process. The three principle electrical quantities that can be adjusted are the voltage or electrical potential applied to the tube (kVp), the electrical current that flows through the x-ray tube (mA), and the duration of the exposure or exposure time (s).The circuit is actually a circulatory system for electrons. They pickup energy as the pass through the generator and transfer their energy to the x-ray tube anode.

The energy that will be converted into x-radiation (and heat) is carried to the x-ray tube by a current of flowing electrons as shown above. As the electrons pass through the x-ray tube, they undergo two energy conversions, as illustrated previously: The electrical potential energy is converted into kinetic (motion) energy that is, in turn, converted into x-radiation and heat. When the electrons arrive at the x-ray tube, they carry electrical potential energy. The amount of energy carried by each electron is determined by the voltage or kVp, between the anode and cathode. For each kVp of voltage, each electron has 1 keV of energy. By adjusting the kVp, the x-ray machine operator actually assigns a specific amount of energy to each electron [Holmes et al 2013]. After the electrons are emitted from the cathode, they come under the influence of an electrical force pulling them toward the anode. This force accelerates them, causing an increase in velocity and kinetic energy. This increase in kinetic energy continues as the electrons travel from the cathode to the anode. As the electron moves from cathode to anode, however, its electrical potential energy decreases as it is converted into kinetic energy all along the way. Just as the electron arrives at the surface of the anode its potential energy is lost, and all its energy is kinetic. At this point the electron is traveling with a relatively high velocity determined by its actual energy content. A 100-keV electron reaches the anode surface traveling at more than one

half the velocity of light. When the electrons strike the surface of the anode, they are slowed very quickly and lose their kinetic energy; the kinetic energy is converted into either x-radiation or heat. The electrons interact with individual atoms of the anode material; two types of interactions produce radiation. An interaction with electron shells produces characteristic x-ray photons; interactions with the atomic nucleus produce Bremsstrahlung x-ray photons.

2.1.3 X-ray Production Process

The electrons within an atom each have a specific amount of binding energy that depends on the size (atomic number, Z) of the atom and the shell in which the electron is located. The binding energy is the energy that would be required to remove the electron from the atom. It is actually an energy deficit rather than an amount of available energy. The binding energy of electrons within an atom plays a major role in the production of characteristic x-radiation. The interaction that produces the most photons is the Bremsstrahlung process where electrons that penetrate the anode material and pass close to a nucleus are deflected and slowed down by the attractive force from the nucleus. The energy lost by the electron during this encounter appears in the form of an x-ray photon. All electrons do not produce photons of the same energy.

The high-energy end of the spectrum is determined by the kilovoltage (kVp) applied to the x-ray tube. This is because the kVp establishes the energy of the electrons as they reach the anode, and no x-ray photon can be created with energy greater than that of the electrons. The maximum photon energy, therefore, in keV is numerically equal to the maximum applied potential in kVp (kilovolts). In some x-ray equipment, the voltage applied to the tube might vary during the exposure because of the cycle nature of the alternating current (AC) electrical system. . The maximum photon energy is determined by the maximum, or peak, voltage during the voltage cycle. This value is generally referred to as the kilovolt peak (kVp) and is one of the adjustable factors of x-ray equipment. In addition to establishing the maximum x-ray photon energy, the kVp has a major role in determining the quantity of radiation produced for a given number of

electrons, such as 1 mAs, striking the anode. Since the general efficiency of x-ray production by the Bremsstrahlung process is increased by increasing the energy of the bombarding electrons, and the electronic energy is determined by the kVp, it follows that the kVp affects x-ray production efficiency.

On the other hand the type of interaction that produces characteristic radiation involves a collision between the high-speed electrons and the orbital electrons in the atom. The interaction can occur only if the incoming electron has a kinetic energy greater than the binding energy of the electron within the atom. When this condition exists, and the collision occurs, the electron is dislodged from the atom. When the orbital electron is removed, it leaves a vacancy that is filled by an electron from a higher energy level. As the filling electron moves down to fill the vacancy, it gives up energy emitted in the form of an x-ray photon. This is known as characteristic radiation because the energy of the photon is characteristic of the chemical element that serves as the anode material.

Actually, a given anode material gives rise to several characteristic x-ray energies. This is because electrons at different energy levels (K, L, etc.) can be dislodged by the bombarding electrons, and the vacancies can be filled from different energy levels. The kVp value also strongly influences the production of characteristic radiation where no characteristic radiation will be produced if the kVp is less (numerically) than the binding energy of the K-shell electrons. The x-ray beam that emerges from a tube has a spectrum of photon energies determined by several factors. A typical spectrum is shown in (Fig 2.6) and is made up of photons from both Bremsstrahlung and characteristic interactions.

The relative composition of an x-ray spectrum with respect to Bremsstrahlung and characteristic radiation depends on the anode material, kVp, and filtration. In a tungsten anode tube, no characteristic radiation is produced when the kVp is less than 69.5.At some higher kVp values generally used in diagnostic examinations; the characteristic radiation might contribute as much

as 25% of the total radiation. In molybdenum target tubes operated under certain conditions of kVp and filtration, the characteristic radiation can be a major part of the total output (Ball & Moore's, 2008).

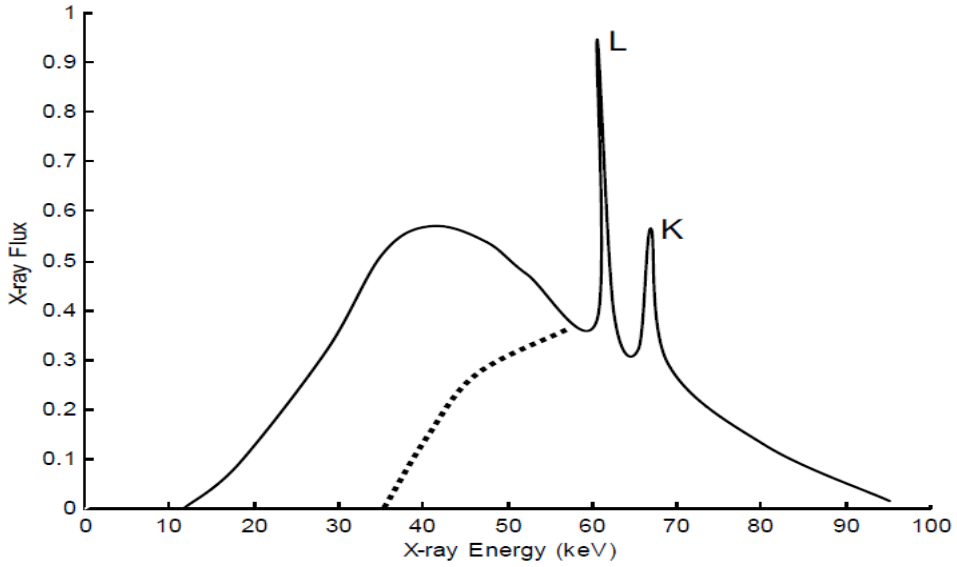

Figure 2.6: Photon Energy Spectrum for a Machine Operating at 100 KVP (Chris & Dominic, 2005)

2.1.4 Types of Radiographic Image Formation and Processing

There are several fundamental differences between SFR systems and digital (CR or DR) systems in terms of the physical processes involved in image acquisition. The different processes introduce different constraints on the factors determining image quality, such as spatial resolution, contrast, and noise.

2.1.4.1 Conventional or Screen/Film Radiography (SFR)

In this type of radiography (Fig 2.7), radiation is originally recorded via a normal photographic film where energetic X-ray photons are absorbed in silver halide (NaB-NaI) crystals, generating extremely small amounts of free silver. During chemical processing of the X-ray film, grains with small amounts of free silver are totally changed to metallic, nontransparent silver, while the remaining untreated silver halide is removed with fixative. To increase sensitivity and thus lower radiation dose, photosensitive film emulsions are often thicker and occasionally coated on both

sides of the film in contrast to normal photographic film. Any film has a specific range of optimal sensitivity (exposure range from completely transparent to completely black). Although modern equipment is normally assisted by electronic exposure meters, the correct choice of film, exposure time, exposure current and high voltage are controlled by the technologist. Sensitivity is improved by placing the X-ray film in contact with two sheets of intensifying screen, consequently lowering radiation exposure of the patient. The intensifying screen contains chemical compounds of rare earth elements, which emit visible blue-green light when hit by X-rays or other ionizing radiation types. This permits the use of photographic film with thinner emulsions and more normal sensitivity to visible light (Jensen and Wilhjelm, 2006). Intensifying screens have a considerable blurring effect on radiographic image quality, which depends on the thickness and type of screen. The main factor to consider in the selection of intensifying screens for a specific radiographic examination is the balance between patient exposure and image quality or more specifically between receptor sensitivity and image blurring. Screens that produce sharp images generally have low sensitivity and require moderately high exposure. On the other hand, screens with high sensitivity cannot produce images with high visibility of detail, owing to greater blurring (Sprawls, 2005).

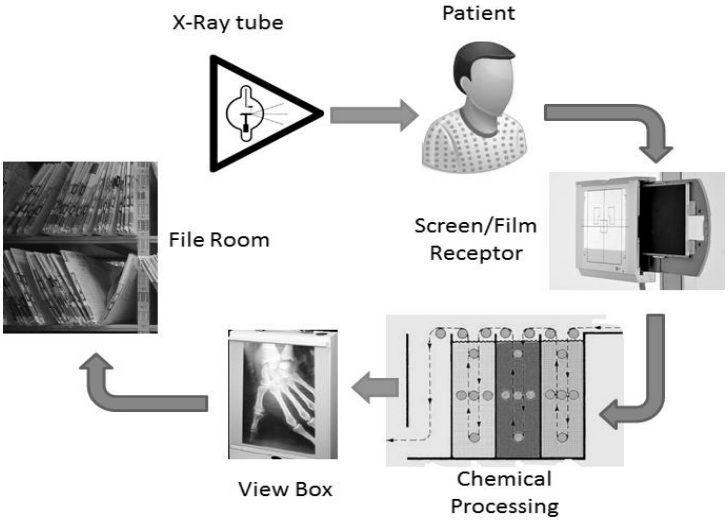

Fig 2.7: Screen/film radiography

Most receptors are given a nominal speed rating by the manufacturer. The actual speed varies, especially with the x-ray spectrum (kVp) and film processing conditions. The sensitivity (speed) of an intensifying screen-film receptor depends on the type of screen and film used in addition to the conditions under which they are used and the film is processed. The most significant effect of intensifying screens on image quality is that they produce blur which related to the thickness and light transparency of the intensifying screen. The major issue in selecting intensifying screens for a particular clinical application is to compromise between patient exposure and image quality or, more specifically, between receptor sensitivity (speed) and image blurring (visibility of detail). Screens that produce maximum visibility of detail generally have low absorption efficiency (sensitivity) and require a relatively high exposure. On the other hand, screens with a high sensitivity (speed) cannot produce images with high visibility of detail because of the increased blurring. The range of receptor sensitivity and speed values used in radiography is shown in (Table 2.1) below.

Table 2.1: The range of receptor sensitivity and speed values used in radiography

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Speed	Sensitivity (mR)
1200	0.1
800	0.16
400	0.32
200	0.64
100	1.28
50	2.56
25	5.0
12	10.0

2.1.4.2 Computed Radiography (CR)

2.1.4.2.1 History of CR

CR is a radiographic imaging digital technology introduced by Fujifilm in the 1980s. The technique uses a specific storage phosphor plate similar to intensifying screens to capture the image before transfer to a computer. The design and physics of IPs are very similar in concept to conventional phosphor screens used with film (Rowlands, 2002) .Fig 2.8 shows a comparison of conventional screen versus imaging phosphor plate. Upon exposure of phosphor plates to X-rays, part of the radiation energy is absorbed by electrons, which temporarily store the image. The latent image produced is read by scanning the imaging plate with a laser light. The electrons then release visible light, which is detected and converted to a digital image (Greene et al, 1992).The image is stored on the computer as a digital file, and can be viewed, transferred electronically, or printed out on film or paper. Additionally, the computer system allows management of the processed image to enhance viewing (John et al, 2004).

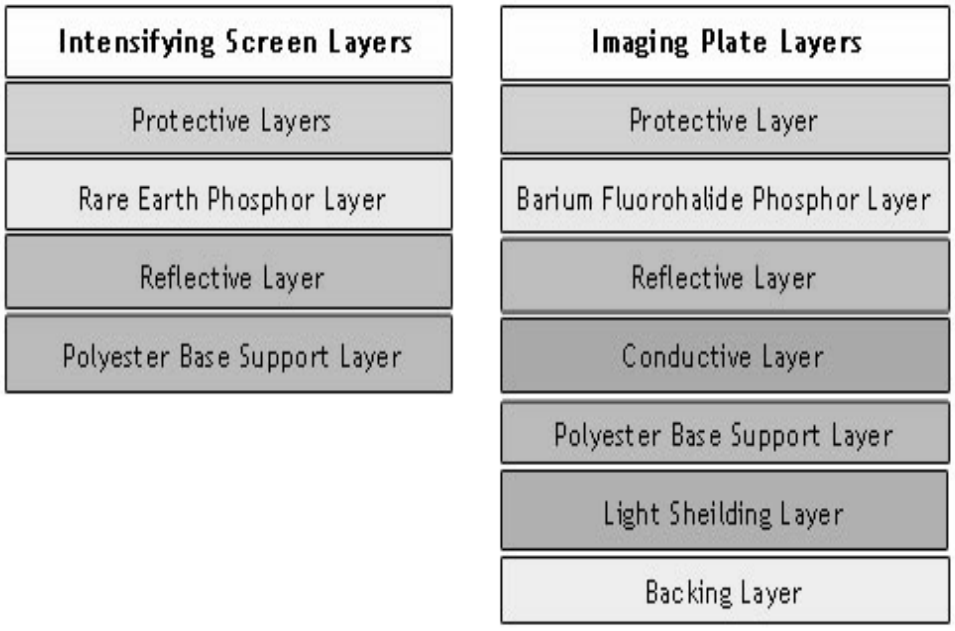

Fig 2.8: Comparison of conventional screen versus imaging phosphor plate (Fuji, 2000)

2.1.4.2.2 CR Image Formation & Processing

The fundamental of CR imaging is illustrated in Figure 2.9 below:

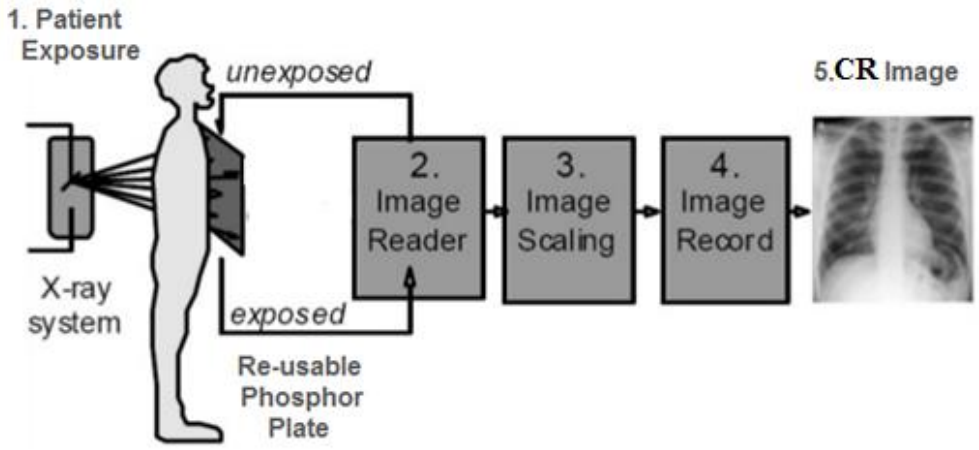

Figure 2.9: Image formation In CR (Zhao et al, 2006)

The CR image formation and processing is summarized as follows:

1. Using standard X-ray equipment, the IP (within the cassette) is exposed. The x-ray photons pass through the subject and strike the IP to form the latent image.
1. The IP is typically bar-coded at an Image and Information Processing (IIP) station to ensure proper processing.
2. The Cassette is then inserted into the CR Reading Unit and the IP is mechanically removed for processing.
3. The IP is transported through the system where is scanned with a high-energy laser beam of a specific wave length (Fig 2.10). The stored energy is set free as emitted light known as Photostimulable Luminescence (PSL) having a wave length different from that of the laser beam.
4. The PSL is collected and passed through a photomultiplier, then converted to a digital signal.
5. Data recognition processes occur to meet the specified diagnostic need. The signals are reconstructed for output with a specified set of image processing parameters applied. The image can be sent to another Computer and/or Laser printer.

6. After the readout and image processing is completed, the IP is exposed to high intensity light erasing any latent image.
7. The IP is then returned to the cassette, ready to be used for another image acquisition

2.1.4.3 Digital Radiography (DR) Image Processing

2.1.4.3.1 History of DR

The development of computed radiography (DR) over the past two decades has improved radiological imaging. The development of digital radiography begins with the rapid development and use of computer technologies. Digital radiography was launched in the middle of 1980swith a steady growing, and it is now replacing screen film radiography (SFR) in the all radiology applications (Bansal,2006).The use of digital image capture devices in (DR) gives the advantages of immediate image preview and availability; elimination of costly film processing steps; a wider dynamic range as well as the ability to apply special image processing techniques that enhance overall display quality of the image. The following table (Table 2.2) gives a timeline on the evolution of digital imaging in the Radiology world.

Table 2.2: The evolution of digital imaging in the Radiology world

Year	Development
1980	Computed Radiography (CR) , storage phosphors
1987	Amorphous selenium –based image plates
1990	Charged- coupled device(CCD) slot-scan direct radiography
1994	Selenium drum DR
1995	Amorphous silicon-cesium iodide (scintillator) flat -panel detector
1995	Selenium-based flat-panel detector
1997	Gadolinium-based (scintillation) flat -panel detector
2001	Gadolinium-based (scintillation) portable flat -panel detector

2.1.4.3.2 DR Image Formation and Processing

In DR image data are recorded with direct electronic detection devices. This eliminates the manual steps required in manipulating the cassette and the time needed for PSP read-out and processing. A variety of image capture configurations are used in DR systems. These configurations can consist of either large-area, flat-panel detectors with integrated thin-film transistor (TFT) readout mechanisms, or integrated PSP plate scanning mechanisms. Alternatively, DR systems can house an optic lens that immediately translates the analog image to a digital image with a charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) image sensor. Facilities should note that whereas CCD units can be serviced if problems arise, TFT mechanisms must be entirely replaced if they malfunction. In general, DR imaging processes result in an almost instant display of the desired diagnostic image on a monitor and can substantially reduce the amount of time needed for successful imaging study. Flat-panel DR systems can either be characterized as providing a direct or indirect image capture. Indirect systems accomplish image capture through a process in which a scintillator turns x rays into light during exposure. A silicon photodiode then converts this light into an analog electrical charge. The TFT accomplishes the storage, digital translation, and readout of this electrical charge. Direct systems, meanwhile, house a selenium-based x-ray photoconductor that turns X rays into an electrical charge, which can then be processed by the TFT. This eliminates the photodiode process and the step of converting x rays into light. In the present day, manufacturing companies supply a host of digital imaging solutions with diverse detector technologies. Digital detectors allow the usage of digital picture archiving and communication systems in which images are stored digitally and shared using web-based technology with no image loss. Digital radiography additionally facilitates higher patient throughput and greater dynamic range of detectors with reasonable reduction in radiation dose (Körner et al, 2007).

