ASSESSMENT OF ENTRANCE SKIN DOSE FOR PATIENTS UNDERGOING DIAGNOSTIC X-RAY EXAMINATION IN AHMADU BELLO UNIVERSITY TEACHING HOSPITAL SHIKA, ZARIA, NIGERIA

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTERS OF RADIATION BIOPHYSICS

DEPARTMENT OF PHYSICS,
FACULTY OF PHYSICAL SCIENCE,
AHMADU BELLO UNIVERSITY ZARIA, NIGERIA.

MAY, 2021

DECLARATION

I declare that the work entitled, **"Assessment of Entrance Skin Dose for Patients Undergoing Diagnostic X-Ray Examination in Ahmadu Bello University Teaching Hospital Shika, Zaria, Nigeria"** has been carried out by me in the Department of Physics Ahmadu Bello University, Zaria under the supervision of Dr. N.N Garba and Dr. M.A Onoja. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any University.

_____ _____

Arinde Olubunmi Odunola **Date**

CERTIFICATION

This dissertation entitled **"Assessment of Entrance Skin Dose for Patients Undergoing Diagnostic X-Ray Examination in Ahmadu Bello University Teaching Hospital Shika, Zaria, Nigeria"** meets the regulations governing the award of degree of Master of Science in Radiation Biophysics in Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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Dean, School of Postgraduate Studies

DEDICATION

This work is dedicated to Almighty God, and to my entire family for their prayers and support towards the success of this research work and the entire program.

ACKNOWLEDGEMENTS

All thanks, praises and glories are due to Almighty God for his protection, provision, guidance, love as well as the strength through the course of this programme.

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(Amen).

ABSTRACT

The consequences of ionizing radiation are less evident at low doses but the associated risks are of significant importance. Unnecessary radiation exposure to patients can lead to cancer induction in patients. This research is aimed at assessing the entrance skin dose for patients undergoing diagnostic X-ray examination at Ahmadu Bello University Teaching Hospital Shika, Zaria, Nigeria. Thermoluminescence and Caldose_x 5.0 software were used to assess the entrance skin dose of adult patients undergoing examination of the chest (AP/LAT), lumbar spine (AP/LAT), knee (AP/LAT), femur (AP/LAT) and pelvis (AP) and Effective dose was calculated. The patient's data and exposure parameters considered were age, sex, weight, examination type, projection posture, tube potential and current-time product. The mean ESD and ED obtained using TLD are 0.32 mGy and 0.016 mSv, 0.43 mGy and 0.021 mSv, 0.30 mGy and 0.035 mSv, 0.68 mGy and 0.081 mSv, 0.16 mGy and 0.002 mSv, 0.16 mGy and 0.002 mSv, 0.27 mGy and 0.003 mSv, 0.19 mGy and 0.002 mSv, 0.89 mGy and 0.038 mSv for chest (AP/LAT), lumbar spine (AP/LAT), knee (AP/LAT), femur (AP/LAT) and pelvis (AP) respectively. The mean ESD and ED obtained using Caldose _x 5.0 software were 0.94 mGy and 0.047 mSv, 1.36 mGy and 0.021 mSv, 2.29 mGy and 0.114 mSv for chest (AP/LAT) and pelvis (AP) respectively.

In conclusion, the values of ESD and ED obtained using Caldose software were higher than the values obtained from TLD but compared favorably with internationally established diagnostic reference levels. Therefore, the values are within safe limits and do not pose any significant health risk to the patients. The effective dose by comparison, indicate that radiation risk factors (RRFs) are relatively low.

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LIST OF ABBREVIATIONS

ESD Entrance skin dose

ED Effective dose

TLD Thermoluminescence dosimeter

DRL Diagnostic Reference Levels

AP Anterior-posterior

LAT Lateral kVp Peak

kilovoltage mAs

Milliamperes

FSD Focus to skin distance.

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Medical diagnostic procedures used to define and diagnose medical conditions are currently the greatest manmade source of ionizing radiation exposure to the general population (Edward et al, 2015). The use of ionizing radiation in medicine began immediately after the discovery of X-rays by Roentgen in 1895. Ionizing radiation is the portion of the electromagnetic spectrum with sufficient energy to pass through matter and physically dislodge orbital electrons of an atom to form ions. These ions, in turn, can produce biological changes when introduced into tissues. Owing to the establishment of both benefits and detriments, science has sought to exploit and maximize the beneficial aspects of ionizing radiation while minimizing the unavoidable side effects. This led to the formation of the International Committee on Radiological Protection (ICRP) in 1948, which work is to provide guidance for the setting of radiation protection criteria, standards of practice and limits in dose (ICRP, 1970).

Entrance skin dose is a directly measurable quantity, often measured using Thermoluminescence dosimeters (TLD) (ICRP 1996). It is a measure of the radiation dose that is absorbed (mGy) by the skin as it reaches the patient. It is used in radiography to set diagnostic reference levels that establishes a benchmark for the optimization in using medical radiation, ensuring departments adhere to the principles of radiation protection.

Regular control and dosimetry can help the physician and physicist to ensure that the dose received by patients who undergo radiological procedures is in accordance with the ALARA (As Low As Reasonably Achievable) principle and does not exceed the amount required to obtain favorable radiographic scan.

Entrance Skin Dose (ESD) is recommended by the International Atomic Energy Agency (IAEA) as the most appropriate patient dosimetry quantity in simple radiographic examinations, primarily due

to the convenience of measurement, easy comparison with other studies in different countries or dose reference levels (DRLs), and proportionality to patient effective dose that is used to find the probability of radiation-induced complications (IAEA, 2004).

The need for radiation dose assessment of patients arising from diagnostic X-ray examinations has been highlighted by the increasing knowledge of the hazards associated with low doses of ionizing radiations. The major benefit of using the effective dose is that this parameter accounts for the absorbed doses and relative radio-sensitivities of the irradiated organs in the patients and, therefore, better quantifies the patient risk (ICRP, 1991).

1.2 Statement of the Problem

The use of radiation in medical imaging which is continually increasing coupled with the amazing advances within imaging has made it necessary to review the way in which radiography should be regarded.

Sharifat and Olarinoye (2009) obtained the entrance skin dose from the diagnostic X-ray Centers in Minna and Ibadan, Nigeria for the common radiological examinations and found doses for chest examination to be higher than those in published works and IAEA. The doses obtained for skull and abdomen examination were found to be within acceptable IAEA recommended limits. Haval et al. (2017) carried out a research in three government hospitals in Duhok City focusing on five routines radiographic examination and obtained ESD values for abdomen, pelvis and skull examinations to be slightly above the diagnostic reference level while a much higher value than the diagnostic reference level was obtained for chest and cervix.

The radiographic examinations for the previous works were limited to common and routine examinations carried out in the hospitals studied and the use of Solid-state dosimeter and Thermoluminescence dosimeter respectively, in determining the entrance skin dose.

This survey will combine the use of Thermoluminescence dosimeter and CALDose _X software to obtain improved results and compare the outcome of the methods used. It will also help to set a guidance dose for these examinations so that radiographers in ABUTH and other hospitals can always compare their dose with it and take remedial action without affecting image quality if need be. Efforts can also be made by mandating radiographers and radiologists to take part in various refresher courses for them to be aware of the recent developments on how to carefully select technical parameters that will not compromise image quality but lead to a reduction in patient dose and employing special staff of Medical Physics in the evaluated hospitals.

