RADIATION DOSE AUDIT OF COMMON X-RAY DIAGNOSTIC PROCEDURES OF PATIENTS AND IMPLICATIONS FOR CANCER INCIDENCE IN SOUTHWESTERN NIGERIA

BY

JIMOH CHRISTOPHER OLOWOOKERE

B Sc. (Hons) (Ilorin), M. Sc., M. Phil. (Ibadan)

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ABSTRACT

One of the objectives of x-ray examination is high quality images; however administered radiation doses may be harmful to patients' health. Data on radiation dose to patients are scarce, and thus hinder the determination of local and national reference dose levels specific to a country owing to the differences in patient anatomy and radiological practice among nationals of different countries**.** This study was therefore, designed to determine the patient doses, local reference dose levels and estimate cancer risk based on administered dose at selected radiodiagnostic centres in Southwestern Nigeria.

Twelve radiodiagnostic centres were purposely selected across Lagos (3); Ogun (2); Oyo (1); Osun (4) and Ekiti (2) for this study. Exposure parameters including: peak voltage; tube load (mAs); focus-to-skin distance were obtained from x-ray machines during radiographic procedures. Quality control (QC) tests were performed using standard calibration method. Anthropometric data from 689 consented subjects were obtained for chest (353) Postero-Anterior (PA) and Antero-Posterior (AP) for abdomen (20), pelvis (35), skull (56), lumbar spine (87), thigh (12), leg (46), knee (17) and hand (63) examinations. Measurement of Entrance Surface Dose (ESD) was carried out with thermoluminescent dosimeters and converted to Dose-Area Product (DAP). Organ Dose (OD) and Effective Dose (ED) were determined using appropriate software. Organ doses were used to estimate the expected number of cancer incidences resulting from the examinations. Preliminary Local Reference Dose Levels (PLRDLs) were determined, and Patient Parametric-Exposure Estimation (PPEE) models which served as guides in the choice of appropriate exposure parameters for dose optimisation were developed. Data were analysed using descriptive statistics and compared with National Radiological Protection Board levels.

The QC results showed that 66.7% of the x-ray machines fall within the internationally acceptable tolerance limit of ±5.0% of exposure parameters reproducibility. The ESD (mGy) for chest PA, abdomen AP, pelvis AP, lumbar spine AP, skull AP, leg AP, knee AP, hand AP and thigh AP were 2.32 ± 0.19, 11.72 ± 2.62, 4.05 ± 0.54, 4.74 ± 0.72, 7.07 ± 0.67, 1.27 ± 0.19, 1.59 ± 0.34 ± 0.19,0.50 ± 0.05; and the DAP (Gy cm^2) were 3.06 ± 0.30,17.16 ± 4.96, 3.28 ± 0.47, 2.72 ± 0.44,4.53 ± 0.05,1.15,1.53 ± 0.23,0.92 ± 0.13,0.18 ± 0.02 for chest PA, abdomen AP, pelvis AP, lumbar AP, skull AP, leg AP, knee AP, hand AP and hand AP projections respectively. The ED ranged from $0.08 - 2.56$ mSv. The ranges of cancer incidences expected per annum for patients undergoing chest PA examinations for different organs were: lung (227-452), breast (28-207), easophagus (8-26), stomach (28-78)

and liver (14-95). The proposed PLDRLs for ESD (mGy) and the corresponding DAP (Gy cm^2) were; 2.95(3.14), 22.31(28.59), 6.63(4.77), 5.87(3.20), 9.04(5.06), 1.51(2.04), 2.78(2.09), 2.39(1.44), 0.69(0.25) chest PA, abdomen, pelvis, lumbar spine, skull, leg, knee, hand and thigh (AP projections) respectively. The determined PLDRLs were higher than the National Radiological Protection Board reference levels by factors ranging from 1.70-19.70 and 2.20-31.40 for ESD and DAP, respectively. The developed models for estimating patient thickness(t_s) from weight (W) were: $t_{s,male,chest} = 0.15W + 12.14$ $(R^2 = 0.91)$ and $t_{s,female,chest} = 0.17W + 11.79$ $(R^2 = 0.90)$ for standard male and female adults respectively.

Patients undergoing selected diagnostic x-ray procedures in Southwestern Nigeria received high doses and have increased risk of cancer. The established local reference levels could help in dose optimisation for radiological practices in Southwestern Nigeria.

Keywords: X-ray examinations, Local reference dose levels, Dose optimisation, Cancer

Word Count: 496

DEDICATION

This work is dedicated to

Pa Simon Ajayi

Who desired to see this work, but never lived long enough

to see me start elementary school

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CERTIFICATION

This is to certify that Mr Jimoh Christopher OLOWOOKERE of the Department of Physics, University of Ibadan, carried out this work under my supervision.

Supervisor
Dr N.N. Jibiri
B. Sc.(Hons) (Jos) M. Sc., Ph D (Ibadan)
Senior Lecturer, Department of Physics,
University of Ibadan, Ibadan

TABLE OF CONTENTS

CH.APTER THREE: MATERIALS AND METHODS

LIST OF FIGURES

Page

LIST OF TABLES

Page

ABBREVIATIONS AND ACRONYMS

AAPM	American Association of Physicists in Medicine
ABD	Abdomen
ACoR	The American College of Radiology
AD	Absorbed Dose
ADR	Absorbed Dose Rate
AEC	Automatic Exposure Control
AED	Automatic Exposure Device
ALSH 1	Alimosho State Hospital unit 1
ALSH 2	Alimosho State Hospital Unit 2
ANHS	Omo Anikilaya Infirmatry, Ijebu Ode
AP	Anteroposterior
ARF	Attributable Risk Fraction
AYHS	Ayotola Hospital, Sagamu
BOD	Body Organ Dose
BR	Background Risk
BSF	Backscatter factor
C	Calculation
CEC	Commission of the European Community
CERD	Centre for Energy, Research and Development/ Obafemi Awolowo University
CH	Chest

CoR	College of Radiographer
CRCPD	Conference of Radiation Control Programme Directors
CT	Computed Tomography
$CTDI_w$	Weighted Computed Tomography Dose Index
CUDR	chlorodeoxyuridine
CX	Convetional X-ray
DAP	Dose-Area Product
DDREF	Dose and Dose Rate Effectiveness Factor
DNA	Deoxyribonucleic Acid
DRL	Diagnostic Reference Level
DX	Dental X-rays
DXA	Dual energy X-ray Absorptiometry
EAR	Excess Absolute Risk
EC	European Commission
ECC	Element Correction Coefficient
ED	Effective Dose
EKSUTH	Ekiti State University Teaching Hospital, Ado –Ekiti
ESD	Entrance Surface Dose/ Entrance Skin Dose
EUR	European Guidelines on Quality Criteria
EXD	Exit Dose
FD	Field Dosimeter
FFD	Focus-to-film distance
FKJSH	Ifako-Ijaye General Hospital
FMC	Federal Medical Centre, Ido
FMC*	Federal Medical Centre, Owerri
FRPS	Ferderal Radiation Protection Service
FSD	Focus-to-surface distance

HD	Hand
HPA-RPD	Health Protection Agency- Radiation Protection Department
HVL	Half Value layer
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiological Units and Measurement
ICTP	International Centre for Theoretical Physics
INDX	Industrial X-rays
IPEM	Institute of Physics and Engineering in Medicine
IPSM	Institute of Physical Sciences in Medicine
ISL	Inverse Square Law
kVp	kilovoltage peak
LAR	Lifetime Attributable Risk
LAT	Lateral
LBS	Lumbo Sacral
LDRLs	Local Diagnostic Reference Levels
LET	Linear Energy Transfer
LiF	Lithium Fluoride
LSJ	Lumbo Sacral Joint
LTH 2	LAUTECH Teaching Hospital, Osogbo Unit 2
LTH1	LAUTECH Teaching Hospital, Osogbo Unit 1
mAs	milliampere seconds
MB	Middle Belt/ of Nigeria
MED	Medical Exposure Directive
MOSFET	Metal-Oxide Semiconductor Field Effect Transistor
NCRP	National Council on Radiological Protection
NDRL	National Diagnostic Reference Levels

NE	North East/of Nigeria
NEXT	National Evaluation of X-ray Trend
NHA	National Hospital Abuja
NHS	National Health Service
NIRPR	National Institute for Radiation Protection and Research
NK	Neck
NNRA	Nigeria Nuclear Regulatory Authority
NOHSC	National Occupational Health and Safety Commission
NRC	National Research Council
NRL	National Radiation Laboratory
NRPB	National Radiological Protection Board
OAGSH	Orile –Agege State Hospital
OAUTHW	Obafemi Awolowo University Teaching Hospital Annex, Wesley Ilesha
OAUTHC	Obafemi Awolowo University Teaching Hospital, Ile-Ife
OD	Organ Dose
OSL	Optically Stimulated Luminescence
PA	Posteroanterior
PED	Patient Equivalent Diameter
PEL	Pelvis
PLRDLs-G	Preliminary Local Reference Dose Levels within a group
PLRDLs-N	Preliminary Local Reference Dose Levels within Nigeria
PPEE	Patient Parametric Exposure Estimation model
PMT	Photomultiplier Tube
QA	Quality Assurance
QC	Quality Control
RCF	Reader Calibration Factor
RDRL	Regional Diagnostic Reference Level

RMD	Reference Man Dose
RMS	Reference Man Size
RNA	Ribonucleic Acid
RV	Reference Value
SDAH	Seveth Adventist Hospital, Ile- Ife
SE	South East/of Nigeria
SEM	Standard Error on Mean
-SH-	Sulphydryl group
SK	Skull
SS	South South/ of Nigeria
SSDL	Secondary Standard Dosimetry Laboratory
SW	South West/ South Western/ of Nigeria
TAR	Tissue-Air-Ratio
TLD	Thermoluminescent Dosimeter
TTPC 1	Two Tees Diagnostic Centre, Ibadan Unit 1
TTPC 2	Two Tees Diagnostic Centre, Ibadan Unit 2
U	Uncertain
UK	United Kingdom
UNSCEAR	United Nation Scientific Committee on Effect of Atomic Radiation
US	United States
VHS	Victory Hospital, Iwo
WHO	World Health Organisation

CHAPTER ONE

INTRODUCTION

1.1 Background to the Research

The use of x-ray for diagnostic and therapeutic purposes is on the increase in the modern health care. It has continued to play a significant and leading role over other imaging techniques. However, x-ray examinations constitute the most significant manmade source of radiation exposure to the world population (UNSCEAR, 2000). Although x- ray procedure is assumed to produce net benefit, the potential for radiation-induced injuries to the patients exist. Understanding the level of patient and personnel doses and the factors that affect them, therefore, becomes very important. (Parry *et al.*, 1999). The necessity of continual assessment of radiation dose delivered to patient during x-ray examinations is of great concern. This assessment is important because of the hazard of ionising radiation. Regular measurement of radiation dose as indicated in the documents of the international regulatory bodies (EC, NRPB-HPA, ICRP) helps to ascertain the variation and level of patient dose and the causes of the variation (Johnston and Brennan, 2000). Dosimetry serves as a useful tool for investigating areas in need of adjustments and dose reduction (NRPB, 1992).

Surveys on radiation exposure to the population arising from medical examinations and treatment are recommended as a useful tool in radiation exposure surveillance and protection at local, regional, national and international levels (UNCSEAR, 2010). According to the European Commission (EC, 2008), the situation should be reassessed ideally every 5 to 10 years due to the pace of technological developments in the field of radiology and the evolution of medical practice. In the United Kingdom under the control of National Radiological Protection Board (NRPB), dose survey and auditing of most facilities are carried out continually and five-yearly reviews are done, the results of the exercises are published in order to show the state of practice and dose reduction effort in place.

Significant variations in patients' dose for the same x-ray projection by different hospitals have been reported in international, national and regional studies (Warren-Forward and Millar, 1995). Various surveys of patient dose provide important information on the levels of patient exposure and offer insight into the causes of variations: patient attributes,

radiographic procedures, technical and equipment factors, and level of quality assurance put in place (Johnston and Brennan, 2000). Studies indicate that substantial dose reduction during the x-ray examination is possible without detriment to the image quality (Ng *et al*., 1998; Charnock *et al*., 2013).

In order to achieve dose reduction and efficient radiation protection, unnecessary and unproductive radiation exposures are eliminated. The main tools for achieving these aims are justification of practices and optimisation of protection (EC, 1999). In diagnostic radiography, optimisation is interpreted as being as low dose as reasonably achievable and consistent with the required image quality necessary for obtaining the desired diagnostic information. Considerable evidences abound which indicate that substantial dose reduction is possible through regular dose audit, feedbacks, application of optimisation principle and use of guidance levels without detriment to patient care or diminishing the quality of image produced (NRPB, 1992). In view of the observed wide variations in patient dose levels for the same x-ray examinations within and among hospitals, for example up to a factor of 100 (Faulkner and Corbett, 1998), the International Commission on Radiological Protection (ICRP) has recommended the use of diagnostic reference levels (DRLs) as an aid to keeping doses as low as reasonably achievable (ICRP, 1996). The use of DRLs serves as a first step in the optimisation of diagnostic radiography. As corrective dose descriptor, diagnostic reference levels (DRLs) has been defined in European legislation as "dose level in medical radiodiagnostic practices or, in the case of radiopharmaceuticals, levels of activity for typical examinations for group of standard sized patient or standard phantoms for broadly defined types of equipment". These levels are not expected to be exceeded when good and normal practice regarding diagnostic and technical performance is applied (CEC, 1996).

The DRL is a value that is derived from a population dose survey and represents the third quartile in the range of doses observed. Because the guidance dose level corresponds to the 75th percentile, it indicates that 75% of individuals receive dose less than this value. This also implies that dose reduction should be possible for the 25% of individuals whose doses exceed the guidance value (IAEA, 1996). By using DRLs, one could find hospitals where doses are exceptionally high and where practice may need to be improved through revision of techniques and/or equipment. Additionally, the purpose of DRLs according to the Commission of the European Community (CEC) is to encourage departments to investigate their patient radiation dose levels and if these doses exceed the recommended DRLs, then the department should investigate the causative factors of the high doses.

Guidance levels could be set on regional basis. In addition, both national diagnostic reference levels (NDRLs) and local diagnostic reference levels (LDRLs) are expected to be determined within a country. The purpose of introducing the LDRLs in clinical practice is to verify that the dose descriptors (ESD or DAP) measured in a particular hospital are below the defined reference values, set after trials in many hospitals (Maccia *et al*., 1996). This provides a framework to reducing variabilities observed among the hospitals. However, it is possible that in a large hospital where many radiological departments are present all examinations use ESD lower than the corresponding national diagnostic reference levels (NDRLs), even though some differences between various departments still exist. In this case a subtler and more refined use of DRLs concept is adopted to calculate ESD values that are to be used only locally (within the local hospital), as local diagnostic reference levels (LDRLs), in order to improve an already good situation. The study of LDRLs is encouraged as further step in patient dose optimization beyond the simple use of national or international DRLs (Ramsdale *et al*., 2001).

1.2 Statement of Problem

In Nigeria, x-ray diagnostic examination (conventional or computed tomography) is an integral part of both the local and national health care. Several million diagnostic examinations involving conventional radiography and computed tomography (CT) are performed annually in the 36 states and Abuja. The number of the facilities and examinations are on the increase in the country in the last few years. As a result of the increase in the number of examinations, it is expected that individuals and population doses would increase also. However, with the increase in the number of medical x-ray diagnostic examinations, there are no commensurate quality assurance programmes on the machines available and proportionate dose measurement efforts. Besides, in spite of the expansion in the use of x-ray in last two decades, effective arrangement for justification of exposure, optimisation of protection in the diagnostic centres are not yet widely adopted. An earlier survey carried out (Olowookere *et al*., 2008) in 22 x-ray departments in the South West (SW), South South (SS) and Mid West (MW), Nigeria reveals that only 4.5% of the surveyed hospitals calibrate their machine regularly. The findings revealed that 81.8% of the 22 facilities have never measured radiation doses received by the patients examined at their centres as stipulated in the Medical Exposure Directives 97/43/EURATOM (EC, 1999).

In Nigeria, the Nigerian Nuclear Regulatory Authority (NNRA) is charged with the full responsibility of nuclear safety and radiation protection. This national regulatory body is

empowered to categorize and monitor activities involving the use and processing of ionising radiation from nuclear and medical practices in Nigeria. In this regard, the NNRA in her document (NNRA, 2015) made provision for minimum requirements for equipment maintenance in line with international regulatory policies. The Nigerian Nuclear Regulatory Authority is responsible for the monitoring of the radiation exposure resulting from nuclear and medical practices in Nigeria.

Several dose measurements had previously been carried out in Nigeria, these include: Ajayi and Akinwumiju, 2000; Ogunsehinde *et al*., 2002; Ogundare *et al*., 2004a; Ogundare *et al*., 2004b; Obed *et al*., 2007; Egbe *et al*., 2008, and Jibiri and Adewale, 2014. Recently, Akinlade *et al*., 2012, carried out certain investigations on dose-area product in four hospitals in Nigeria. Most of the earlier published works in Nigeria were carried out more than six years ago and few centres were included in the studies. Owing to the dynamic nature of radiation dosimetry, and the risk inherent in excessively high radiation doses emanating from diagnostic imaging, it is required according to the Code of Practice for the use of x-rays in medical diagnosis of the National Radiation Laboratory (NRL-C5, 2010) of New Zealand that: "radiation surveys of the x-ray facilities of persons licensed for the use of x-rays for medical diagnosis or research on humans be carried out for auditing compliance at intervals between surveys of 2 years and not exceeding 4 years". This is in agreement with the requirements of the Nigerian Nuclear Regulatory Authority which stipulate that "every administered dose shall be recorded" (NNRA, 2015). Based on this requirement for the safety of the population being exposed, it is necessary to reexamine the radiation dose received by patients. In addition, it is essential to expand the scope of the existing data to cover a geopolitical zone of the country in order to ascertain the level of patient exposure in Nigeria. In 1997 the essentially voluntary system of dose measurement and management, developed by the International Commission on Radiological Protection (ICRP), became mandatory in the European Union (EC, 1997) for all the Union members to carry out dose measurements in their various countries.

Unfortunately, in Nigeria in spite of the requirements put in place by the NNRA for patient dose assessment and management, less attention is paid to dose assessment and hence dose optimisation, because of lack of facilities to carry it out. Moreover, in diagnostic radiology in Nigeria, the major concern of the Radiologists, Radiographers and the Physicians is the quality of image produced for diagnostic purposes; very little concern is paid to the dose delivered to the patients. However, for effective patients' dose management

and optimisation, data on the level of patient exposures are essential to develop a dose quality control system and adequate patient protection during radiographic examinations.