Table 2.3 shows summary comparing properties of CR and DR modalities (Herrmann, 2008).

Table 2.3: Summary comparing properties of CR and DR modalities

	Computed Radiography	Digital Radiography
Image acquisition process	• A PSP plate within the cassette is exposed • Latent image is captured in the plate as electrons are excited when exposed to radiation • Cassette is placed in a reader to capture and analyze the image data Laser and analog - to digital convertor translates signal to digital binary code	• Build in image captured plates are used (no cassette required) • Large-area, flat-panel detectors with integrated TFT readout mechanisms, or optic lens used to translate the analog image to digital image
Image Quality	• Digital environment presents opportunities to improve image interpretation and diagnostic strength • Potential of low image noise and lower Radiation exposure with appropriate system adjustments	• Digital environment presents opportunities to improve image interpretation & diagnostic strength • Potential of low image noise and lower radiation exposure with appropriate system adjustments • May offer potential for better image quality with lower radiation dose than CR
Potential Advantages	• Unlimited manipulation and position of image receptor	• Shorter turnaround time for viewing image • Freeing of staff time
Potential Disadvantages	• Slower, more complex workflow	• Higher cost

CR=Computed Radiography; **DR**= Digital Radiography; **PSP**= Photostimulable phosphor; **TFT**= thin film transistor

Digital Radiography (DR) systems as shown in Fig 2.10 can be divided into direct and indirect depending on the type of x-ray conversion used. Direct conversion requires a photoconductor that converts x-ray photons into electrical charges by setting electrons free (Yaffe et al, 1997).Photoconductor materials used in DR include amorphous selenium, lead iodide, lead oxide, thallium bromide, and gadolinium compounds but most commonly used element is selenium. The newer generations of direct conversion digital radiography (DR) systems make use of a layer of selenium with a corresponding underlying array of thin-film transistors (TFTs). (Körner et al, 2007).

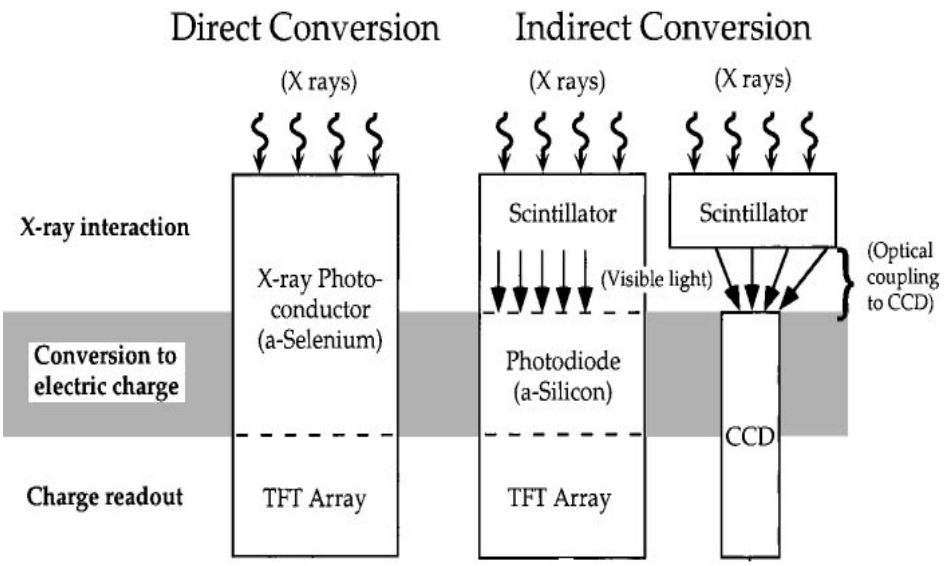

Figure 2.10: Direct and indirect x-ray conversion in DR (Radiology, 1999)

Indirect-conversion detectors, on the other hand, have a two-step process for x-ray detection; a scintillator is the primary material for x-ray interaction. When x rays strike the scintillator, the x-ray energy is converted into visible light, and that light is then converted into an electric charge by means of photo detectors such as amorphous silicon photodiode arrays or CCDs. In both direct- and indirect-conversion detectors, the electric charge pattern that remains after x-ray exposure is sensed by an electronic readout mechanism, and analog-to-digital conversion is performed to produce the digital image (Harrell. et al, 1999).

2.1.5 Image quality in Projection Radiography

2.1.5.1 Backgrounds

Image quality in diagnostic radiography, defined as the ability of the image receptor to record each point of the image as a point on film, involves many factors. The quality mainly depends on the characteristics of the imaging and processing equipment, techniques applied, and clinical criteria required to fulfill the diagnostic purpose. The ultimate purpose in radiography practice is to establish an acceptable balance between obtaining images of satisfactory quality for clinical purposes and the lowest possible radiation dose. SFR images are assessed based on four quality

factors, specifically, density, contrast, resolution and distortion. Table 1 summarizes the primary and influencing factors determining the quality of each image and their effects on radiographic film quality (Bontrager, 2005).

2.1.5.2 Image Quality in Film-Screen Radiography (FSR)

2.1.5.2.1 Film Images

Film images (Radiographs) provide a two dimensional image of anatomical structures. The exposed film must undergo chemical processing for the image to be visible. The various shades of grey displayed on the image are representative of the densities of atomic numbers of the tissues being examined.

2.1.5.2.2 Exposure Factors for FSR

The exposure factors (Technique Factors) which selected from the control panel by the operator includes:

- Kilovoltage (kVp) which controls the penetration power (energy) of the beam
- Milliamperage (mA) which controls the number of x-ray produced
- Exposure Time (ms) which controls the duration of the exposure

Each of these exposure factors has a specific effect on the quality of the radiographic image, and each of these factors will be determined by many variables, including the atomic number and thickness of the anatomic part, the speed of the film screen system, and the suspected pathology (Bontrager, 2005).

2.1.5.2.3 FSR Quality Factors

Film screen (Conventional) images are evaluated based on four quality factors. These factors include; density, contrast, resolution and distortion. Each of these four factors has specific parameters by which it is controlled. Table 2.4 presents FSR primary and controlling factors.

Table: 2.4: Image quality factors and their controlling/influencing factors in FSR.

Image Quality Factor / Definition	Primary Controlling Factor(s)	Main Influencing (Secondary) factors and their effects on image quality
Radiographic Density: The amount of blackening on processed x-ray film	▪ **mAs**: Control the number of emitted X-rays mAs (+)* = Density(+)	▪ kVp (+) = Penetration (+) = **Density** (+) ▪ SID (+) = X-ray intensity (-) = **Density** (-) ▪ F/S speed (+) = Response to x-ray (+) = **Density**(+) ▪ Object thickness (+) = Attenuation (+) = **Density** (-) ▪ Processing developer time/temp. (+) = **Density** (+) ▪ Grid Ratio (+) = Attenuation (+) = **Density** (-)
Radiographic Contrast: The difference in density on adjacent areas of a radiographic image	▪ **kVp**: Control the energy (penetration power) of x-rays and hence controls attenuation kVp (+) = Contrast(-)*	▪ Scattered radiation (+) = Contrast (+) ▪ Object thickness (+) = Scattered (+) = Contrast(-) ▪ Processing developer time/temp. (+) = Contrast (-) ▪ Use of Grid (+) = Scattered (-) = Contrast (+) ▪ Collimation (+) = Scattered (-) = Contrast (+)
Resolution The recorded sharpness (details) of structures on the image	▪ **Geometric Factors:** - Focal spot size (+) = Geometric sharpness (-) - Source Image Receptor Distance (SID) (+) = Geometric sharpness (+) - Object Image Receptor Distance (SID) (+) = Geometric sharpness (-) ▪ **Film screen system:** - Film/Screen Speed (+) = Sharpness (-) ▪ **Motion:** - Motion (+) = Sharpness (-)	
Distortion The misrepresentation of object size or shape as projected onto the radiographic recording media	▪ **SID** (+)= Image Size Distortion (Magnification) (-) ▪ **OID** (+)= Image Size Distortion (Magnification) (+) ▪ **Object image receptor alignment** ▪ **Central ray alignment/centring** Misalignment = Image Shape Distortion (elongation/ foreshortening) (+)	

* (+) = Increased * (-) = Decreased

2.1.5.2.3.1 Density

Density in radiography is defined as the amount of blackening on the processed film image .The primary controlling factor of density is mAs which control the number of x-rays emitted from the x-ray tube and the duration of the exposure. Other factors that affect radiographic density includes; source to image receptor distance (SID) , kVp , part thickness , chemical development time/temperature , use of grid, and film- screen speed. Table 2.4: shows the effect of different factors on radiographic density.

2.1.5.2.3.2 Contrast

Radiographic contrast is defined as the difference in density on adjacent areas of a radiographic image. As illustrated in Figure 2.11 the contrast and visibility of objects that ultimately appears in the image is developed in steps and determined by many factors,

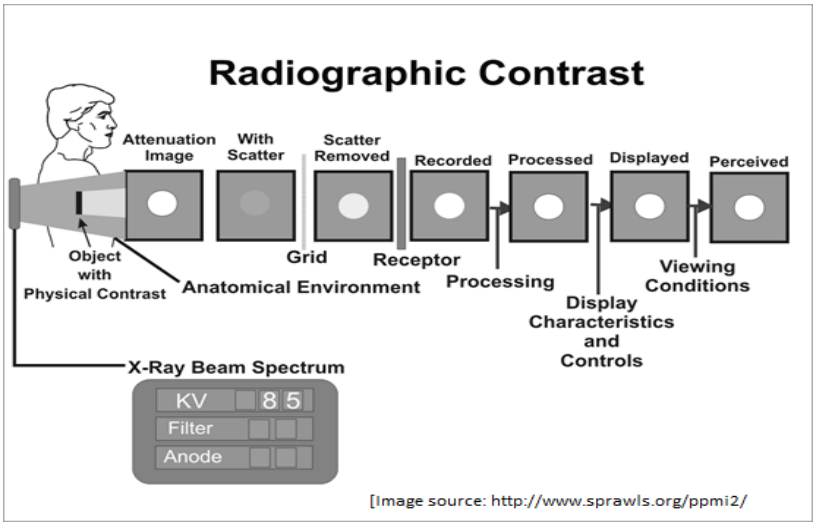

Figure 2.11: Factors That Affect Radiographic Contrast

Contrast also can be described as long scale or short scale contrast, referring to the total range of all optical densities from the lightest to the darkest part of the radiographic image. The primary controlling Factor in film screen radiography is the Kilovoltage (kVp) which controls the penetration power (energy) of the produced x-ray beam. The higher the kVp result in the greater energy and the more uniformly the x-ray beam penetrates the various mass densities of all tissues. Therefore higher kVp produces less variation in attenuation resulting in lower contrast. (Fig 2.12) shows the scale and relative measures of contrast according to the applied kVp.

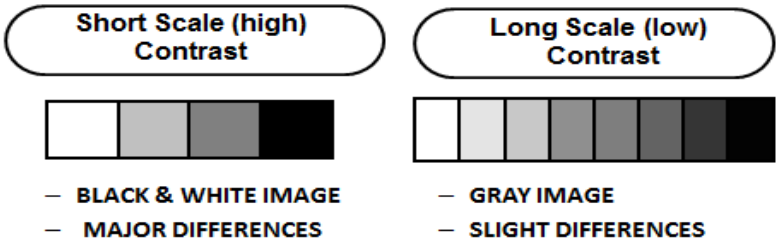

Figure 2.12: Scale and relative measures of contrast

Other factors that affect radiographic contrast includes; the amount of scatter radiation received by the film, the use of grid, collimation of the beam, and the tissue density. The amount of scatter produced dependent on the intensity of the x-ray beam, the amount of tissue irradiated, and the type/thickness of the tissue. Close collimation of the x-ray field reduces the amount of tissue irradiated, thus reducing the amount of scatter produced, thus increasing contrast. Close collimation also reduces the radiation dose to the patient and the technologist (Bontrager, 2005).

2.1.5.2.3.3 Resolution

Resolution is defined as the recorded sharpness (Recorded details) of structures on the image. Resolution of film screen images is measured and expressed as line pairs per millimeter (lp/mm), which is typically 5 to 6 lp/mm. degradation or lack of resolution is known as blur or unsharpness. Resolution of film screen imaging is controlled by geometric factors film screen system, and motion. Geometric factors that influence resolution are focal spot size, source to image receptor distance (SID), and object to image receptor distance (OID).The effect of these factors are explained in (Table 2.4).

2.1.5.2.3.4 Distortion

Distortion is defined as the misrepresentation of object size or shape as projected on the radiographic image. There are two types of distortion: size distortion (magnification) and shape distortion. The four primary controlling factors of distortion are the source image receptor distance (SID), the object image receptor distance (OID), the object image receptor alignment, and the central ray alignment. Increasing the SID results in less image magnification, on common practice 40 inches (100-102 cm) SID is used for most radiographic exam except chest radiographs which obtained at a minimum SID of 72 inches (180cm) keep less magnification of the heart as well as other structures within the thorax. The other radiographic exam that requires an increasing in the SID is the lateral cervical spine which obtained at 60 to 72 inches (150-180cm) to compensate for the increased OID and provide for less magnification.

The effect of object image receptor distance (OID) on magnification (size distortion) is illustrated in Fig. 2-13.The closer the object being radiographed to the image receptor, the less magnification and the better detail or resolution.

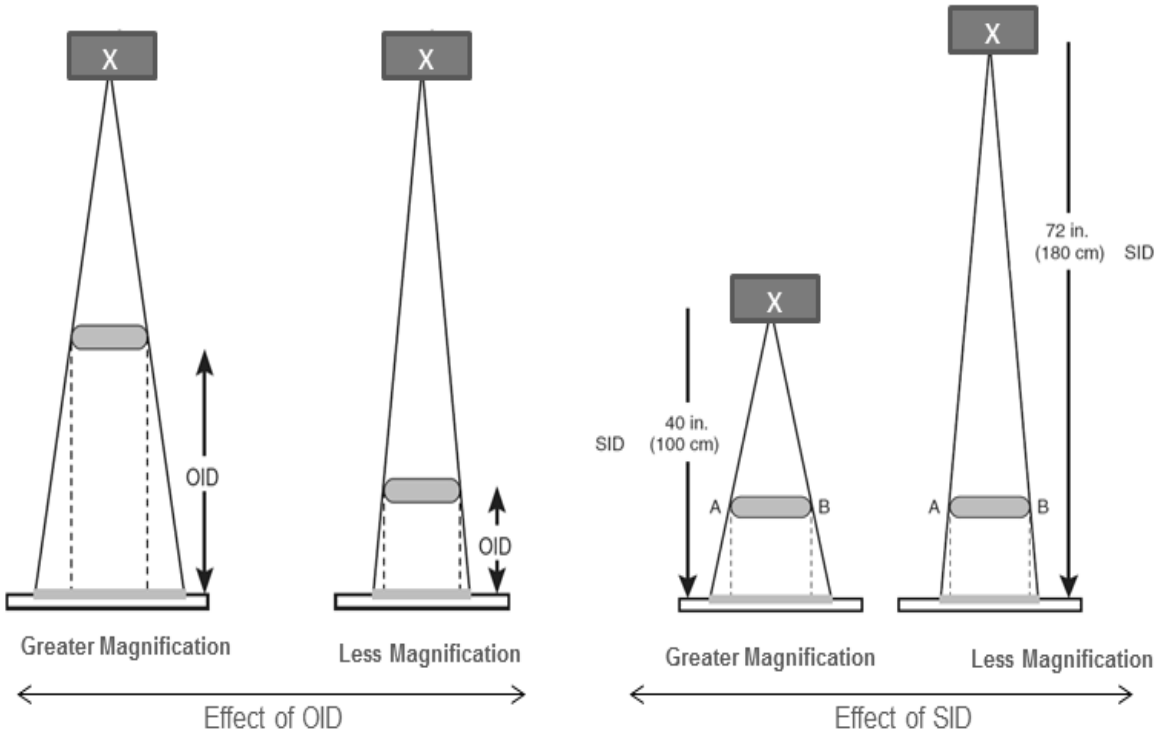

Figure 2.13: The relationship between OID, SID and image magnification

On the other hand correct central ray and object image receptor alignment is important factors in minimizing possible image distortion. The object image receptor alignment refers to the alignment of the part to be examined in relation to the plane of the image receptor(IR) .Any misalignment of the part to be examined in relation to the plane of the image receptor (IR) will result in shape distortion. The central ray alignment is also an important factor in radiography. The center of x-ray beam (CR) has no divergence, because it projects the part at 90 degrees (perpendicular) to the plane of the image receptor (IR). Therefore the least shape distortion occurs at the center of the x-ray, while increases when the angle of divergence increased from the center of the x-ray beam to the outer edges.

2.1.6 Image Quality in Digital Radiography

2.1.6.1 Digital Radiographic Images

Digital radiographic images are a numeric symbol of X-rays that pass through the patient. The digital image is formed by a matrix of picture elements (pixels). Each pixel represents a small portion of the original information. The processing of digital images requires systematic highly complex mathematical algorithms. Control and optimization of digital image quality are achieved through a number of manipulation techniques to enhance image appearance. The advantage of digital imaging over SFR is the ability to post-process the image, specifically, enhancing the electronic image in order to improve diagnostic quality.

2.1.6.2 Digital Image Quality Factors

As with SFR, many factors affect image quality in digital radiography, including brightness, contrast, resolution distortion, exposure index and noise, as presented in Table.2.5.