1.3 Aim and Objectives

The aim of this research is to assess the entrance skin dose to patients undergoing diagnostic Xray examinations in Ahmadu Bello University Teaching Hospital, Shika, Zaria, Nigeria.

The objectives are:

- To measure the entrance skin dose (ESD) arising from X-ray examination of the chest, lumbar spine, femur, knee, and pelvis using Thermoluminescence dosimeters.

- To determine the ESD arising from X-ray examination of the chest, lumbar spine and pelvis using CALDose_X 5.0 software.

- To calculate effective dose (ED).
- To compare the results of ESD and ED obtained from the two methods.

1.4 Justification

Diagnostic imaging and interventional radiology procedures are increasingly used to diagnose a wide range of illnesses and injuries. Inappropriate use of these technologies can lead to unnecessary radiation exposures. Reduction of unnecessary radiation exposure by justification of radiological medical procedures has always been the primary aim of radiation protection.

This research is to estimate the entrance skin dose for patients undergoing diagnostic x-ray examinations to provide local diagnostic reference levels for some diagnostic X-ray examinations at ABUTH. It serves as a means for optimization of the radiation protection practices as well as the level of compliance by the hospital to the international regulations on limiting radiation exposure to patients.

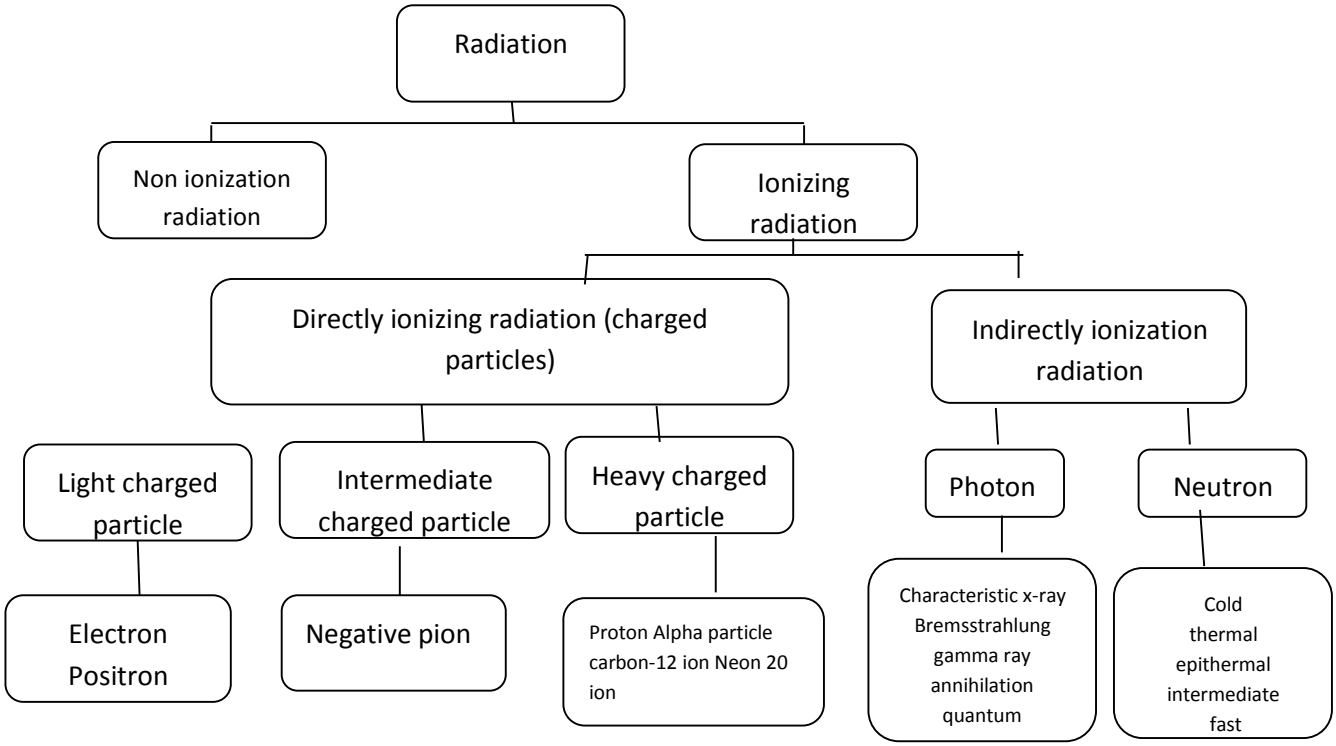
1.5 Scope of the Study

This study focused on Radiography Department of Ahmadu Bello University Teaching Hospital (ABUTH) Shika, Zaria. The dose quantity Entrance skin dose was measured, and effective dose was evaluated.

A total of 100 adult patients were taken into considerations and the examinations were limited to chest, lumbar spine, knee, femur, and pelvis X-ray with projections of both Anterior-Posterior (AP) and Lateral view (LAT). These selected examinations are the most common examinations usually carried out on a daily basis.

CHAPTER TWO
LITERATURE REVIEW

2.1 Ionizing Radiation



Radiation is an energy that travels through space or matter in the form of wave or particle. Radiation can be categorized into charged particulate radiation (fast electrons and heavy particles) and uncharged radiations (electromagnetic radiations and neutrons). It can also be classified into ionizing and non-ionizing radiation (IAEA, 2005).

The ionizing radiation of interest in this research is the X-ray which is a type of photon radiation that can penetrate very deeply and sometimes can only be reduced in intensity by materials that are quite dense, such as lead or steel. In general, photon radiation can travel much greater distances than alpha, or beta radiation and it can penetrate body tissues and organs when the radiation source is outside the body (CNSC, 2012). Photon radiation can also be hazardous if photon-emitting nuclear substances are taken into the body.

Fig 2.1 Classification of Ionizing Radiation (Podgorsak, 2014).

2.1.1 X-ray

An X-ray (radiograph) is a noninvasive medical test that helps Physicians diagnose and treat medical conditions. Imaging with X-rays involves exposing a part of the body to a small dose of ionizing radiation to produce pictures of the inside of the body. X-rays are the oldest and most frequently used form of medical imaging (ACR, 2020).

The X-ray was discovered by Wilhelm Conrad Röntgen on 8 November 1895 in Würzburg, Germany. Röntgen, a Professor of Physics, conducted experiments focusing on light phenomena and other emissions generated by discharging an electrical current in a highly evacuated glass tube known as the Crookes tube. A Crookes tube is simply a glass bulb invented by Sir William Crookes. It consists of an electrode at each end: a metallic (aluminium) cathode, and an anode that attracts electrons (Gelderen, 2004). When a high voltage was applied to the electrodes, electrons formed at the cathode will be pulled towards the anode and strike the copper with a remarkably high energy. Röntgen discovered that very penetrating radiations were produced from the anode, which he called X-rays (Assmus, 1995).

X-rays are produced when a heated filament (cathode) within an X-ray tube generates electrons that are accelerated to a tungsten target (anode) by application of high voltage (50-150 kV_p) to the tube. The electron creates an electric field that interacts with the nucleus of the anode, thereby releasing energy in the form of X-rays. The flow of electrons from the filament to the target is called the tube current and is described in units of milliamperes (mA).

The benefits of using high quality X-ray imaging in diagnosing disease and in the guidance of therapeutic procedure is well known. The production of diagnostic radiograph of acceptable quality depends on many factors such as film composition, processing technique and X-ray machine performance. Of these, machine performance plays the most important role, because a small change in radiographic technique factors such as peak kilovoltage (kVp) or milliampere

(mAs) can greatly affect the image quality (USFDA, 2015).