1.3 Justification of the Study

The nature and the uses of x-rays for non-invasive diagnostic procedure have been very helpful in healthcare services. However, owing to the risks associated with the use of ionising radiation during diagnostic examinations, it is essential to carry out radiation doses audit regularly to ascertain the level of patient and population dose. Conventional x-ray procedures have been in use for the past five decades in Nigeria. Other modalities such as dental x-rays, mammography, fluoroscopy and computed tomography (CT) were later introduced into the national healthcare service. The introduction of different radiographic facilities into Nigeria has greatly enhanced the healthcare of the citizenry. Moreover, to ensure dose optimisation during diagnostic examination, the International Commission on Radiological Protection (ICRP) has recommended the use of diagnostic reference levels (DRLs) as the first step in the optimisation of diagnostic radiography (ICRP, 1996). However, a study conducted by Martins *et al*. (2013) in Africa and other five continents indicates that; there is no adequate legislation on dose measurements in Nigeria, there is no license issued after dose measurement is carried out in compliance with international regulation, indicating that adequate attention is not accorded dose measurement during accreditation and licensing of diagnostic centres. More importantly the same report shows that there is no record of established diagnostic reference levels in Nigeria in any form. Against this backdrop, it is needful to undertake dose audit in radiological departments towards establishing diagnostic reference levels in the country. This stems from the fact that a diagnostic reference level is specific to a country; because of differences in patient anatomy, equipment and radiological practices among nationalities. Diagnostic reference levels presently in use in the country are foreign to Nigeria. These therefore, do not give the true representation of benchmark against which comparison could be made in Nigeria. Determination of diagnostic reference levels will assist in radiation protection of patients, dose optimisation and future policy making in Nigeria.

Moreover, it is essential that, due to changing equipment, imaging staff and the increase in the number of cancer incidence in the country, an extensive dose survey is necessary to ascertain the level of patient dose and compliance with acceptable dose limit in

Nigeria. Achievement of this goal will go a long way in reducing patient dose in Nigeria through appropriate feedback mechanism.

1.4 Aim of the Study

In view of the need for regular dose assessment to ensure optimisation of dose received by patients during diagnostic examinations; the aim of this study was to determine patient doses and diagnostic reference levels.

1.5 Objectives of the Study

The objectives of this study are:

(1) to investigate and determine the dose received by patients in selected x-ray centres in some locations in Southwestern Nigeria;

(2) to carry out local and regional dose audits and compare the results with the existing dose data in Nigeria and published reference dose levels in other advanced countries of the world;

(3) to explore the possibility of determining and proposing preliminary reference dose value, action level and provide feedback to the management of the participating hospitals and,

(4) to estimate the expected cancer incidence arising from common x-ray diagnostic examinations in Southwestern Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Radiation

Radiation is the energy that moves through space from one object, the source to another object with which it interacts with. There are two general types of radiation: photon (quanta) and particulate. They can also be classified as ionising and non-ionising.

2.1.1 Electromagnetic Radiation

Photon energy does not contain matter, only energy, since it contains no matter, it has no mass or weight. This type of radiation is designated as electromagnetic radiation (e-m radiation). Within the electromagnetic waves family (spectrum) are a number of specific types of radiation that are used for different purposes. These include such familiar radiations as radio waves, infra-red rays, visible light, ultraviolet rays, x-radiation and gamma radiation. These types of radiation require no material medium for their propagation. Electromagnetic radiation is characterised by wavelength (λ), frequency (ν) and energy per photon (E). Electromagnetic waves (e-m waves) travel in straight lines; however the trajectory can be altered by interaction with matter. The interaction can occur either by absorption or scattering (Bushberg *et al*., 2002).

The e-m radiation used in diagnostic imaging include: (i) x-rays which are produced outside the nucleus and are used in radiography and computed tomography (CT) imaging (ii) gamma rays, which emanate from within the nuclei of radioactive atoms and are used to image the distribution of radiopharmaceuticals; (iii) visible light, which is produced in detecting x- and gamma rays and is used for the observation and interpretation of images, and (iv) radiofrequency e-m radiation in the frequency modulated (FM) region, which is used as the transmission and reception signal for magnetic resonance imaging (MRI).

2.1.2 Particulate Radiation

This type of radiation consists of small particles of matter moving through space at high velocity. They carry energy because of their motion. Particle radiation comes primarily

from radioactive materials, outer space or machines that accelerate particles to a very high velocity, such as linear accelerator, betatrons, and cyclotrons. The particle radiation differs from e-m radiation in that the particles consist of matter and have mass. The type of particle radiations most frequently used in clinical medicine include high-velocity electron radiation (beta minus: $e^{-} or\ \beta^{-}$), positron (beta plus: $e^{+} or\ \beta^{+}$), proton (p), alpha particle (α) and neutron. Particle radiation is generally not used as an imaging radiation because of its low tissue penetration. When radiation such as x- radiation interacts with matter such as human tissue, it transfers energy to electron, thus creating a form of electron radiation within the material. Many types of particle radiation are produced as by-products of photon production by a number of radioactive materials used in medical imaging.

2.1.3 Non-ionising Radiation

Electromagnetic radiations with energy below the far-ultraviolet region are called non-ionising radiations. Non-ionising radiations do not strip atoms of electrons as they pass through matter. This group of radiation includes radio-waves, infra red rays, visible light and far-ultraviolet radiation.

2.1.4 Ionising Radiation

Electromagnetic radiation of higher frequency than the near-ultraviolet region of the spectrum carries sufficient energy per photon to strip electron off the atom (or to remove bound electrons from atomic shells) as they pass through matter thus producing ionized atoms and molecules. Radiation in this portion of the spectrum is called ionising radiation. These include part of ultraviolet radiation, x-radiation, gamma rays and cosmic rays.

2.2 Production of X-rays

X-rays are produced when highly energetic electrons interact with matter and convert their kinetic energy into electromagnetic radiation. A device that accomplishes such a task consists of an electron source, an evacuated path for electron acceleration, a target electrode, and an external energy source to accelerate the electron. A typical x-ray tube is shown in Figure 2.1

To produce x-rays, a source of electron is required. The source of electron is a coil of tungsten wire that is heated by passing an electric current of a few amperes through it. At high temperatures, electrons at the coil's surface gain enough energy to escape from the

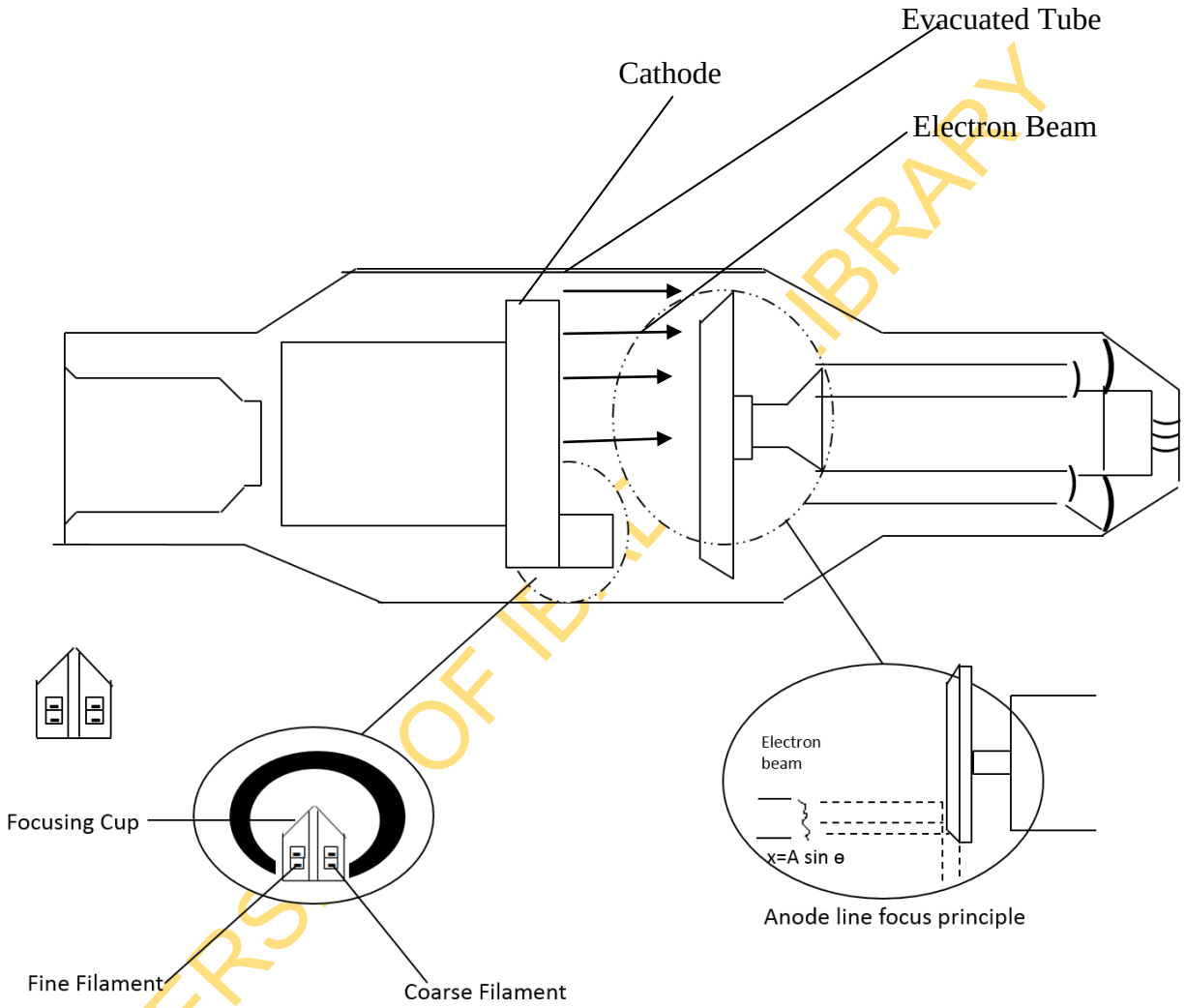

Figure 2.1 A typical diagnostic X-ray tube showing the cathode assembly and rotating anode structure

surface. The filament is mounted inside a cup-like structure called the focusing cup, as the electrons are emitted from the filament; the negative potential of the focusing cup pinches the electrons together into an electron beam that is accelerated toward the positively charged anode. The filament and focusing cup collectively are referred to as the cathode assembly.

In most x-ray tubes, two filaments are provided: a coarse filament and fine filament. The fine filament is used when a small focal spot is desired; however, the current across the x-ray tube is limited with fine filament because the small tungsten coil provides a relatively small surface area for the emission of electrons. When high tube current is needed, the coarse filament is used; this results, however, in a large focal spot with some increase in image unsharpness. The electrons emitted are accelerated towards the anode by a high voltage imposed between the two electrodes. The space between the electrodes is evacuated to prevent collisions between the electrons and molecules of air.

The conversion of electron kinetic energy into electromagnetic radiation produces x-rays. The kinetic energy gained by the electron is proportional to the potential difference between the cathode and the anode. On impact with the target, the kinetic energy of the electron is converted to heat and x-rays. The vast majority of interactions produce unwanted heat by small collisional energy exchange with electrons in the target. The intense heating limits the number of x-ray photons that can be produced in a given time without destroying the target. Occasionally, an electron comes within the proximity of a positively charged nucleus in the target electrode. Coulombic forces attract and decelerate the electron, causing a significant loss of kinetic energy and a change in the electron's trajectory. An x-ray photon with energy equal to the kinetic energy lost by the electron is produced. This radiation is termed bremsstrahlung.

Anodes of x-ray tube are made of materials of high atomic number to enhance the production of x-rays, and high melting point to withstand the production of heat in the anode. Furthermore, the anode should rapidly conduct heat away from the target region where the electron impinges on the anode.

In all but very low-power diagnostic x-ray units, the anode is mounted on the axle of an induction motor so that it rotates at 3,000 to 10,000 revolutions per minutes during exposure. By spreading the heat over a circular strip of the anode rather than concentrating it on a small area of the anode, the ability of the anode to withstand high heat production is greatly improved.

Geometric unsharpness is influenced strongly by the size of the focal spot (the region in the anode where the x-rays are produced). The apparent size of the focal spot can be reduced by titling the anode at a sharp angle with respect to the incoming electron beam. By this technique, termed the line focus principle, the projected size of the focal spot appears smaller than the actual size. The actual size, A, of the focal spot and the projected or apparent size, a, of the focal spot is as given in equation 2.1.

$$a = A \sin \theta \qquad 2.1$$

Where θ is the target angle (the angle between the anode and perpendicular to the electron beam). This angle varies from 7 to 20 degrees in diagnostics x-rays, to yield apparent focal spots between 0.3 mm and 2 mm.

A rotating anode and the line focus principle change the distribution but not the amount of heat produced in the anode. This heat must be transferred in some manner from the anode to the environment. The only mode of heat transfer available is radiation from the anode to the cooling oil surrounding the glass envelope of the x-ray tube. The oil is often pumped through a water-or-air-cooled heat exchanger to transfer the heat to the environs.

2.3 Interaction of X-rays with Matter

X-ray photons are produced by the interaction of energetic electrons with matter at atomic level. The interaction of x-rays with matter is important in diagnostic imaging and nuclear medicine. The selective interaction of x-ray photon with the structure of human body produces the diagnostic image: the image produced can be viewed and used for diagnosis. In addition, during interaction certain energy is deposited along the path of travel of the x-ray, others are scattered or deflected from the original direction and deposit part of their energy.

The nature of interaction depends on the energy of x-rays photons, the nature of tissue and the thickness of the area in question. Three forms of interaction are considered based on the energy of the photon.These are: photoelectric effect, Compton effect and pair production. These interactions play significant roles in diagnostic radiology and nuclear medicine. The direct interaction of ionising radiation (x-rays) with critical biological molecules leads to their ionization into free radicals. However, the indirect interaction of ionising radiation involves the action of the created primary and secondary free radicals with biologically important molecules which cause radiobiological damage.

Radiation produces excitation and ionization at random, so that in a complex system such as a living matter, those molecules that are most abundant are those most likely to become ionised. It follows that when living material, which is 70 – 90% water, is irradiated, most of the absorbed energy will be taken up by water molecules. The absorbed energy could result in stochastic or deterministic effects. The stochastic effect could be as a result of low doses affecting few cells or possibly only a single cell. Such damage may not cause any symptoms in the organism, and may be repaired subsequently. Any radiation damage that has occurred may not become apparent for years or even decades. It may then be difficult or impossible to link the observed abnormality with the exposure to radiation, since all the effects of low dose radiation can occur spontaneously or can be caused by other agents. There is no threshold for stochastic effect and the probability of occurrence increases steadily as the dose increases

On the other hand, high doses of radiation that damage many cells produce effects that can be related specifically to the radiation exposure. Some of these effects occur quite quickly, within days, such effects include skin burn, radiation sickness and damage to the lens of the eyes. For each of these effects to occur, a minimum radiation dose or threshold has to be exceeded, severity of the effect increases with dose. Effects of this type are called deterministic effects.

2.4 Risk Description

The term risk is the probability of occurrence of hazardous event or phenomenon. For example, the probability of developing cancer after exposure to potential carcinogens or getting involved in auto crash after taking alcohol. Every human endeavour constitutes a level of risk or the other. Presently, society is increasingly aware that medical procedures expose the public, personnel and patient to risks of harm. Therefore, in any individual case of risk estimation, it is necessary to have accurate knowledge of radiation dose to the entire exposed organs. The probability that an exposed individual will incur some deleterious stochastic effect is a function of dose D, and can be generalized as (NRC, 2002):

$$f(D) = (\alpha_o - \alpha_1 D + \alpha_2 D^2) exp - (\beta_1 D + \beta_2 D^2) \qquad 2.2$$

Where α_o, α_1, α_2, β_1 and β_2 are coefficient and are positive, α_o is the spontaneous or natural incidence of the effect. The function can also be written as equation 2.3 based on the

assumption of BEIR IV that the risk at low doses would continue in a linear fashion without a threshold and that the smallest dose has the potential to cause a small increase in risk to human. The assumption is termed the "linear-no-threshold" (LNT) model.

$$f(D) = (\alpha_o - \alpha_1 D) \quad 2.3$$

The risks of different health effects are mutually exclusive so that the total risk *R* of the different effects is given by:

$$R = \sum P_i \quad 2.4$$

Where P_i is the probability that the individual will suffer an effect.

The term detriment (D_e) is used to specify the mathematical expectation of harm and it takes into account both the probability of occurrence and the severity of the effect, it is defined as:

$$D_e = \sum P_i g_i \quad 2.5$$

Where g_i is the severity factorof organ *i*. Lung cancer and most other severe cancers are fatal with

$g = 1$ so are all other severe genetic effects. For skin and other non-lethal cancers $g < 1$

For a group of *N* people, the collective detriment (Beninson, 1975) is:

$$G = N \sum P_i g_i \quad 2.6$$

The weighting factor w_T was introduced to account for the radiosensitivity of each tissue and is defined as the proportion of detriment of tissue *T* when the whole body is uniformly irradiated. The effective equivalent dose to an individual is

$$H_e = \sum H_T W_T \quad 2.7$$

Where H_T is the dose to tissue T.

$$G = R_f N H_e \quad 2.8$$

Where R_f, the constant of proportionality is called the total risk factor and is equal to 6.5 x$10^{-3}$$Sv^{-1}$ (Ahmed and Daw, 2014)**.** The quantity $R_f H_e$ expresses the individual detriment. In

the case of continuous exposure, the effective dose equivalent is expressed per unit time. Radiation effect is cumulative so the detriment can be calculated for a range of time.

2.4.1 Cancer Risk Estimation

Due to fast growing use of radiation in medicine, estimation of possible late effects of radiation, including potential cancer risk, has become issues of great concern. Since physicians make the decision to order or perform a radiological procedure, it is very important to provide them with objective information about possible radiation associated risk. Based on this background, Ivanov *et al*. (2012) developed a methodology for estimating the cancer risks of diagnostic medical exposures based on ICRP Publications 103 models (ICRP, 2007a). Organ dose, age, and gender are used as basic parameters. This model could be used for simple and complex procedures.

According to the ICRP model (Ivanov *et al*., 2012), in an unexposed population, the basic risk factor is the background cancer mortality or incidence rate denoted as λ_o (the annual number of cancer deaths or cancer cases per 100,000 population). Due to exposure to radiation, λ_o increases by $\delta\lambda$, the overall cancer mortality or incidence rate λ is then given by:

$$\lambda = \lambda_o + \delta\lambda \qquad 2.9$$

but

$$\lambda_o = \lambda_o(a, l, s, t) \qquad 2.10$$

Where l is the tumor site, a is age, s, gender and calendar time t.

The radiation associated increment depends on radiation dose, D from other sources beside the background , attained age a, tumor site l, gender s, and the age at exposure g:

$$\delta\lambda = \delta\lambda(g, a, l, s, D) \qquad 2.11$$

and equation 2.9 becomes:

$$\lambda(g, a, l, s, D, t) = \lambda_o(a, l, s, t) + \delta\lambda(g, a, l, s, D) \qquad 2.12$$

The radiation increment $\delta\lambda$ is an excess absolute risk (EAR) for the attained age a, exposure age g and radiation dose D.

The knowledge of the value of EAR could be used in the estimation of the lifetime attributable risk (LAR) of developing cancer at the l site after single exposure to dose D at

the age *g*. The LAR (*g,l,s,D*) is a sum of values of excess of absolute risk for the attained age. It can also be defined as additional cancer risk above and beyond baseline cancer risk. LAR can be calculated for specific as well as for all cancers combined (Smith-Bindman *et al*., 2009). However, it is necessary to take into account the "healthy" survivor function, the probability that an unexposed individual will be alive and free of cancer of the site *l* from age *g* to the age *a*. The value of LAR can be computed using:

$$LAR\ (g,l,s.D) = \frac{1}{DDREF}\ x \sum_{a=g}^{a_{max}} S(s,l,g,a) x\ EAR(g,a,l,s,D) \qquad 2.13$$

Where *S(s,l,g,a)* is a healthy survivor function and DDREF is dose and dose rate effectiveness factor which is taken as 2 (ICRP, 2007a).