2.1.6.2.1 Brightness

Brightness is the intensity of light representing the image pixels on the monitor. Digital imaging systems are designed to display the optimal image brightness under a wide range of exposure factors, and controlled by processing software through digital processing algorithms. The operator can apply the post processing algorithms to modify the pixel values of the image .Windowing is used to manipulate and adjust the brightness of the digital image after exposure by altering the window level (WL) within a certain range .The smoothing and edge enhancement of the image also can be increased for better brightness.

2.1.6.2.2 Contrast

Contrast in digital imaging is defined as the difference in brightness between light and dark areas of the displayed image. Digital imaging systems are designed to electronically display the optimal image contrast under a wide range of exposure factors. The radiographic contrast is controlled by processing software through digital processing algorithms. The operator can adjust

the contrast of the digital image after exposure by manipulating the window width (WW) within a certain range. In digital imaging each picture element (pixel) demonstrates a single shade of grey when viewed on the monitor (Bontrager, 2005).

Table: 2.5: Image quality factors and their controlling/influencing factors in DR.

Image Quality Factor	Definition / Controlling Factor(s)
Brightness	▪ **Definition:** The intensity of light representing image pixels on the monitor ▪ **Controlling factors:** The optimal digital image brightness is influenced by a wide range of exposure factors, and controlled by processing software through digital processing algorithms. The operator can apply post processing algorithms to modify pixel values of the image. Windowing is used to manipulate and adjust the brightness of the digital image after exposure by altering the window level (WL) within a certain range. Smoothing and edge enhancement of the image can also be increased for better brightness.
Contrast	▪ **Definition** The difference in brightness between light and dark arrears of an image ▪ **Controlling factors:** Control of scatter radiation is an important factor in obtaining the appropriate image contrast through correct use of grid, close collimation, and selection of optimal KVPp ▪ Radiographic contrast is affected by the digital processing computer through application of predetermined algorithms. Through post processing, the user can manipulate the contrast of the digital image
Resolution	▪ **Definition** The recorded sharpness or detail of structures on the image ▪ **Controlling factors:** Traditional factors as for film screen imaging besides acquisition pixel size inherent to the digital imaging detector and display matrix. Perceived resolution of the image dependent on the display capabilities of the monitor
Distortion	▪ **Definition** The misrepresentation of an object size or shape as projected onto recording media ▪ **Controlling factors:** As for film screen imaging, the factors that affect distortion are the source image receptor distance (SID), object image receptor distance (OID), object image receptor alignment, and central ray alignment (Table.1)
Exposure Index (EI)	▪ ***Definition:*** EI is a measure of the amount of exposure received by the image receptor ▪ ***Controlling factors:*** EI is dependent on mAs, total detector area irradiated, and beam attenuation. The exposure index is indicative of image quality. Equipment manufacturers provide a recommended EI range for optimal image quality
Noise	▪ **Definition:** random disturbance that obscures or reduces clarity. ▪ **Controlling factors:** Technologists must ensure that exposure factors used for examination are not beyond those required for the projection by checking the exposure index to avoid needless overexposure of the patient. On the other hand, scattered radiation is a potential source of noise that can be controlled by the use of grids and correct collimation. Image noise may also be related to the electronic system, non-uniformity of the image receptor or power fluctuations.

The demonstrated range of possible shades of grey is related to pixel's bit which controls the contrast resolution of the image. On the other hand the control of scatter radiation s is an important factor in obtaining the appropriate image contrast through correct use of grid, close collimation, and selection of optimal kVp (Bontrager, 2005).

2.1.6.2.3 Resolution

Resolution in digital imaging is a combination of the traditional factors as for film screen imaging beside the acquisition pixel size which inherent to the digital imaging detector and the display matrix. Minimum resolution size in digital imaging is measured in microns ranged from 100-200 microns which equal to approximately 5 to 2.5 line pairs per mm. Resolution describes the ability of an imaging system to distinguish or separate (i.e., resolve) objects that are close together. The resolving capability of a particular imaging process is determined by the amount of blur. When blur is present, the images of individual objects begin to run or blur together until the separate objects are no longer distinguishable. Figure 2-14, below illustrates the effect of blur on resolution.

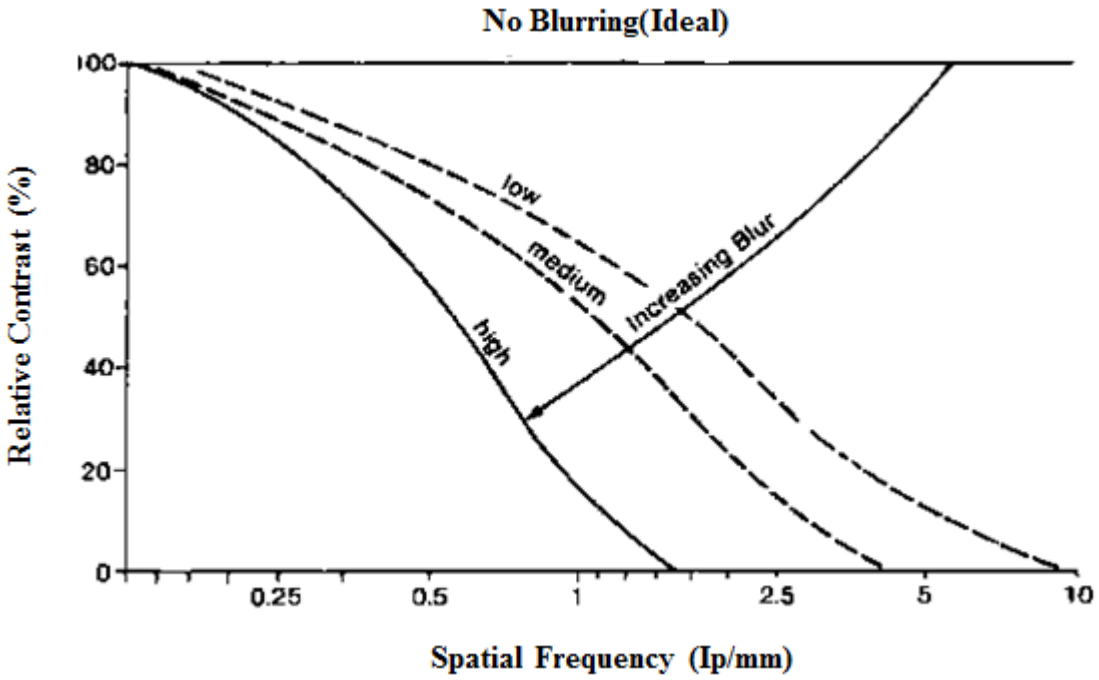

Figure 2.14: Effect of blur on Resolution

When no blur is present, all of the line-pair groups can be resolved. As blur is increased, however, resolution is decreased, and only the lines with larger separation distances are visible (Sprawls, 2005).

2.1.6.2.4 Distortion

As for film screen imaging the factors that affect distortion are the source image receptor distance (SID), the object image receptor distance (OID), the object image receptor alignment, and the central ray alignment.

2.1.6.2.5 Exposure Index

Exposure index (EI) is the measure of the amount of exposure received by the image receptor (IR). It is dependent on mAs; total detector area irradiated, and beam attenuation. The exposure index is indicative of the image quality. Equipment manufacturers provide a recommended EI range for optimal image quality (Bontrager, 2005).

EI in digital radiography can be compared to film speed and blackening in film-screen. When film was used, the accuracy of the exposure was obvious based on the appearance of the image. Digital systems post-process images and display adequate contrast and brightness at a much wider range. Therefore, adequate exposure can only be assessed through image noise or burn-out. Secondary workstations such as those used by technologists for image review are often of lower resolution and brightness than those used for diagnosis. Because of this, it is often difficult to assess whether an image is noisy or not. The exposure index is meant to be an indication of whether the noise levels are acceptable (AAPM, 2009).EI is derived from the mean detector entrance exposure which is derived from the mean pixel value of the image. Most systems use a histogram analysis in order to calculate the mean pixel value (Neitzel, 2004).

Although EI is always derived from the IR exposure, equipment manufacturers calculate the numeric value differently as shown in table 2.5, resulting in different ranges and definitions. Also, there is variation between units purchased from the same manufacturer based on different IRs and software (Carlton & Adler, 2006).Different IRs has different detective quantum

efficiency (DQE). A high DQE results in lower noise levels [AAPM, 2009]. Therefore, all systems have a different index and are difficult to compare across systems.

Table: 2.5: Examples of calculating the numeric value of EI by different manufacturers

Manufacturer	Method Of (EI) Calculation
Fuji CR	Fuji uses a sensitivity number (S) that is related to the amount of amplification required by the photomultiplier tube to adjust the digital image. S is inversely proportional to exposure. Properly exposed images should have an S between 150-250 (Carlton & Adler, 2006, p. 367)
Kodak CR	Kodak uses the term Exposure Index, which is directly proportional to exposure. Properly exposed images should have an EI between 1,800-2,200 (Carlton & Adler, 2006), A change of 300 in the EI indicates a change of a factor of 2 in the exposure to the IR.
Philips DR	Philips uses an EI that is inversely proportional to exposure. This index is represented in bigger discrete steps (e.g., 100, 125, 160, 200, 250, 320, 400, 500, etc). Each step requires a 25% change in exposure to occur (AAPM, 2009). An optimal exposure lies between 200 and 800.
GE DR	GE uses the detector exposure index (DEI) which compares the detector exposure to the expected exposure value (AAPM, 2009).
Siemens	Siemens uses an Exposure Index (EXI). EXI is calculated by dividing the field into a 3x3 matrix and assessing only the central segment, and is based on the selected organ program. EXI is directly proportional to dose. Doubling dose doubles the EXI. EXI depends on organ program, whether manual exposure or AEC was used, and the measuring field (AAPM, 2009).

2.1.6.2.6 Noise

Noise is defined as a random disturbance that obscures or reduces the clarity. In radiographic this translates into grainy or mottled appearance of the image. One way to describe noise in digital imaging is the concept of signal-to-noise-ratio (SNR), where the number of x-ray photons that strike the detectors (mAs) can be considered the "signal" while other factors that negatively affect the final image are classified as "noise".A high SNR is desirable in imaging where the signal (mAs) is greater than the noise in order to demonstrate low-contrast soft tissue structures. A low SNR is undesirable as low signal (mAs) with the accompanying high noise obscures soft tissue detail and demonstrates a grainy or mottled image .Technologists must ensure that

exposure factors used for desired exam are not beyond what is required for the projection by checking the exposure index so as not to overexpose the patient needlessly. On the other hand the scattered radiation is a potential source of noise that can be controlled by the use of grids and correct collimation. Image noise also can be related to the electronic system, nonuniformity of the image receptor, or power fluctuations (Bontrager, 2005).

2.1.7 Overview of Radiation Protection and Dosimetry in Projection Radiography

2.1.7.1 Biologic Damage Potential.

When x- radiation penetrates the human body, it deposits energy. The energy absorbed from exposure to radiation is termed a dose. The quantities of this dose are classified as: absorbed, equivalent, and effective dose.

The absorbed dose is the deposited amount of energy in a material, and measured by the gray (Gy). The equivalent doses calculated when multiplying the absorbed dose by the radiation weighting factor (WR) and offers the degree of harm of different types of radiation. Multiplying the equivalent dose by the risk factor related to a specific tissue or organ provides the effective dose which measured in sievert. Table 2.7summarizes the weighting factor for the various tissues (NCRP, 1993).

Table 2.7 The weighting factor of the various tissues

Tissue/Organ sensitivity	Tissue weighting factor (W_t)
Gonads	0.2
Bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01

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The hypothetical nonthreshold curve of radiation dose-response states that the response to radiation in terms of biologic effects is directly proportional to the dose of radiation (Fig.2.14). Additionally, no known level of radiation dose exists below which the chance of sustaining biologic damage is zero.

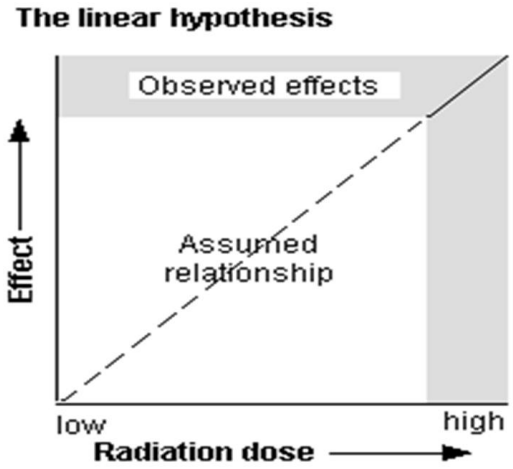


Figure 2.15 Linear No threshold model (ICRP, 2005)

The extent of biologic effects (genetic and somatic) of radiation exposure depends on several factors, including quantity of radiation to which tissue is exposed, capability of radiation to ionize tissue, and the particular body parts and areas exposed to radiation. Ionization produces the greatest biologic damage in the human body when a substantial dose of densely ionizing (high-LET) radiation is delivered to a large or radiosensitive body area. Table 2.8 presents the radiation equivalent dose (EqD) and biologic effect following acute whole-body exposure (Alice et al, 2005).

Table 2.8 Radiation equivalent dose (EqD) and biologic effects of acute whole-body exposure

Radiation EqD (Sv)	Subsequent Effect
0.25	Blood changes (e.g. Measurable hematologic depression, decrease in the number of lymphocytes present in the circulating blood
1.5	Nausea , Diarrhea
2.0	Erythema (diffuse redness over an area of skin after irradiation)
2.5	If dose is administered to gonads, temporary sterility
3.0	50% chance of death
6.0	Death

2.1.7.2 Evaluation of Patient Doses

When performing radiographic examinations, patient doses can be evaluated as entrance surface air kerma (ESAK), the dose administered to the skin where an X-ray beam enters the body, which includes the incident air kerma and backscattered radiation from exposed tissue. ESAK(mGy) is measured using dosimeters or through calculations from the applied exposure factors and measurements of X-ray tube output (George et al, 2004). Another method is the kerma-area product (KAP), defined as the product of the dose in air (air kerma) within the X-ray beam and the beam area, that enables measurement of overall radiation entering a patient. KAP can be measured using an ionization chamber fitted to the X-ray tube. The two methods can be applied to calculate and monitor radiation doses for the various radiological examinations, compared to guidance and diagnostic reference levels (DRL). Many research bodies have been active in the area of DRL, including the International Atomic Energy Authority (IAEA) and International Commission on Radiological Protection (ICRP). The objective of DRLs is to aid in preventing the administration of unnecessary radiation doses to patients that do not support the clinical purpose of a radiographic exam. Tables 2.9 and 2.10 present examples of DRLs for adult and pediatric patients' in common radiographic projections, respectively. Each X-ray facility should set up DRLs following international guidelines with regular assessments and application of corrective action in cases where these levels are exceeded.

Table 2.9 DRLs for selected radiographic projections of adult patients

Radiographic Exam/ Projection	ESD per projection (mGy)		
	(General, U.K) IPSM,1992	IAEA, 1996	(General), EC 1996
Skull AP/PA	5	5	5
Skull LAT	3	3	3
Chest PA	0.3	0.4	0.3
L. spine AP	10	10	10
L. spine LAT	30	30	30
Abdomen AP	10	10	10
Pelvis AP	10	10	10

Table 2.10 DRLs/ projection (uGy) for selected projections of standard five-year old paediatric patients

Radiographic Exam	ESD per projection (uGy)	
	NRPB (2000)	EC (1996)
Skull AP/PA	1100	1500
Skull LAT	800	1000
Chest PA	70	100
Chest LAT	-	200
Abdomen AP	500	1000
Pelvis AP	600	900

2.1.7.3 Comparison of entrance surface dose in SFR, CR and DR

Published literature by the IAEA states that patient dose is a significant concern in digital imaging. With CR and DR, the dose may be increased two to four times or more, and it is difficult to observe differences among the images. Manufacturers of digital imaging systems typically provide an Exposure Index (EI) for each image to optimize image quality and patient dose. EI, an excellent quality control tool, refers to the radiation dose received by the digital imaging receptor, and should be the same for all images of a given radiographic projection. Measurement of EI provides a moderately easy way to monitor the radiation dose used and ascertain dose changes due to different radiographers, X-ray rooms, or over time (IAEA, 2015). A study of radiation doses to patients undergoing standard radiographic examination by Compagnone et al (2006) showed that doses used for computed radiography are higher than those for the conventional screen–film and direct digital radiography. Effective doses for direct digital radiography were ~29% and 43% lower than those for SFR and CR, respectively. Another study conducted by Aldrich et al (2006) focusing on surface doses to patients during chest, abdomen and pelvis radiography showed that CR doses are similar or higher than those for film-screen and lower for DR, compared to FSR, with the possibility of changing the algorithm to decrease the dose to one-quarter of the original value with satisfactory image quality in CR. A survey by Ziliukas et al (2010) revealed that the main problems for exceeding DRLs for standard patients and for all examinations in Lithuania were attributable to

the use of low kilovolt technique, lack of automatic exposure control systems or improper adjustment, in addition to insufficient training of staff. The positive aspect of digital imaging, compared to conventional imaging, is the ability to provide a wide dynamic range using digital detectors besides post-processing capabilities, which allows extension of image information avoids retakes and helps to lower the patient dose (Persliden, 2004).

2.1.8 Radiation Protection in Diagnostic Radiology

Radiation protection objectives

- To avoid any clinically important radiation induced deterministic effect by obeying to dose limits that are beneath the threshold levels
- To limit the risk of stochastic responses to a level as weighted against societal needs, values, benefits acquired, and economic considerations

2.1.8.1 Justification

Justification is the baseline for optimization in diagnostic radiology as stated by the ICRP shall be applied in three levels.

(1) **The first Level:** Is the proper use of radiation in medicine should accepted as doing more good than harm to society.

(2) **The second Level:** Procedures specification: to determine whether the radiological procedure will improve the diagnosis or not

(3) **The second Level:** The particular application of a procedure to an individual patient should be judged to do more good than harm to an individual patient.

2.1.8.2 Optimization

Optimization in diagnostic radiology signifies balancing diagnostic information (image quality) and patient dosage through identifying an image acquisition technique that maximizes the

perceived information content and minimizes radiation risk or keeps it at a reasonably low level (ALARA). Fig.2.16 summarizes the optimization cycle in diagnostic radiography.