2.2 Physics of X-ray production

There are two different mechanisms by which X-rays are produced. One give rise to bremsstrahlung X-rays and the other characteristic X-rays (Khan, 2012).

2.2.1 Bremsstrahlung X-rays

The process of bremsstrahlung is the result of interaction between a high-speed electron and a nucleus. The electron while passing near a nucleus may be deflected by the action of Coulomb forces of attraction and loses energy as bremsstrahlung, a phenomenon predicted by Maxwell's general theory of electromagnetic radiation. According to this theory, energy is propagated through space by electromagnetic fields. As the electron with its associated electromagnetic field passes in the vicinity of a nucleus, it suffers a sudden deflection and deceleration. As a result, a part or all its energy is dissociated from it and propagates in space as electromagnetic radiation (Khan, 2012). Since an electron may have one or more bremsstrahlung interactions in the material and an interaction may result in partial or complete loss of electron energy, the resulting bremsstrahlung photon may have any energy up to the initial energy of the electron. Also, the direction of emission of bremsstrahlung photons depends on the energy of the incident electrons. At electron energies below about 100 keV, X-rays are emitted equally in all directions. As the kinetic energy of the electrons increases, the direction of X-ray emission becomes increasingly forward. Therefore, transmission-type targets are used in megavoltage X-ray tube accelerators in which the electrons bombard the target from one side and the X-ray beam is obtained on the other side. In the low voltage X-ray tubes, it is technically advantageous to obtain the X-ray beam on the same side of the target i.e., at 90 degrees with respect to the electron beam direction

(Khan,2012) The energy loss per atom by electrons depends on the square of the atomic number (Z^2). Thus, the probability of bremsstrahlung production varies with Z^2 of the target material.

However, the efficiency of X-ray production depends on the first power of atomic number and the voltage applied to the tube. The term efficiency is defined as the ratio of output energy emitted as X-rays to the input energy deposited by electrons Khan (2012). It can be shown that:

$$\text{Efficiency} = 9 \times 10^{-10}\, Z \times V \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

where V is tube voltage in volts. From the above equation it can be shown that the efficiency of X-ray production with tungsten target (Z = 74) for electrons accelerated through 100 kV is less than 1% with the rest of the input energy (~99%) appearing as heat. The accuracy of above equation is limited to a few microvolts (Khan, 2012).

2.2.2 Characteristics X-rays

Electrons incident on the target also produce characteristic X-rays as a result of coulomb interactions between the incident electrons and atomic orbital electrons of the target material (collision loss). An electron with kinetic energy E_0 may interact with the atoms of the target by ejecting an orbital electron from its shell such as a K, L, or M electron, creating a vacancy thereby leaving the atom ionized and an electron from a higher-level shell fills the resulting orbital vacancy (Khan, 2012). In doing so, the energy is radiated in the form of electromagnetic radiation. The energy difference between the two shells may either be emitted from the atom in the form of a characteristic X-ray as shown in Fig 2.2, i.e., characteristics of the atoms in the target and of the shells between which the transitions took place or transferred to an orbital electron that is ejected from the atom as an Auger electron. With higher atomic number targets and the transitions involving inner shells such as K, L, M, and N, the characteristic radiations emitted are of high enough energies to be considered in the X-ray part of the electromagnetic spectrum (Khan, 2012).

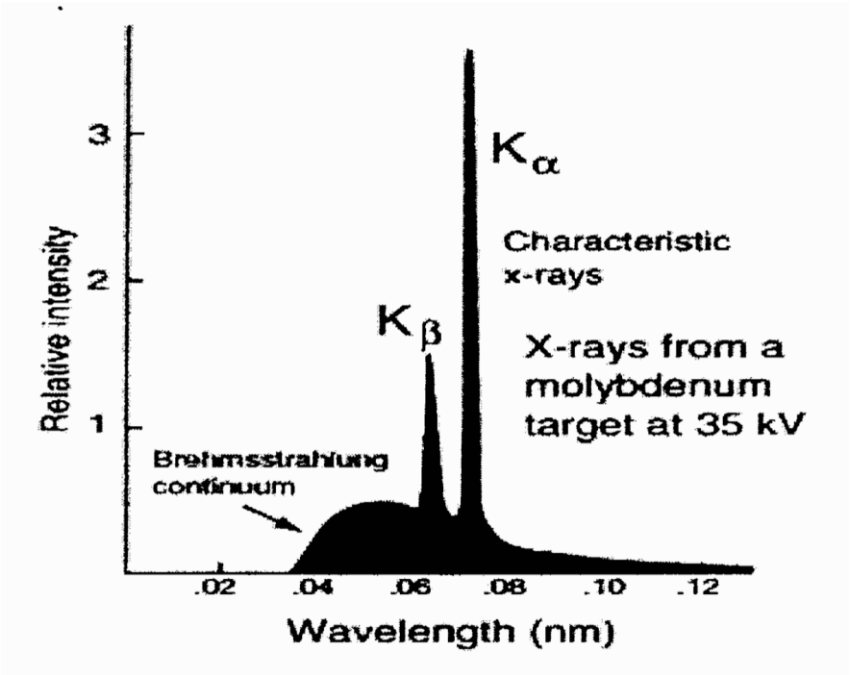
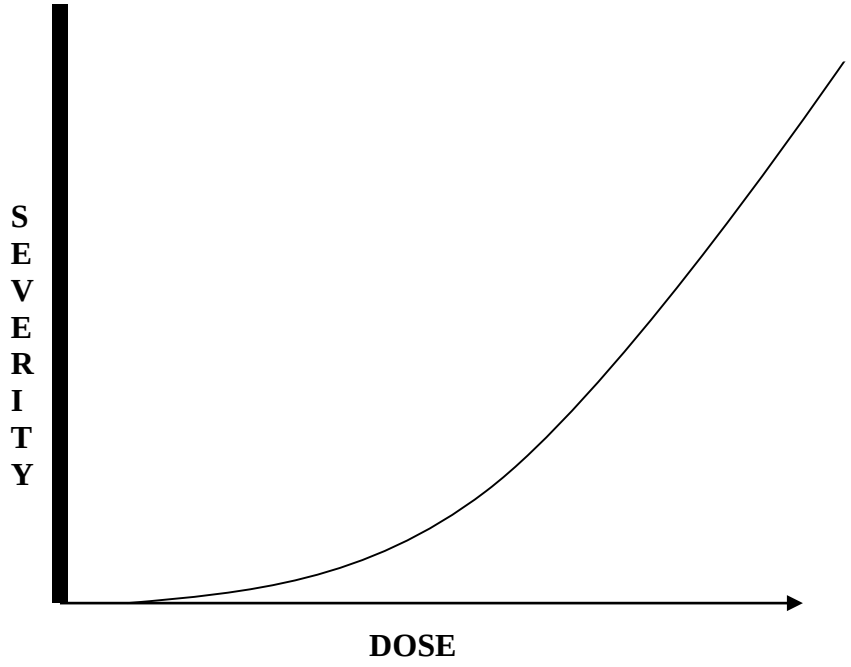


Fig. 2.2 Characteristics X-rays

2.3 Biological Effects of Radiation

According to the ICRP 2007 recommendations, adverse health effects from radiation exposure are grouped in two general categories, i.e., harmful tissue reactions (deterministic effects) and stochastic effects (of random or statistical nature). Harmful tissue reactions (deterministic effects) resulting from the killing/malfunctioning of cells is characterized by a certain dose called "threshold". The reason for the threshold is that a serious malfunction or death of a critical population of cells in each tissue should be sustained before injury is expressed in a clinically relevant form. As shown in Fig. 2.3 the frequency of the injury increases with dose as the number of affected cells is directly proportional to the severity of the effect. Fig. 2.4 illustrates the way in which the severity of the damage above the dose-threshold, including the impairment of the capacity for tissue recovery, increases with dose. It has been recognized that tissue reactions can be modified after irradiation using some biological response modifiers (Domenech, 2017). Some examples are antioxidants, radical scavengers, apoptosis inhibitors, anti-inflammatory drugs, growth factors and others.