In addition to the LAR of cancer mortality or incidence, one can use an attributable risk fraction, ARF, of mortality or incidence of cancer at the site *l* in males or females exposed to dose *D* at the age g. Mathematically, *ARF* is taken as the ratio of LAR to the overall lifetime risk of mortality or incidence:

$$ARF\ (g,l,s,t,D) = \frac{LAR\ (g,l,s,D)}{LAR\ (g,l,s,D)+BR\ (g,l,s,t)}\ x\ 100\% \qquad 2.14$$

Where *BR (g,l,s,t)* is a lifetime background risk of site specific cancer mortality or incidence, It can be calculated from the exposure age g. The background risk of cancer incidence rate is estimated by summing up background incidence rates with allowance for the disease-free lifetime from the age of exposure g. The background risk of cancer mortality rates is estimated by summing background mortality rates with allowance for the probability of being alive from the age at exposure g. In the general case:

$$BR(g,l,s,t) = \sum_{a=g}^{a_{max}} \lambda_o(a,l,s,t) x\ S(s,l,g,a), \qquad 2.15$$

Where $S(s,l,g,a)$ is the probability of disease-free life of unexposed population from age g to age *a* if the background risk of incidence is calculated, and $S(s,l,g,a)$ is the probability of unexposed population being alive from age g (age at exposure) to age *a* (attained age) if the background risk of mortality is estimated.

For easy calculation of ARF(ARF^{inc}, ARF^{mort}), values of lifetime attributable risk of cancer incidence and mortality (LAR^{inc}, LAR^{mor}) of males and females exposed to 1 mGy for different age groups (0-80 yr) per 10,000 population are tabulated based on ICRP 103(ICRP, 2007a) and Preston *et al*, (2007). Additionally, lifetime background risk of cancer incidence and mortality, BR (BR^{inc} and BR^{mort}) are also tabulated elsewhere (Ivanov *et al*., 2012). In the estimation of ARF, knowledge of the organ dose, D and number of organs found per site is essential. However, LAR^{inc} and LAR^{mor} are calculated by multiplying the specific organ dose, D by the tabulated life attributable risk of cancer incidence/mortality for the individual (male or female) exposed to 1 mGy at the relevant age per 10,000 population. Summation of the LAR^{inc} or LAR^{mort} for different organs at a particular site (e.g. chest-lung, breast, easophagus, stomach and liver) is obtained.

2.5 Principle of Quality Assurance and Quality Control Test

Generally, quality assurance (QA) is a management technique that can be used to moderate any system that results in a product (Hendra, 1986). When setting up a QA programme, it is necessary to define both the final product and the system that produces it.

In diagnostic radiology, QA is carried out to ensure the production of high quality diagnostic images for minimum patient radiation dose (NRPB, 1988). This requires a quality control (QC) programme involving the selective testing of each major system component on a regular basis to ensure optimum performance within the system (BIR, 1988). The major systems in diagnostic radiology concern x-ray production, x-ray detection, images processing and images viewing (West, 1993). For a given system, there are many possible variables that might be monitored, and it is important to balance the potential dose saving against the cost of monitoring. In the case of x-ray production for example, it may be adequate to confine regular testing to automatic exposure devices (AEDs), radiographic output and beam alignment, once the initial check has been performed. A quality assurance programme also includes reject analysis.

2.6 The Need for Radiation Protection of the Public and Patients

In order to comply with the recommended dose level prescribed by both the international and local radiation protection authorities, it is essential to regularly monitor the exposure of the public, personnel and patient to the ionising radiation. This monitoring is important to ensure that the doses received comply with the acceptable limit required. This

is what brought about the concept of radiation protection. Radiation protection is the science of safeguarding the personnel, public and patient from incessant, unwanted and unnecessary radiation. Radiation protection involves the accurate measurement of radiation dose to radiation workers and the public and the design of methods that could be used to reduce the radiation dose received.

The detrimental effects of ionizing radiation were recognized early enough with the result that the history of radiation protection is very nearly as long as that of x-rays themselves. Until recently, however, the main focus of radiation protection in hospitals has been on the protection of the hospital staff rather than protection of the patient. The principal reason for this is that when a patient is irradiated during the course of a medical procedure it is the patient that benefits, in contrast no benefit accrues to a member of staff who has been irradiated. In addition, it has been held as an article of faith for many years that the benefits to the patient far outweigh the risks,

The following are the reasons for radiation protection of both the patient and the public: (i) radiation is damaging and the current knowledge of radiation has shown that the risk factors have increased. The authoritative report from the International Commission on Radiological Protection Report 60 (ICRP, 1991) has revised the risks upwards by a factor of three-to-four fold. (ii) Medical irradiation is by far the largest man-made contribution to radiation burden of the population. It has been shown (Wotton, 1993) that 90% of the radiation dose from the artificial sources is due to medical work. (iii) Current practice in diagnostic radiology is undergoing continuous evolution in response to technological developments. For example, both the numbers of CT scanners, and the number of CT examinations, have shown an appreciable rise since the introduction of the technique in 1972. (iv) Hospital x-ray equipment is often badly adjusted and badly used. The joint report of the National Radiological Protection Board and the Royal College of Radiologists stated that 'at least 20% of the x-ray examinations currently carried out in the UK are clinically unhelpful in the sense that the probability of obtaining information useful for patient management is extremely low' (NRPB, 1990). (v) Due to financial pressure on the health sector, funds are not readily available and as a result medical equipment are not kept up to date, nor supplemented or replaced by alternatives using non-ionizing radiations where they exist.

Moreover, measurement of radiation dose delivered to patient helps to (1) establish the approximate radiation risk from a particular examination (2) establish typical effective

doses and set up nationally and internationally agreed standards (3) measure the risk to an individual patient (4) ensure compatibility with the agreed and established standard procedures in individual x-ray department or even individual x-ray rooms which results in patient doses that are broadly compatible with national and international standards (5) establish a well-defined protocol to achieve the goals set (6) to monitor the collective dose to the population.

Finally, it is the nature of low dose radiation injuries that makes them apparently intangible. That is, they may occur at some considerable time after exposure and it is not possible to predict with certainty in which exposed individual the injury will occur. This has implications for radiation protection measures.

The aim of radiation protection as stated by the ICRP is to prevent detrimental deterministic effects and to limit the possibility of stochastic effecst to levels deemed to be acceptable. The aim is achieved by (a) setting dose equivalent limits at levels which are sufficiently low to ensure that no threshold dose is reached even following exposure for the whole of an individual's life-time. (b) keeping all justifiable exposures as low as reasonably achievable.

In radiation protection the principles of justification, optimisation and dose limitation are very essential tools for dose reduction.

2.6.1 Principle of Justification

The Principle of justification implies that the benefit to the patient and society of a radiological procedure must outweigh the risks for the patient associated with radiation exposure. The ultimate objective is to perform only procedures which result being positive or negative is expected to comfort the diagnosis or to change patient management; otherwise the practice is not justified. One must keep in mind that the benefit is immediate for the patient while the stochastic risk of low doses of ionising radiation if it exists is very small and at a long term.

2. 6.2 The Principle of Optimisation

The concept of optimisation as indicated in ICRP publication 26 states, " The limitation of stochastic effects is achieved by keeping all justifiable exposures as low as reasonably achievable, economic and social factors being taken into account" (ICRP, 1997). Similar words were used in the European Union council directive 97/43/Euroatom (EU, 1997) and they are known as the ALARA principle (As Low As Reasonably Achievable).

One interpretation of the ALARA principle, and the one used in this document, is that the exposure to the patient should be adjusted to obtain the required diagnostic information, not to get the best image quality possible. The process of reaching this goal is called optimisation in this document.

In general, efficient radiation protection includes the elimination of unnecessary or unproductive radiation exposure. One of the tools used in dose optimisation is the diagnostic reference levels (DRL). It assists in the optimisation of protection by helping to avoid unnecessarily high doses to the patient. The system for using DRLs includes the estimation of patient doses as part of regular quality assurance program.

2.6.3 Principle of Dose Limitation

The principle of dose limitation implies using adequate standard protection of patient, public and personnel even for the most highly exposed individuals.

2.7 Dose Descriptors

When an x-ray tube is in operation, the radiation beams are released. This beam can be used to create images of whatever is being examined, this radiation penetrates objects and human bodies, passes through them, and the radiation energy is reduced in the process. The concept of dose can mean different things according to the circumstance, for example according to the site where the dose is measured or the procedure.

2.7.1 Incident Dose

The incident dose is the dose measured in the middle of a radiation field on the surface of a body or a phantom. However, it is only measured at this point if there is no body in the path of the x-ray beam. Thus there is no scatter radiation from the body during this measurement. The unit of incident dose is Jkg^{-1}.

2.7.2 Entrance Surface Dose (ESD)

This is a measure of the radiation dose absorbed by the skin where the x-ray beam enters the patient. It includes the scattered radiation from the patient. Entrance surface dose (ESD) can be measured directly with thermoluminescent dosimeters or computed from measurements made with an ionization chamber (Sprawls, 1993; Vano *et al*., 1995 and McParland, 1998).

Another reliable method which can be used in the measurement of ESD is the use of x-ray output, technique factors and the backscatter factors (BSF). The BSF enables the true absorbed dose to be calculated. It is defined as the factor by which the radiation dose is increased by radiation scattered back from the body. The use of the backscatter factor in calculations of ESD account for the radiation scattered back to the surface of the patient and it is said to depend partially on the energy and field size of the x-ray beam, but they are typically in the range of 1.30 to 1.40 (Wagner *et al*., 1997).

It is suggested in European guidelines that the BSF for adult radiography be 1.35 and 1.30 for paediatric radiography (CEC, 1996). In addition, Tung *et al.* (2001) suggested that to obtain entrance skin dose in air with backscatter (ESD_{air}) the following formula could be used.

$$ESDair(mGy) = FAE\ (mR)\ x\ 8.69x10^{-3}\ x\ BSF \qquad 2.16$$

Where FAE is the free in air exposure with inverse square correction Sprawls (1993), and $8.69x10^{-3}$ is the conversion factor of FAE from mR into absorbed dose in the unit of mGy

The ESDair was recommended by IAEA (1996) as the dose descriptor for guidance levels in diagnostic radiography. Due to its simplicity and indication of the maximum skin dose, it is used for the periodic checking of patient dose (Robinson, 1990). However, the ESD has little biological significance regarding the health risks, it is the dose descriptor used for the guidance level in conventional radiography.

2.7.3 Exit Dose (EXD)

The exit dose serves in the evaluation of the x-ray image and energy imparted to the patient while the radiation travels through the patient's body (organ and tissue). It is measured in the radiation field in the immediate proximity to the surface of the body where the beam exits from the body. The quantity of dose deposited in the body, or the body dose could be calculated on the basis of the exit dose and the surface dose.

2.7.4 Absorbed Dose (AD)

Human body absorbs a larger percentage of the radiation energy delivered to it. The portion of an x-ray beam that is absorbed depends on the penetrating ability of the beam and the section of the body exposed. It is the quantity that expresses the concentration energy absorbed at a specific point within the body tissue or is a measure of energy deposited per unit mass. It provides a means to gauge the potential of biological effects. Absorbed dose is

greater for the tissue near the entrance surface than for those deeper within the body. Absorbed dose is a measure of energy deposited per unit mass and provides a means to gauge the potential for biological effects, it is given by:

$$D = \frac{dE}{dm} \qquad 2.17$$

Where *dE* is the mean energy imparted by ionizing radiation to a material of mass *dm* and *D* is the absorbed dose measured in the unit of gray (Gy) or milligray (mGy).

2.7.5 Absorbed Dose Rate (ADR)

This is the amount of energy deposited in a given period of time and it is typically measured in units of milligray per minute or hour (mGy/min or mGy/h).

2.7.6 Dose-Area Product (DAP)

Dose-area product (DAP) is a product of surface area of a patient that is exposed to radiation at the skin entrance and the radiation dose ($ESDair(mGy)$) at this surface (SI unit Gy cm^2) or, it is defined as the dose integrated over the beam area

$$DAP = \int D\ (x,y)dx\ dy \qquad 2.18$$

Measurement of dose-area product is suitable for achieving optimum degree of safety during the radiological examination of patient. DAP is a valuable radiation dose descriptor because radiation-induced biological effects are directly related to both the magnitude of the radiation dose and the total amount of tissue that is irradiated (Nickoloff *et al*., 2008). It is also useful for continuous quality control assurance, as well as analysis of performance of x-ray machines.

DAP could be measured by two methods, viz; direct measurement through the use of a transmission ionization chamber at the surface of x-ray tube collimator, and by indirect method otherwise called mathematical method. DAP is independent of distance from the tube, and may be taken to be equivalent to the product of the entrance surface dose (without backscatter) and the entrance field size (Chappel, 1998). It is usually measured in the unit of mGy cm^2 or Gy cm^2. Occasionally air kerma-area product may be specified instead when DAP meter has been calibrated in terms of dose in air rather than dose in the tissue.

2.7.7 Organ Dose (OD)

Organ dose refers to the radiation absorbed dose delivered to the organs of a patient during a radiologic examination. Specific organs of interest include, but not limited to, active bone marrow, thyroid, breast, gonads, and the lens of the eyes. Dose to the embryo or fetus may also occur during diagnostic procedures, and knowledge of conceptus dose is critical to responsible patient management (Parry *et al*., 1999).

2.7.8 Kerma

This is the kinetic energy released in matter. It is defined as the amount of energy transferred from the incident x-rays to charge particle per unit mass in the medium of interest. Kerma includes any energy subsequently given up as a photon (ie , bremsstrahlung), but excludes any further energy transfer to other charged particles. The unit of air kerma is the same as the unit for absorbed dose (gray-Gy or milligray-mGy).

2.7.9 Effective Dose (ED)

It is not usual that a given irradiation will affect only one organ. More commonly, several organs will receive radiation doses. In this situation it is more convenient to be able to express the multiplicity of doses as a single value which represents the hypothetical radiation dose that would have the same effects (risk) if it was applied uniformly to the whole body. This combined value is the effective dose, and measured in sievert. It is calculated by multiplying the equivalent dose in each organ, H_T, by a tissue weighing factor, W_T and summing the result; it is expressed as:

$$E = \sum H_T . W_T \qquad 2.19$$

The major benefit of using the effective dose is that this parameter accounts for the absorbed doses and relative radiosensitivities of the irradiated organs in the patient and, therefore better quantifies the patient risk (UNSCEAR, 1993) which is the motivation for all patient dosimetry studies in diagnostic radiology.

Moreover, the effective dose to a patient undergoing any examination may be compared to that of any other radiological procedure as well as natural background exposure and regulatory dose limits, which are increasingly, expressed using effective dose values (NRC, 1995).

2.8 Factors Affecting Patient Dose

The dose delivered to a patient depends on many factors. These factors include: beam energy and filtration, collimation, grids and patient size. Other factors include; screen-film combinations and film processing condition.

2.8.1 Beam Energy and Filtration

Beam energy primarily depends on the peak kilovoltage (kVp) selected and the amount of filtration in the beam. If all other variables are held constant, ESD will change as the square of the change in peak voltage. The selection of higher kVp increases the average energy of the x-ray and therefore beams penetrability. As the beam becomes more penetrating, more x-rays will reach the image receptor during the same period of time. In practice, this may allow for the use of a lower tube current or a shorter exposure, thus reducing the dose to the patient.

Diagnostic radiography units are required by regulations to contain a total filtration (which includes the tube wall and any other added filtration) of at least 2.5 mm Al equivalent if they are operated at tube potential above 70 kVp. This filtration preferentially absorbs the low-energy x-rays in the beam. Absorption primarily takes place with x-rays of less than 40 keV of energy, and virtually all x-rays below 10 keV are absorbed (Sprawls, 1993). Without filtration, this low energy radiation would most likely be completely absorbed in the patient. Because image formation requires transmission of x-rays through the patient to expose the image to receptor, low energy x-rays contribute to patient dose without contributing to the image.

In effect the added filtration serves to further increase the average energy of the beam. In the range of energies of x-rays used in diagnostic radiology, however, increasing the average energy of the x-ray beam will decrease the contrast of the resulting image. Therefore, to reduce patient dose the goal should be to use the highest peak kVp possible that results in acceptable image contrast.

2.8.2 Collimation

During radiographic procedure, the area of the patient exposed to the x-ray beam is limited to the area of clinical interest. Tissues inside the primary beam receive doses that are order of magnitude higher than doses received by tissues outside the primary beam. By using collimation to expose only the area of clinical interest, one can substantially reduce unnecessary patient exposure.

Use of collimation has another important effect: By reducing the area of the x-ray beam, the amount of scattered radiation that reaches the image receptor is also decreased. The resulting images thus have better contrast.

2.8.3 Grids

Grids are introduced into radiography to reduce the amount of scattered radiation that reaches the image receptor. Modern grids do an exceptional job, resulting in images with much improved contrast. Unfortunately, this improved contrast comes at the cost of increased patient dose. A grid also absorb a portion of the primary x-rays- that is, those that would have contributed to exposing the image receptors- and the only way to achieve the degree of exposure required to produce the image is to increase the amount of radiation incident on the grid and therefore the patient. A grid removes a much larger fraction of scattered x-rays than unscattered, or primary, x-rays, and the doses are typically increased from two to five times those encountered without the use of grids. This proportion is commonly referred to as the Bucky factor and represents the ratio of the dose with grid to dose without a grid (Bushberg *et al*., 1994). The higher-quality images achieved with a grid, however may result in fewer retakes and more accurate diagnoses.

2.8.4 Patient Size

The patient size, shape and composition affect the radiation dose received by patients during radiological examinations (Chapple *et al*., 1995). As the thickness of the area being imaged increases, the amount of radiation (dose) incident on the patient increases because adequate x-rays penetration is needed to create an acceptable image. This will increase both the patient entrance dose and the dose-area product. In addition to this, a larger patient may require a larger field size to image a given organ, and the proportion of beam energy absorbed in the body will be greater than for smaller patient.

Although the examiner has little or no control over patient size, it is beneficial to know the types of exposures expected for examinations of different anatomical areas and patients of different sizes. Technique charts that display suggested radiographic technique factors for various examinations and patient thicknesses placed near the operator's console may be helpful in the selection of appropriate technique factors that match each patient size in order to enhance quality image and still optimize dose.

2.8.5 Screen-Film Combinations and Film Processing Conditions

In recent times, most radiographic intensifying screens are composed of rare earth elements. Previously, calcium tungstate was the commonly used material. The speed, or overall efficiency, of calcium tungstate screen is often referred to as Par speed and is assigned an arbitrary speed of 100. The speed numbers are relative; that is, a 400 speed system requires only half the dose used with a 200-speed system, which requires half the dose used with a 100- or Par, speed system. The use of a faster screen-film combination can substantially reduce dose, and modern rare earth screen may also be used. Faster systems result in some loss of detail, but if the examination in question permits less detail, the faster systems are used.