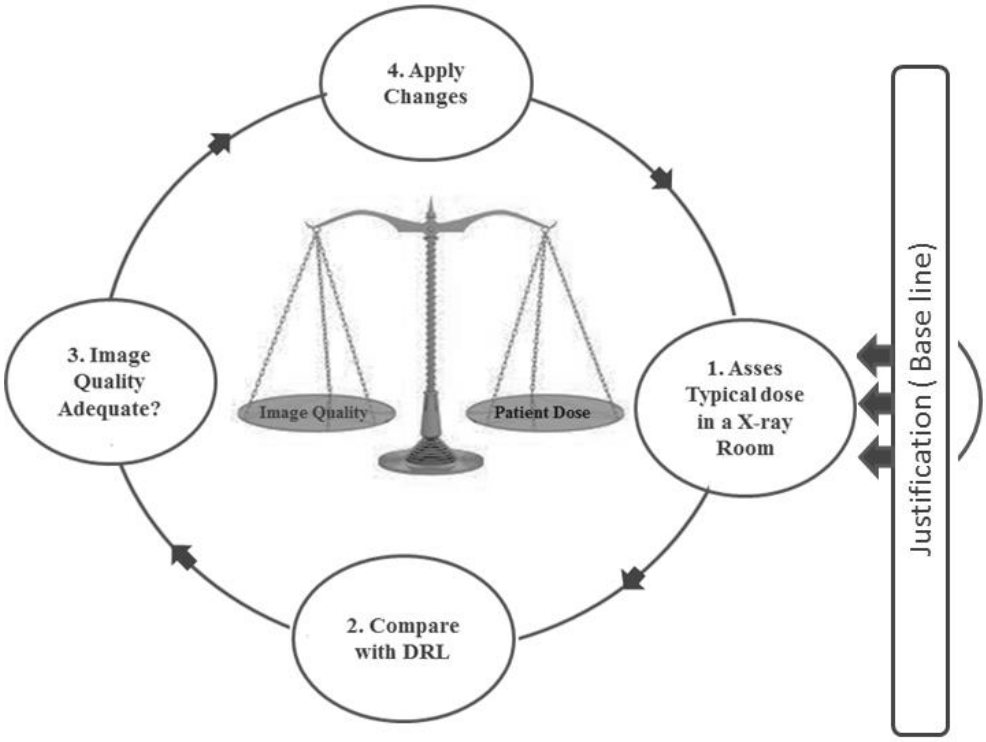


Fig.2.16 Optimization cycle in diagnostic radiography

The factors that affect patient dose and image quality and form the backbone of optimization in diagnostic radiology fall into three categories: facilities and equipment, operational condition and application factors.

2.1.8.3 Dose limits

The concept of radiation exposure and of the associated risk of radiation-induced malignancy is the basis of the effective dose limiting system. Information contained in Report No. 116 of the National Council on Radiation Protection and Measurement (NCRP) and Publication No. 60 of the International Commission on Radiological Protection (ICRP) serves as a resource for the revised recommendations. Future radiation protection standards are expected to continue to be based on risk. The effective dose (*E*) limiting system is the method used for assessing radiation exposure to radiation workers and the general public and its associated risk of biologic damage. These limits

can express for whole-body exposure, partial-body exposure, and individual organs exposure. In diagnostic radiology practice, it is seldom necessary to exceed even 1/10 the appropriate DL. However, because the basis for the DL assumes a linear, non-threshold dose-response relationship, all unnecessary radiation exposure should be avoided. (Bushong, 2009)

2.1.8.3.1 Staff Dose Limits

Dose reduction to the staff can be reduced by the optimisation of patient exposure; thus, the introduction of the diagnostic reference levels (DRL) will certainly improve the control of staff exposure. Moreover, the application of radiation protection simple rules will result in minimizing the staff exposure as much as possible.

2.1.8.3.2 Diagnostic Reference Levels (Patients)

To improve the optimization in diagnostic procedures, the ICRP recommends the use of Diagnostic Reference Levels (DRLs) to ensure the doses do not deviate significantly from internationally reported levels and those achieved at peer departments for that procedure unless there is a known, relevant, and acceptable reason for this deviation. Practitioners and referrers should understand the following hits about DRL for best practices (ICRP, 2007):

1) DRLs are not dose limits; they should be used as investigation levels;
2) DRLs are not applicable to individual patients;
3) Comparison with DRLs shall be made using mean/ median values of a sample of patient doses
4) The use of DRLs should be made in conjunction with the evaluation of the required image quality or diagnostic information
5) DRLs should be applied with flexibility allowing tolerances for patient size, condition, etc.
6) Values that are UNDER the DRLs may not necessarily be optimized values
7) Values that are OVER the DRLs should require an investigation and optimization of the x-ray system or operational protocols;

8) The goal in using DRLs is not to reduce patient doses if image quality or diagnostic information is compromised

9) Compliance or faults with DRLs should be discussed with the staff of the imaging department.

2.1.8.4 Facilities and Equipment

Recognition of the status and performance of radiography equipment forms an important part of optimization. Quality assurance (QA) and quality control (QC) programs should be established for every X-ray facility. QC starts with identifying the purchase specification of imaging equipment based on facility objectives, appropriate checks (Acceptance Testing) before equipment use, identifying equipment usage and replacement policies, along with regular quality control and maintenance, monitoring, recording and auditing of practice (Fig 2.17). QC programs should be initiated in every X-ray facility and cover a selection of the most important parameters associated with the applied X-ray examination (EUR, 1996).

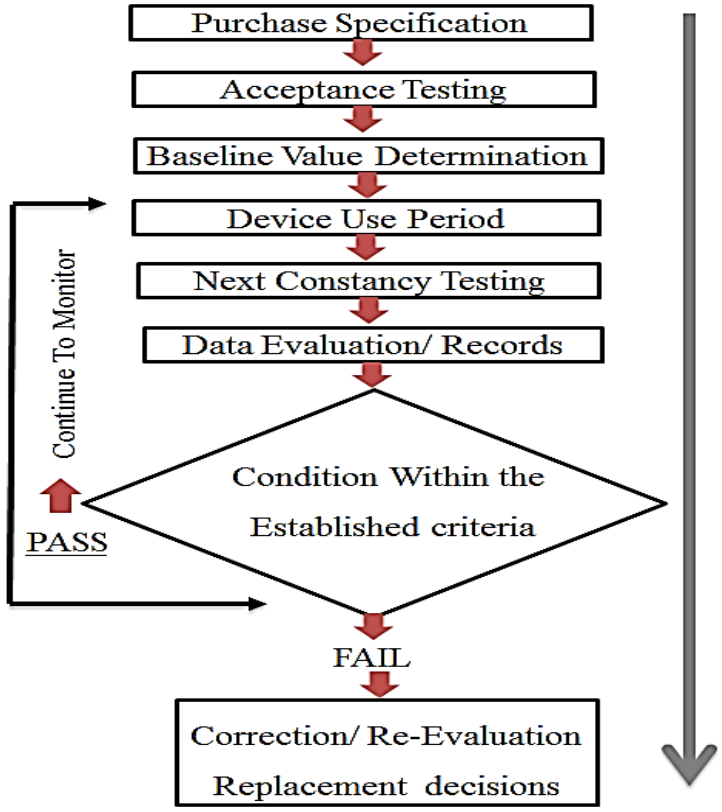


Fig.2.17 Equipment Life Cycle

2.1.8.5 Image Quality Criteria

Establishment of quality criteria for each radiographic examination/projection is an essential part of optimization. These criteria fall into three categories: diagnostic requirements, radiation dose to patients and good radiographic techniques, as stipulated by the European guidelines on quality criteria for diagnostic radiographic images (EUR, 1996).Tables 2.11, 2.12 and 2.13 presents the Quality Criteria for PA chest, AP abdomen and AP pelvis X-ray respectively.

Table 2.11 Sample Quality Criteria for PA Chest X-ray [EUR.16260 EN]

1.DIAGNOSTIC REQUIREMENTS

1.1. Image criteria

1.1.1. Performed at full inspiration (as assessed by the position of the ribs above the diaphragm – either 6 anteriorly or 10 posteriorly) and with suspended respiration

1.1.2. Symmetrical reproduction of the thorax, as shown by central position of the spinous process between the medial ends of clavicles

1.1.3. Medial border of the scapulae outside the lung fields

1.1.4. Reproduction of the whole rib cage above the diaphragm

1.1.5. Visually sharp reproduction of the vascular pattern in the whole lung, particularly peripheral vessels

1.1.6. Visually sharp reproduction of:

(a) trachea and proximal bronchi **(b)** borders of the heart/ aorta **(c)** diaphragm & lateral costo-phrenic angles

1.1.7. Visualization of the retrocardiac lung and mediastinum

1.1.8. Visualization of the spine through the heart shadow

1.2. Important image details

1.2.1. Small round details in the whole lung, including the retrocardiac areas: high contrast: 0.7 mm diameter, low contrast: 2 mm diameter

1.2.2. Linear and reticular details out to the lung periphery: high contrast: 0.3 mm in width, low contrast: 2 mm in width

2. **CRITERIA FOR RADIATION DOSE TO THE PATIENT:**

Entrance surface dose for a standard-sized patient: 0.3 mGy

1. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUES

3.1. Radiographic device: vertical stand with a stationary or moving grid

3.2. Nominal focal spot value: ≤ 1.3

3.3. Total filtration: ≥ 3.0 mm Al equivalent

3.4. Anti-scatter grid: r = 10; 40/cm

3.5. Screen film system: nominal speed class 400

3.6. FFD: 180 (140-200) cm

3.7. Radiographic voltage: 125 kVp

3.8. Automatic exposure control: chamber selected – right lateral

3.9. Exposure time: < 20 ms

3.10. Protective shielding: standard protection

Table 2.12 Quality Criteria for AP Abdomen X-ray [EUR.16260 EN]

1. DIAGNOSTIC REQUIREMENTS

1.1 Image criteria

1.1.1. Reproduction of the area of the whole urinary tract from the upper pole of the kidney to the base of the bladder

1.1.2. Reproduction of the kidney outlines

1.1.3. Visualisation of the psoas outlines

1.1.4. Visually sharp reproduction of the bones

1.2. Important image details: calcifications of 1.0 mm

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

Entrance surface dose for a standard-sized patient: 10 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1. Radiographic device: grid table

3.2. Nominal focal spot value: ≤ 1.3

3.3. Total filtration: 1.3 mm Al equivalent

3.4. Anti-scatter grid: r = 10; 40/cm

3.5. Screen film system: nominal speed class 400

3.6. FFD: 115 (100-150) cm

3.7. Radiographic voltage: 75-90 kVp

3.8. Automatic exposure control: chamber selected — central or lateral

3.9. Exposure time: < 200 ms

3.10. Protective shielding: where appropriate, gonad shields should be employed for male patients.

Table 2.13 Quality Criteria for AP Pelvis X-ray [EUR.16260 EN]

3.DIAGNOSTIC REQUIREMENTS

3.1. Image criteria

1.1.1. Symmetrical reproduction of the pelvis as judged by the imposition of the symphysis pubis over the midline of the sacrum

1.1.2. Visually sharp reproduction of the sacrum and its intervertebral foramina

1.1.3. Visually sharp reproduction of the pubic and ischial rami

1.1.4. Visually sharp reproduction of the sacroiliac joints

1.1.5. Visually sharp reproduction of the necks of the femora which should not be distorted by foreshortening or rotation

1.1.6. Visually sharp reproduction of the spongiosa and corticalis, and of the trochanters

1.2. Important image details 0.5 mm

3.2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

Entrance surface dose for a standard-sized patient: 10 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1. Radiographic device: grid table

3.2. Nominal focal spot value: ≤ 1.3

3.3. Total filtration: ≥ 3.0 mm Al equivalent

3.4. Anti-scatter grid: r = 10; 40/cm

3.5. Screen film system: nominal speed class 400

3.6. FFD: 115 (100-150) cm

3.7. Radiographic voltage: 75-90 kVp

3.8. Automatic exposure control: chamber selected — central or lateral

3.9. Exposure time: < 400 ms

3.10. Protective shielding: where appropriate, gonad shields should be employed for male patients, and for Female patients, if possible.

2.1.8.6 Operational Conditions Associated with Optimization

Standardization of operational conditions plays a major role in optimization. An example of operational conditions that should be standardized for better outcome, as stated in the European guidelines on quality criteria for diagnostic radiographic images (EUR., 1996) and other published literature is presented in Table 2.14.

Table 2.14 Summary of Operational Conditions Associated with Optimization

Operational Condition	Implication	Brief Process of Standardization
Radiographic Exposure (AAPM 2002 and Alice et al 2014)	Knowledge and correct use of the appropriate radiographic exposure factors are necessary owing to their considerable impact on patient dose and image quality	▪ Setting of exposure charts for conventional systems ▪ Programming of exposure factors for digital systems Use of high kVpp and low mAs where possible to reduce dose ▪ Adapt exposure factors to clinical situation and pathology ▪ Adapt exposure factors to patient weight
Image processing[4, 12] (AAPM 2002) and (Körner, et al 2007)	Optimal processing in FSR promotes image quality because poorly processed radiographs result in poor diagnostic information, leading to repeated and increased patient exposure Post-processing techniques in DR provide an advantage over FSR by enhancing the electronic image to improve diagnostic quality. This allows the generation of good quality images with no requirement of additional radiation exposure	▪ Processor sensitometery in FSR ▪ Calibration and consistent quality control of CR and DR systems
Image Viewing Conditions (AAPM 2002)	Accurate reporting on diagnostic information in radiographs is best achieved when viewing conditions are standardized with the specific requirement	▪ 100 cd/m^2 light intensity incident on the viewer's eye ▪ Colour]of the illumination should be white Low level of ambient light in the viewing room
Retake Analysis (AAPM 2002) and (Alice et al 2014)	Analysis of the reasons for image retakes aids in solving the existing problems with setting of corrective actions to close the loop.	▪ Retake rates should not exceed 5% of the total images ▪ Implementing and maintaining a repeat analysis program

2.1.8.7 Application factors Associated with Optimization

Radiology request forms are referral links and communication tools between physicians and the radiology staff for performing radiological investigations; however, their importance is often underestimated(Akinola et al., 2012).Incomplete radiology request forms are common occurs impacting the workflow and efficiency of radiology departments in hospitals. Incomplete request forms can increase the risk of performing the wrong procedure, using an incorrect protocol of imaging technique, imaging the wrong patient or inaccurately interpreting the results. The increased risk to patient safety and potential for delayed treatment, combined with the frustration experienced and time wasted by radiology staff, make this a significant problem. Furthermore, exams may need to be repeated and this can result in unnecessary radiation exposure and delays in investigating and treating other patients. The decision to refer the patient to radiology department must be justified by the clinical information; this is a legal requirement as part of the 'as low as reasonably achievable' (ALARA) principle, (ARPNSA, 2012). A study conducted by Andrew et al, reveals good outcome in providing the essential request data and selection of the appropriate procedures with less mistakes by junior physicians when distributing radiology request guidelines and gave them lecture on commonly made mistakes. On the other hand the quality of medical images is determined based on several application variables controlled by the technologist/radiographer that positively or negatively affect radiographic quality. An overview of the application factors that contribute extensively to the optimization process are varies from patient education, preparation and communication to the technical parameters applied by the technologist which must be standardized and applied carefully to achieve the desired image quality that support the diagnosis. Table 2.15 provides summary of these factors, their implication and brief processes about how to achieve the requisite optimization.

Table 2.15 Summary of application Factors associated with optimization and good imaging performance

Application Factor	Implication	Brief Process of Optimization
Justification and Referral Guidance (AAPM, 2002) and (Bontrager , 2005)	▪ Absence of definite clinical indications will unnecessarily expose the patient to radiation ▪ High quality images without diagnostic benefit is considered a malpractice ▪ Patient clinical data is one of the baselines for standardization	▪ Referral justification ▪ Providing complete requisition including guidelines and clinical history and by referring physicians
	Examples for technique adaptations	
	Referral Aspect / **Sample Adaptation**	
	Patient Age **Vs.** Exposure Factors: **0-5** years; requires **25%** of adult mAs **6-12** years; requires **50%** of adult mAs	
	Clinical Information **Vs.** Exposure Factors: **Pathological indications require more (+) or less (-) kVpp, standard**:- **Abdomen** – Ascites**(+)** , crohn's disease **(-)** **Chest -** Pleural effusion **(+) ,** Pneumothorax **(-)** **Skeleton:** Osteopetrosis **(+)** , Rheumatoid arthritis **(-)**	
	Clinical Information **Vs.** Correct position: **Pathological indications require selection of specific pat projection, compared to standard**. **Abdomen-** Bowel obstruction, **Chest-** Pleural effusion E.g., lateral decubitus if patient is unable to stand	
Patient education, preparation and communication (Alice et al, 2014)	Communication with the patient and effective patient education before examination minimizes the possibility of patient movement and contributes positively to image quality and radiation dose	▪ Establishment of a patient education policy ▪ Appropriate patient communication and provision of clear instructions
Patient Immobilization (Alice et al, 2014)	Patient movement during exposure impairs diagnostic outcome leading to the requirement of additional radiation exposure	▪ Use of immobilization devices ▪ Use of short exposure time
Protection of sensitive organs during exposure (AAPM 2002) and (Alice et al, 2014)	Special attention is required to reduce radiation dose that results in biologic damage to sensitive organs	▪ Use of protective shielding ▪ Excluding radiosensitive organs from primary irradiation whenever possible. ▪ Selection of the appropriate exposure factors
Reducing the effects of Scatter Radiation (Bontrager, 2005) and (David et al, 2006)	The removal of scatter radiation improves radiographic image contrast. Scatter within the patient increases with the applied kVp and appears on the image receptor as a misplaced event, adding to image noise.	▪ Use of X-ray grids ▪ Apply air gap technique (e.g., cross-table lateral C. spine) ▪ Optimal selection of exposure factors with practical collimation to the area of question ▪ Tissue Compression (if applicable)

2.2 Previous studies

The leading contribution to radiation exposure to the general population as a whole arises from diagnostic X-rays Imaging. Proper protection of the patient from radiation is the foremost aim of modern health policy, and an understanding of the relationship between radiation dose and image quality is of crucial importance in optimizing medical diagnostic radiology. In this part, published previous studies will be carefully reviewed to evaluate the current knowledge of patient's radiation exposure assessment methods and to review their contribution in increasing the probability of cancer risks due to planar imaging. This data will help in exploring methods of dose management and optimization. Previous literature in this study will be classified into two parts: national and international literature.