Fig.2.3 Relationship between dose and the frequency (Domenech, 2017).



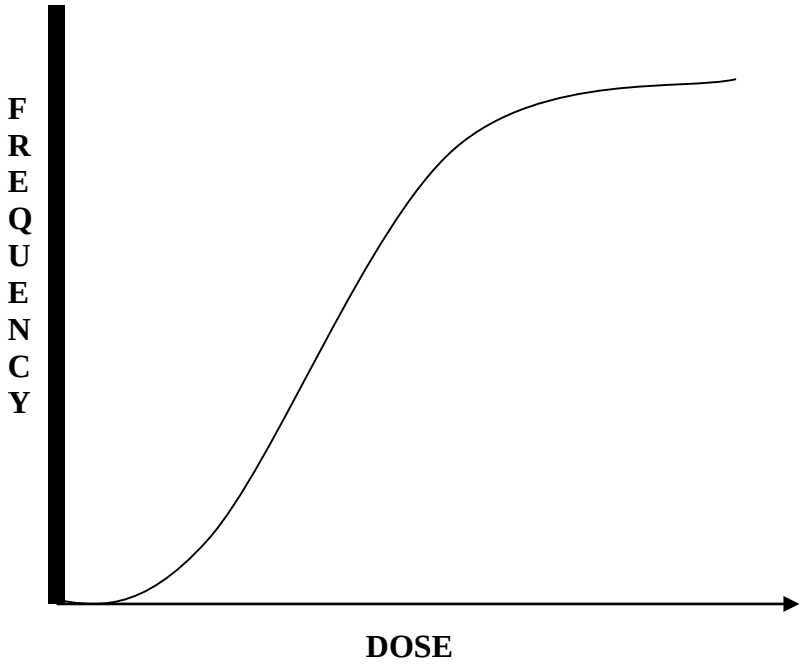


Fig.2.4 Relationship between severities of tissue reactions (Domenech, 2017).

Tissue reactions are also characterized by different periods of latency, so it could be distinguished between early tissue reactions detected in a few days or weeks (on a timescale of hours to weeks), and late tissue reactions, detected months to years after the irradiation. Early tissue reactions may be of the inflammatory type, resulting from cell permeability changes and histamine release (e.g.,

erythema), or they may be reactions resulting from cell loss e.g., mucositis (ICRP, 2005). Late tissue reactions are called "generic" if they arise as a direct result of damage to that tissue or "consequential" if they occur because of an early cellular damage (ICRP, 2012). In view of different individual radio-sensitivity, it is accepted that the dose-threshold for a specific tissue reaction is the dose that produces the same tissue reaction in the 1–5 % of the total exposed individuals. Updated information on dose thresholds corresponding to doses that result in about

1% incidence of morbidity and mortality for various organs and tissues is available in the ICRP (2007) recommendations. Some examples are temporary sterility in 3–9 weeks from an acute absorbed dose of 0.1 Gy in the testes; depression of blood forming process in 3–7 days from an acute absorbed dose of 0.5 Gy in the bone marrow; and cataracts in several years from an acute absorbed dose of 0.5 Gy (ICRP, 2012). The most severe tissue reaction is death. Mortality after irradiation is generally the result of severe cell depletion in tissues or other major dysfunction of one or more vital organs of the body. Enough high acute doses to the whole body in noticeably short periods of time may lead to lethal disorders. Although there is great uncertainty in the lethal dose-threshold on account of the general health of individuals, the immediate medical assistance received and other specific factors, absorbed doses between 3–5 Gy may cause death in 50 % of exposed individuals in a lapse of 1–2 months (ICRP, 2005).

2.4 Radiation Protection

2.4.1 External radiation protection

The three basic methods used to reduce the external radiation hazard are time, distance, and shielding. Good radiation protection practices require optimization of these fundamental techniques.

A. Time

The amount of radiation an individual accumulates will depend on how long the individual stays in the radiation field, because:

Dose (mrem) = Dose Rate (mrem/hr) x Time (hr)

How long a person can stay in an area without exceeding a prescribed limit is called the "stay time" and is calculated from the simple relationship:

Stay Time = Limit (mrem) / Dose Rate (mrem/hr)

B. Distance

The amount of radiation an individual receives will also depend on how close the person is to the source. Point sources of x- and gamma radiation follow the inverse square law, which states that the intensity of the radiation (I) decreases in proportion to the inverse of the distance from the source (d) squared:

$$I\alpha\frac{1}{d^2} \quad \text{..... (2.2)}$$

So, for intensity I_1 at distance d_1, and intensity I_2 at distance d_2:

$$I_1d_1^2 = I_2d_2^2 \quad \text{..... (2.3)}$$

Therefore, by knowing the intensity at one distance, one can find the intensity at any other distance (RSSC, 2011).

C. Shielding

When reducing the time or increasing the distance may not be possible, shielding material can be used to reduce the external radiation hazard. The proper material to use depends on the type of radiation and its energy. Lead is a common shielding material for X-rays and gamma radiation because it has a high density, is inexpensive, and is relatively easy to work with. When working with a radionuclide that emits multiple types of radiation such as beta particles and gamma radiation, it is sometimes necessary to shield with several materials. The less penetrating beta radiation can first be

shielded with a layer of plastic or Plexiglas, thereby slowing, or stopping the beta particles while reducing the production of bremsstrahlung. The more penetrating gamma radiation would require an additional layer of shielding. Types of shielding and amount of shielding vary depending on photon energy. A good rule of thumb: shield the less penetrating radiation type first then proceed to shield the more penetrating type. This usually decreases both scattering and the total amount of shielding material required (RSSC, 2011).

2.4.2 Justification of diagnostic radiology procedures

The ICRP states that the principle of justifying any decision that alters the radiation exposure situation should be more beneficial and less harmful (Rehani, 2012). Justification is considered one of the most critical steps in medical radiation protection as stated by the European Society of Radiology (ESR, 2011). Many researchers show the deficit in knowledge about diagnostic imaging risks among medical professionals, both referring doctors and radiological staff. Hence, the biological impact of the examination must be clear for the referring clinicians and radiologist, whereas the justification implies that the necessary results cannot be achieved with other methods that would pose a lower risk for the patient (Khong, 2013).

Justification includes three main levels (IAEA, 2014).

a) General justification of the practice by weighing the diagnostic or therapeutic benefit against the radiation risk considering the availability of alternative modality that does not involve ionizing radiation.

b) General justification of clinical procedure done by the health authority in cooperation with appropriate professional bodies should be updated frequently bearing in mind the advances in knowledge and technological developments.

c) Individual justification for patients carried out through consultation between the radiologist and the patient. The patient's request shall be appropriate wherein it should include the history of the patient's clinical situation, previous radiological procedure, the urgencies for this radiological procedure and the characteristic of radiological exposure.

The implementation of the justification principle is mainly achieved through the Referral Guideline for each patient in the diagnostic radiology.