The film processor should be functioning according to the film manufacturers' recommendation. If temperature, transport rate, or replenishment rates differ substantially from recommended values, the effects on image quality can be significant. Poor image quality can lead to modification of radiographic techniques, which in turn directly affect patient dose.

2.9 Dose Measurement

Radiation doses could be measured at the skin surface either directly by using thermoluminescent dosimeter (TLD) or it may be calculated indirectly using exposure parameters. Organ dose can be calculated by the use of table of percentage depth dose or to use the tissue-air ratio (TAR) obtained from measurement in a range of phantoms.

The use of TLD is practical only for superficial dosimetry, unless it is formed invasively by inserting the chips, using cathether into the patient. Nonetheless, a good estimate of gonadal dose can be made by TLD dosimeters fixed to the testicles. Generally speaking, however, the only way of obtaining doses to organ such as the lungs or kidneys is to measure the external dose and then to use either physical or mathematical models to estimate the internal dose (Myer, 1993).

2.9.1 Radiation Dosimeter

A radiation dosimeter is a device, instrument or system that measures or evaluates, either directly or indirectly, the quantities of exposure, kerma, absorbed dose or equivalent dose, or their derivates (rates), or related quantities of ionizing radiation. A dosimeter along with its reader is referred to as dosimetry system.

Measurement of a dosimetric quantity is the process of finding the value of the quantity experimentally using dosimetry systems. The result of measurement is the value of a dosimetric quantity expressed as the product of a numerical value and an appropriate unit. Examples of dosimetry systems include: ionization chamber dosimetry systems (chambers and electrometers, cylindrical ionization chambers, parallel plate ionisation chambers, brachytherapy chambers, extrapolation chambers), film dosimetry system (radiographic films, radiochromic film), semiconductor dosimetry systems (silicon diode dosimetry system, MOSFET dosimetry,), Luminescence dosimetry system (thermoluminescence dosimetry-TLD, optically stimulated luminescence dosimetry-OSL). Other dosimetry systems include but not limited to alanine/electron paramagnetic resonance dosimetry, plastic scintillator dosimetry system, diamond dosimeter, gel dosimetry system.

To function as a radiation dosimeter, it must possess at least one physical property that is a function of the measured dosimetric quantity and that can be used for radiation dosimetry with proper calibration. In order to be useful, a radiation dosimeter must exhibit several desirable characteristics. For example, in radiotherapy exact knowledge of both the absorbed dose to water at a specified point and its spatial distribution are of importance, as well as the possibility of deriving the dose to an organ of interest in the patient. In this context, the desirable dosimetric properties are characterized by accuracy and precision, linearity, dose or dose rate dependence, energy response, directional dependence and spatial resolution.

2.9.2 Linearity of Dosimeter

Ideally, the dosimeter reading *M* should be linearly proportional to the dosimetric quantity *Q*. However, beyond a certain dose range a non-linearity sets in. The linearity range and the non-linearity behaviour depend on the type of dosimeter and its physical characteristics.

In general, a non-linear behavior should be corrected. A dosimeter and its reader may both exhibit non-linear characteristics, but their combined effects could produce linearity over a wide range.

Integrating systems measure the integrated response of a dosimetry system. For such systems the measured dosimetry quantity should be independent of the rate of that quantity. Ideally, the response of a dosimetry system $\frac{M}{Q}$ at two different dose rates should remain

constant. In reality, the dose rate may influence the dosimeter readings and appropriate corrections are necessary.

In addition, the response of a dosimetry system is generally a function of radiation beam quality (energy). Since the dosimetry systems are calibrated at a specified radiation beam quality (or qualities) and are used over a much wider energy range, the variation of the response of a dosimetry system with radiation quality (called energy dependence) requires correction.

Ideally, the energy response should be flat, that is the system calibration should be independent of energy over a certain range of radiation qualities. In reality, the energy correction has to be included in the determination of the quantity Q for most measurement situations.

The variation in response of a dosimeter with the angle of incidence of radiation is known as the directional or angular dependence of the dosimeter. Dosimeters usually exhibit directional dependence, due to their constructional details, physical size and the energy of the incident radiation. Directional dependence is important in certain applications, for example in *in vivo* dosimetry while using semiconductor dosimeter.

Since the dose is a point quantity, the dosimeter should allow the determination of the dose from a very small volume. The position of the point where the dose is determined, that is, its spatial location should be well defined in a reference coordinate system.

Thermoluminescent dosimeters (TLD) come in very small dimensions and their use, to a great extent, approximates a point measurement. Film dosimeters have 2-D and gel 3-D resolution, where the point measurement is limited only by the resolution of the evaluation system. Ionisation chamber type dosimeters, however, are of finite size to give the required sensitivity, although the new type of pinpoint microchambers partially overcomes the problem.

Direct reading dosimeters (e.g. ionization chambers) are generally more convenient than passive dosimeter (i.e. those that are read after due processing following the exposure, for example TLDs and films). While some dosimeters are inherently of the integrating type (e.g. TLDs and gels), others can measure in both integral and differential modes (ionisation chambers).

Dosimeters such as ionisation chambers are reusable, with no or little change in sensitivity within their lifespan; however some dosimeters are not reusable (e.g. films) and

some dosimeters are quite rugged (i.e. handling will not influence sensitivity, for example ionization chambers), while others are sensitive to handling (e.g. TLDs).

2.10 Uncertainty in Measurement

The uncertainty associated with a measurement is often expressed in terms of accuracy and precision. The precision of dosimetry measurement specifies the reproducibility of the measurements under similar conditions and can be estimated from the data obtained in repeated measurements. High precision is associated with a small standard deviation of the distribution of the measurement results. The accuracy of dosimetry measurements is the proximity of their expectation value to the 'true value' of the standard quantity. Results of measurements cannot be absolutely accurate and the inaccuracy of a measurement result is characterized as 'uncertainty'.

The uncertainty is a parameter that describes the dispersion of the measured values of a quantity; it is evaluated by statistical method or by other methods, has no known sign and is usually assumed to be symmetrical.

The error of measurement is the difference between the measured value of a quantity and the true value of that quantity. An error has both a numerical value and sign. Typically, the measurement errors are known exactly, but they are estimated in the best possible way, and, where possible, compensating corrections are introduced. After application of all known corrections, the expectation value for error should be zero and the only quantities of concern are the uncertainties.

Uncertainties can be divided into two different types: type A and type B. This division is based on whether the uncertainties can be estimated by repeated measurements or not. Type A uncertainty can be estimated from repeated measurements. Type B standard uncertainties cannot be estimated by repeated measurement; rather, they are unintelligent guesses or scientific judgments of non-statistical uncertainties associated with the measurement. They include influences of the measuring process, application of correction factors or physical data taken from the literature.

2.11 Luminescence Dosimetry

Some material upon absorption of radiation, retain part of the absorbed energy in metastable states. When this energy is subsequently released in the form of ultraviolet, visible or infrared light, the phenomenon is called luminescence. Two types of luminescence, fluorescence and phosphorescence, are known, which depend on the time

delay between stimulation and the emission of light. Fluorescence occurs with a time delay of between 10^{-10} and 10^{-8} s and phosphorescence occurs with a time delay exceeding 10^{-8} s. The process of phosphorescence can be accelerated with a suitable excitation in the form of heat or light.

If the exciting agent is heat, the phenomenon is known as thermoluminescence and the material is called thermolumiscent dosimeter (TLD). A thermoluminescent dosimeter (TLD) is used for the purpose of dosimetry. On the other hand if the exciting agent is light, the phenomenon is referred to an optically stimulated luminescence (OSL). The optically stimulated luminescence system is based on the principle similar to that of thermoluminescence dosimetry. Instead of heat, light (from laser) is used to release the trapped energy in the form of luminescence. This is a novel technique offering a potential for in vivo dosimetry in radiotherapy. The integrated dose measured during irradiation can be evaluated during OSL directly afterward.

2.11.1 Thermoluminescence Dosimetry

Thermoluminescence is thermally activated phosphorescence; it is the most spectacular and widely known radiation-induced, thermally-activated phenomenon. Its practical applications include; industrial, environmental, archaeological pottery dating and personal radiation dosimetry. The main advantages of TL dosimeters over other detectors are: wide useful dose range, small physical size, re-usability, and therefore more economical. There is no need for high voltage or cables and it does not affect the radiograph produced for most radiation types (Aschan, 1999). These properties make TL detectors very useful tools for clinical dosimetry, and an important tool for clinical and environmental dosimetry (Kron, 1995).

2.11.2 Principle and Operation of Thermoluminescent Dosimeter (TLD)

Thermoluminescent dosimeter (TLD) is a thermally activated phosphor in which ionizing radiation causes trapping of freed electrons or (holes) at lattice defects in crystal structure. Thermoluminescence (TL) is the emission of light that occurs when electrons escape from the traps and return to stable state. The escape probability could be greatly increased by raising phosphor temperature. If the TL emission is obtained and plotted against time during which the temperature is varied, a glow curve is obtained with several peaks which correspond to various energies of the emptied traps.

Thermoluminescence is a two-step procedure. The first step is to expose the TLD material to the radiation (Figure 2.2a). A portion of the absorbed radiation energy is used to raise electrons to higher energy levels. A characteristic of TLD material is that some electrons are trapped in the higher energy locations. The number of electrons that remain in the elevated energy positions is proportional to the amount of radiation energy absorbed, or the absorbed dose. The second step is to place the irradiated TLD material in a special reader unit. This unit heats the TLD material and measures the amount of light emitted during the heating process (Figure 2.2b). Heating frees the trapped electrons and allows them to drop to their normal low energy positions. The energy difference between the two electron locations is given off in the form of light. By calibrating the system, the light output is converted into absorbed dose values.

A useful phenomenological model of the thermoluminescence mechanism is provided in terms of the band model for solids. The storage traps and recombination centres, each type characterized with an activation energy (trap depth) that depends on the crystalline solid and the nature of the trap, are located in the energy gap between the valence band and the conduction band. The states just below the conduction band represent electron traps, the states just above the valence band are holes traps. The trapping levels are empty before irradiation (i.e. the hole traps contain electrons and the electron traps do not).

During the irradiation the secondary charged particle lift electrons into the conduction band either from the valence band (leaving a free hole in the valence band) or from an empty hole trap (filling the whole trap).

2.11.3 Thermoluminescent Dosimeter (TLD) Reader

A basic TLD reader system consists of a planchet for placing and heating the TLD, a photomultiplier tube (PMT) to detect the thermoluminescence light and convert it into electrical signal linearly proportional to the detected photons fluence and an electrometer for recording the PMT signal as a charge or current.

The thermoluminesce intensity emission is a function of TLD temperature T. Keeping the heating rate constant makes the temperature (T) proportional to time (t), and so the thermoluminescence intensity can be plotted as a function of time (t) if a recorder output is available with the TLD measuring system. The resulting curve is called glow curve.

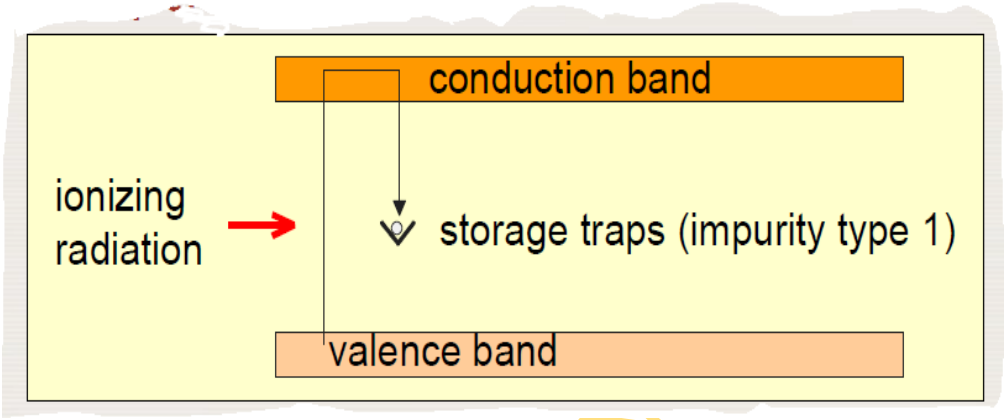

Figure 2.2 a Mechanism of thermoluminescent dosimetry (Irradiation)

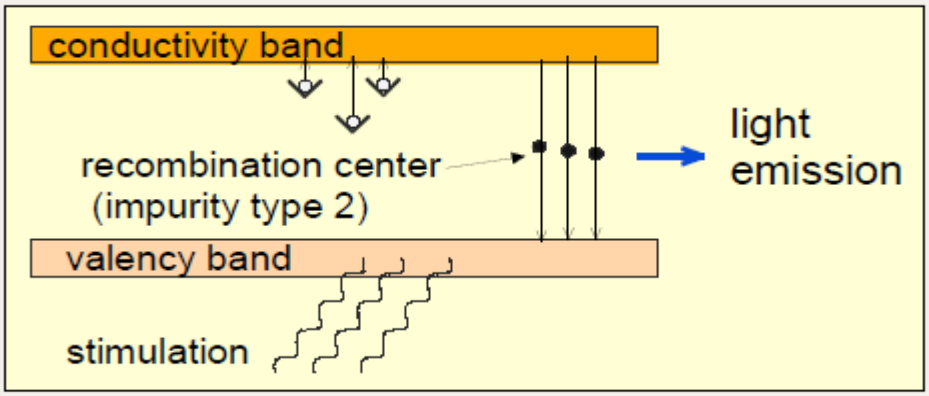

Figure 2.2 b Mechanism of thermoluminescent dosimetry (heating)

In general, if the emitted light is plotted against the crystal temperature one obtains a thermoluminescence glow curve. The peaks in the glow curve may be correlated with trap depths responsible for thermoluminescence.

It has been shown that the main dosimetric peak of the LiF:Mg,Ti glow curve between 180^{o} C and 260^{o} C is used for dosimetry (Izewska and Rajan, 2013). The peak temperature is high enough so as not to be affected by room temperature and still low enough so as not to interfere with blackbody emission from the heating planchet.

The total thermoluminescence signal emitted (i.e. the area under the appropriate portion of glow curve) can be correlated to dose through proper calibration. As regard the response of the signal with time, the thermoluminescence signal decreases in time after the irradiation due to spontaneous emission of light could occur at room temperature, this is termed fading. Typically, for LiF:Mg,Ti, the fading of dosimetric peak does not exceed a few percent in months after irradiation. The thermoluminescence dose response is linear over a wide range of doses used in radiotherapy, although it increases in the higher dose region, exhibiting supralinear behavior before it saturates at even higher doses.

Thermoluminescent dosimeters need to be calibrated before they are used. To derive the absorbed dose from the thermoluminescence reading, a few correction factors have to be applied, such as those for energy, fading and dose response non-linearity.

2.11.4 Applications of Thermoluminescent Dosimeter

Applications of TLDs in both diagnostic radiology and radiotherapy are for dose monitoring during routine examination, dose auditing for radiation protection and dose reduction, determination of diagnostic reference level, and personal dose monitoring. Others include: in vivo dosimetry on patients, (total body irradiation, brachytherapy), verification of treatment techniques in various phantoms, dose comparisons among hospitals.

2.12 Radiation Dose Assessment

Dose assessment of employees and of the public in all the hospitals where x-rays are used are required and is deemed appropriate, in order to ensure compliance with the recommendations of regulatory bodies. This is in line with the Medical Directive (97/43/Euratom) that stipulates that radiation dose should be measured in every hospital and doses should be compared to the reference doses established by competent authorities. Doses could be measured directly and may be assessed through relevant radiation parameter

(NOHSC, 1995). It is also expected that dose assessment record should include sufficient details to allow later assessment, if necessary.

In addition, where dose estimates depend in particular circumstances on computational factors that may change over time, such as personal protective factors or parameters taken from the scientific literature or from ancillary measurements, those factors should be recorded (NOHSC, 1995).

Several tangible efforts have been put in place by many researchers in the assessment of radiation dose few years after the discovery and application of radiation in examination and treatment. The dose determination is carried out to ensure that the dose delivered to the patient satisfies the established guidance levels.

As x-rays pass through atoms and molecules in human tissue ionization takes place through the deposition of energy. This process of ionization is the first step in series of events that may lead to biological effects (Parry *et al*., 1999). Due to the attendant biological effect on exposure of patient to radiation, the measure of the energy deposited per unit mass (dose) is required. However, different dosimetric parameters such as entrance surface dose, organ dose, energy imparted and effective dose have been used by various researchers to either express patient doses or quantify the patient risk.

Because of the importance attached to the patient dose, various researchers have employed different methods for assessing entrance surface dose. A great deal of effort has been put in place for the assessment of this dosimetry parameter because it is the physical quantity recommended for monitoring the diagnostic reference levels (DRLs) in conventional radiography (Compagnone *et al*., 2005). Moreover, the methods for measuring it are clearly described in European Commission guidelines (CEC, 1996).

Entrance surface dose could be measured using thermoluminescent dosimeter placed on the surface of the patient (Geijer, 2001). The use of TLD is possible because it does not interfere with radiographic image and thus do not disturb clinical procedures. Thermoluminescent dosimeter disc is sensitive in all direction; therefore the dose value from TLD measurement includes backscatter.

2. 12.1 Challenges of Paediatric Dose Assessment

Dose optimization is of particular importance in paediatric radiology for a number of reasons: (1) there is greater chance for expression of radiation induced effects (such as cancer) for children than for the adult population (Stather *et al*., 1988), (2) some examinations are carried out with greater frequency for the children especially, the

premature or sick neonates which receive a large number of examinations during the first few months of life, as their health conditions are monitored, and this can sometimes continue through early childhood, (3) children will often be uncooperative during x-ray examinations, and this leads to repeat or longer exposures, (4) comparison of paediatric dose data are also problematic. This is due to the wide range of patient sizes involved (neonate to adolescence-0-15 years). The variability in age band and sizes create problems in both the actual dosimetry such as the application of the organ dose data (Chapple, 1998) meant for adult to paediatric patients of different age groups and sizes.

The issue of variability in paediatric patient sizes is one of the most basic problems in paediatric dosimetry. However, the works of Chapple (1998) and Hart *et al*. (2000) have identified and addressed the variability. The works of the aforementioned authors could also be used to solve the problem of standard-sized patient that aids in dose comparison.

Against this background radiation dose measurement of paediatric patients is very important and because of significantly lower radiation dose than for adult, sometimes comparable with background fluctuations, greater sensitivity is required in the equipment used to record accurately the parameters such as ESD or DAP. This may require the use of calculation to estimate the dose or it may require the purchase of specialised equipment for making measurement (Broadhead *et al*., 1997). Repeated emphasis has been on regular patient radiation dose measurement in all radiological departments, diagnostic reference levels determined and applied to optimise patient protection.

2.12.2 Frequency of Dose Assessment

According to the Code of Safe Practice for the use of x-rays in Medical Diagnosis designed by National Radiation Laboratory (NRL-C5, 2010) of New Zealand, it is required that, the auditing of x-ray facilities of persons licensed to use x-rays for medical diagnosis or research on humans shall be performed by qualified Health Physicists. The auditing is to ensure compliance with acceptable code of practice. The interval between surveys (audits) shall not exceed the following:

- Radiography - 4 years;
- Fluoroscopy - 2 years;
- CT facilities - 2 years;
- Mammography - 2 years.