2.2.1 Previous studies in Sudan

Sulieman (2015) measured the patient radiation doses during certain diagnostic radiography procedures estimated organs equivalent and effective doses. A total of 220 adult patients underwent 9 radiographic X ray imaging procedures were examined. This study was conducted Sharg Elneel Model Hospital (A), Fidail Hospital (B), Al-Amal Hospital (C) and Medical Corps Hospital (D), Khartoum state, Sudan. The entrance surface air kerma (ESAK) was measured for four radiographic examinations using thermo luminescence dosimeters (TLD-GR200A). A total of 220 patients were examined in four hospitals. The mean ESAK (mGy) for the chest, hand, knee joint, leg, shoulder, foot, arm, ankle and lumbar spine were 0.40±0.04, 0.36±0.03, 0.64±0.07, 0.39±0.04, 0.35±0.02, 0.54±0.02, 0.26±0.02, 0.46±0.03 and 1.98±1.1, respectively. The overall effective dose was 0.16±0.05 mSv. The results of ESAK were comparable with previous studies. Patient's doses showed wide variations in the same types of x-ray examination due to the choice of exposure factors, technique, focus-to-film distance, filter, film-screen speed and the output of the x-ray units and processor quality were used.

Babikir et al (2015) assessed patient ESAK during chest and abdominal X-ray procedures in screen film radiography (SFR) and computed radiography (CR) to establish dose reference levels. Patients' doses were measured in five hospitals for a total of 196 patients. ESAK was calculated from exposure parameters using DosCal software. The X-ray tube output (mGy mAs^{-1}), accuracy of exposure factors, linearity and reproducibility were measured using an Unfors Xi dosimeter. The overall mean and range of ESAK during chest X-ray were 0.6±0.3 (0.1–1.3) mGy, while for abdominal X-rays they were 4.0±3.2 (1.3–9.2) mGy. Hospital with a CR system was found to use relatively higher doses. Dose values for abdominal X-ray procedures were comparable with previous studies. The dose for chest X-ray procedure was higher by a factor of 2–3 compared with the current international reference levels.

In a pivotal study, Elshiekh et al (2015) published a comparative study of adult patient doses in film screen and computed radiography in some Sudanese hospitals. The study was performed to compare adult patient doses in film screen (FS) and CR diagnostic X-ray examinations in some hospitals in Sudan over a period of 1 y; during this period of time, the CR systems were introduced to replace FS systems. Radiation doses were estimated for 354 patients in five hospitals (two FS units and three CR units). ESAK was estimated from incident air kerma using patient exposure parameters and tube output. Dose calculations were performed using CALDOSE X 3.5 Monte Carlo-based software. In FS, third quartile of ESAK values for skull PA, skull LAT, chest PA, pelvis AP, lumbar spine AP and lumbar spine LAT were 1.5, 1.3, 0.3, 1.9, 2.8 and 5.9 mGy, respectively, while in CR, third quartile of ESAK values for the same examinations were 2.7, 1.7, 0.18, 1.7, 3.2 and 10.8 mGy, respectively. Comparable ESAK values were presented in FS and CR units. The results are important for future dose optimization and setting national diagnostic reference levels.

In another study, Suliman and Mohammedzein (2015) estimated the radiation exposure of adult patient for common diagnostic X-ray examinations in Wad-madani, Sudan in order to derivate of local diagnostic reference levels. Radiation doses were estimated for 307 patients in six public hospitals comprising 7 X-ray units in Wad-madani, Sudan. Entrance surface air kerma (ESAK) was estimated in a three step protocol: First, X-ray unit output Y(d) was measured at a distance, d for different peak tube voltages and tube loadings (mAs). Next, incident air kerma (Ki) was calculated from Y(d) using inverse square law combined with patient exposure factors. ESAK was calculated from Ki using backscatter factor, B. Mean ESAK values are comparable to those reported in other countries and are below reference dose levels. The estimated mean ESAK values are: 0.3, 2.2, 2.2, 2.9, 2.8, 3.1, and 7.5 mGy for chest PA, Skull AP/PA, Skull LAT, Abdomen, Pelvis AP, Lumbar Spine AP and Lumbar Spine LAT examinations, respectively. The results are used for dose optimization, and to propose local diagnostic reference levels.

In addition to that, Suliman et al (2015) estimated the examination frequency and collective and per caput effective doses arising from medical X-ray procedures in Sudan, 2010. Information was collected from 30 hospitals performing radiography, computed tomography (CT), fluoroscopy and interventional radiology (IR) procedures. The estimated annual number of examinations was 33 million radiographic X-ray procedures (99 %), 0.34 million CT exams per year (14 % paediatrics CT), 0.02 million fluoroscopy and IR procedures. The estimated annual number of examinations was 326 per 1000 people. The estimated annual collective and per caput effective doses from medical X-ray procedures mount 7197 man Sv and 0.18 mSv, respectively. The study offered the first projection of frequency and population dose from medical X-ray examinations in Sudan and provides estimates of the impact of the medical X-ray procedures at the national level.

Another study by, Babikir et al (2014) reviewed the radiation dose and image quality in planar radiography. The study reviewed the available literature regarding imaging factors that affecting

individual dose that related to the inappropriate use of X- ray machine caused by malpractices such as over exposure or inaccurate collimation of radiation filed. In order to reduce individual exposure and in accordance with the ALARA principle, several strategies have been implemented over the last few years which are based on X-ray emission or optimization of exposure parameters (i.e. mAs, kVp, collimation, clinical indication and referral criteria), or which take account of the individual patient's characteristics. These strategies allow optimization of image quality while keeping individual exposure at the lowest level. We review here these different strategies taking into account the relationship between image noise and different exposure parameters. Data from the literature are discussed, and current technological developments are considered. Digital systems reduced patient doses with high image quality if the technologist or radiographer is well trained in radiological protection and image quality in radiology.

Furthermore, Ahmad et al (2012) the number of fluoroscopy and fluoroscopically guided procedures has been substantially growing in developing countries at the same time advanced and sophisticated equipment are used in some hospitals. However, radiation protection requirements are not necessarily well adopted. In this study nine fluoroscopy X-ray units in Sudan were examined for compliance with international standards. The tests included: beam quality, entrance surface air kerma, image quality and radiation field measurements. Staff radiation protection tools such as lead aprons and eye glasses were also visually examined to find out whether international recommendations were fulfilled and to determine the level of staff awareness. The measured peak tube voltage deviation exceeded the recommended tolerance level in 30 % of the measurements. The results of patient doses measurements exceeded the recommended reference dose levels in 43 % of the measurements; however image quality and radiation field generally fulfilled the requirements for most units. The study revealed that a

considerable number of fluoroscopy units were not performing according to the international standards and highlights the need of optimisation of radiation protection.

Furthermore Suliman et al (2007) measured the Entrance surface doses (ESD) to patients undergoing selected diagnostic X-ray examinations in Sudan. ESD per examination was estimated from X-ray tube output parameters in four hospitals comprising eight X-ray units and a sample of 346 radiographs. Hospital mean ESDs estimated range from 0.17 to 0.27 mGy for chest AP, 1.04-2.26 mGy for Skull AP/PA, 0.83-1.32 mGy for Skull LAT, 1.31-1.89 mGy for Pelvis AP, 1.46-3.33 mGy for Lumbar Spine AP and 2.9-9.9 mGy for Lumbar Spine LAT. With exception of chest PA examination at two hospitals, mean ESDs were found to be within the established international reference doses. The results are useful to national and professional organizations and can be used as a baseline upon which future dose measurements may be compared.

2.2.2 International Previous Studies

Stadnyk et al (2015) reported the frequencies and effective doses for the most common X-ray diagnostic examinations in Ukraine and were assessed in the frame of the European Commission (EC) Study on European Population Doses from Medical Exposure (Dose Datamed 2). The average effective doses for all radiographic procedures were estimated using the ODS-60 software (Finland). The estimation of the effective doses for the chest film fluorography was carried out from the results of own representative measurements with Thermoluminescent (TL) dosimetry and a standard Alderson-Rando phantom. The effective doses for fluoroscopy procedures were assessed using the Russian guidelines for estimation of effective doses. For all other X-ray examinations and procedures [computed tomography (CT), angiography and interventional procedures], typical effective dose values were taken from the EC Guidance RP154. The most frequently performed in Ukraine is chest film fluorography, with 389

examinations per 1000 population annually, reflecting in the greatest contribution to the total collective effective dose (CED) of 428 mSv per 1000 population (44 %). The total frequency and CED from all X-ray diagnostic examinations and procedures were estimated to be 1218 examinations and 1060 mSv per 1000 populations, respectively. The expected additional cancer risk from X-ray diagnostic examinations and interventional procedures is 2680 cases per year, with 1200 of them due to the contribution of chest fluorography. The main important action in radiation protection of patients in diagnostic radiology is the organisation of the monitoring of patient doses for different types of X-ray diagnostic examinations and replacement of chest film fluorography with digital X-ray systems.

In addition to that, Mori and Muto (2014) evaluated the patient's radiation doses in terms of ESD in CR and SFR for 1,297 hospitals regarding the radiation exposure conditions of X-ray examinations. From the survey results, the study calculated the ESD (first quartile, median, third quartile, and mean) using the NDD calculation method. In the case of chest radiography (adult patients) by CR, the entrance surface dose was 150% of the median value for the overall examination and 160% of the median value for orthochromatic screen systems. The CR exposure set-up using a lower voltage and higher mAs than the F/S method was found to result in a high entrance surface dose. We also found a difference in patient dose among hospitals using CR. Mean surface dose in CR system was 0.12 mGy in a quartile, 0.19 mGy in the middle and 0.27 mGy in the third quartile. Among the hospitals which showed higher doses of third quatile them above mentioned, dose differences of a quartile were distributed 2 to 10 times higher them mean exposure doses.

A published study by Korir et al (2013), reported the frequency and collective dose of medical procedures in Kenya. It was the first comprehensive national survey on frequency and radiation dose imparted to the population from radiological procedures was carried out in Kenya and

reported here. This survey involved assessment of frequency, typical patient radiation exposure, and collective effective dose from general radiography, fluoroscopy, interventional procedures (IPs), mammography, and computed tomography. About 300 x-ray facilities across the country were invited to participate in the survey, and a 31% response was recorded. The individual and collective radiation burdens of more than 62 types of paediatric and adult radiological examinations were quantified using effective and collective dose. The average effective dose for each radiological examination was assessed from the x-ray efficiency performance tests and patient data from over 30 representative radiological facilities. The results found indicated that over 3 million x-ray procedures were performed in 2011, resulting in an annual collective effective dose of 2,157 persons and an annual effective dose per capita of 0.05 mSv. The most frequent examinations were general radiography (94%), computed tomography (3.3%), and fluoroscopy (2.5%). Although the contribution of computed tomography was small in terms of frequency, this procedure accounted for 36% of the effective dose per capita. General radiography was the most frequent type of examination with a contribution of 55% of the effective dose per capita.

Spelic et al (2010) reported the findings from nationwide evaluation of x-ray trends surveys conducted in 2001, 2002, and 2003 of clinical facilities that perform routine radiographic examinations of the adult chest, abdomen, lumbosacral spine, and upper gastrointestinal fluoroscopic examinations. The authors randomly identified clinical facilities were surveyed in approximately 40 participating states. For the surveyed radiographic exams, additional facilities that use computed radiography or digital radiography were surveyed to ensure adequate sample sizes for determining comparative statistics. State radiation control personnel performed site visits and collected data on patient exposure, radiographic/fluoroscopic technique factors, image quality, and quality-control and quality-assurance practices. Results of the other surveys were compared with those of previous surveys conducted in 1964 and 1970 by the U.S. Public Health

Service and the Food and Drug Administration. An estimated 155 million routine adult chest exams were performed in 2001. Average patient entrance skin air kerma from chest radiography at facilities using digital-based imaging modalities was found to be significantly higher ($p < 0.001$), but not so for routine abdomen or lumbosacral spine radiography. Digital-based imaging showed a substantial reduction in patient exposure for the radiographic portion of the routine upper gastrointestinal fluoroscopy exam. Long-term trends in surveyed diagnostic examinations show that average patient exposures are at their lowest levels. Of concern is the observation that a substantial fraction of surveyed non-hospital sites indicated they do not regularly have a medical physics survey conducted on their radiographic equipment. These facilities are likely unaware of the radiation doses they administer to their patients.

On the other hand, Teferi et al (2010) calculated the ESDs received by patients undergoing PA chest X-ray examinations in major public hospitals in Addis Ababa, thereby to establish the first Ethiopian LDRLs as part of ongoing dose reduction program. The entrance dose in air per examination was measured in eight hospitals comprising nine X-ray units and a sample of 192 radiographs. The entrance dose in air was measured using dositime dx X-ray Digital Dosimeter and Exposure Time Meter. The data were analyzed statistically, and the minimum, median, mean, maximum, and third quartile values of ESDs are reported Finally, the proposed LDRLs are compared with the international reference dose values reported by the Commission for European Community (CEC), the International Atomic Energy Agency (IAEA) and the National Radiological Protection Board (NRPB).The third quartile value of the distribution of mean doses at individual hospitals participating in this survey is found to be 1.08 Milligray (mGy). Hospitals mean ESDs for PA chest X-ray examination is found with the range of 0.0.76 to 1.48 mGy. Most of the ESD measured doses were slightly greater than the NRPB, CEC and IAEA reference doses.

The results of the present study indicate a need for Quality Assurance (QA) programs to be undertaken to avert considerable cost and high patient doses. The results are useful to national and professional organizations and can be used as a baseline upon which future dose measurements may be compared.

Hambali et al (2009) compared the entrance surface dose (ESD) and image quality of adult chest and abdominal X-ray examinations conducted at general practitioner (GP) clinics, and public and private hospitals in Malaysia. The surveyed facilities were randomly selected within a given category (28 GP clinics, 20 public hospitals and 15 private hospitals). Only departmental X-ray units were involved in the survey. Chest examinations were done at all facilities, while only hospitals performed abdominal examinations. This study used the x-ray attenuation phantoms and protocols developed for the Nationwide Evaluation of X-ray Trends (NEXT) survey program in the United States. The ESD was calculated from measurements of exposure and clinical geometry. An image quality test tool was used to evaluate the low-contrast detectability and high-contrast detail performance under typical clinical conditions. The median ESD value for the adult chest X-ray examination was the highest (0.25 mGy) at GP clinics, followed by private hospitals (0.22 mGy) and public hospitals (0.17 mGy). The median ESD for the adult abdominal X-ray examination at public hospitals (3.35 mGy) was higher than that for private hospitals (2.81 mGy). Results of image quality assessment for the chest X-ray examination show that all facility types have a similar median spatial resolution and low-contrast detectability. For the abdominal X-ray examination, public hospitals have a similar median spatial resolution but larger low-contrast detectability compared with private hospitals. The results of this survey clearly show that there is room for further improvement in performing chest and abdominal X-ray examinations in Malaysia.

Compagnone et al (2006) compare radiation doses to patients undergoing standard radiographic examinations using conventional screen-film radiography, computed radiography and direct digital radiography; entrance surface dose and effective dose were calculated for six standard examinations (a total of 10 projections) using standard patient exposure parameters for the three imaging modalities. It was found that doses for computed radiography (all examinations) were higher than the doses for the other two modalities; effective doses for direct digital radiography were approximately 29% and approximately 43% lower than those for screen-film radiography and computed radiography, respectively. The image quality met the criteria in the European guidelines for all modalities.

Vano et al (2007) to retrospectively evaluate patient radiation doses in projection radiography after the transition to computed radiography (CR) in the authors' hospital. The hospital's ethical committee approved the study and waived informed consent. In 2001, a dose reduction initiative was implemented, which involved collecting radiographic parameters, calculating patient entrance doses, and monitoring changes with an online computer, and a training program for radiographers was conducted. A database with 204 660 patient dose values was used to compute changes in patient doses over time. Sample sizes ranged from 1800 to 23 000 examinations. Doses were compared with European and American reference values. Kruskal-Wallis and Mann-Whitney tests were used for statistical analysis. Median values for patient entrance doses increased 40%-103% after implementation of CR. Initial increases were corrected during the 1st year, and additional dose decreases were achieved after the dose reduction initiative was launched. At present, doses range between 15% and 38% of the European diagnostic reference levels established for screen-film radiography and between 28% and 41% of the reference values recommended by the American Association of Physicists in Medicine, representing an effective 20%-50% reduction in the initial values for CR. Though patient doses can increase considerably

during the transition from conventional screen-film radiography to CR, dose management programs, including specific training of radiographers and patient dose audits, allow for reductions of the previous values.

Ciraj et al (2003) assessed patient doses from conventional diagnostic radiology procedures in Serbia and Montenegro for a total 491 procedures for 11 different examination categories. The dose was measured using X-ray tube output data; the entrance surface dose for each x-ray procedure was calculated, as well as the effective dose for each patient. Except for chest PA examination, all estimated doses are less than stated reference levels for plane film examinations. For fluoroscopy examinations, the total kerma-area product was measured and the contributions from fluoroscopy and radiography were assessed. The study of kerma-area product reference doses confirms that dose level for complex fluoroscopy investigations are closely related to technique and individual patient variation, in terms of fluoroscopy time and number of radiography exposures. Survey data are aimed to help in development of national quality control and radiation protection programme for medical exposures

Lu et al (2003) conducted work to compare computed radiography ~Kodak CR 400! And film/screen combination ~Speed 400! Systems in regards of patient dose, technique settings, and contrast-detail detectability. A special contrast-detail phantom with drilled holes of varying diameter ~details! And varying depth ~contrast! was utilized. Various thicknesses of the Lucite sheets were utilized to simulate scattering tissues. Images of the phantom were acquired using a range of 60–120 kVp for film/screen and CR with a conventional x-ray tube and then for CR with additional 2 mm aluminum added filtration to the x-ray beam. The patient entrance skin dose was measured while maintaining 1.6 o.d. for film/screen images and 1900 Exposure Index for CR images. CR phantom images were displayed on the diagnostic workstation for soft copy reading as well as printed on films for hard copy reading on view box. Four physicists evaluated

the images by scoring the threshold target depth along the row of the same target diameter. Detection ratio was calculated by counting the number of detectable targets divided by the total number of targets in the phantom. The overall score was related to the patient entrance skin dose, kVp, and the thickness of the scattering material. The patient entrance skin dose was reduced as the additional aluminum filter was added to the x-ray beam. Our findings suggested using a higher kVp setting and additional added filtration would reduce the patient entrance skin dose without compromising the contrast-detail detectability, which was compensated by the contrast manipulation on soft-copy display workstations.