2.4.3 Optimization of radiological protection

Once examinations are justified, they are required to be optimized (performed at a lower dose while maintaining efficiency and accuracy) (Rehani, 2012). The basic aim of the optimization is adhering to principle of ALARA (as low as reasonably achievable) for each radiological procedure. Optimization of patient's examinations includes three main aspects (Khong, 2013). First, the radiological equipment should work properly, delivering the appropriate exposures and compliant with established standards of installation and performance during the installation time and after the routine use. Second, the adequate selection of technical imaging parameters to optimize the radiation exposure level according to the size of the patient should be considered carefully. Third, implementation of diagnostic reference levels (DRLs) to ensure patient safety.

2.4.3.1 Diagnostic reference levels (DRLs)

The guidance level for radiological imaging has been recommended by international organizations as a means of patient dose reduction and tool of optimization. A DRL value is advisable for investigation if the dose value exceeds the regulatory value but it is not a dose limit for patient undergoing medical exposure. The concept of DRL is applied to dose quantity (e.g., incident air kerma, entrance surface air kerma and kerma area product, etc.) (Rehani, 2012). The upper DRL is taken as the high level of radiation dose for the patient (third quartile value of dose distribution

obtained in the survey) and ICRP does not specify the quantity. Yet it should meet the needs of respective area of the local bodies where it is considered as a national task (Khong, 2013).

2.4.4 Dose limit

The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits. These are aimed at ensuring that no individual exposed to radiation risks from such practices which are judged to be unacceptable in any normal circumstances. For medical purpose, dose limits are not applied. If a practice is justified and protection optimized, the dose to patient will be as low as compatible with the medical procedure. Any further constraint of doses might lead to the patient's detriment (IAEA, 1996).

2.5 Basic Concepts of Radiation Protection (Quantities and Units)

2.5.1 Average absorbed dose in organs

Several quantities are used to quantify the magnitude of the exposure to the patient in diagnostic radiology such as entrance surface dose (ESD), entrance surface air kerma (ESAK) and kerma area product (KAP). The averaged absorbed dose is the energy deposited in the organ divided by the mass of that organ. It represents the basic physical quantity that can be correlated with the stochastic or the deterministic effects (Khong, 2013). The SI unit for absorbed dose is joule per kilogram (J/kg) and it is commonly known as the Gray (Gy). The average absorbed dose is given by the following equation (Eq 2.13):

$$D_T = \varepsilon_T / m_T \quad \text{..... (2.4)}$$

Where ε_T is the energy imparted to the organ or tissue over the mass m_T of that organ or tissue.

2.5.2 Equivalent dose

The equivalent dose H_T to an organ or tissue T is calculated for individual organs. It is based on the absorbed dose to an organ, to account for the effectiveness of the type of radiation (Rehani, 2012). It is recommended by the ICRP for risk–benefit assessment. It is equal to the product of a radiation weighting factor W_R for the type of radiation R (Table 1) and the organ dose D_T:

$$H_T = W_R D_T \quad \text{……} \quad (2.5)$$

The SI unit of Equivalent dose is millisievert (mSv).

Table 2.1 Radiation weighting factors.

Radiation type and energy range	Weighting factors (W_R)
X-rays, gamma rays, electrons, positrons, muons at all energy	1
Neutrons < 10 keV	5
Neutrons 10 keV to 100 keV	10
Neutrons > 100 keV to 2 MeV	20
Neutrons 2 MeV to 20 MeV	10
Neutrons > 20 MeV	5
Protons > 2 MeV	2
Alpha particles, fission fragments	20

2.5.3 Effective dose

Effective dose (E) was first introduced by the ICRP in Publication 60 (ICRP, 1990) and revised in the ICRP 113 (ICRP, 2009). It is defined as the sum of overall risk to the body organs. It is the

addition of the equivalent dose H_T to all organs, each adjusted to account for sensitivity of the organ to radiation W_T:

$$E = \Sigma W_T H_T \quad \text{..... (2.6)}$$

This quantity measures the combined detriment from stochastic effects for all organs and tissues based on mean doses to a reference person. Also, it is used for comparison of the risk related dose burdens from different types of diagnostic procedure, or in inter-comparison of procedures performed in different hospitals or countries (Delis *et al*, 2013). Effective dose is expressed in millisieverts (mSv). The tissue weighting factors W_T are shown in Table 2 considering variations in radiation sensitivity between organs.

Table 2.2 Tissue weighting factors.

Tissue or Organ	Tissue weight factor W_T	$\sum W_T$
Bone marrow, colon, lung, stomach, breast, remainder tissues	0.12	0.72
Gonads	0.08	0.08
Urinary bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04

2.6 Thermoluminescence dosimeter (TLD)

These dosimeters are in many forms and shapes; however, they are in form of crystals such as CaF_2, LiF and $CaSO_4$. They emit light if they are heated after having been exposed to radiation. They do this effectively when they contain impurities such as Mn (Greening, 1985). The TLD may be in form of powder, impregnated plastics discs and extruded chips or rods each containing phosphor materials. After irradiation, the phosphor is placed in a planchet in the 'TLD reader' where it is heated for about 300ºC in an oxygen free (Nitrogen) environment. The general principle of TLD lies in the transition of electrons. When the material absorbs radiation energy, electrons are trapped by the impurities at

certain energy levels (upper) and emission of light occurs at visible spectrum when heated as the electron fall back (lower) to the ground state

(Oberhefor and Scharman, 1981).

2.6.1 Mechanism of TLD

Crystals that deviate from ideal ones exhibit some imperfections by having missing positive or negative ions. As a result of these imperfections, areas of localized charges (potential wells) exist within the lattice of the crystals. When the crystal is irradiated, it liberates electrons from the normal lattice ions, thereby creating a positive hole. The liberated and the nearby hole can thus migrate through the crystals as free charge existing within the conduction band until they become bound at these points of lattice imperfections. An electron and a negative ion vacancy combine to form an F center. A hole and a positive ion vacancy combine to produce H or V center. Two adjacent F centers form an M center and R center is formed by the combination of three F centers (Oberhefor and Scharman, 1981).

Discrete number of energy levels exists within the systems due to energy quantization because of the hole or electrons being trapped within potential well. The liberated electrons are then free to move in the crystal and may be re-trapped either at other trapping centers or at the emission centers. When heat is applied to the irradiated crystal however, most of the electrons trapped at the emission centers lose some energy via emission of some visible radiation. They become fixed back in the crystals as valence band electrons. The radiation emitted during this transition constitute the Thermoluminescence, Tl (McKinlay, 1981). The introduction of impurities into the crystals, which is deliberate, increases the number of traps and can increase the

Thermoluminescence efficiency of the material. These are activators. The centers to which they give rise can have their own characteristics energy levels and transition between them gives rise to emission of corresponding characteristic energies (Greening, 1985).

2.6.2 Glow curve

This is the plot of luminescence versus temperature at constant heating rate (Cember, 1986). It is obtained by heating the irradiated TLD crystal at uniform rate and measuring the light output by photomultiplier tube, PMT, as the temperature increases. The temperature at which maximum light output occurs is a measure of binding energy of the electron in the trap. More than one peak at different temperature indicates different trapping sites. The total amount of light produced is proportional to the number of trapped excited electrons and the amount of energy absorbed from the radiation. Thus, the intensity of the light emitted is proportional to the radiation dose (Cember,

1986).