2.12.3 Benefits of Dose Assessment

The last 50 years of radiation dosimetry in the United States have shown that the regular use of quality control programmes for diagnostic radiology equipment and the establishment of diagnostic reference levels (DRLs) by the National Evaluation of x-rays Trends (NEXT) have played vital roles in reducing patient radiation doses. Based on the NEXT report on patient average entrance surface dose (ESD) and data such as reference dose levels, a 50-70% reduction in average ESD was achieved during the period of 40 years (1964-2004) in chest PA, abdomen AP, and lumbar-sacral spine AP procedures. In the reports of NRPB, it is indicated that 20 years of regular patient dose monitoring has reduced DRLs by more than 50% (Hart *et al*., 2007).

As a result of the benefits of dose assessment, different countries and nations have developed legal frame work for dose assessment and possible dose reduction. This stems from the fact that radiation is useful but it is no respecter of nationality or national boundaries. This specific characteristic of radiation calls for regular dose assessment in every health institution using x-rays.

2.12.4 Radiation Dosimetry Activities in other Countries

In line with required standard practice and as part of quality assurance program in Estonia (Finland), doses in various paediatric radiographic examinations (of pelvis, chest, spine and skull) were assessed in three x-ray departments by Kepler *et al*. (2002). Entrance surface dose to paediatric patients were estimated from dose-area product (DAP) measured with DAP meter and ESD calculated by using examination technique factors and DAP data. Furthermore, the ESD was also calculated using machine output and technique factors. Result of the investigation revealed that DAPs for pelvis radiograph without a grid were 10% higher than when a grid was used for a 14 cm thick patient.

Another study carried out to compare the ESD and technique factors in West Midland (UK) with CEC criteria specifically for lateral lumbar spine radiograph, revealed in part that 18% of the departments used a mean focus-to-film distance (FSD) of less than 100 cm, and 64% of the department investigated used kVp less than 90kV while 18 % exceeded the reference dose of 30 mGy. Moreover, a mean TLD dose of 19.9 mGy was obtained from patients whose individual weights ranged between 50-90 kg (McNeil *et al*., 1995). They concluded that existence of considerable variation between the mean calculated/direct dose ratio (0.64 -144) for each department demonstrated the importance of direct dose measurements.

A measurement carried out in East Anglia (Wade *et al*., 1995) has been used to identify rooms where doses are above average and the reason for the high doses in those rooms. Direct method was employed during the measurements which spanned a period of two years and over 1200 ESDs were measured during the period. Results of the investigation demonstrated that the reference dose for East Anglia are well below the NRPB reference doses for all views except for measurement on PA chest where a high kVp were in general giving higher skin dose than departments using a low kVp. Specifically, all departments exceeding the (NRPB, 1990) reference dose were using high kVp with grids. Another important finding of the study was that, for all views, there was little difference between the average ESDs for private departments and National Health Service (NHS) department (NHS= 5.7 mGy, Private = 7.8 mGy). The study indicated the possibility of dose reduction by about 30% by the choice of appropriate exposure factors.

Another radiation dose survey was carried out in the neo-natal unit of Aberdeen Maternity Hospital, Scotland (UK) using an indirect method. The team of investigators considered TLD chips unsatisfactory because their placement contravene the infection control protocol in neo-natal unit, caused unnecessary disturbance to the baby and the dosemeters produced artifacts coupled with the fact that doses were near the limit of sensitivity (Wraith *et al*, 1995). Quality control tests of machines investigated were conducted to ascertain their consistency. The final dose results as a follow up of initial trial indicated a dose reduction of between 20 and 50% by increasing filtration and the tube potential without impairment to diagnostic image quality.

In another study, Persliden *et al*, (1996) investigated the radiation dose delivered at small intestinal biopsies in children. The study was carried out in Sweden. About 42 of the 43 paediatric departments were included in the study involving 257 biopsies and measurements carried out using TLD. The results show a considerable variation of both duration of fluoroscopy and radiation dose (range of 0.1-14 mSv). The report concluded that a 6-fold reduction of radiation dose was obtained in one department through optimization of all technical conditions, such as x-ray equipment, technical devices and through the method of sedation.

Other works on radiation dose and energy imparted carried out in Europe include; Rannikko *et al*. (1997), Chapple *et al*. (1998), Crawley *et al*. (2000), Geijer (2001), Brennan and Johnston (2002), Compagnone *et al*. (2005), Ciraj-Bjelac *et al*. (2007). Others include: McNeil *et al*. (1995), Cook *et al*. (2001), Theocharopoulous *et al*. (2002), Friberg *et al*.

(2007), Dougeni *et al*. (2007), George *et al.* (2004), Kiljunen *et al*. (2007), Tsapaki *et al*. (2007), Hadnadjev *et al*. (2012), and Santos *et al*. (2014).

Some works were carried out specifically to address dose delivered to the paediatric patients because of the importance attached to the dose delivered to them. These works include: Faulkner *et al*. (1998), Chapple *et al*. (1992), Chapple *et al*. (1994), Chapple *et al*. (1995) and Gonzalez *et al*. (1995).

Other researchers have worked on population dose (collective dose) in Europe. The following are some of the notable dose assessment carried out earlier in Europe: Diaconescu and Iacob (2002) in Romania, Scanff *et al*. (2008), and Samara *et al.* (2012) in Switzerland.

Dose measurement is not only limited to Europe, some countries in Asia have undertaken dose measurements in time past. These countries are: Turkey (Meric *et al*., 1998); Malaysia (Ng *et al*., 1998, Hambali *et al*., 2009); Saudi Arabia (McParland *et al*., 1996, McParland, 1998); India (Kumaresan *et al*., 2011); Japan (Yasuda, 2009; Kobayashi *et al*., 2014), South Korea (Lee *et al*., 2010) and Iran (Toosi and Akbari, 2012; Tossi *et al*., 2014).

In North and Latin Americas, dose measurements were carried out to find out the level of patient exposures both in conventional radiography and computed tomography. The following are some of the published works on dose measurement in the two continents: USA: Huda and Gkanatsios, 1997; Gkanasios and Huda, 1997; Huda and Gkanatsios, 1998; Ware *et al*., 1999; Huda *et al*., 2000; Gray *et al*., 2005; Mettler *et al*., 2009; Miller *et al*., 2009; Hendrick, 2010; Brazil: Freitas and Yoshimura, 2009; Osibote *et al*., 2007, and in Canada: Osei and Darko, 2013).

The measurement of dose delivered to patient during diagnostic imaging in Africa gained prominence less than three decades ago. It does not mean that the medical use of radiation started then, but inadequate facilities and personnel might have prevented earlier measurements of radiation dose resulting from medical imaging. Quick reviews of some dose measurements in Africa are as follows: Schandorf and Tetteh, 1998 (Ghana), Muhogora and Nyanda, 2001 (Tanzania), Mohammadain *et al*., 2004 (Sudan), Suliman *et al*., 2006 (Sudan), Suliman and Elshiekh, 2008 (Sudan), Halato *et al*., 2008 (Sudan), Admassie *et al*., 2010 (Ethiopia). Apparently, dose survey activities have gained prominence in Sudan. This could be as a result of availability of facilities to undertake such surveys.

2.13 Dosimetry Activities in Nigeria

In an attempt to obtain a representative picture of dose data in conventional radiography in Nigeria, available literature were examined to ascertain the extent of patient dose measurements in Nigerian hospitals and diagnostic centres. This is the requirement of Nigerian Nuclear Regulatory Authority and other international regulatory bodies for conventional routine examinations.

In spite of the fact that conventional x-radiation procedures have been carried out in Nigeria for more than five decades, reasonable measurements of doses delivered to the patients during the routine examinations did not start until less than three decades ago (Ajayi and Akinwumiju, 2000).

One of the earliest dose measurement activities was carried out by Ajayi and Akinwumiju (2000). In the study, spreads were reported in the values of the doses measured. The spread was attributed to the differences in the size of patients examined. Another study was carried out by Farai and Obed (2001). The study of the duo focused on occupational dosimetry.

This was followed by a study on dose measurements carried out by Ogunsehinde *et al*. (2002). It was partly a follow up of the work of Ajayi and Akinwumiju (2000). The study was carried out in three hospitals in southwestern Nigeria; they found that ESDs obtained were greater than the CEC reference dose in three of the five rooms investigated. The works of Ajayi and Akinwumiju (2000) and Ogunsehinde *et al*. (2002) were financed by the International Atomic Energy Agency (IAEA).

In another study, Ogundare *et al*. (2002) measured absorbed dose to dental patients in two hospitals. A review of the available literature indicate that in the same year (2002) similar dose survey was carried out in the middle belt of Nigeria by Agba (2002).

Other concerted efforts were made by other researchers at measuring doses delivered to the patients during diagnostic examinations. Two of the major works were carried out by Ogundare *et al*. (2004a) and Ogundare *et al*. (2004b). In the latter work, the target group was paediatric patients. In 2006, an important study based on assessment of doses to patients' eyes from dental x-ray examination was carried out by Hussaini and Oresegun (2006). In the study both adult and paediatric patients were considered in their measurements. Literature review has shown that the works of Hussaini and Oresegun (2006), and that of Ogundare *et al*. (2002) are the dental dosimetry carried out until 2006, an indication that radiation doses received by patient during dental examinations have probably

not been adequately measured and documented. Dental radiography involves intraoral screen films either to provide views of the upper or lower teeth together, or to demonstrate full tooth pulp, root and gum anatomy (Schandorf and Tetteh, 1998).

As part of dose measurements in Nigeria, Jibiri and Oguntade (2007) estimated the genetically significant dose to the occupationally exposed individuals in two medical and industrial establishments in Nigeria. In this assessment, linear non-threshold model was used to assess the continuous personnel radiation dose monitoring data over a period of three years (1998-2001).

Another study was carried out by Obed *et al*. (2007) to assess the dose delivered to patient in nine selected hospitals. In another study Egbe *et al.* (2008) carried out a study on peadiatric patients. Also Egbe *et al*. (2009 a) undertook a study of doses and image quality for chest radiographs in three Nigerian hospital. During the same year, a study was carried out on a baseline study of entrance dose and image quality for lumbar spine radiography in Calabar (Egbe *et al*., 2009 b).

Furthermore, another interesting study involving both the southern and the northern parts of the country was carried out by Sherifat and Olarinoye (2009). In their work entrance skin doses (ESD) of patients undergoing routine diagnostic examinations were measured. One hospital was selected in the north (Minna) and the other in Ibadan. Similarly, Akinlade *et al*. (2012) carried out DAP surveys in four different hospitals in Nigeria. Three of the hospitals are located in the South West, while one is located in the middle belt of Nigeria. One important feature of the study carried out by this team is the measurement of dose-area product (DAP). The dose descriptor (DAP) takes care of the biological effects of radiation. In addition, the four hospitals considered in their study are part of the best and well equipped in Nigeria. Other works carried out in Nigeria especially in the South-South (Portharcourt) was that of Esen and Obed (2012). The doses delivered to the patient were estimated using CalDose software. Jibiri and Adewale (2014) carried out survey on doses received by 26 patients undergoing computed tomography (CT) of the cranium in a large teaching hospital in southwestern Nigeria (Ile-Ife). The survey included both paediatric and adult patients.

Table 2.1 is a summary of dose measurement activities carried out in Nigeria. The table (Table 2.1) shows the mode of investigation, the financing body, study location and the target groups. Other items in the table include the number of patients included in the investigations, radiographic view examined and imaging modalities used. In this analysis

only conventional radiography (dental radiography and industrial radiography included) were considered. Information in the table indicates that mammography is visibly missing. This implies that adequate works (dose measurement) on mammography have not been carried out in Nigeria.

It is clear that thousands of mammography examinations are carried out annually in Nigeria (especially in Teaching hospitals and private clinics) without adequate documentation of the patient dose and technical parameters used during the examination. Mammography is mainly used for diagnostic purposes. Breast screening for early detection of breast cancer is essential for early treatment.

Computed tomography (CT) is one of the imaging technologies used in Nigeria, largely in teaching hospitals and few private hospitals. Because the CT scan represents the most remarkable advances in medical imaging since the discovery of x-rays, CT examinations are requested for ever–growing arrays of clinical problems and also as replacements for the historic conventional radiographs and fluoroscopic procedures. This imaging modality according to the NCRP report no. 160 (1) is the second largest contributor to collective effective dose (Schauer and Linton, 2009). However, adequate attention has not been paid to the measurement of doses delivered by CT facilities in Nigeria.

Out of the 17 literature shown in Table 2.1, thirteen used thermolumiscent dosimeter (TLD) for their investigation, two used both TLD and calculations. Meanwhile, five used only calculation for the dose assessment. The use of calculation for dose assessment is a welcome development especially if software is used for this purpose. The study of Davies *et al*. (1997) shows that ESDs calculated using software (DoseCal software, CALDose) are within 20% compared with ESDs measured using TLDs. Other reasons for using software are that the minimum radiation dose that can be measured with TLD-100, LiF:Mg, Ti is about 100 μGy and the ESDs in paediatric patients can be as low as 50-80 μGy and these make TLDs unsuitable (IPSM, 1992; Burke and Sutton, 1997) for the low doses.

Table 2.1: Summary of some dosimetry activities in Nigeria.

Name of Researchers	Method of investigations	Financing body	Study location	Target groups	Number of X-ray units (patients)	Radiographic view(s) investigated	Type of investigation
Ajayi and Akinwumiju, 2000	TLD	IAEA	SW	Adult	U	CH, SK, LBS, HD	CX
Farai and Obed, 2001	TLD	U	SW	Adult/ Occupational	2	--	CX/ INDX
Ogunsehinde *et al*., 2002	TLD	IAEA	SW	Adult	3-5 Rooms (75)	CH, SK,	CX
Ogundare *et al*., 2002	TLD	U	SW	Adult	2 Rooms	HD, NK	CX
Agba *et al*., 2002	C	Nil	MB	Adult /Paediatric	1 (100)	CH	CX
Ogundare *et al*., 2004a	TLD	University Grant	SW/SS	Adult	3 (171)	ABD, PEL, LBS	CX
Ogundare *et al*., 2004b	TLD	U	SW	Paediattric	3 (139)	CH, SK, ABD, PEL, LBS	CX
Hussaini and Oresegun (2006)	TLD	Nil	SW	Adult/ Paediatric	1 (110)	SK (Eyes)	DX
Jibiri and Oguntade, 2007	TLD/C	Nil	NE,SW, SS	Adult	4 (400)	CH, LSJ	CX/INDX
Obed *et al*., 2007	C	Nil	SW	Adult	U	CH, SK,ABD,PEL	CX
Egbe *et al*. (2008)	TLD	Nil	SE	Paediatric	3 (195)	CH,ABD ,LBS,SK,PEL	CX
Egbe *et al*. (2009a)	TLD/ C	U	SE	Adult	3 (169)	CH	CX
Egbe *et al*. (2009b)	TLD	U	SE	Adult	2 (74)	LBS	CX
Sherifat and Olarinoye, 2009	TLD	Nil	SW, MB	Adult	2 (294)	SK, CH, ABD	CX
Akinlade *et al*., 2012	C	(Training Provided, by IAEA, ICTP)	SW, MB,	Adults	4 (336)	ABD,CH,LBS,HD PEL	CX
Esen and Obed, 2012	C	Nil	SS	Adult	1 (102)	CH	CX
Jibiri and Adewale, 2014	TLD	Nil	SW	Adult/ Paediatric	1 (26)	Skull (eyes)	CT

TLD- Thermoluminescent dosimeter, C- Calculation, U-Uncertain, IAEA- International Atomic Energy Agency, SW-South West, SS-South South, SE-South East, NE-North East, MB-Middle Belt, CH-Chest, ABD- Abdomen, PEL- Pelvis, LBS- Lumbo Sacral, SK-Skull, NK-Neck, LSJ-Lumbo Sacral Joint, HD-Hand. CX-Chest X-rays, DX-Dental X-rays, INDX-Industrial X-ray, CT-Computed Tomography.

The third column of Table 2.1 shows that out of the seventeen documented investigations three were sponsored (two by IAEA and one through University grant) and an indirect sponsorship was provided via training in one of the studies. The geographical distribution of dose assessment (column 4) indicates that most of the works were carried out in south-west, south-south and middle belt of Nigeria. Only one reported data of northern origin, however the facilities used are traceable to the south west. This trend indicates that only few dose measurements were carried out in the northern part of the country. This situation could be attributed to the unavailability of dose measuring facilities in the northern part of the country. Most of the researchers: Egbe *et al*. (2008); Sherifat and Olarinoye (2009); Egbe *et al*. (2009a and b) (from SS, SW and MB) used facilities of former Federal Radiation Protection Service (FRPS), University of Ibadan. The use of QC kit and calculation method or software could be adopted in the absence of TLD chips or badges. Measurements of dose and comparison with the reference dose helps in both dose optimisation and dose reduction, therefore, it is important to ensure nationwide measurements of dose as done in the US and UK some years ago (Hart *et al*., 2012). Presently, more radiation dose data are needed in Nigeria to ascertain the level of patient exposures towards ensuring dose optimisation.

2.14 Quality Assurance and Dose Data in Nigeria

If radiation dose monitoring of patients is neglected in any part of the country, it exposes the population to a greater incidence of cancer and malignant diseases. The reports of the researchers presented in Table 2.1 reveal that only few (four) actually carried out the quality control test of the x-ray machines investigated. Quality control (QC) test is an integral part of quality assurance (QA) programme. The World Health organization (WHO) defined QA as an organized effort by the staff operating a facility to ensure that the diagnostic images produced by the facility are of sufficiently high quality so that they consistently provide diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation.

Film rejects analysis is another important part of QA in any large x-ray department. Reject analysis helps to identify weak areas of radiographic and radiological practice in the department. In addition, it enables one to note any improvement after quality assurance measures have been put into practice in any radiological centre.

Aside standard x-ray equipment performance checks, WHO have recommended that QA programmes should include periodic measurements of patient ESD which should be

compared with established reference values. This information should be reported back to those clinically and physically directing the medical exposure so that any necessary corrective actions can be taken (Schandorf and Tetteh, 1998). In a situation where the QC tests and dose measurements are not available, necessary corrective measure that enhances dose optimisation is not possible; therefore population dose is increased greatly. Results of earlier preliminary study carried out in this study in three geo-political zones of Nigeria on facilities using ionising radiation for diagnosis, indicate that; 81.8% of the departments investigated had never calculated nor documented the value of dose delivered during diagnostic examinations as stipulated by Medical Exposure Directive 97/43/EURATOM (CEC, 1996).

In another study, Egbe *et al*. (2008a) attributed the difference in the results obtained in a study carried out in South- South (SS) zone (ESD recorded in SS is higher than SW) on paediatric patients to the citing of the FRPS in the SW which provided in a way, facilities for dose measurements and QC tests.