Geijer et al 2002 evaluated the radiation dose-image quality relationship with clinical experience from scoliosis radiography, coronary intervention and a flat-panel digital detector. The authors were evaluated and compared to the standard screen-film method. Radiation dose was measured as kerma area-product (KAP), ESD and effective dose; image quality was assessed with a contrast-detail phantom and through visual grading analysis. Accuracy in angle measurements was also evaluated. The radiation dose for digital exposure was nearly twice as high as the screen-film method at a comparable image quality while the dose for pulsed fluoroscopy was very low but with a considerably lower image quality. The variability in angle measurements was sufficiently low for all methods. Then, the digital exposure protocol was optimized to a considerably lower dose with a slightly lower image quality compared to the baseline. The authors also evaluated the Flat-panel detector using amorphous-silicon direct digital flat-panel detector was evaluated using a contrast-detail phantom, measuring dose as entrance dose. The flat-panel detector yielded a superior image quality at a lower dose than both

storage phosphor plates and screen-film. Equivalent image quality compared to storage phosphor plates was reached at about one-third of the dose.

Ng et al (1999), studied the medical radiation usage for diagnostic radiology in Malaysia (a Level II country) for 1990-1994 is reported, enabling a comparison to be made for the first time with the United Nations Scientific Committee on the Effects of Atomic Radiation Report. In 1994, the number of physicians, radiologists, x-ray units, and x-ray examinations per 1,000 populations was 0.45, 0.005, 0.065, and 183, respectively. (Level I countries had averages of 2.6, 0.072, 0.35, and 860, respectively). In 1994, a total of 3.6 million x-ray examinations were performed; the annual effective dose per capita to the population was 0.05 mSv, and the collective effective dose was 1,000 person-Sv. Chest examinations contributed 63% of the total. Almost all examinations experienced increasing frequency from 1990 to 1994 except for barium studies, cholecystography, and intravenous urography (-23%, -36%, -51%). These decreases are related to the increasing use of ultrasound and greater availability of fiberoptic endoscopy. Notable increases during the same period were observed in computed tomography (161%), cardiac procedures (190%), and mammography (240%). In order to progress from Level II to Level I status Malaysia needs to expand and upgrade radiological service in tandem with the health care development of the country.

In summary, patient's dose measurements were performed for SFR, CR and Direct Digital systems (DDR). Most of the studies published in Sudan were showed that patient's exposure in terms of ESAK or ESD were comparable with previous studies. Furthermore, Patient’s doses showed wide variations were reported all previous studies for the same types of x-ray examination due to the choice of exposure factors, technique, focus-to-film distance, filter, film-screen speed and the output of the x-ray units and processor quality were used. The dose for certain studies was higher by a factor of 2–3 compared with the current international reference levels. Optimization is recommended, especially for CR systems.

Other study monitored the frequency of radiologic procedures and population dose from medical X-ray examinations in Sudan and provides estimates of the impact of the medical X-ray procedures at the national level. Digital systems reduced patient doses with high image quality if the technologist or radiographer is well trained in radiological protection and image quality in radiology. In addition to that, considerable variation of fluoroscopy units was not performing according to the international standards and highlights the need of optimization of radiation protection. It was found that doses for computed radiography (all examinations) were higher than the doses for the other two modalities; effective doses for direct digital radiography were approximately 29% and approximately 43% lower than those for screen-film radiography and computed radiography, respectively.

Regular monitoring of patient doses for different types of X-ray diagnostic examinations and replacement of fluorography units with digital X-ray systems was recommended. Digital-based imaging showed a substantial reduction in patient exposure for the radiographic portion of the routine upper gastrointestinal fluoroscopy exam. Long-term trends in surveyed diagnostic examinations show that average patient exposures are at their lowest levels. The flat-panel detector yielded a superior image quality at a lower dose than both storage phosphor plates and screen-film. Equivalent image quality compared to storage phosphor plates was reached at about one-third of the dose.

CHAPTER THREE

Materials and Methods

3.1 Materials

- The data of this study was collected from ten x-ray departments in teaching, university and private hospitals in Khartoum state.
- Data of the technical parameters used in general radiographic procedures was taken during July 2012 –July 2015.
- The images included in this study were produced at the mentioned hospitals from patients referred to the Radiology Departments with no additional radiation exposure to patients for study purposes.

3.2 Method

This study involved experimental measures and technical surveys of the various parameters that could affect the patient radiation dose and image quality in of common radiographic procedures

3.2.1 X-ray departments and machines

Ten X-ray departments in ten hospitals coded from H1to H10 with different X-ray systems from different manufacturers were involved in this study. The machine characteristics, installation dates are presented in Table 3.1.

Table 3.1 Machines characteristics

Hospital Code	System type	Model/ Install. date	Filtration(mm Al)	Processing Type
H1	Conventional	Toshiba KXO-15E (2011)	3.0	SFR
H2	Conventional	Toshiba (2013)	2.5	SFR
H3	Conventional	Toshiba (1994)	2.5	SFR
H4	Conventional	Toshiba (2007)	2.5	SFR
H5	Conventional	Shimadzu (2004)	2.5	SFR
H6	Conventional	Shimadzu1/2P13DK (2008)	2.5	SFR
H7	Conventional	Shimadzu1/2P13DK (2008)	2.5	SFR
H8	Conventional	Siemens (2004)	2.5	SFR
H9	CR	Toshiba KOX-30 (2011)	3.0	CR
H10	CR	Shimadzu (2013)	3.0	CR

The selected departments in Soba University Hospital (H1), Ibrahim Malik Teaching Hospital (H2), Ibnsina Specialist Hospital (H3), Khartoum Teaching Hospital (H4), Khartoum Emergency Hospital (H5) Bahri Teaching Hospital (H6), Bahri Emergency Hospital (H7) and Ribat University Hospital (H8) were equipped with conventional/screen film radiography (SFR) systems, using chemical processing with film speeds of 400, while the Royal Diagnostic Centre (H9) and Fedail Diagnostic Centre (H10) utilized a CR system.

3.2.2 Patients Demographics and Technical Factors

A total of 846 adult patients were included in the study. Patients were divided into groups according to the X-ray procedure and X-ray machine used. Patient demographic data are presented in Table 3.2, while the radiographic technique factors for the conducted chest, abdominal and pelvic X-ray procedures are presented in Table 3.3.

Table 3.2 Mean and range values of patient's demographic data (age, height, weight and body mass index (BMI)) for patients undergoing PA Chest x-rays

Hospital	X-ray Exam	No. of Patients	Age (Yrs.)	Height (cm)	Weight (Kg)	BMI (kg/cm^2)
H1	Chest	30	34(24-45)	156(140-172)	40(60-85)	19.7(28.7-30.6)
	Abdomen	25	41(17-77)	164.2(130-177)	64.6(45-95)	24.0(15.6-30.3)
	Pelvis	23	34(24-45)	171.2(155-178)	72.6(67-88)	24.7(21.1-28.3)
H2	Chest	35	42(20-80)	160(145-1175)	60.1(45-82)	23.4(19.33)
	Abdomen	35	56.6(20-85)	171.9(160-189)	70.1(52-90)	23.7(19.9-25.2)
	Pelvis	26	37.5(18-59)	172.1(160-182)	74.2(70-87)	25.1(22.6-27.8)
H3	Chest	40	53.2(19-80)	167(148-181)	65(38-110)	23.3(15.5-45.8)
	Abdomen	21	41.2(18-80)	164(130-177)	65.5(40-120)	24.5(13.8-44.1)
	Pelvis	25	37.9(21-73)	169.8(155-179)	74.1(61-90)	25.7(22.6-30.8)
H4	Chest	30	51.0(21-86)	152(120-200)	75.2(55-110)	34.2(19.6-49.3)
	Abdomen	20	55.6(35-78)	143.3(130-160)	65(50-80)	32.1(25.4-41)
	Pelvis	27	38.3(27-83)	172.7(165-180)	73.4(60-84)	24.7(18.7-29)
H5	Chest	36	35(19-47)	165(148-183)	63(45-85)	23.6(20.5-31.3)
	Abdomen	25	38.6(19-73)	164.8(145-189)	62.1(53-92)	23(18.4-28.7)
	Pelvis	31	38.5(19-51)	176.4(170-187)	71.8(60-91)	23.1(19.1-28.7)
H6	Chest	41	50.3(20-75)	164(150-186)	68.2(45-90)	25.4(15-31.2)
	Abdomen	22	21(18-25)	136(100-158)	40(15-55)	19.7(15-22.2)
	Pelvis	28	43.9(31-65)	173.5(163-181)	69.8(64-79)	23.4(20-26.3)
H7	Chest	30	48.9(20-75)	164.6(148-186)	69.7(45-90)	25.7(15-31.2)
	Abdomen	20	31.9(18-52)	172.2(158-192)	73.1(53-93)	24.4(21.5-27.8)
	Pelvis	22	47.3(37-68)	168(158-175)	66.3(55-80)	23.3(18.6-25.6)

H8	Chest	25	42.1(20-75)	166(145-180)	67.0(45-95)	25.0(14-35)
	Abdomen	21	56.7(20-85)	170.7(160-185)	70(52-90)	24.4 (19-35.2)
	Pelvis	28	40.4(20-65)	164.1(150-173)	63.9(55-90)	23.6 (19.6-30.1)
H9	Chest	35	56.0(25-80)	166(150-190)	85.0(60-120)	31.3(21-46)
	Abdomen	30	47.4(29-75)	171(160-180)	85.8(70-100)	29.4(27.3-35)
	Pelvis	29	57.6(45-75)	170.3(162-185)	63.2(57-78)	21.7(17.5-25.5)
H10	Chest	36	55.9(23-87)	166.2(148-192)	83.8(60-115)	30.5 (21-44.9)
	Abdomen	33	40(21-75)	172.9(159-186)	76.5(57-90)	25.6 (22.3-30.1)
	Pelvis	27	43.2(28-51)	170.3(150-180)	68.5(59-83)	23.6 (20-28.5)

Table 3.3 Technique factors for patients undergoing PA chest, AP Abdomen and pelvis x-ray

Hospital	X-ray exam	Focal Spot	Screen film sensitivity	Focus to-Film Distance(cm)	Tube voltage range ~kVpp	tube current time product range ~mAs	Anti-scatter grid
	Chest	Broad	400	180	81.2(75-90)	16.5(8-20)	Yes
H1	Abdomen	Broad	400	100	76.5(75-80)	27.6(15-40)	Yes
	Pelvis	Small	400	100	75.9(75-80)	30.3(30-40)	Yes
H2	Chest	Broad	400	180	70.1(62-80)	17(8-25)	Yes
	Abdomen	Broad	400	100	67.6(60-75)	29.5(20-40)	Yes
	Pelvis	Small	400	100	78.6(75-85)	32.5(25-40)	Yes
	Chest	Broad	400	180	71.3(60-90)	20.9(8-32)	Yes
H3	Abdomen	Broad	400	100	74.8(65-92)	21.3(16-32)	Yes
	Pelvis	Small	400	100	76.8(70-85)	20.1(15-30)	Yes
	Chest	Broad	400	180	71.5(54-80)	14(7.2-17.7)	Yes
H4	Abdomen	Broad	400	102	76(80-84)	27.3(16-50)	Yes
	Pelvis	Small	400	102	73.8(65-82)	24.6(15-40)	Yes
	Chest	Broad	400	180	70.5(55-85)	13.2(8.5-18)	Yes
H5	Abdomen	Broad	400	100	76(70-80)	25.1(20-30)	Yes
	Pelvis	Small	400	102	75.3(75-82)	28.1(15-40)	Yes
	Chest	Broad	400	180	73.6(58-86)	12.7(5-18)	Yes
H6	Abdomen	Broad	400	102	67.3(64-70)	20.3(16-25)	Yes
	Pelvis	Small	400	100	74.6(65-85)	22.5(15-40)	Yes
	Chest	Broad	400	180	74.5(65-85)	13.9(8-20)	Yes
H7	Abdomen	Broad	400	100	72.6(60-85)	27.4(15-40)	Yes
	Pelvis	Small	400	100	73.7(70-75)	25(20-40)	Yes
	Chest	Broad	400	180	68.4(56-82)	16.6(6-22)	Yes
H8	Abdomen	Broad	400	100	80.4(75-87)	28.2(22-36)	Yes
	Pelvis	Small	400	100	78.3(70-90)	32(25-40)	Yes
	Chest	Broad	N/A	180	81(72-90)	17.8(6-25)	Yes
H9	Abdomen	Broad	N/A	102	80(80-80)	54.9(40-70)	Yes
	Pelvis	Small	N/A	102	76.2(70-80)	17.6(14-22)	Yes
	Chest	Broad	N/A	180	82(70-95)	14.9(8-22)	Yes
H10	Abdomen	Broad	N/A	102	80(65-75)	45.5(40-50)	Yes
	Pelvis	Small	N/A	102	75.5(70-82)	17.1(15-20)	Yes

3.2.3 Clinical Referral Criteria

Data from request forms were assessed using a standard data collecting sheet (Appendix.1). The study comprises evaluation of radiology request forms for the studied x-ray procedures in each selected department to measure the compliance of referring physicians in providing adequate general and clinical data required for the procedure with evaluating the radiologist's positive diagnostic responses according these referral information's.

3.2.4 Equipment quality control (QC)

Basic quality control (QC) tests of the X-ray machines, including tube output, exposure factors (kVp, mAs and time) accuracy, linearity and reproducibility, and collimator accuracy, was performed to check their performance in compliance with international standards as a baseline for assessing image quality. QC tests on the X-ray machines were performed by experts from the Sudan Atomic Energy Commission using Unfors Xi dosimeters (Unfors, Inc., Billdal, Sweden) and following the recommendations of the American Association of Physicists in Medicine (AAPM) report 74, and the Institute of Physics and Engineering in Medicine (IPEM) report 91.The evaluation of collimator accuracy and beam alignment were performed using a collimator beam alignment test tool, model 07-661-7662. Densitometry measures (medium density, density difference, and Base+Fog) were performed using an RMI densitometer, serial number 211-2176F, to measure the optical densities of sample radiographs and compare them to the standard values (Trenton, 2003).

3.2.5 Dose calculation

The radiation doses for patients involved in this study were assessed and compared to internationally-recommended diagnostic reference levels (DRLs).The study received ethical approval from the institutional review board (IRB) and informed consents were obtained from all patients prior to the procedure. Patient demographic data comprising; gender, age, height,

weight, and body mass index (BMI, kg/m^2) were evaluated using standard data collection sheets. The patient entrance surface air kerma (ESAK) was assessed using data of exposure factors (kVp and mAs)and radiation output of each radiographic machine, ESAK was calculated using the following equation:-

$$ESAK\,(mGy) = OP\left(\frac{kV}{80}\right)^2 mAs\left(\frac{100}{FSD}\right)^2 BSF \qquad (1)$$

Where kV is the applied tube voltage; mAs is the applied current to time product; FSD is the focus to skin distance; OP is the radiation output in mGy measured at 80 kVp at1 meter distance, and BSF is the backscatter factor.

The obtained ESAK was used to calculate the effective dose (E) following the National Radiological Protection Board recommendations (NRPB) (Hart et al., 1994). Effective doses calculated using the statistical computational methods based on Monte Carlo techniques using the conversion coefficients of each radiographic projection. Then results were compared with the published doses.

3.2.6 Repeat (Reject) analysis

Retake analysis provides an overall impression of consistency related to image quality, acting as a link between a department's quality assurance effort and the consistency of its image quality. Analysis was performed on image records involved in this study across the ten hospitals to assess the overall rejection rates along with rates per X-ray examination to identify the common causes of retakes so as to produce further recommendations on improving image quality. Repeat rate was calculated using the following formula (CRCPD, 2001):

$$\text{Repeat (Rejection) rate (\%)} = \frac{\text{Number of repeated films}}{\text{Total number of used films}} \times 100 \qquad (2)$$

3.2.7 Image analysis

3.2.7.1 Evaluation Criteria

Although the important imaging requirement is detection of abnormalities, most assessments of clinical image quality in a radiology department must be based on visualization of normal anatomy since the majority of images are normal, and technical assessment of a range of abnormalities would be impractical. Visual grading analysis is the preferred method when evaluating image quality by means of anatomical structures in clinical images.

The evaluation criteria used in this study correspond to the European guidelines on Quality Criteria for Diagnostic Radiographic Images. The diagnostic requirements of each of the examinations involved in this study were presented in tables 3.4, 3.5 and 3.6.

Table 3.4 PA Chest radiographs diagnostic requirements (EUR16260 EN)

1. DIAGNOSTIC REQUIREMENTS
1.1.Image criteria
1.1.1. Performed at full inspiration (as assessed by the position of the ribs above the diaphragm – either 6 anteriorly or 10 posteriorly) and with suspended respiration
1.1.2. Symmetrical reproduction of the thorax, as shown by central position of the spinous process between the medial ends of clavicles
1.1.3. Medial border of the scapulae outside the lung fields
1.1.4. Reproduction of the whole rib cage above the diaphragm
1.1.5. Visually sharp reproduction of the vascular pattern in the whole lung, particularly peripheral vessels
1.1.6. Visually sharp reproduction of: **(a)** trachea and proximal bronchi **(b)** borders of the heart and aorta **(c)** diaphragm and lateral costo-phrenic angles
1.1.7. Visualization of the retrocardiac lung and mediastinum
1.1.8. Visualization of the spine through the heart shadow
1.2. Important image details
1.2.1. Small round details in the whole lung, including the retrocardiac areas: high contrast: 0.7 mm diameter, low contrast: 2 mm diameter
1.2.2. Linear and reticular details out to the lung periphery: high contrast: 0.3 mm in width, low contrast:2 mm in width

Table 3.5 AP Abdomen radiographs diagnostic requirements [EUR16260 EN]

1. DIAGNOSTIC REQUIREMENTS
1.1 Image criteria
1.1.1. Reproduction of the area of the whole urinary tract from the upper pole of the kidney to the base of the bladder
1.1.2. Reproduction of the kidney outlines
1.1.3. Visualisation of the psoas outlines
1.1.4. Visually sharp reproduction of the bones
1.2. Important image details: calcifications of 1.0 mm

Table 3.6 AP Pelvis radiographs diagnostic requirements [EUR16260 EN]

1. DIAGNOSTIC REQUIREMENTS
1.1 Image criteria
1.1.1. Symmetrical reproduction of the pelvis as judged by the imposition of the symphysis pubis over the midline of the sacrum
1.1.2. Visually sharp reproduction of the sacrum and its intervertebral foramina
1.1.3. Visually sharp reproduction of the pubic and ischial rami
1.1.4. Visually sharp reproduction of the sacroiliac joints
1.1.5. Visually sharp reproduction of the necks of the femora which should not be distorted by foreshortening or rotation
1.1.6. Visually sharp reproduction of the spongiosa and corticalis, and of the trochanters
1.2. Important image details 0.5 mm

3.2.7.2 Visual grading analysis (VGA)

The VGA approach provides methodology which can be applied to clinical studies. Simpler techniques are required for carrying out routine assessments in X-ray departments for evaluating local performance and for deciding whether techniques are appropriate for different applications. In this study reference images for PA chest, AP abdomen and AP pelvis radiographic examinations were taken at standard technical parameters in each hospital and used for the visual grading analysis. The quality of the images under analysis was compared with that of the reference image, using the structures criteria defined in table 2 3.2, 3.3 and 3.4.The result from the visual grading was evaluated using a calculated visual grading analysis score (VGAS) (Almean et al 2000). The analysis was conducted for each image, including the observations of all observers:

$$\text{VGAS} = \frac{\text{Sum of scores}}{\text{Number of scores}} \qquad (3)$$

The analysis was conducted by expert radiologists and senior technologists (with > 10 years' experience).The image criteria were scored as good, satisfactory or poor based on the diagnostic requirements as recommended by the European guidelines. Results were evaluated and compared among various hospitals and x-ray procedures in reference to the European guidelines on image quality criteria to determine their compliance levels.