2.6.3 TLD readout system

This is the detection, amplification and recording of the maximum intensity of the light emitted by a TLD to a useful signal. When the TLD is heated, the light intensity amplifies in a PMT and is fed into a digital display component. The system is usually a comparator and any measurement of dose relies on the read out of identical dosimeter exposed (McKinlay, 1981). This shows that the instrument is always calibrated to suit the given TLD using known doses.

The TLD reader used is the Harshaw model 4500 with WinREMS located at the Centre for Energy Research and Training. It is a tabletop instrument used for Thermoluminescence dosimetry (TLD) measurements of a wide variety of TL materials in many forms and sizes. This model incorporates two photomultiplier tubes in a sliding housing, with both Planchet and hot gas (nitrogen or air) heating methods. The TL element maybe heated by hot gas or by a Planchet. Hot gas is used for whole body and environmental TL cards and extremity dosimeters, while the Planchet is used for unmounted TL elements: chips, disks, rods, and powders.

The system consists of two major components: the TLD reader and the Windows Radiation Evaluation and Management System (WinREMS) software resident on a personal computer (PC), which is connected to the Reader via a serial communications port.

The Reader basic external components include a front control panel consisting of a start button, three LED status lights (Ready, Cycle, and Fault), and a power indicator light; a sample drawer assembly; and a lens drawer.

The rear panel houses a voltage selectable power input module with the fuse access, a fitting for nitrogen gas tubing, and an RS-232-C serial communication port. A power On/Off switch is located on a small panel on the right side of the Reader.

An electronic Reference Light is built into the Drawer for monitoring the performance of the instrument. It is used as part of a daily QC check and may be read at operator-specified interval during the normal reading process.

The photomultiplier tube (PMT) Assembly is cooled to a constant temperature to maintain consistent performance. Nitrogen is routed through the PMT chamber to eliminate condensation.

2.6.4 CALDose_X 5.0 software

CALDose_X is a tool that enables the calculation of the Incident air kerma (INAK) based on the output curve of an X-ray tube and of the Entrance surface air kerma (ESAK) by multiplying the INAK with a backscatter factor, as well as organ and tissue absorbed doses for the adult posture specific female FASH and the male MASH phantoms, using conversion coefficients (CCs) normalized to the INAK, the ESAK or the Kerma area product (KAP) for examinations frequently performed in X-ray diagnosis. Additionally, CALDose_X determines the risks of cancer incidence and cancer mortality for the examination selected by the user (Kramer et al, 2008).

CALDose_X can be used:

i. to calculate the INAK based on the output curve of the X-ray equipment, ii. to assess the ESAK to control compliance with diagnostic reference levels,
iii. to calculate organ and tissue absorbed doses for patients with anatomies like

the MASH and the FASH base phantoms, iv. to assess the effective dose based on ICRP103 and/or the patient's cancer risk,

v. to demonstrate how organ and tissue absorbed doses, i.e., the radiation risk for the patient, depend on the proper selection of the exposure parameters. This information can be used in educational programs to train radiologists and technicians to understand how to perform

X-ray examinations with the minimum exposure to the patient, vi. to compare organ and tissue absorbed doses, effective doses, or radiation risks from different radiological procedures, or from different X-ray units, or from different hospital, etc., to identify high and low risk examinations, or cases of good and bad practice and vii. to make risk assessments for surveys on radiological exposures, considering risk factors for the age and gender distribution of the patient populatn under consideration (Kramer et al, 2008).

2.7 Review of Previous Work

Akbar *et al* (2015) measured the entrance skin dose and calculated effective dose for common diagnostic x-ray examinations in Kashan, Iran. Entrance surface dose (ESD) was measured based on the exposure parameters used for the actual examination and effective dose (ED) was calculated by use of conversion coefficients calculated by Monte Carlo methods. The ESDs and EDs reported in this study, except for examinations of the chest, were generally lower than comparable reference dose values published in the literature. It was concluded that use of newer equipment and use of the proper radiological parameter can significantly reduce the absorbed dose and recommended that radiological parameter in chest examinations be revised.

Ibitola et al (2018) carried out a study on entrance skin dose measurement and evaluation (for all ages) at the State Specialist Hospital, Okitipupa, Ondo State, Nigeria. Entrance skin doses for randomly selected patients between 0-4 years, 5-9 years, 10-17 years and above 18 years old undergoing X-ray chest (PA) examinations were measured using Thermoluminescence dosimeters

and evaluation of the source-to-skin distance (SSD) records for the patients during the x-ray chest examinations were carried out. The values reported in this study were within safe limits and they do not pose any significant health risk to the patients of all age ranges or the health workers. The effective radiation doses were computed, and by comparisons, was found that the radiation risk factors (RRFs) are relatively low.

Ibrahim et al (2014) established the trend of dose received by patient during x-ray examination in Federal Medical Centre, Keffi in Nasarawa State, Nigeria. Entrance skin doses (ESDs) for a common type of x-ray procedures, namely chest (AP/PA) were measured considering a total of 200 patients within the age of 15 to 68 years old. The skin dose to patients was determined by calculation from the x-ray tube parameters and exposure radiographic parameters using Edmonds (1984) skin dose formula. The ESDs measured for this type of x-ray procedures were found to be lower than or in agreement with the guidance level set by the Nigerian Basic Ionizing Radiation Regulation (NBIRR, 2003) standard and other international bodies and does not pose any significant health risk to the patience or the workers.

Ademola *et al* (2013) estimated the Entrance skin doses (ESD) and Effective dose (ED) to pediatric patients during chest, skull, abdomen, and pelvis examination in five Nigeria hospitals using DoseCal software. The median ESD values in all the examinations were compared with the NRPB and EC reference level and were found to be lower except for Chest posterior-anterior and Chest lateral examinations. The mean effective doses were compared with those found in literature and were found to be comparable. Data shows that there is variation in the result of the ESD obtained and so adherence to guidelines should be demonstrated.

Ofori *et al* (2014) used the CALdose_X 5.0 software to assess the Entrance Skin Doses (ESD) and Effective Doses (ED) of adult patients undergoing X-ray examinations of the thorax/chest (PA/RLAT), pelvis (AP), cervical spine (AP/LAT), thoracic spine (AP) and lumbar spine (AP) in three public hospitals. The patient's data and exposure parameters captured into the software

included age, sex, examination type, projection posture, tube potential and current-time product. The mean ESD and ED of seven different examinations were calculated using the software and compared with published works and internationally established diagnostic reference levels.

Nsikan and Racheal (2015) assessed Patients Entrance Skin Dose from Diagnostic X-ray Examination at Public Hospitals of Akwa Ibom State, Nigeria. Caldose_X 5.0 software program was used in estimating ESDs based on 720 patient's information and technical exposure parameters for six examinations. The obtained results were comparable to the international reference dose levels, except for the PA projection of the thorax.

Mohamed (2010) carried out a study as a part of a comprehensive project to establish a national diagnostic reference level, for the first time in Saudi Arabia using Thermoluminescence Dosimeters. Seven of the most common X-ray examinations (10 projections) were included. This study consisted of 200 patients who were referred for X-ray examinations at King Khalid

University Hospital (KKUH). The selected X-ray examinations were skull (PA), kub (AP and LAT), ankle (AP and LAT), foot (AP/OBL and LAT/OBL), hip (AP and LAT) and sinuses paranasal (AP). It was discovered that the patient Mean dose values recorded at KKUH were varied from those recorded at other national hospitals. Wide variations in patient dose arising from a specific type of X-ray examination at different national hospitals suggests that significant reductions in patient dose would be possible without affecting image quality. The data of this study will be useful for the formulation of NDRLs, and it will also provide local diagnostic reference levels for some diagnostic X-ray examinations at KKUH and other national hospitals in Saudi Arabia.