Another important aspect worthy of note in Table 2.1 is the paucity of dose data on paediatric patients and extremities in Nigeria. Analysis of the published studies on dose data as shown in the literature reviewed, show that only two groups (Ogundare *et al*., 2004b and Egbe *et al*., 2008) worked solely on paediatric patient. The study on paediatric patients is very important because (1) they are more radiosensitive than adults (2) they have longer life span than adult patients and there is likelihood of manifestation of effects during the productive adult years if exposed at an early age (3) paediatric patients have smaller body size. Radiation protection in paediatric radiology deserves special attention in Nigeria. United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR) has reported that children exposed to radiation at an age below 2 years are two- to three- fold sensitive when compared with adults (UNSCEAR, 2000). It is therefore important that radiation dose to children be closely monitored and optimised. It is also important to fund researches based on optimisation of paediatric dose.

Columns 6 and 7 of Table 2.1 show that the percentage of patients/radiographs considered in the published works is still very small compared with the number of radiographic examinations carried out in Nigeria yearly. It is quite important to note that more radiographs could be investigated and technical parameters documented so that the parameter leading to high doses can be identified and corrected in order to enhance dose optimisation.

Information presented in Table 2.1 also indicates that only Ajayi and Akinwumiju (2000) made an attempt to measure the radiation dose to extremity (hand). Dose to extremities such as; foot, forearm, humerus and knee were not measured by any other researcher. Data on dose from extremity examinations are equally important because of the presence of bone marrow. Excess exposure of bone marrow could result in leukemia. Therefore, dose to these parts of the body should be considered in order to ascertain the level of exposure of the patients imaged.

The trends of published research findings and dose measurements carried out in Nigeria indicate that there is no adequate participation of the national body responsible for ionising radiation monitoring in the data collection and sponsorship of the dose monitoring efforts. Literature also indicate lack of proper documentation of dose data (in Nigeria) necessary for future policy formulation and correction after thorough analysis of the trend over a certain period (five years as done in UK) as obtainable in developed and developing countries of the world. One other visibly missing dose optimisation tool in Nigeria but existing in developed countries of the world is the diagnostic reference levels (DRLs).

2.15 Guidance Levels

The necessity of continual assessment of radiation dose delivered to patients during x-ray examinations has been highlighted. These assessments are important because of the hazard of ionising radiation. The requirement of regular measurement of radiation dose as indicated in the documents of the international regulatory bodies (EUR) helps to ascertain the variation of patient dose and their causes (Johnston and Brennan, 2000). This serves as a useful tool in investigating areas in need of dose reduction (Shrimpton *et al*., 1986, NRPB, 1992).

Significant variations in patient dose for the same x-ray projection by different hospitals have been reported by international, national and regional studies (Warren-Forward and Millar, 1995; Contento *et al*., 1998). These various surveys of patient dose have provided important information on the levels of patient exposure and provided an insight into causes of the variations: which include patient features, technical and equipment factors, level of quality assurance put in place and exposure parameter. Studies indicate that substantial dose reduction during the x-ray examination is possible without detriment to image quality (NRPB, 1992; Oritz *et al*., 1995; Ng *et al*., 1998).

2.15.1 Diagnostic Reference Levels (DRLs)

In order to achieve dose reduction, there is a requisite for guidance on appropriate levels of patient exposure (Wall, 1996). In view of the observed wide variations in patient dose levels for the same x-ray examinations within and among hospitals, for example up to a factor of 100 (Faulkner and Corbett, 1998), the International Commission on Radiological Protection (ICRP) has recommended the use of diagnostic reference levels (DRLs) in her publication 60 (ICRP, 1990). The body also proposed that the diagnostic reference levels (DRLs) should be used as an aid to keeping doses as low as reasonably achievable (ICRP, 1996).

The International Commission on Radiological Protection (ICRP) has recommended the use of diagnostic reference levels (DRLs) as a first step in the optimisation of diagnostic radiography (ICRP, 1996). The DRLs are values derived from population dose surveys and represent the third quartile in the range of doses observed. The guidance dose level corresponds to the 75 percentile, implying that 75 % of individuals receive doses less than this value. This also implies that dose reduction should be possible for the 25% of individuals whose doses exceed the guidance value (IAEA, 1996).

The use of DRLs are essentially guides to the rather indistinct borderline between " good and normal practice" and "bad and normal practice". It should not be bypassed if good and normal practices are used. By using DRLs, it is possible to find those hospitals where doses are exceptionally high and where practice may need to be improved through revision of technique or equipment. It is important to clearly state that DRLs are not the suggested or ideal dose for a particular procedure or an absolute upper limit for dose. Rather they represent the dose level at which an investigation of the appropriateness of the dose should be initiated (McCollough, 2010). In conjunction with an image quality assessment, a Medical Physicist is expected to work with the Radiologist and Imaging Scientist to determine whether or not the required levels of image quality could be attained at lower dose levels.

Diagnostic reference levels act as "trigger levels" to initiate quality improvement. Their primary value is to identify dose levels that may be unnecessarily high- that is, to identify those situations where it may be possible to reduce dose without compromising the required level of image quality. The use of DRLs has been shown to reduce the overall dose and the range of doses observed in clinical practice.

2.15. 2 The Specific Nature of DRLs

The document of ICRP publication no. 73 (2) section 102 (ICRP, 1996) states that; the selected (DRLs) values will be specific to a country to a region. According to Oritz *et al*. (1995), universal DRLs may not be suitable for all countries. Also, Johnston and Brennan (2000) in their study emphasized the importance of each country establishing her own DRLs appropriate to her equipment and radiological practice (based on national and regional reality, equipment and human resources) (Freitas and Yoshimura, 2009). They also recommended that due to changing equipment, techniques and training received by the personnel that influence patient dose, repeated and regular dose survey should be carried out to enable reference levels to be applicable to the current radiographic situation ensuring optimum patient protection. In addition, determination of DRLs in diagnostic radiology should be based on doses measured in various types of hospitals, clinics and practices and not only in well-equipped hospitals. Kiljumen *et al*. (2007) observed that due to variation in sizes of patients and patient doses among the various age group of patients, the use of single reference size (reference man) as suggested by CEC (1996) and Kyriou *et al*. (1996) is impractical (Chougule, 2005).

2.15.3 Legal Requirement of DRLs

Determination of diagnostic reference levels has become a legal requirement of many countries with relevant law backing the establishment, these countries include: Finland (Kiljunen *et al*., 2007); UK (Crawley and Rogers, 2000); and Brazil (Freitas and Yoshimura, 2009). The list underscores the need for every country to determine both her national and local diagnostic reference levels.

Following the inclusion of European Union Directives (EU Directive 97/43-EUROATOM) into member states law in May, 2000, all the radiology department were given the legal obligation to promote the use of DRLs (Johnston and Brennan, 2000). Ever since, the directives have been followed by the member states. The United Kingdom carried out its survey in mid 1980s, determined the National Diagnostic Reference Levels (NDRLs). In 1996 the NRPB reviewed all dose data received from the radiology departments throughout the country that have been following the national protocol (Hart *et al.*, 1996). Analysis of the data received in 1990 from 375 UK hospitals; were further undertaken in 1995, 2000, 2005 and 2007 (Montgomery and Martin, 2000; Hart *et al*., 2002; Hart *et al*., 2007) and subsequent reviews were carried out and DRLs updated and refined (Hart *et al*., 2012)

Other member states such as France, Germany, Italy, Spain, Sweden, Switzerland, Irish Republic and the US have established their NDRLs at various times (IRSN, 2004; Bundesamt, 2003; Compagnone *et al*., 2005; Holm and Leitz, 2002; Aroua *et al*., 2007; Johnston and Brennan, 2000; Gray *et al*., 2005). Other countries that have determined their NDRLs are; Spain, Republic of China, India, Brazil, South Korea, Finland, South Africa (Gonzalez *et al*., 2004; Tung *et al*., 2001; Sonawane *et al*., 2009; Freitas and Yoshimura, 2009; Lee *et al*., 2010; Nyathi *et al*., 2009).

The diagnostic reference levels include all the procedures frequently undertaken during radiodiagnosis in radiology departments of the hospitals for example; chest, skull, thoracic spine, abdomen, pelvic and so on. Others include; fluoroscopic examinations, dental radiography, Computer Tomography (CT), angiography.

In Nigeria, conventional radiography, fluoroscopy and Computer Tomography are gaining more and more prominence. These imaging technologies deliver radiation doses to the patient. However, CT delivers higher radiation doses to patients of up to 20 mSv and radiation induced cancer risk up to 1 in 100 per examination (Wall, 2001), hence the urgent need for reference doses for routine conventional radiography and CT examinations in Nigeria. All the reference doses currently used in Nigeria are of European and American origin and do not reflect the state of practice in the country. Some of those reference doses were determined several years ago and have undergone several reviews. It is therefore uncertain whether the European and American NDRLs recommended by NRPB and AAPM (American Association of Physicists in Medicine) are applicable in Nigeria radiographic practice; since according to Oritz *et al*. (1995), universal NDRLs may not be suitable for Nigeria because of differences in practice, equipment, training, experience of the personnel and patient size (anatomical buld).

2.15.4 Dose Quantities required for Establishing DRLs

It is necessary to provide a practical system that allows hospitals (x-ray departments) to compare the radiation doses delivered to patients. In order to do this, the dose must be expressed in terms of dose quantities that are clearly defined and that can be easily measured directly or calculated from readily available exposure parameters (Wall, 2004). The dosimetric parameter should bear a close to linear relationship to the dose. The following have been widely adopted for DRLs: radiography and fluoroscopy- ESD (mGy) and DAP, (Gy. cm^2); CT - Weighted computed tomography dose index ($CTDI_w$) per slice

in serial CT scanning or per rotation in helical CT scanning and Dose-length product (DLP) per complete CT examination; mammography - the mean glandular dose (MGD, mGy).

2.15.5 Local Diagnostic Reference Levels (LDRLs)

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) reports that similar examinations in different countries and different districts of the same country may have values stemming from cultural, scientific, and practical differences between regions. As a result, DRLs can be separately determined for a city, geographical area, or large health care centres as local diagnostic reference levels (LDRLS). The purpose of introducing the LDRLs in clinical practice is to verify that the ESDs used are below the defined reference values, set after trials in many hospitals (CEC, 1996; Maccia *et al*., 1996). This provides a framework to reduce variability among the hospitals.

However, it is possible that in large hospitals where many radiological departments are present, all examinations used ESD lower than corresponding National Diagnostic Reference Levels (NDRLs), even though some differences between the different departments still exist. In such cases a subtler and more refined use of local diagnostic reference levels (LDRLs) concept can be adopted locally (within local hospitals), to increase the already good situation. The study of LDRLs is encouraged as a further step in patient dose optimization beyond the simple use of national or international diagnostic reference levels (Ramsdale *et al*., 2001). The LDRL reflect local situation and allow for effective control, therefore place a great responsibility on the employer to determine the LDRLs values.

2.15.6 Regional Diagnostic Reference Levels

In most cases medical physics support in diagnostic radiology in some countries is often organised on regional basis, therefore there are advantages in establishing regional DRLs (RDRLs) as part of scientific support programme for optimisation of radiological practices among groups of hospitals. Consequently, the performance of an individual hospital or sites with few x-ray rooms can also be compared with that of larger groups expressed in terms of regional diagnostic reference dose (RDRLs) value (Charnock *et al*., 2013).

2.15.7 National Diagnostic Reference Levels

The national diagnostic reference levels (NDRLs) form an efficient, concise and powerful standard for optimisation of radiation protection of a patient (Compagnone *et al*., 2004). To determine the value for each standard procedure requires a nationwide survey of dose of standard patient. The established reference value serves as standard value against which LDRLs, RDRLs and individual hospital dose may be compared and it is expected to a certain degree that the ESD of every radiological department should be lower than the NDRLs. The most important purpose of NDRLs is to verify that most radiological departments are using ESDs below defined values in order to identify those few radiological departments that are performing badly by using ESDs that are abnormally high and well away from the optimum, so that corrective action can be concentrated where it is most urgently required.

The NDRLs act as the first step towards optimizing patient doses on a national scale, by identifying the really bad performers. Establishment of NDRLs could help to reduce the dose delivered to the patient in the country.

In order to obtain meaningful values, measurement must be carried out on significant number of patients (10-20 minimum) or experiment with phantoms. However, if it is not possible to accumulate data on 10 patients then smaller sample sizes can be used once the mean patient weight is in the following range: 50-90 kg, 65-75 kg, 60-80 kg.

2.15.8 Established Diagnostic Reference Levels

Several efforts have been put in place at determining the reference levels in Europe, North and South America, Asia and in Africa.

In Europe, Wraith *et al*. (1995), Johnston and Brennan (2000), George *et al*. (2004), Gonzalez *et al*. (2004), Compagnone *et al*. (2005), Tsapaki *et al*. (2007). Several other researchers have undertaken the establishment of diagnostic reference levels in some other countries. These include: Martins *et al*., 1994; Hart *et al*., 2000; Crawley and Rogers, 2000; Tung *et al*., 2001; Gray *et al*., 2005; Skrk *et al*., 2006; Edmond, 2009; Lee *et al*., 2010; Hadnadjev *et al*., 2012; Toosi and Malekzadeh, 2014; Shandiz *et al*., 2014; Santos *et al*., 2014; Friberg *et al*., 2014.

As regards the assessment of patient dose arising from diagnostic radiology in the UK as well as establishing national diagnostic reference levels, an important part of the UK's patient dose monitoring strategy has been the periodic national patient dose audits undertaken by the NRPB in 1986, 1995, 2000, 2009 and 2010 which started with 3000

radiographic examinations in 20 hospitals in 1986 (Shrimpton *et al*., 1986). Moreover, by 2010 the survey expanded to 350,000 radiographical dose records (185,000 DAPs and 165,000 ESD) from 320 hospitals throughout the United Kingdom collected over a 5-year period Hart *et al*. (2012) according to the National patient dose Protocol (Charnock *et al*., 2013). The measurements were carried out using TLD and/or DAP meter in individual x-ray rooms on representative samples of at least 10 adult patients (NRPB, 1992). The ESD and DAP values obtained from the surveys have subsequently formed the basis for establishing NDRLs (IPEM, 2004).

2.15.9 Optimisation Programme in Nigeria

A research conducted on approaches to aspects of optimization of protection in diagnostic radiology in six continents by Martins *et al*. (2013) reveals that there are no legislations on dose measurements in seven out of thirteen countries investigated in Africa (Nigeria inclusive). The report also show that there is no license issued after dose measurement is carried out in compliance with international regulation in ten out of thirteen countries investigated in Africa (Nigeria inclusive). This is follow up of the information in Table 2.1. This is an indication that adequate attention is not accorded dose measurement during accreditation and licensing of diagnostic centres in these countries.

Furthermore, the aspect of optimisation of patient procedures shows that there is no code of practice of optimisation, no license is issued for optimisation and there is no regulation on the optimisation of dose delivered to patients. As regards the establishment of DRLs, the same research report indicates that there are no records of established DRLs in (1) Computed Tomography (CT) (2) Paediatric CT (3) Mammography (4) radiography (5) Paediatric Radiography (6) Fluoroscopy (7) Dental Radiography (Martins *et al*., 2013).

In order to determine the radiation doses usually delivered to the patient during routine diagnostic examinations, it is essential to gather information on technical parameters used and either make dose estimates for actual patient examination or obtain doses using the appropriate phantoms. In order to determine the acceptability of dose levels, standard values with which results can be compared are required. The DRLs as optimization tool were developed by the International Commission on Radiological Protection (ICRP, 1996) to fulfill such a role, and their use is mandated in many countries and in the basic safety standard. More importantly, the DRLs must be established considering the national or regional (local) reality and taking into account the equipment and human resources available (Freitas and Yoshimura, 2009).

This status of dose surveys and the conditions of non-legislation of dose optimisation call for the determination of diagnostic reference levels in Nigeria.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes different types of facilities investigated, materials and methods used for the measurement of doses (ESD, DAP, OD and ED) . It also describes the method of calibration of dosemeters (TLD chips), correction of patient sizes and standardization of dose to patients.

3.2 Selection of Centres for the Study

The healthcare facilities investigated in this study were purposely selected to include different types of healthcare centres using x-rays available in the country; they include Private owned Hospitals, State-owned Hospitals, University Teaching Hospitals and Federal Medical Centres. In addition, geographical distribution of the hospitals was also taken into consideration in the selection of the hospitals to fulfil the desired goal of covering Southwestern Nigeria. Cooperation and permission of the managements of the diagnostic centres were also central in the selection of the hospitals. The selected x-ray centres are presented in Table 3.1.

3.3 Personnel and Quality Control Test

The summary of the personnel and the quality control (QC) tests carried out at different centres is presented in Table 3.2, while the specific features of machines and x-ray rooms investigated are presented in Table 3.3.

Table 3.1: Different Centres Investigated during the study

Centre	Types of Centre				
	State institution	Private institution	Teaching hospital	Federal Medical centre	Number of X-ray Unit (s)
FMC Iddo (Ekiti)	-	-	-	✓	1
EKSUTH Ado (Ekiti)	-	-	✓	-	1
OAGSH Agege (Lagos)	✓	-	-	-	1
FKJSH Fakojaiye (Lagos)	✓	-	-	-	1
ALSH (1 and 2) Alimosho (Lagos)	✓	-	-	-	2
TTPC (1 and 2) Ibadan (Oyo)	-	✓	-	-	2
VHS Iwo (Osun)	-	✓	-	-	1
LTH 1 Osogbo (Osun)	-	-	✓	-	1
LTH 2 Osogbo (Osun)	-	-	✓	-	1
SDAH Ile-Ife (Osun)	-	✓ (TH)	-	-	1
OAUTHW Ilesha (Osun)	-	-	✓	-	1
ANHS Ijebu Ode (Ogun)		✓	-	-	1
AYHS Sagamu (Ogun)	-	✓	-	-	1
Total	3	5	4	1	15

TH = Teaching Hospital

Table 3.2: Personnel and Status of Quality Control activities carried out at the different Centres investigated

Centre	QC Test Activities	**Personnel** Radiologist	Radiographer	Darkroom Tech	Med Phy/ RPO
FMC Iddo (Ekiti)	P	1	3	4	2(R)
EKSUTH Ado (Ekiti)	-	1	2	2	-
OAGSH Agege (Lagos)	-	1	1	2	-
FKJSH Fakojaiye (Lagos)	P	1	1	2	-
ALSH Alimosho (Lagos)	-	1	1	1	-
TTPC Ibadan (Oyo)	P	1	4	2	-
VHS Iwo (Osun)	-	1	1	1 (R)	-
LTH 1 Osogbo (Osun)	-	14	3	6	-
LTH 2 Osogbo (Osun)	-	14	1	6	-
SDAH Ile-Ife (Osun)	-	1	1	1	-
OAUTHW Ilesha (Osun)	-	3	5	2	-
ANHS Ijebu Ode (Ogun)	P	1	2	2(R)	-
AYHS Sagamu (Ogun)	-	1	2	2(R)	-

P = partial QC test carried out, R = Radiographer, (R)= other personnel used as Radiographer, RPO = Radiation Protection Officer`

Table 3.3: Specific features of x-ray units in the investigated Centre

Centres	Phase	Availability of chart	Model	Date Manufactured/Installed	Total filtration (mm Al)	Output mGy/mAs	Exposure Rate (mGy/s)	Collimator Light Availability
FMC	3	NA	Ralco	NA/2013	2.0	0.3859	0.5267	A
EKSUTH	3	A	Allenger 40	2012/NA	0.9	0.3892	0.4471	A
OAGSH	3	NA	Picker	NA/2013	2.5	-	-	A
FKJSH	1	A	Generic	2007/2009	2.0	-	-	A
ALSH 1	3	A	Generic	2007/2009	2.0	0.4531	0.4467	A
TTPC 1	3	NA	Allenger 525	2007/NA	0.9	0.2069	0.7633	A
TTPC 2	3	NA	Allenger 525	2007/NA	0.9	0.3998	-	A
VHS	1	NA	Acoma Japan	1983/NA	NA		-	N/A
LTH 1	3	NA	Neo Diagnomax	1982/NA	3.0	0.1825	0.3246	A
LTH 2	3	NA	Allenger 40	NA	NA	0.2889	2.1083	A
SDAH	3	NA	--	2009/2011	2.5	0.1938	0.8538	A
OAUTHW	3	NA	Siemen	2007/NA	2.7	0.6102	3.500	A
ANHS	3	NA	Ralco	NA/2013	2.2	0.3064	0.1722	A
AYHS	3	NA	GEC Medical	1974/-NA	3.0	0.02146	0.1158	A
ALSH 2 (Digital)	1	A	Siemens Mobile MinXray	2013/2013	2.2	--	--	A

A: Available, NA: Not available

3.4 Radiation Dose Measurement

The development and application of any optimisation method is based on a framework of good dosimetry. Radiation dose to a patient may be described using different dose descriptors such as Entrance Surface Dose (ESD), Dose-Area Product (DAP), Organ Dose (OD) and Effective Dose (ED). In the following sections, methods used in determining ESD, DAP, OD and ED are described.