CAHPTER FOUR

Results

4.1 Evaluation of Clinical Referral Criteria

Table 4.1 Illustrates the number and completion rates of requisitions data among various hospitals And radiographic exams

Hospitals	Suggestive clinical history					
	Chest x-ray		***Abdomen x-ray***		***Pelvis x-ray***	
	Complete	Incomplete	Complete	Incomplete	Complete	Incomplete
H1	(25)83%	(5) 17%	(23)92%	(2) 8%	(20)87%	(3)13%
H2	(27)77.1%	(8) 22.9%	(25)71.4%	(10)28.6%	(22)85%	(4)15%
H3	(25) 83.3%	(10) 16.7%	(30)85.7%	(5)14.3%	(21)81%	(5)19%
H4	(23)76.7%	(7)23.3%	(17)85%	(3)15%	(21)78%	(6)22%
H5	(28) 77.8%	(8)22.2%	(21)84%	(4)16%	(26)84%	(5)16%
H6	(32)78%	(9)22%	(20)91%	(2)9%	(21)75%	(7)25%
H7	(33) 80.5%	(8) 19.5%	(16)73%	(6)17%	(20)71%	(8)29%
H8	(18)72%	(7)28%	(15)71.4%	(6)28.6%	(17)61%	(11)39%
H9	(31)88.6%	(4)11.4%	(27)90%	(3)10%	(25)86%	(4)14%
H10	(31) 86.1%	(5) 13.9%	(29)87.9%	(4)12.1%	(25)93%	(2)7%

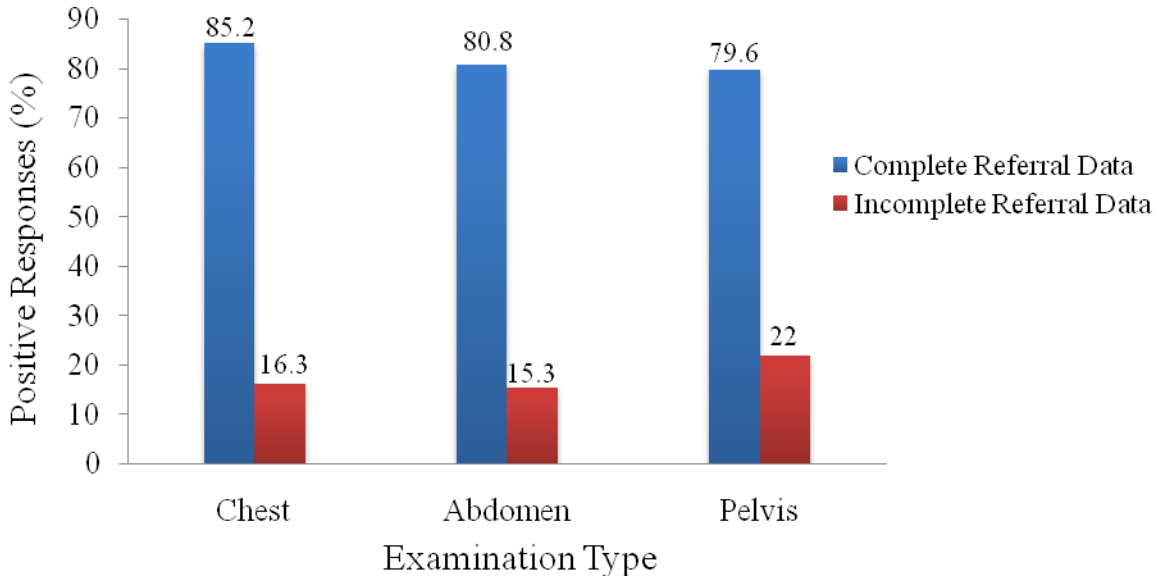


Fig.4.1 Illustrates the Average radiologist's positive diagnostic responses compared the provided Clinical Information (%)

4.2 Equipment QC Tests

Table 4.2.A Illustrates the QC checks on x-ray machines outputs compared to Tolerance levels

Parameters and Tolerance Levels (%)	Hospital									
	H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**	**H10**
kVp accuracy (5%)	3.9	4.5	3.8	1.2	1.2	1.6	0.7	1.0	0.6	0.9
Timer accuracy (5%)	2.1	3.1	4.9	0.5	0.4	0.6	0.9	3.0	0.8	0.3
Exposure Reproducibility (2%)	0.1	0.8	0.7	0.6	0.9	0.3	0.6	0.2	0.4	0.9
mAs& exposure linearity (10%)	2.7	2.1	4.3	3.7	4.6	2.2	4.1	2.5	3.2	1.8
Radiation output (5%)	3.0	1.1	2.0	0.7	1.9	0.2	1.3	1.0	0.9	1.1

Table 4.2.B Illustrates the QC checks on machines collimators compared to Tolerance levels

Collimator Parameters	Hospital									
	H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**	**H10**
working	✓	✓	X	✓	✓	✓	✓	X	✓	✓
Light working	✓	✓	X	✓	✓	✓	✓	X	✓	✓
Light edge clear	✓	✓	X	✓	✓	✓	✓	X	✓	✓
Cross indication	✓	✓	X	✓	✓	✓	✓	X	✓	✓
Cross centered	✓	✓	X	✓	X	✓	X	X	✓	✓

✓ = Yes X =No

Table 4.3 Illustrates the processing problems & causes across the different hospitals using FSR systems

Hospital	Processing Errors	Cause
H1	None	-
H2	Increased medium density and density difference, Increased Base + Fog	High developer temperature; film handling artifacts, film fogging
H3	Increased medium and density difference, Increased Base + Fog	Safelight problems, exhausted fixer
H4	None	-
H5	Decreased medium density and density difference	Weak developer/reduced replenishment rate
H6	None	-
H7	None	-
H8	Increased medium density and density difference, Increased Base + Fog	contaminated developer film storage and handling problems

4.3 Patient dose measurement

Table 4.4 Illustrates the Mean patients ESAK (mGy) and effective dose (mSv) for chest, abdomen and Pelvis x-ray procedures

Hospital	Chest X ray		Abdomen X ray		Pelvis X ray	
	ESAK(mGy)	ED(mSv)	ESAK(mGy)	ED(mSv)	ESAK(mGy)	ED(mSv)
H1	0.3 ± 0.02	0.06	3.8± 2.3	0.35	3.9± 1.8	0.66
H2	0.6 ± 0.04	0.11	3.1 ± 1.2	0.23	3.7± 1.4	0.63
H3	0.7 ±0.3	0.13	2.4±2.5	0.22	2.1 ± 1.4	0.36
H4	0.5±0.5	0.10	3.6±1.6	0.33	2.9 ± 1.7	0.49
H5	0.4±0.6	0.08	2.9±1.9	0.27	3.7 ± 0.9	0.63
H6	0.4±0.3	0.08	1.9±0.7	0.14	2.3±1.9	0.39
H7	0.4±0.7	0.08	3.9±0.8	0.36	3.3 ± 1.2	0.56
H8	0.5±0.2	0.85	3.7±0.9	0.41	4.1 ± 1.7	0.70
H9	0.8±0.4	1.66	6.2±2.3	0.68	4.9 ± 2.1	0.83
H10	0.9 ± 0.6	1.86	5.1 ± 3.02	0.56	4.7 ± 2.3	0.80

Table 4.5 Illustrates the Comparison of mean ESAK for chest and abdominal and Pelvis radiography in this study with DRLs from other studies

DRL (ESAK/mGy)	Examination		
	Chest X rays	Abdomen X rays	Pelvis X rays
AAPM[Report 74,2002]	0.25	4.5	-
NRPB[Report 2002]	0.2	6.0	4.0
US[Gray et al 2005]	0.25	4.5	-
EC[DRLs 1999]	0.3	-	10
UK[Hart D et al 2009]	0.15	4.0	4.0
Present Study	0.5	3.7	3.6

4.4 Rejection Analysis

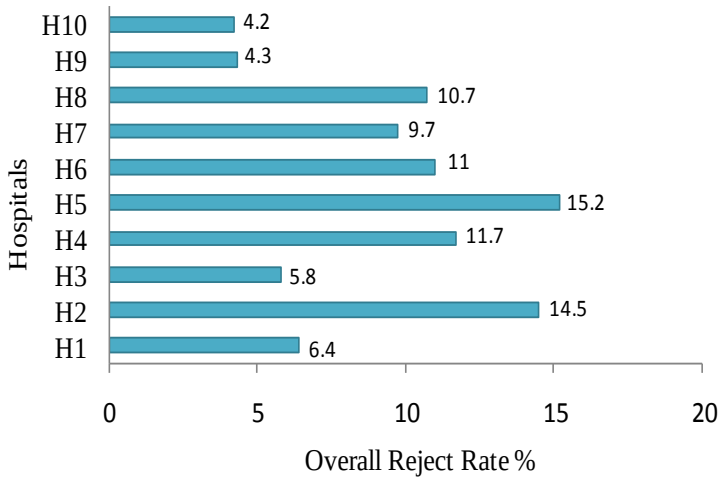


Figure 4.2 Illustrates the overall reject rates among different hospitals

Table 4.6 Illustrates the distribution of reject rates according to causes among different hospitals

Hospital	Overall Rejection Rate (%)	Rejection Rate according to cause (%)				
		Image Processing Errors	Patient Preparation & Instructions Errors	Exposure Factors Errors	Collimator Errors	Positioning and patients movement Errors
H1	6.4	-	2.5	1.3	-	2.6
H2	14.5	5.2	2.1	4.1	3.1	-
H3	5.8	1.2	3.4	-	-	1.2
H4	11.7	-	5.2	5.2	-	1.3
H5	15.2	7.6	-	5.4	2.2	-
H6	11	-	3.5	3.3	-	4.2
H7	9.7	-	6.9	1.4	-	1.4
H8	10.7	1.2	-	1.2	6.0	2.3
H9	4.3	-	4.3	-	-	-
H10	4.2	-	2.1	1.05	-	1.05

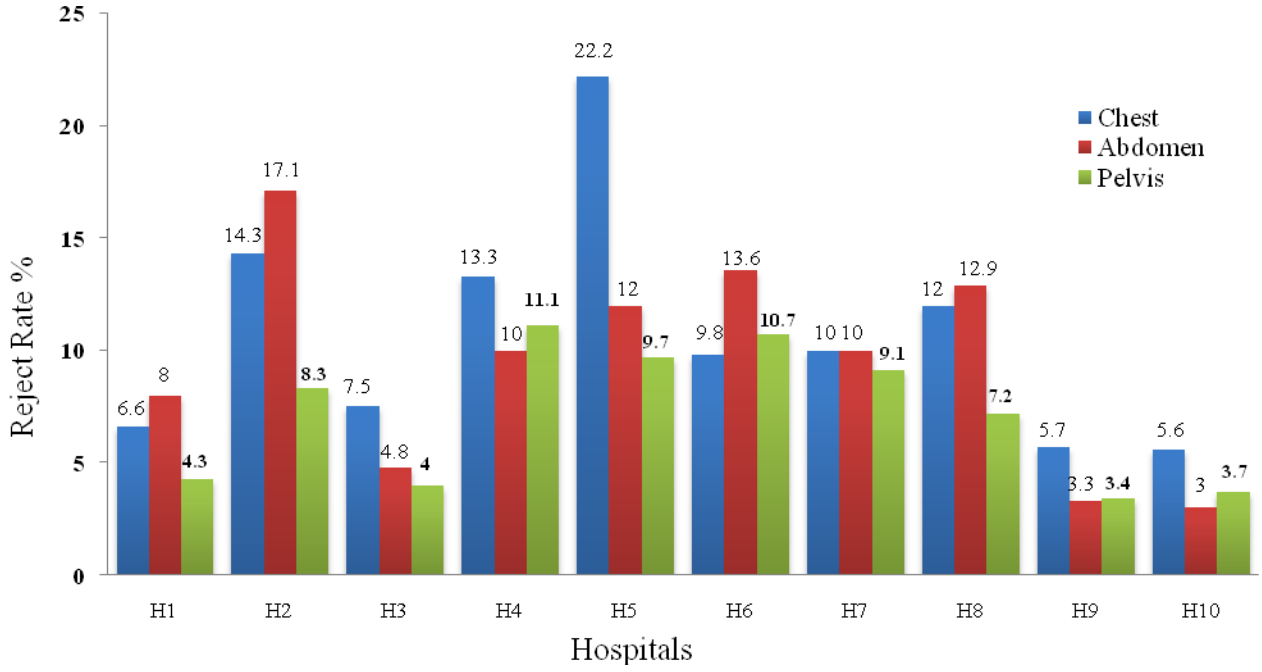
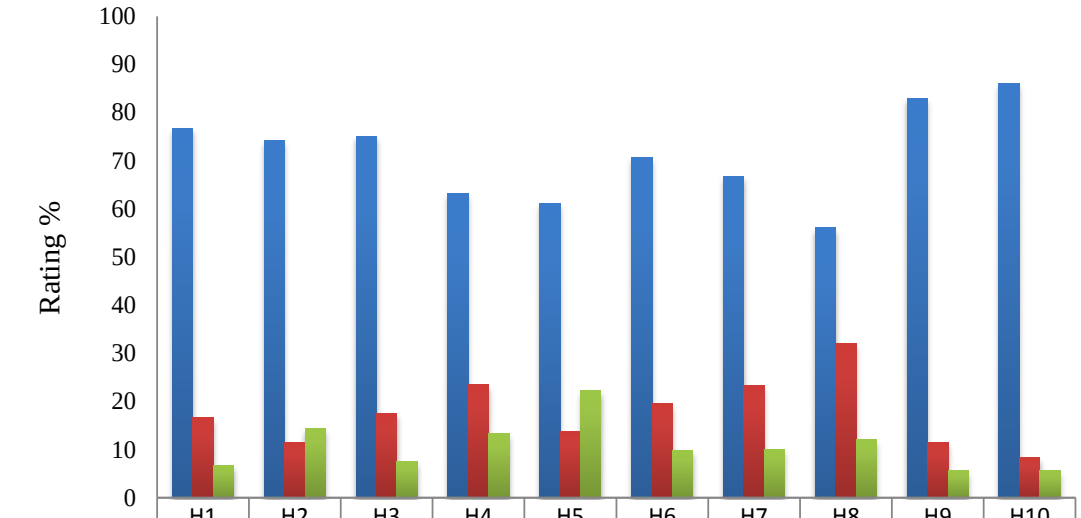


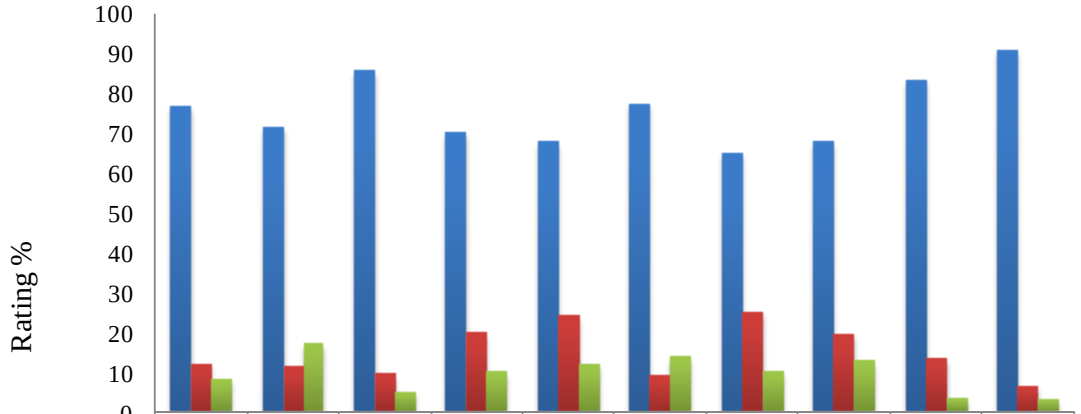
Figure 4.3 Illustrates the reject rate by examination type among the various hospitals

4.5 Image Criteria Analysis



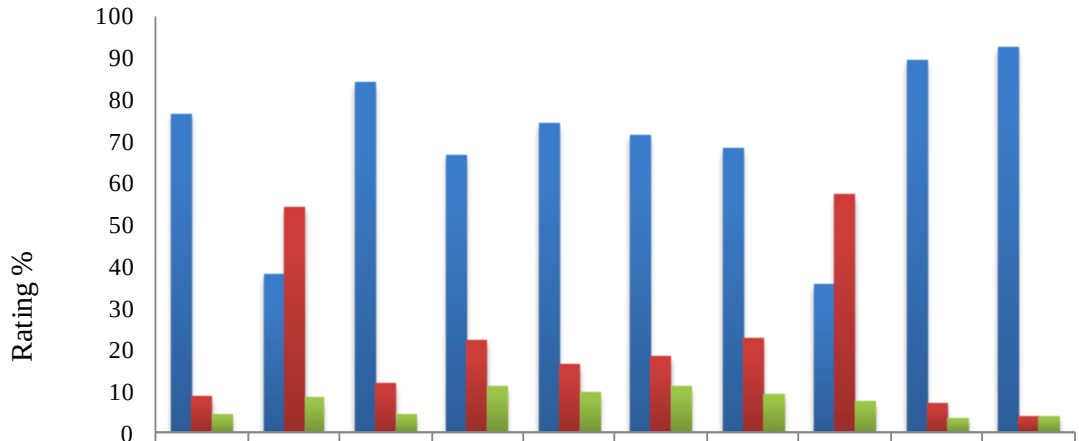
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
Good	76.6	74.3	75	63.3	61.1	70.7	66.7	56	82.9	86.1
Satisfactory	16.7	11.4	17.5	23.4	13.8	19.5	23.3	32	11.4	8.3
Poor	6.7	14.3	7.5	13.3	22.2	9.8	10	12	5.7	5.6

Figure 4.4 Illustrates the PA chest Compliance Rates with the Image Criteria (EUR16260 EN)



	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
Good	76.6	71.5	85.7	70	68	77.3	65	67.7	83.4	90.9
Satisfactory	12	11.4	9.5	20	24	9.1	25	19.4	13.3	6.1
Poor	8	17.1	4.8	10	12	13.6	10	12.9	3.3	3

Figure 4.5 Illustrates the AP Abdomen Compliance Rates with the Image Criteria (EUR16260 EN)



	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
Good	76.6	37.9	84	66.6	74.2	71.4	68.2	35.7	89.7	92.6
Satisfactory	8.8	53.8	12	22.3	16.1	17.9	22.7	57.1	6.9	3.7
Poor	4.3	8.3	4	11.1	9.7	10.7	9.1	7.2	3.4	3.7

Figure 4.6 Illustrates the AP Pelvis Compliance Rates with the Image Criteria (EUR16260 EN)

CHAPTER FIVE

Discussion, Conclusion and Recommendations

5.1 Discussion

5.1.1 Evaluation of Clinical Referral Criteria

As noticed in the analyzed clinical referral data in Table 4.1 and Figure 4.1, the complete relevant clinical history significantly increases true-positive diagnosis rates: 85.2% for chest, 80.8% for abdomen, and 79.6% for pelvis x-rays. On the other hand, the average positive diagnostic responses for the patients with insufficient clinical information across the hospitals were very low: 16.3%, 15.3%and 22% for chest, abdomen, and pelvis radiographs readings respectively. These findings reflect the importance of providing sufficient justified clinical information to avoid exposing patients to unnecessary radiation without diagnostic benefit. Referring physicians play a vital rule in optimization through procedure justification with providing clear clinical history and the purpose for requesting x-ray procedures.