CHAPTER THREE
MATERIALS AND METHODOLOGY

3.1 Materials

- Thermoluminescence dosimeter (Solaro)
- TLD Reader (Harshaw Model 4500)
- Conventional X-ray machine (3GT-2)
- CALDose_X 5.0 Software
- Black polythene bag
- Weighing scale
- Cello tape

3.2 Methodology

3.2.1 Data collection

The data were collected from Ahmadu Bello University Teaching Hospital, Shika, Zaria. A total of 100 patients undergoing routine X-rays examination consisting of posterior anterior (PA) and the lateral (LAT) view were considered. The data included age, sex, weight, height, and exposure parameters (tube voltage and tube current-time product setting).

3.2.2 Calibration of TLD chips

The chips are LiF of 5mm by 5mm in size, originally calibrated and supplied by Thermo Fisher Scientific of USA. These chips were annealed and rechecked at the Centre for Energy Research and Training, ABU, Zaria, using the TL processor Harshaw model 4500 by Thermo Electron Corporation, USA.

The TLD reader was subjected to a proficiency test by sending annealed golden cards from the Centre for Energy Research and Training to a secondary standard dosimetry laboratory (SSDL) of the Nigeria Institute of Radiation Protection and Research, a department in the Nigeria Nuclear Regulatory Authority (NNRA).

3.2.3 Entrance skin dose and Effective dose measurements

i. TLD chip was attached to the changing gowns of the patients, on the area of interest to be examined. 100 cases consisting of chest, lumbar spine, knee, pelvis, and femur were considered. Parameters such as patient's weight and age were recorded. After the exposure, the TLDs were kept in a black polythene bag to prevent loss of data. The readings were then taken at Centre for Energy Research and Training.

ii. The measurements were taking and recorded using TLD reader, after which the TLD chips were annealed for further use.

iii. Caldose_X 5.0 software interface consisted of age, type of examination, examination projection, peak tube voltage, tube current, focus to detector distance, back scatter factor (BSF), incident air kerma (INAK), entrance surface air kerma (ESAK) e.t.c. The exposure parameters were inputted and the ESD calculated. iv. Furthermore, the effective dose was calculated from the values of entrance skin dose obtained using both TLD and Caldose software.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Patients Information and Exposure Parameters

A total of 100 patients were assessed in this study. The summary of the exposure parameters is presented in Table 4.1. For all examinations, the age ranges from 21 years to 81 years, weight ranges from 45kg to 106kg, kVp ranges from 55 kV to 110 kV, mAs ranges from 3.2 mAs to 20 mAs and FSD ranges from 85cm to 175cm, with respective mean ranges of 44.1-60.8 years, 65.7 kg -76.1kg, 59.3kV-98.2kV, 3.9mAs-20.2mAs and 108.0cm-157.9cm for age, weight, kVp, mAs and FSD. The wide ranges of the kVp, mAs, FSD were due to various patient weights, heights, thicknesses, and radiographic techniques employed by the operators.

Table 4.1: Mean values of Patients information and exposure parameters for five routine X-ray examinations (9 projections).

Radiograph	Projection	Age(yrs)	Weight(kg)	Voltage(kVp)	Current(mAs)	FSD(cm)
Chest	AP	48.8 (27-81)	73.35 (45-106)	85.35 (90-110)	10.26 (8-12.5)	155.0 (140-175)
	LAT	42.0 (26-60)	75.00 (45-98)	93.1 (86-96)	11.75 (10-12.5)	157.9 (145-175)
Lumbar	AP	58.7 (40-74)	73.9 (52-90)	90.4 (76-98)	16.45 (12.5-20)	106.5 (85-110)
	LAT	60.8 (45-72)	76.1 (52-95)	98.2 (92-108)	20.2 (16-25)	110 (-)
Knee	AP	53.6 (38-65)	74.4 (60-91)	63.3 (55-68)	4.08 (3.2-6.0)	110 (-)
	LAT	51.4 (37-68)	67.1 (55-78)	59.3 (55-64)	3.88 (3.2-6.0)	110 (-)
Femur	AP	44.1 (21-65)	65.7 (49-80)	77.0 (70-80)	6.46 (4.0-8.0)	115.8 (110-120)
	LAT	53.8 (45-64)	73.1 (58-85)	78.3 (75-80)	7.26 (4.0-8.0)	112.5 (110-120)
Pelvis	AP	56.6 (50-74)	68.4 (58-78)	81.8 (70-92)	12.4 (8.0-16)	108 (105-110)

+Ranges are shown in parentheses.

4.2 Entrance Skin Dose and Effective Dose.

The mean entrance skin dose (ESD) for all examinations which was measured using thermo luminescence dosimeters (TLD) was found to range from 0.11 mGy to 2.12 mGy (Table 4.2). The patients undergoing knee examination received the lowest mean ESD of 0.16 mGy ± 0.004 while the highest mean ESD of 0.89 mGy ± 0.169 was observed for patients undergoing pelvic examination. Variations in the patient doses may be due to the speed class of film screen combinations, manual exposure control settings and patient size.

Showing in Table 4.3 is the calculated mean entrance skin dose (ESD) for two examinations in three projections using Caldose_X 5.0 software. The ESD ranged from 0.4 mGy to 3.64 mGy. The mean ESD ranges from 0.94 mGy ± 0.109mGy for chest AP examination to 2.29 mGy±0.395 for pelvic examination. The software limits the tube voltage for the lumbar examination to be within 60kV to 80kV therefore the ESD cannot be calculated as tube voltage used for most lumbar examination is 90kV and above in the hospital under study.

The lowest mean ED of 0.002 mSv was obtained for femur examination while the highest mean ED of 0.038 mSv was obtained for pelvis examination using TLD. The Caldose software presents a higher ED than TLD. The highest and lowest mean ED obtained using Caldose are

0.114 mSv and 0.047 mSv for pelvis and chest (LAT) examinations, respectively.

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Table 4.2: Distribution of ESD (mGy) and ED (mSv) obtained using TLD for five routine X-ray examinations.

Radiograph	Projection	ESD			ED
		Mean	Min	Max	
Chest	AP	0.32 (0.023)	0.19	0.56	0.016 (0.001)
	LAT	0.43 (0.044)	0.20	0.59	0.021 (0.002)
Lumbar	AP	0.30 (0.025)	0.20	0.42	0.035 (0.003)
	LAT	0.68 (0.059)	0.43	1.01	0.081 (0.007)
Knee	AP	0.16 (0.010)	0.11	0.20	0.002 (0.000)
	LAT	0.16 (0.004)	0.14	0.18	0.002 (0.000)
Femur	AP	0.27 (0.020)	0.18	0.39	0.003 (0.000)
	LAT	0.19 (0.004)	0.16	0.21	0.002 (0.000)
Pelvis	AP	0.89 (0.169)	0.43	2.12	0.038 (0.006)

+Standard error of mean is shown in parentheses.

Table 4.3: Distribution of ESD (mGy) and ED (mSv) obtained using Caldose_X 5.0 software for two routine x-ray examinations.

Radiograph	Projection	ESD			ED
		Mean	Min	Max	
Chest	AP	0.94 (0.109)	0.4	2.04	0.047 (0.005)
	LAT	1.36 (0.166)	0.76	2.18	0.021 (0.008)
Lumbar	AP				
	LAT				
Pelvis	AP	2.29 (0.395)	1.07	3.64	0.114 (0.020)

+Standard error of mean is shown in parentheses.