3.5 Preparation of TLD Chips and Calibration

Direct dose measurement was carried out using TLD-100^{TM} (LiF) chips of dimension 3x3x1 mm obtained from Stanford Dosimetry, LLC (Bellingham, United States). A total of 130 chips were acquired and pre-annealed using an oven at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife to empty any residual electrons trapped in the metastable state during the previous exposures. The chips were annealed at a temperature of 400^{o} C for 1 hour and allowed to cool down in the oven for at least 17 hours. The chips were further kept for another 24 hours before use after annealing. The dosimeters were packed in black polythene pouches to prevent the effect of visible light. The chips were divided into 13 batches, with each batch containing 10 chips, labelled A1…… A10; B1……..B10; C1…….C10; for easy identification. The 13 batches were presented for calibration at the Secondary Standard Dosimetry Laboratory (SSDL) of National Institute for Radiation Protection and Research (NIRPR), University of Ibadan. During the calibration, each batch (10 chips) was exposed to a uniform radiation (80 kV, 1 mA, 142 s (142 mAs), with dose rate of 50.2 mGy hr^{-1}) in turn from a standard x-ray unit. The chips were taped to a water phantom placed at a distance of 200 cm from the x-ray focus before they were irradiated. The irradiated chips were kept for 24 hours before reading and calibration. During the calibration of the TLD chips, element correction coefficients (ECC) and reader calibration factors (RCF) were calculated using Harsaw TLD Reader Model 3500 (manual) and WinRems software (Saint-Gobain Crystals & Detector,Wermelskirchen, Germany). Golden chips (reference chips) were selected and bad dosimeters were discarded while the field dosimeters were made available for use.

3.6 Determination of Element Correction Coefficients (ECCs)

Since not all the TL dosimeters can be manufactured to have exactly the same Thermoluminescent Efficiency (TLE) which is defined as the emitted TL light intensity per unit absorbed dose, the individual Element Correction Coefficients (ECCs) must be defined, developed and applied. A typical batch of TLDs has a variation of 10-15% (one relative standard deviation). This can be reduced to 1-2% by application of ECCs. The method of ECC generation is based on relating the TL efficiency of each TL dosimeter of the entire dosimeter population to the mean TL efficiency of a small subset of this population that is used only for calibration purposes. When the ECC is applied to the response of each of the Field Dosimeters (FDs), its TL efficiency is virtually identical to the mean value of the FDs group and, as a result, all the TL dosimeters ideally have the same TL efficiency (Harsaw, 2001)

The Element Correction Coefficients (ECC) of the TLD chips were obtained by the TLD reader using equation 3.1 and stored in the database of the TLD Reader: ECC is given by (Harsaw, 2001):

$$ECC = \frac{\langle TLD \rangle}{TLD_j} \qquad 3.1$$

Where $\langle TLD \rangle$ is the average of readings of all TLDs and $TLDj$ individual reading of TLDs. The acceptable range of ECC was selected. The selected range determines the deviation from the mean, for example, range of 0.745 to 1.431 indicates that dosimeters which fall outside this range are referred to as bad dosimeter (BDs) and cannot be used as field dosimeter (FD). While those within the selected range are called field dosemeter (FD) and are used for the measurement. In this work the ECCs used ranged between 0.742 and 1.368.

3.7 The Reader Calibration Factors (RCF)

For the Reader to be able to consistently convert stored TL information to measurable electric signals (charge), it is convenient to express the ratio between the average TL response of the FD and the delivered radiation quantity L in terms of one variable. Since the numerical value of this variable will be mainly dependent on the condition of the Reader at a given date and time, it is appropriate to call this variable Reader Calibration Factor (RCF). The value of the RCF, although not expressed yet in terms of "real" dose units, provides the main link between the TL response in terms of charge or

counts and the absorbed dose or dose equivalent in terms of gray (Gy) and seivert (Sv) respectively.

The RCF is defined as:

$$RCF = \frac{<Q>}{L} \quad 3.2$$

Where $< Q >$the average is reported charge of a set of Field Dosimeters exposed to a known quantity of radiation L (Harsaw, 2001). In this work, the value of RCF used was 0.03324. After the calibration processes the FDs were annealed at a temperature of 400^{o} C for 1 hour using an oven and left to cool in the oven for about 17 hours. The FDs were further kept for 24 hours thereafter before use.

3.8 Machine and Patient Parameters

Data based on the exposure parameters and patient characteristics such as kVp (tube potential), FFD (focus to film distance), FSD (focus to skin distance), mAs (tube load-product of tube current and time), filtration of the machine (inherent and added), exposed film area (assumed to be beam area), thickness of the exposed (irradiated) part of the body; projections (e.g. AP, PA) were recorded during the routine exposure. Other patient anthropometrical data such as height, weight, sex and age of the patient were recorded at the time of examinations. Only films that were considered suitable for diagnosis by the radiographer/radiologist were used for this study in all the hospitals. This ensured that all dose levels used were representative of diagnostic image. While almost all the radiographs were found diagnostically acceptable, major differences in techniques were evident reflecting the disparity in experiences among staff at different hospitals. The age groups included are: 0 to 15 years (assumed to be paediatric patient), and >15 years (adult patient).

3.9 Output Measurement

The outputs of the machine in mGy(mAs)$^{-1}$ at a distance of 1 m were obtained using calibrated QC kit (kV meter-NERO^{TM} 6000M, manufactured by Victoreen, INC, Cleveland, Ohio, USA). This was used to test linearity and reproducibility of kV and mAs. The outputs of the machine were measured at a voltage of 80 kV and 10 mAs as the potential across the x-ray tube and the anode current are highly stable at this voltage (Suliman and Elshiekh, 2008). The factory calibrated QC kit (shown in Figure 3.1) was cross calibrated with the

facilities of the Secondary Standard Dosimetry Laboratory (SSDL) of the National Institute of Radiation Protection and Research (NIRPR), Physics Department, University of Ibadan. The cross calibration is traceable to the National Institute of Standards and Technology, USA (NIST), meanwhile, the factory calibration was still valid at the time of measurement. The NERO kV meter measured the output of the machine in mR (millirontgen) and the dose rate in R/s (rontgen per second) as shown in Table 3.4. The mR was converted to mGy using a conversion value of 0.007783 (Anderson-Evans, 2011)

3.10 Ion Chamber

A parallel-plate ion chamber was used to measure exposure expressed in rontgens, or air kerma expressed in grays. The ion chamber is essentially the same as other ion chamber devices widely used to measure exposure. The major difference between the ion chamber used in this study and a conventional chamber is in the mounting which contributes scatter to the chamber. Directly beneath the ion chamber is the shielded diode assembly and a large lead plate. Therefore, the ion chamber is not x-ray transparent as are most other ion chambers, which is important for measurement involving transmission feedback systems.

3.11 Computer (Microprocessor)

A microprocessor was used to sample data from the diode amplifier at a rate of one sample every 132 microseconds. The array of data points was used to calculate the kV and time quantities.

The display unit was coupled to the microprocessor. This consists of different pushbuttons. The pushbutton area is divided into colour–coded groups. Besides the kVp (average kVp, maximum kVp and effective kVp) of the machine, exposure time and radiation output and dose rate can also be measured using QC kit. The voltage applied across an x-ray tube determines the quantity and energies (quality) of x-rays produced during an exposure. Peak kilovoltage (kVp) is the maximum voltage applied across the x-ray tube and governs the maximum energy of x-radiation produced (CRCPD, 2003**)**. Accurately calibrated and consistent kVp's are important in diagnostic imaging to control both optical density and contrast of the x-ray image as well as radiation dose to the patient.

Figure 3.1: The quality control tests using the QC kit at one of the centres

Table 3.4: Specifications of QC kit (NERO kV Meter)

Quantities	Description	Values
Kilovoltage	Accuracy	• Within 3% or 3 kVp, whichever is greater(Tungsten target x-ray tubes) • Within 3% or 1 kVp, whichever is greater(Molybdenum target x-ray tube)
	Precision	±0.5 %
	Range	Tungsten Target Tube: 27-155 kVp in the five ranges (27-42, 35-60, 50-85, 70-120, 100-155) Molybdenum Target Tube: One range, 21-150 kVp.
Time	Accuracy	Within 2% or 2 ms, whichever is greater
	Precision	± 0.3 ms
	Range	1 ms to 10 sec
Exposure	Accuracy	It has programmable correction factor. Without correction ± 15%
	Precision	± 1mR
	Range	10 mR to 10 R (could display air kerma in μGy)

3.12 Entrance Surface Dose (ESD) Measurement

European Commission Guidelines (CEC, 1996) suggested different methods for estimating entrance surface dose. These include the use of thermoluminescent dosimeter (TLD) and the use of exposure factors and machine output. According to EU, the ESD of the patient can be estimated from the knowledge of the exposure factors used (kVp, mAs, FSD) and measurement of output of the x-ray machine as a function of the exposure factors.

Thermoluminescent dosimeters (TLDs) were used for dose measurement in this work. The use of TLD for ESD measurement is the most reliable method if the dosemeter is properly calibrated. However, the method of dose calculation is a realistic alternative to dosemeter method [as measurement with TLD] (Kyriou *et al*., 2000; Mohammadain *et al*., 2004 and Azevedo *et al*., 2006). Another reason for using this method is that the minimum radiation dose that can be measured with TLD100, Li:Mg, Ti is about 100 μGy. But, ESDs in paediatric radiology can be as low as 50-80 μGy and that makes TLDs inappropriate for low doses (NRPB, 1992; Burke and Sutton, 1997).

The ESD can be calculated using equation 3.3 (Davies *et al*., 1997; Suliman and Elshiekh 2008).

$$ESD = O/P \; x \left(\frac{kV}{80}\right)^2 x \; mA\,s \; x \left(\frac{100}{FSD}\right)^2 \; xBSF \qquad 3.3$$

Where O/P is the output in mGy $(mAs)^{-1}$ of the x-ray tube at 80 kV and at a distance of 100 cm and at a tube current-time product (mAs) of 10 mAs, FSD is the focus-skin distance (in cm) and BSF is the backscatter factor. While $\left(\frac{100}{FSD}\right)^2$ is the inverse square term.

Both adult and paediatric patients undergoing routine radiological examinations were investigated between November, 2011 and March, 2014. Nine different procedures were considered during the investigation. These include; chest PA, abdomen AP, pelvis AP, lumbar spine AP, skull AP, leg AP, knee AP, hand AP and thigh AP.

A total of 689 patients (600 adults and 89 paediatrics) were included in the study during the period of investigation. A pair of highly-sensitive and tissue equivalent LiF (TLD-100) labelled dosemeters were placed in the primary beam of x-ray where it intercepted the patient's surface at a right angle to the irradiated region of the patient during

the exposure of the patient to measure the ESD. Each chip was sealed in black labelled polythene pouch to prevent them from being contaminated. A pair of labelled chips was also placed in coded transparent polythene for easy identification and recording. Due to its size and composition, TLD chip does not cast a shadow on the radiograph. After the exposure, irradiated chips were kept for 24 hours before reading with Harsaw 3500 TLD Reader at the National Institute of Radiation Protection and Research, University of Ibadan.

During the irradiation, exposure parameters such as; kVp, mAs, FSD, FFD, filtration, model of machine, and area of radiographs (size) were recorded. Patient parameters such as height, weight, sex, thickness of the irradiated region of patients were also recorded. The chips were withdrawn and read after each exposure. The read chips were annealed again after each exposure and reading before they are reused to enhance good response.

During the investigation, the reason for carrying out the study was made known to patients (subjects) in order to obtain their consent. Only patients who consented were included in this work. Radiation dose of patients who declined were not measured, especially on religious grounds. In some of the centres visited, written descriptions of the procedure were required, while some demanded that research ethical committee form be completed and assessed before investigations and use of facilities could be allowed. All these ethical procedures were followed and requisite approvals were given.

3.13 Dose-Area Product (DAP) Estimation

Dose-Area Product (DAP) is the product of the absorbed dose in air (ESD) and the irradiated area (A). This dose parameter is not only a quick and simple measurement, but also a valuable radiation dose descriptor. Its advantage is that the biological effects of radiation are dependent on radiation dose and the irradiated area of the body. Dose-area product (DAP) is also used for quality assurance and functional analysis of x-rays machine (NRPB, 1992; Hart *et al*., 2002; Nickoloff *et al*., 2008 and Shandiz *et al*., 2014). The dose-area product (DAP) could also be estimated from the measured ESD and the beam area-obtained from the area of the film (Dougeni *et al*., 2007; Akinlade *et al*., 2012). Dose-area product in this study was estimated using equation 2.18 in section 2.7.6.

3.14 Organ Dose Estimation and Risk Calculation.

The organ dose used to calculate the cancer incidence and mortality in the study was estimated using DoseCal Software. This software was extensively used for patient organ dose measurements in diagnostic radiology, and it produced reliable results in previous studies (Mohammadain *et al*., 2004; Suliman and Elshiekh, 2008).

Effective dose has been a useful dose descriptor that allows for comparison between different techniques and protocols (Tootel *et al*., 2014). However, in the recent times lifetime risk of cancer incidence, sometimes referred to as lifetime biological risk is a concept that has been suggested by a number of researchers as an alternative to effective dose to allow a comparison of risk from non-uniform dose distribution (Brenner, 2008; Brenner, 2011; Brenner, 2012). The organ dose was used to estimate life attributable risk (LAR) and attributable risk fraction (ARF) as described in section 2.5.1.

3.15 Effective Dose Estimation

The concept of effective dose was introduced by ICRP to provide a summation of radiation dose to tissues and organs for purposes of radiological protection (ICRP, 1991), however it has become a useful quantity in medical exposure. It is a useful measure for comparing risks from various sources of radiation exposure, including those resulting from diagnostic procedures and background radiation. For a non-uniform irradiation, effective dose is used to provide an estimate of corresponding uniform whole-body dose that would result in the same stochastic detriment.

In this work, effective dose to patients was estimated using OrgDose V2 software. The software uses normalized organ dose results of Monte Carlo calculations modeling the conditions of exposure relevant to 68 common radiographic views of adults and children (Hart *et al*., 1996). Estimate of equivalent number of chest x-rays are obtained and equivalent duration of radiation exposure was also assessed using the software.

3.16 Calculation of Equivalent Patient Diameter

Thicknesses of the irradiated regions (chest, skull, pelvis, lumbar spine and abdomen) of each patient were measured during the routine examination. However, the measurement of patient thickness using a rule does not take into account the composition of the patient, therefore, a simple estimate of patient average chest thickness was made from height and body weight (g) data by assuming a patient is a water cylinder of unit density (1 g cm^{-3}) as shown in Figure 3.2.

The equivalent cylindrical diameter D_e is given by equation 3.4 (Lindskoug, 1992; Chapple *et al*., 1995; Giejer, 2001).

$$D_e = 2\left(\frac{W}{\pi x H}\right)^{0.5} \quad 3.4$$

Where W = body mass (g) and H = body height of the patient (cm).

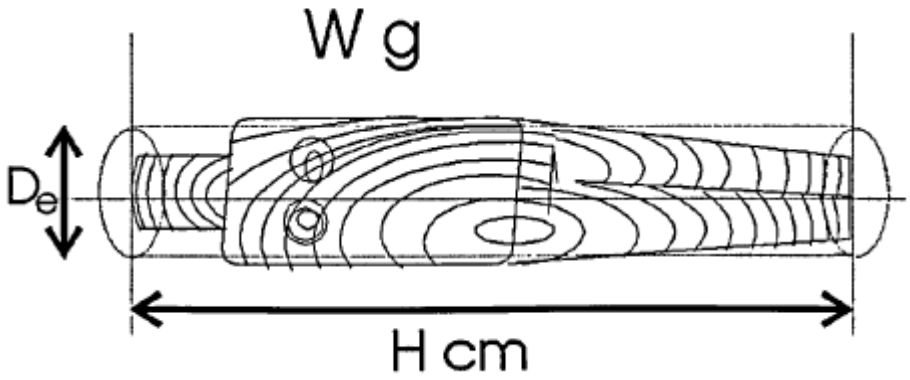

Figure 3.2: Human body modeled as a water cylinder to determine equivalent diameter (Chapple,1998)

The equivalent cylinder diameter, D_e includes both weight and height, it takes the average density into consideration. Consequently this carries some information about the body shape. The computation of D_e is useful in energy computation and in ESD and DAP correction factor. The transformation of patient weight and height data to patient equivalent diameter (Lindskoug, 1992) takes care of variability that depends on patient size. In order to allow comparisons to be made between data, the National Protocol (NRPB, 1992) recommends selecting patients so that the mean weight of the sample lies within ±5kg of 70 kg, and excluding much outside 70 ± 10 kg, at least for frequent examinations, so that the average value of the doses will be a good indicator of a typical dose to an average patient. Using this approach could significantly reduce the amount of data that could potentially be collected and, for small sample sizes; the average dose may not be typical due to the variation of size and body composition within the band of weights. It is extremely difficult to collect a sizeable data of standard size patients in Nigeria. More importantly, there is a wide range in paediatric patient sizes from a newborn baby to a 15 year-old adolescent. Paediatric patients can be divided into five standard-sized groups, that is, newborn, 1, 5, 10 and 15 years. Therefore, reference doses for paediatric radiology can sensibly be established for specific sizes of children.