5.1.2 Equipment QC Tests

The QC checks results on X-ray machines across the ten x-ray departments were within tolerance limits as presented in Table 4.2.A.

The collimation test results findings (Table 4.2.B). reveals partial failure in the cross centered test in hospital H5 and H7 while results shows complete failures in hospitalH3 and H8.Inaccurately collimated beams result in an increase in the size of the irradiated field and hence an increase in the amount of scatter radiation due to a larger volume of tissue being radiographed. X-ray radiation scattered by the patient’s body is one of the main factors contributing to the deterioration of X-ray images [Mazurov et al 2015].

Image processing checks (Table 4.3) revealed density variations with increased base + fog in four hospitals namely H2, H3, H5, and H8. These problems are related to many causes including

processing temperatures, replenishment problems, contamination and chemicals exhaustions beside errors related to film handling and storage conditions.

These findings were evident by the increased number of rejections related to film processing. These results reflect lack of processor QC in these hospitals which directly affects the desired quality and the associated patient dose by increasing the number of retakes.

5.1.3 Patient dose measurement

The mean ESAK values for chest, abdominal and pelvic X-ray procedures across the ten hospitals (Table 4.4) were 0.5 ± 0.3, 3.7 ± 1.7 and 3.6 ± 1.6 mGy, respectively. Comparing these calculated doses to the reported and published DRLs (Table 4.5), the Patient doses showed variation among all hospitals and procedures. These variations in patient doses are correlated to patient size, system performance, and the applied technical factors among the various hospitals. These ESAK variations reflect the need to establish DRLs for these radiographic examinations with keeping in mind that; X-ray systems using CR allow a high tolerance for variations in exposure (Johnston et al 2000).

5.1.4 Rejection Analysis

As shown in Figures 4.2 and 4.3 and Table 4.6 the overall rejection rates among the various hospitals indicated a 9.35% average rejection rate ranging from 4.2% to 15.2%. The highest rates were 14.5% at H2 and 15.2% at H5 while the lowest rates were 4.2% and 4.3% at H9 and H10 respectively.

The most frequent reasons for rejection across the ten hospitals were associated with system errors, exposure factor errors, positioning and patient movement errors as well as failure of patient preparation or instructions prior to exam. The results show low rejection rates in hospitals with CR systems compared to other hospitals using automatic film processing, as illustrated in Figure 4.2. Image processing errors contributed to the majority of rejections across all hospitals with FSR systems (Table 4.6). The causes of these errors were related to the lack of sensitivity of

the regular processors. On the other hand, errors in exposure factors were due to the absence of technical charts or inaccurate manipulation of factors to fit the patient size. Beam collimation errors were found in hospitals in which collimator failures were identified in the QC test performed (Table 4.2). Other reasons included patient preparation and positioning-related errors. In addition the increased rejection rate in chest radiographs is attributing to the increased number of patient compared to the other procedures. Therefore, regular processors sensitometery, preparation of exposure charts and proper selection of exposure factors (kVp and mAs) along with regular QC testing of the radiographic systems with corrective actions, as well as clear patient preparation and instructions prior to examinations are the effective methods for reducing rejection rates and improving the radiographic outcome. The improvement in image receptor technology provides potential for improving the image quality and reducing rejection rates. Regular implementation of retake analysis and review of retakes with immediate corrective action is essential and should be performed as recommended in the published literature (CRCPD, 2001).

5.1.5 Image Criteria Analysis

As shown in Figures 4.4, 4.5 and 4.6, the scores of fulfilled image criteria rated as good were in the range of (56–82.9%), (65–90.9%), and (37.9–92.6%) for chest PA, abdominal AP, and pelvic AP respectively. Combining good scored images with those rated as satisfactory reveals a percentage range of (77.8–94%), (82.9–97%) and (89.3–96%) respectively.

The number of poor scored images which were rated as rejects varied from (5.6–22.2%) for chest, (3–17.1%) for abdomen, and (3.4–11.1%) for pelvic X-rays. These variations were attributed to the various causes identified during rejection analysis (Table4.2). Variations in the technologists' experience also contributed to the quality of the outcome. The standard of radiographs can be maintained at a satisfactory level with good scores through improving image-processing conditions, standardization of the technical factors along with staff training as needed.

When performing radiographic images, patient characteristics and clinical purpose are of most importance and should be carefully noted in order to produce images with acceptable diagnostic quality and reasonable patient radiation dose.

5.2 Conclusion

Optimization of diagnostic radiography is a continuously evolving process encompassing efforts from different medical fields. To balance the required image quality with radiation dose to patients, several factors should be considered, including the properties and status of the imaging system, characteristics of patients and anatomical parts to be examined, and elements of the procedural technique. The baseline of optimization in radiography is to identify the level that supports the required diagnostic image quality, and hence the parameters that provide this level of quality with the lowest possible patient dose, relative to international dose reference levels. This study provides essential data for image quality and patient dose levels for chest, abdominal and pelvis along with the performance of the equipment used. The result shows wide variations of image quality criteria and patient radiation doses for chest, abdomen and pelvis radiography among the ten examined x-ray departments. Diagnostic quality images with reasonable dose reference levels are easy to meet. In fact, for patients in this study and in agreement with other previous studies the measured ESAKs in Sudan were varies from lower to higher than the international reference level, therefore the national radiation protection authorities should re-evaluate the diagnostic reference levels for all planar radiology procedures in Sudan. The numbers of images fulfilling all image criteria were moderately low. This is in agreement with no other studies performed previously for evaluating image criteria, so developing and establishing image quality criteria with judging to be clinically useful as part of optimization process should be stressed.

5.3 Recommendations:

- Establishment of comprehensive quality assurance program within each x-ray department as well as identifying the responsibility of technologists, physicians and radiologists as backbone for optimization.
- Re-evaluation and establishment of dose reference levels for all procedures by national radiation protection authorities (Based on international DRLs)
- Development of image quality criteria manuals for all radiographic procedures with reference to the internationally established DRLs
- Emphasis on staff training in methods of optimization in diagnostic radiology, as one of the strategies for improving the image quality with significant dose reductions. Mandatory CME hours by national authorities should considered for all parties involved in providing the service.
- Clear justifications for requesting radiographic examinations with providing sufficient clinical information are highly recommended to avoid repetition of examination in general. In these studied departments the improvement of radiology requisitions must be stressed to be clinically useful.
- Establishment of comprehensive quality assurance program within each x-ray department as well as identifying the responsibility of technologists, physicians and radiologists as backbone for optimization.
- With considering the cost, shifting to digital technology is a challenge to comply with the radiography advances and meet the desired optimization.
- Programming of the pathological indications in digital systems by equipment manufactures.
- Future studies should be done in optimization of patient radiation dose and image quality for all radiographic examinations following the international standards in order to establish national diagnostic quality criteria and dose reference levels in Sudan.

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Appendices

Appendix (1)

Request Form Evaluation Sheet

Hospital: ……

Answers: Available= (1) Not available= (0)

Required Information	Answer
Patient ID	
Patient age	
Patient Gender	
Last menstrual period (For Females)	
Clinical history	
Previous X rays for the same clinical condition	
Clinical indication	
Clearness of the requested exam	
Date of examination	
Referring physician name	

REMARKS:

_____

_____

_____

_____

Appendix (2)

Radiographic Exam Data collection sheet

Hospital: ……Room No …… Examination Required ……

System Type: Screen Film (SFR) ☐ CR ☐ DR ☐

Patient's data

ID: …… Gender: ……..…. Age: ……..…… (Years)

Height: ……..…… (cm) Weight: ……..…..…..…(Kg)

Patient thickness in the center of the beam……..

Requested Examination……...……

Clinical History (Clinical Diagnosis)

Radiographic data:

KVp: …… mAs: ……..… FFD: ……..….field size: ……..…Grid Type ……

Film speed or CR and DR: detector type:

……..……

Projections:

……..……
……..……
……..……

Dose values:

……..……
……..……
……..……

Appendix (3)

Sudan Atomic Energy Commission
Radiation Safety Institute
Quality Control Procedure for Diagnostic X-Ray Units

INSPECTION NO.:		DATE:	
NAME OF INSTITUTE:			
ADDRESS:			
ROOM NUMBER:		TEL.NO:	

X-RAY GENERATOR			
Manufacturer	**Toshiba**		
MODEL		**SERIAL No**	
DATE PURCHASED			
DATE OF LAST MAINTENANCE		**REPAIR**	
FIXED		**MOBILE**	
TYPE	**RADIOGRAPHICs**		
MAXIMUM KVp			

X-RAY TUBE			
MANUFACTURER	Toshiba		
MODEL		SERIAL No.	
RADIOGRAPHIC		FLUORO	
DATE INSTALLED		FOCAL SPOT SIZE	
DATE OF LAST MAINTENANCE		1.1 REPAIR	
INHERENT FILTERATION		ADDED FILTERATION	
TOTAL FILTERATION			
OPERATIONAL MANUAL		SERVICE MANUAL	

1	**KVp & TIME ACCURACY**									
First Exposure Factors		**KVp**		**mA**		**S**		**mAs**		
FDD		**Wave Form**								
No	KVp	KVp Measured	Corrected KVp	KVp Error%	Accepted*	Time	Time Measured	Time Error (%)	Accepted**	
1										
2										
3										
*	***± 10%**			**	**** ± 10%**					

2	RELATIVE mA & mAs LINEARITY (Using the KV meter)					
KVp		t				
i	mA	R	Acceptable*	mAs	R	Acceptable**
1						
2						
3						
4						
*	$\lvert Ri - (mAs_i * R_1 / mAs_1) \rvert / (mAs_i * R_1 / mAs_1) \leq 10\%$			**	$\lvert Ri - (mA_i * R1 / mA_1) \rvert / (mAi * R_1 / mA_1) \leq 10\%$	

3	mAs CONSISTENCY								
mAs						20			
No	1.2 KVp			1.3 KVp			1.4 KVp		
	mA	t	R_1	mA	t	R_2	mA	t	R_3
Average				Average			Average		
Acceptable				Acceptable			Acceptable		
*	{Sqrt($\sum$(R- $R_{a\,v}$)^2/(n-1))/ $R_{a\,v}$) ≤ 0.05}								

4	KVp AND TIME REPRODUCIBILITY AND LINEARITY TEST									
KVp		t msec		mAs_1		mAs_2 (2* mAs_1)				
No		KVp		Time		D_1(R)		D_2 (R)		
Average										

Coefficient of variation{sqrt($\sum$(D- D_{av})^2/(n-1))/ d_{av} ≤0.05 = 0.074657		
KVp Reproducibility {sqrt($\sum$(KVp- KVp_{av})^2/(n-1))/ KVp_{av} ≤0.05 = 0.0008		
Time Reproducibility {sqrt($\sum$(t-t_{av})^2/(n-1))/ t_{av} ≤0.05} = 0.001		

X_1= $D1_{a\,v}$ / mAs_1		1.5 X2= D2a v / mAs2	
$\lvert x_{1-}\ x_2 \rvert$ =	$x_{1+}\ x_2$ =	0.1*($x_{1+}\ x_2$) =	Acceptable*:
*	$\lvert x_{1-}\ x_2 \rvert \leq 0.1*(x_{1+}\ x_2)$		

6	RADIATION FIELD		
A	COLLIMATOR		
Criteria	Status	Criteria	Status
Light working		Cross indication	
Light edge clear		Cross centered	

B	BEAM ALIGNMENT TEST							
I	PERPENDICULARITY TEST							
F-table top			cm					
KVp		mA		t	msec	mAs		
Balls Images overlap (perpendicularity within 0.5^o)		Ball Image in the 1stcircle (misalignment is 1.5 ^{o})		Ball Image in the 2nd circle (misalignment is 3.0 o)		Ball Image out of circles	Acceptable	
							Yes	No

II	COINCIDING TEST			
FFD	mAs	Measured Variance Long Axis Short Axis	% Variance Long Axis Short Axis	Acceptable*
*	≤ 2% of FFD (2cm)			

Appendix (4)

Image Evaluation Data Collection Sheet

Hospital: ……Room No …… Examination Required ……..……

Overall Evaluation

Optimal (+) High (++) Low (-)

Image characteristics

Image density (Blackening) ☐

Image Contrast ☐

Image Sharpness ☐

Important image details ☐

Image Criteria Assessment : [EUR16260 EN]
Visual Grading Analysis (VGA) :-
Good ☐ Satisfactory ☐ Poor ☐

Image Rejected By: Technologist ☐ Radiologist ☐

Cause Of Image Rejection:

Image Quality Criteria	✓	Remarks
Improper selection technical factors (mAs, KVp or distance)		
Failure to identify patient (wrong patient)		
Improper patient communication/ instructions (patient preparation)		
Incorrect positioning(wrong position or projection)		
Improper use of Collimation		
Improper use of accessories (cassettes, grids , etc)		
Image processing errors		

Others (Please Specify):

Appendix (5)

Thesis outcomes

International (ISI) Publications during Period of Study

1. **E. Babikir,** Hussein A. Hasan, A. Abdelrazig, M. A. Alkhorayef, E. Manssor, A. Sulieman: Radiation dose levels for conventional chest and abdominal X-ray procedures in elected hospitals in Sudan. Radiation Protection Dosimetry 2015 Jul; 165(1-4):102 6.DOI:10.1093/rpd/ncv108 Web link: http://rpd.oxfordjournals.org/content/165/1-4/102.abstract?sid=2d964468-51cd-4351-a164-35225f2e99e4

2. K. Alzimami, A. Suleiman, A. Yousif, **E. Babikir,** I. Salih: Evaluation of radiation dose to neonates in a special care baby unit. Elsevier, Radiation Physics and Chemistry. Volume 104, November 2014, Pages 150-153 Web link: http://www.sciencedirect.com/science/article/pii/S0969806X13006439

3. A. Suleiman, **E. Babikir**, K. Alzimami,, K. Alsafi , M. Alkhorayef , Hiba Omer.Estimation of effective dose during Hystrosalpigography procedures in certain hospitals in Sudan, Applied Radiation and Isotopes. Volume 100, June 2015, Pages 2–6.doi:10.1016/j.apradiso.2015.02.009 http://www.sciencedirect.com/science/article/pii/S0969804315000470

4. A.Sulieman, K.Alzimami, R.Gafar, **E.Babikir,** K.Alsafi, I.I.Suliman. Occupational and patient exposure in coronary angiography procedures. Elsevier, Radiation Physics and Chemistry. Volume, November 2014, Pages 68‑71 Web http://www.sciencedirect.com/science/article/pii/S0969806X13006750c

5. Manssor E, Abuderman A, Osman S, Alenezi SB, Almehemeid S, **Babikir E,** Alkhorayef M, Sulieman A.**:** Radiation doses in chest, abdomen and pelvis CT procedures. Radiat Prot Dosimetry. 2015 Jul; 165(1-4):194-8. Doi: 10.1093/rpd/ncv107. Epub 2015 Apr 6. Web link: http://rpd.oxfordjournals.org/content/165/1-4/194.abstract?sid=2d964468-51cd-4351-a164-35225f2e99e4
6. Sulieman A, Tammam N, Alzimami K, Elnour AM, **Babikir E,** Alfuraih A.: Dose reduction in chest CT examination. Radiation Prot. Dosimetry. 2015 Jul; 165(1-4): Web link: http://rpd.oxfordjournals.org/content/165/1-4/185.abstract?sid=2d964468-51cd-4351-a164-35225f2e99e4

Conference Presentations

7. (ICRM2014).King Faisal Specialist Hospital and Research Centre, (KFSH&RC) Riyadh, KSA. Optimization of Radiation Dose and Image Quality in Projection Radiography: A Review. http://www.radmed.org/documents/ICRM2014%20BOOKLET.pdf

8. International Conference on Radiation Protection in Medicine (RPM 2014), 30th of May to 2nd of June 2014 Varna, Bulgaria. Radiation Dose Levels for Conventional Chest and Abdominal X- ray Procedures in Elected Hospitals in Sudan, (Poster S3A.P12), MEDICAL PHYSICS INTERNATIONAL Journal, vol.2, No.1, 2014 p.135. Web link:http://www.rpm2014.org/images/downloads/MPI-2014-01-p071.pdf