4.3 Comparison of Mean ESD and ED in this study

Table 4.4 compares the mean ESD and ED obtained using TLD to Caldose software. For TLD, the least mean value of E is 0.002mSv for knee (AP and LAT) and femur (LAT) and the highest mean value is 0.081mSv for lumbar (LAT). For Caldose, the least mean value of E is 0.047mSv for chest (AP) and 0.114mSv for pelvis examination.

Table 4.4: Comparison of the Mean values of ESD (mGy) and the ED (mSv) obtained from TLD and Caldose _X 5.0 software**.**

Radiograph	Projection	ESD		ED	
		TLD	CAL	TLD	CAL
Chest	AP	0.32 (0.023)	0.944 (0.109)	0.016 (0.001)	0.047 (0.005)
	LAT	0.43 (0.044)	1.364 (0.166)	0.021 (0.002)	0.068 (0.008)
Lumbar	AP	0.30 (0.025)		0.035 (0.003)	
	LAT	0.68 (0.059)		0.081 (0.007)	
Knee	AP	0.16 (0.010)		0.002 (0.000)	
	LAT	0.16 (0.004)		0.002 (0.000)	
Femur	AP	0.27 (0.020)		0.003 (0.0002)	
	LAT	0.19 (0.004)		0.002 (0.0000)	
Pelvis	AP	0.89 (0.169)	2.287 (0.395)	0.038 (0.006)	0.114 (0.020)

4.4 Comparison of ESD and ED in this Study with various Published work

Table 4.5 present the comparison of ESD in this study with various published works. UNSCEAR (2000) and Abdulla *et al* (2015) uses TLD to obtain ESD values. The value of 0.32 mGy obtained

for chest (AP) in this study, using TLD is slightly higher while Abdulla *et al* (2015) indicate a much higher value of 1.3 mGy in comparison with UNSCEAR (2000). Also, 0.30 mGy obtained for lumbar in this study is within limits when compared to both UNSCEAR and Abdulla *et al* (2015) values. Ofori *et al* (2014) uses Caldose software to obtain ESD. The results obtained for this study using Caldose software is much higher than those of Ofori *et al* (2014) for chest (AP/LAT) and pelvis (AP).

Table 4.6 compares ED in this study with various published works. Comparing the calculated ED values applied in this study with the guide levels of UK (Hart et al., 2010), UK (Wall et al., 2011),

UNSCEAR (2008) references for chest (AP/LAT), lumbar (AP/LAT), femur (AP/LAT) and pelvis (AP) obtained from TLD reveals that ED are within the guide levels while knee (AP/LAT) is slightly higher. However, the ED result obtained in this study from the Caldose software for chest

(AP/LAT) is higher than the values of UK (Hart et al., 2010),UK (Wall et al., 2011), UNSCEAR (2008) and other published work while pelvis (AP) is lower.

Table 4.5: Comparison of ESD (mGy) in this study with other published work.

Radiograph	Projection	Present study		UNSCEAR, (2000)	Ofori et al., (2014)	EC (1996)	Abdulla et al., (2018)
		TLD	CAL	TLD	CAL	PCXMC	TLD
Chest	AP	0.32	0.944	0.31	0.27	0.30	1.3
	LAT	0.43	1.364		0.43	1.50	
Lumbar	AP	0.30		5.95	3.25	5.00	8.57
	LAT	0.68				8.00	21.52
Knee	AP	0.16				0.40	0.49
	LAT	0.16				0.70	0.48
Femur	AP	0.27					
	LAT	0.19					
Pelvis	AP	0.89	2.287		1.31	10	

Table 4.6: Comparison of Effective dose (mSv) from this study compared with other published work.

Radiograph	Projection	Present study		UNSCEAR, (2008)	UK, E-60 (2010)	UK, E-103 (2011)	Akbar *et al*., (2015)	Ciraj *et al*., (2005)
		TLD	CAL	TLD	PCXMC		PCXMC	PCXMC
Chest	AP	0.016	0.047	0.05	0.014	0.014	0.04	0.04
	LAT	0.021	0.068	0.02	0.031	0.038	0.10	0.03
Lumbar	AP	0.035		1.2	0.41	0.39	0.23	0.70
	LAT	0.081		1.2	0.25	0.21	0.13	
Knee	AP	0.002			0.0002	0.0001		
	LAT	0.002			0.0002	0.0001		
Femur	AP	0.003			0.02	0.011		
	LAT	0.002			0.002	0.001		
Pelvis	AP	0.038	0.114	0.28	0.45	0.28	0.28	0.29

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

The assessed ESD for patients undergoing diagnostic x-ray examination at Ahmadu Bello University Teaching Hospital when compared with the International recommended value is within limits for the results obtained using TLD except for chest (AP/LAT) examination which is slightly higher. The Caldose software was also used to assess the ESD of two selected X-ray examinations. Patient data and exposure parameters were captured into the software for the calculations of the doses. The results obtained using Caldose software is much higher than both the recommended values and published values for chest (AP/LAT).

The highest dose is 0.89 mGy for pelvis examination and the lowest is 0.16 mGy for knee examination using TLD. The highest dose is 2.29 mGy for pelvis examination and the lowest is 0.94 mGy for chest AP using Caldose software. ESD for lumbar, knee and femur could not be obtained from Caldose software. The exposure parameters used during lumbar examination is out of range for the parameters on the software and the various examinations on the software do not include knee and femur X-ray examination.

The obtained quantitative data allow better understanding of how different working habits and examination technology influence patient doses and increases their responsibility for the optimization of daily practice. This implies that when technical and clinical factors are optimized, patient doses will reduce substantially while maintaining good quality image with respect to basic principles of radiation protection (justification and optimization).

5.2 CONCLUSION

Based on the results obtained from Ahmadu Bello University Teaching Hospital, the measured ESD values compares favorably with similar works published elsewhere and internationally established diagnostic reference levels. However, the calculated ESD using Caldose software is higher than internationally established diagnostic reference levels and some of other published work.

Effective dose calculated from ESD values obtained using TLD readings is within limits of internationally established diagnostic reference levels for the examinations considered in this study while the ED obtained from Caldose software is slightly higher than internationally established diagnostic reference levels but compares favorably with other published work of Akbar *et al* and Ciraj *et al*.

The values of ESD and ED obtained using Caldose software were higher than the values obtained from TLD but compared favorably with internationally established diagnostic reference levels. Therefore, the values are within safe limits and do not pose any significant health risk to the patients. The effective dose by comparison, indicate that radiation risk factors (RRFs) are relatively low.

Efforts must be made where necessary to maintain the ALARA principle to avoid unnecessary exposure of patients to radiation.

5.3 RECOMMENDATION

i. The Caldose software can be modified to include other X-ray examination that was not available. This includes knee, femur, foot, and others.

ii. The range of tube voltage applied for lumbar examination in the Caldose software should be increased.

iii. Studies on other examinations that were not included in this study should be carried out.

iv. The use of flat panel detectors should be adopted in medical X-ray rooms instead of filmscreen imaging procedure. The flat panel detector lower radiation doses than film-screen systems.

v. Quality control test should be performed regularly on the X-ray machines and corrective actions should be taken where necessary.

vi. Annual workshop and training on radiological procedures should be organized for the Medical Physicists and radiographers to update them with the current trend in diagnostic radiology.

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