Introduction of the concept of patient equivalent diameter enables comparison between dose data for individual patients, including children and among hospitals using standard patient. For the fact that energy imparted correlates more closely with D_e than with weight or patient thickness (it takes into account body shape and composition), the concept of patient equivalent diameter (Lindskoug, 1992; Chapple *et al*., 1995) has been used to correct data from dose survey. In this study this method was used to take care of the issue of patient size. This is described using Figure 3.3.

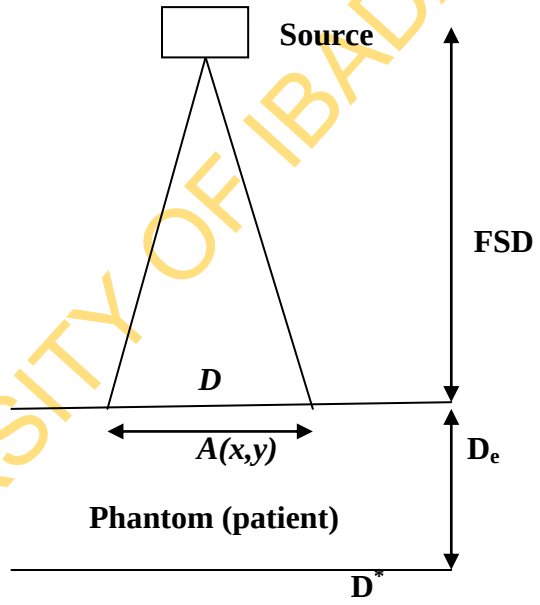

Figure 3.3: Theoretical patient and parameter for deriving effective attenuation coefficient

3.17 Application of ESD and DAP Correction Factors

The parameters *D* and *D** shown in Figure 3.3 (theoretical patient) are the entrance and exit doses respectively, D_e is the thickness of the phantom, *FSD* is focus to skin distance, and *A(x,y)* is the beam area.

Without taking into consideration the heel effect, and with the assumption that the exposure at the exit is uniform, the attenuation through the phantom may most simply be expressed by:

$$D^* = D\, e^{-\mu_{eff} D_e} \qquad 3.5$$

Where μ_{eff} is the effective attenuation coefficient for the phantom. This gives:

$$ln\ D = \mu_{eff} D_e + \ln D^* \qquad 3.6$$

This illustrates a simple relationship between dose and size. It is an approximation, and has been validated and used in previous works (Martins *et al*., 1994 and Chapple, 1998).

However, equation 3.5 neglects the inverse square law expected to account for the reduction in dose due to distance from the source. Applying the inverse square law to equation 3.5, it becomes:

$$D^* = D\, e^{-\mu_{eff} D_e} \left(\frac{FSD}{FSD+D_e}\right)^2 \qquad 3.7$$

Similarly from equation 3.7:

$$ln\ D = \mu_{eff} D_e + 2\ln\left(\frac{FSD+D_e}{FSD}\right) + \ln D^* \qquad 3.8$$

Equation 3.8 can be expressed in terms of DAP if it is required as the dose descriptor of interest. The change in area also includes the inverse square effect:

$$ln\ D = \mu_{eff} D_e + \ln D^* + lnB \qquad 3.9$$

The factor *B* accounts for the scattered photons inside the phantom. It is a complex variable that depends on the beam energy, beam area, phantom thickness and the distance between phantom and image receptor (Chapple, 1998). Incorporating these factors in the expression for variation of DAP gives:

$$\ln DAP = \mu_{eff} D_e + lnD^* + \ln B \quad 3.10$$

As expected, as the phantom thickness increases, the generating potential will also be increased leading to a decrease in effective attenuation coefficient and an increase in *B.* As a first approximation, the simple exponential version of equation 3.10 can be applied to DAP measurements on patients to yield:

$$\ln DAP = \mu_{eff} D_e + c \quad 3.11$$

Where D_e is the effective equivalent diameter and c is a size independent term. Equation 3.11 was used to determine the effective attenuation coefficient μ_{eff} used in NRPB ESD and DAP correction factors shown in equations 3.12 and 3.13 (Hart *et al*., 2000; Kiljunen *et al*., 2007)

$$F_{ESD} = \frac{ESD_s}{ESD_d} = e^{\mu_{eff}(s-D_e)} \quad 3.12$$

$$F_{DAP} = \frac{DAP_s}{DAP_d} = e^{\mu_{eff}(s-d)} \frac{s^2}{d^2} = F_{ESD} \frac{s^2}{d^2} \quad 3.13$$

Where μ_{eff} in equations 3.12 and 3.13 is the effective linear attenuation coefficient, *s* is the thickness of the standard sized patient (22.9 cm), and D_e is the thickness of the imaged patient in the sample. Equations 3.12 and 3.13 convert the measured ESD and DAP into Reference Man Dose (RMD) - dose that a patient would have received if of Reference Man Size (RMS). The importance of this is that it helps in dose optimisation.

Unlike the standard adult with a single standard thickness, paediatric patients, because of the variation in their weights have different standard values depending on the age groups (band) ranging from the neonate to the adolescent. The available data from Hart *et al*. (2000) for age groups of 0, 1, 5, 10 and 15 were interpolated and the corresponding value for specific age groups and procedures were selected as shown in Table 3.5. These values were used with the NRPB correction values to standardize paediatric doses.

Table 3.5: Interpolated standard thickness of the trunk and the head of different age groups of paediatric patients (Hart *et al*., 2000)

Age (yr)	Standard thickness by beam projection (cm)				
	Trunk AP	Trunk LAT	Head AP	Head LAT	Multiplication of the trunk
0	8.5	10.0	12.0	9.0	9.0
1	12.0	15.0	16.0	12.0	13.0
2	12.5	16.0	16.6	12.6	13.5
3	13.0	17.0	17.3	13.3	14.0
4	13.5	18.0	17.9	13.9	14.5
5	14.0	19.0	18.5	14.5	15.0
6	14.4	19.8	18.6	14.5	15.6
7	14.8	20.6	18.5	14.5	16.2
8	15.2	21.4	18.5	14.5	16.8
9	15.6	22.2	18.5	14.5	17.4
10	16.0	23.0	18.5	14.5	18.0
11	16.4	23.8	18.5	14.7	18.6
12	16.8	24.6	18.5	14.9	19.2
13	17.2	25.4	18.5	15.1	19.8
14	17.6	26.2	18.5	15.3	20.4
15	18.0	27.0	18.5	15.5	21.5

3.18 Determination of effective attenuation coefficient for different hospitals

Effective linear attenuation coefficient μ_{eff} was obtained from measurements of entrance dose using TLD chips, while the beam area was obtained from the film. No antiscatter grids were used during exposures. The values of μ_{eff} were obtained from the slopes of equation 3.11 for different hospitals. The values of the determined effective attenuation coefficient obtained from the plot of natural logarithm of DAP against the equivalent diameter, D_e ranges from 0.309 to 0.514 cm^{-1} with mean value of 0.438 cm^{-1} However, for better approximation (close to muscle value), the value of International Commission on Radiation Unit and Measurement (ICRU- muscle Report 17) (ICRU, 1970) was adopted. The ICRU tabulated values for the beam potential of 50, 70, 90 kV as used by Shrimpton, (1981) were interpolated as shown in Figure 3.4 and chose the corresponding attenuation coefficient value for 80 kV (since the kV used during imaging ranged from 50-120kV), that is 0.365 cm^{-1} for both adult and paediatric patients. This stems from the fact that the same set of machines were used for both adult and paediatric patients. The chosen attenuation coefficient at 80 kV falls within the range of calculated value in this study.

The choice of 80 kV stems from the fact that the output of the machine at this potential across the x-ray tube and the anode current are said to be highly stable at 80 kV (Suliman and Elshiekh, 2008). Moreover, the chosen value of effective attenuation coefficient lies within the range of the experimentally determined value.

In this study, the equivalent diameter of a reference man of S_A= 22.9 cm was used for adult patients and for paediatric patients different values of standard size (S_P) were used based on the heterogeneous nature of the different age groups of paediatric patient as shown in Table 3.5.

3. 19 Data Analysis

Data Analyses in this work were carried out using different softwares (1) GraphPad Instat 3.05 software (2000). This is user friendly and interactive software for step by step statistical analysis (multiple regression analysis) (2) Data manipulation and computation were carried out using EXCEL software (2007) (3) GraphPad Prism 5.01 (2007) was used for graphing and data analysis. Interpolations were carried out using Linear Interpolation Calculator (LIC) (Aljundi, 2005).

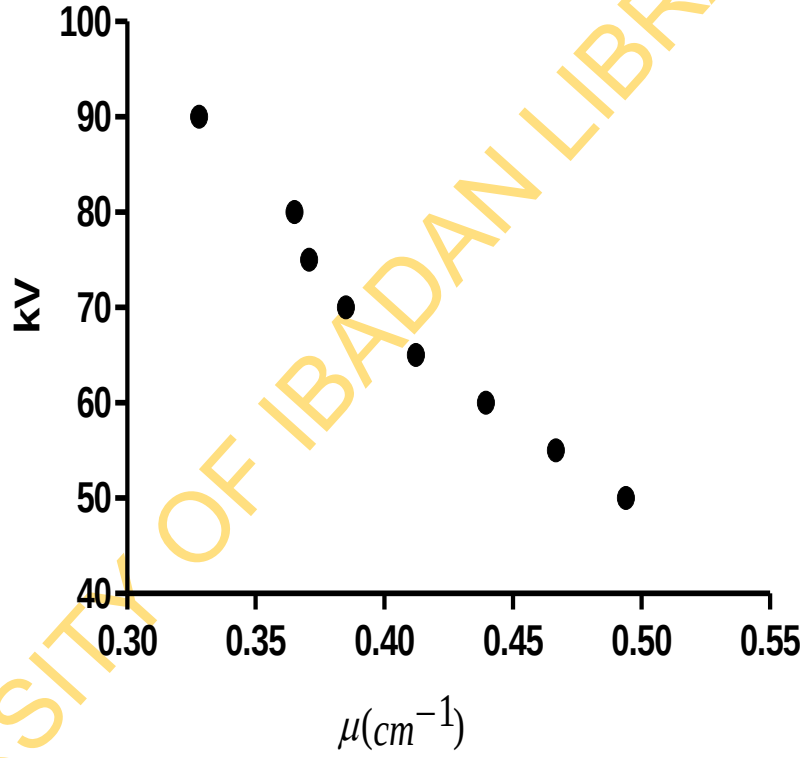

Figure 3. 4: Graph of tube potential (kV) against effective attenuation coefficient

CHAPTER FOUR

RESULTS

4.1 Grouping of the Centres

In this chapter, the results of quality control (QC) tests of facilities (x-ray machines) investigated during the course of this work are presented. Results of radiation doses (ESD, DAP, ED) obtained and radiological parameters selected during the routine examinations are presented and compared with the values published elsewhere. Also, results of the expected number of cancer incidence / mortality of the irradiated patients during the examinations are also presented.

In an attempt to carry out dose audit among various diagnostic centres within the same geographical location and to determine preliminary local reference diagnostic levels (PLRDLs) within each group and wihin Nigeria, the centres studied were divided into two groups, known as GROUP A and GROUP B. Different diagnostic centres constituting each group are shown in Table 4.1.

4.2 The Quality Control Tests on the Outputs of X-ray Units

The results of radiation outputs of different machines plotted against tube potential are presented in Figure 4.1. The graph shows that different machines have varied outputs and the outputs increase with the kV.

Table 4.2 shows the summary of average peak and effective peak voltages for different x-ray units. The table also shows the percentage difference between the average peak voltage, (kVa) and effective peak voltage, (kVe).

Table 4.1: Grouping of the centres studied

State (Units)	GROUP A	State (Units)	GROUP B
Osun (5)	OAUTHW	Lagos (4)	OAGSH
	LTH1		FKJSH
	LTH2		ALSH 1
	VHS		ALSH 2
	SDAH		
Ekiti (2)	FMC	Ogun (2)	ANHS
	EKSUTH		AYHS
		Oyo (2)	TTPC 1
			TTPC 2
Total Units	(7)	Total Units	(8)

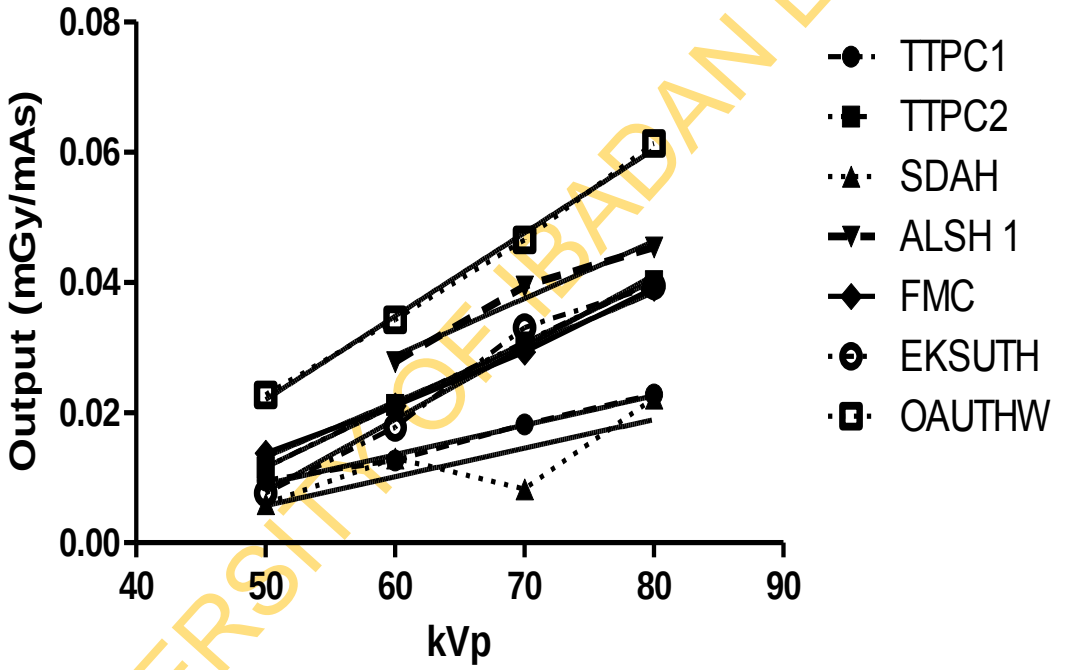

Figure 4.1: Graph showing the relationship between the outputs (mGy/mAs) and x-ray tube potentials (seven units)

Table 4.2: Differences between average peak (kVa) and effective peak (kVe) potential results of different x-ray units

Set kV	Average peak kVa	Effective peak kVe	Percentage difference
TTPC 1			
50	47.6	48.0	-0.84
60	57.5	57.8	-0.52
70	68.4	69.6	-1.75
80	73.3	77.9	-6.27
TTPC 2			
50	47.2	47.7	-1.05
60	58.3	58.6	-0.52
70	70.1	70.5	-0.57
80	81.7	81.9	-0.24
SDAH			
50	40.8	40.9	-0.25
60	55.2	55.8	-1.09
70	54.8	55.2	-0.73
80	69.5	70.1	-0.86
ALSH 1			
50	-	-	-
60	57.6	57.2	-0.69
70	66.7	68.4	-2.55
80	69.8	71.7	-2.72
FMC			
50	48.7	48.6	0.21
60	58.6	58.5	0.17
70	68.3	68.3	0.0
80	77.2	77.3	-0.13
EKSUTH			
50	49.1	49.3	-0.43
60	60.2	60.2	0.0
70	70.4	70.0	0.57
80	82.1	82.4	-0.37
OAUTHW			
50	48.2	48.0	0.42
60	58.3	58.1	0.34

70	68.3	68.2	0.15
80	78.6	78.3	0.38

Table 4.3 shows the results of the ripple factors (%) calculated using the measured voltage output of some of the machines investigated during the quality control tests. Voltage ripple (V_r) is defined as the amount of variation in the applied x-ray tube voltage waveform relative to the peak voltage during x-ray production. This is calculated using equation 4.1:

$$Voltage\ ripple\ (\%) = \frac{V_{max} - V_{min}}{V_{max}} x100 \qquad 4.1$$

The table (Table 4.3) also shows the coefficients of fit of the relationship between the kV selected on the control panel (kVset) and the kV measured using QC kit. The relationship between kVset and kVmeasured is represented by equation 4.2:

$$kV_{mea} = \alpha + \beta kV_{set} \qquad 4.2$$

The coefficients of determination showing goodness of fit and the reproducibility of the machine output for each x-ray unit are also tabulated.

Table 4.4 shows the results of the quality control tests of some machines investigated in the study. During the test, the detector of the kV meter was placed on the couch at a distance of 100 cm from the tube target. The x-ray beam was collimated to the sensitive area of the detector. To determine the variation of the x-ray output, the kVp was set at 80 kV for tube load of 10 mAs. The exposure at the set potential was repeated four times and the mean value obtained. The coefficient of variation (CV) for each centre is also shown in Table 4.4.

Table 4.3: The voltage ripple factor (%) and the linear fit coefficient of the measured tube potential as a function of set tube potential

Hospital	Voltage ripple (V_r) (%)	The linear fit coefficient of measured x-ray tube potential kV (kV_{mea}) as a function of set kV (kV_{set})		Coefficient of determination (R^2)	Reproducibility of output (mGy)
		α	β		
OAUTHW	0.25	-2.586	1.0729	0.9691	1.01
LTH1	0.86	7.406	1.099	0.9764	2.12
LTH2	--	20.903	0.613	0.9852	--
TTPC1	--	5.956	1.164	0.9994	--
TTPC2	--	-14.667	1.283	0.9981	--
SDAH	13.5	-0.663	0.909	0.8913	1.51
ALSH 1	0.72	22.000	0.611	0.9254	1.00
FMC	0.64	1.320	0.952	0.9986	0.99
EKSUTH	0.72	-5.531	1.0921	0.9832	1.02

Table 4.4: The quality control (QC) tests of some x-ray units investigated.

Hospital	Statistical Parameters	Average kVp	Maximum kVp	Effective kVp	Output (mR)	Exposure Time (sec)
OAUTHW	Mean	78.8	79.2	78.5	69.9	0.020
	CV (%)	0.11	0.12	0.51	**0.51**	0.50
LTH1	Mean	90.6	92.5	91.0	20.9	0.067
	CV (%)	0.46	1.39	1.04	**29.1***	30.8
SDAH	Mean	62.6	67.7	66.5	22.2	0.026
	CV (%)	6.95	5.76	6.10	**19.9***	20.8
ALSH 1	Mean	69.6	76.9	71.5	51.9	--
	CV (%)	0.35	0.19	0.13	**0.11**	--
FMC	Mean	77.5	78.5	77.6	44.1	0.084
	CV (%)	0.28	0.36	0.29	**0.41**	0.44
EKSUTH	Mean	82.0	82.9	82.2	44.6	0.099
	CV (%)	0.29	0.39	0.30	**0.38**	0.28

* Indicating machines with high coefficient of variation-CV (machines with problems)

4.3 Local Dose Audit (Entrance surface dose and Dose –Area Product)

The fifteen x-ray units were divided into two groups; GROUP A and GROUP B based on the geographical location, and nearness to each other. GROUP A centres are: OAUTHW, FMC, EKSUTH, LTH 1 and LTH 2, VHS and SDAH while GOUP B is made up of TTPC 1, TTPC 2, ANHS, AYHS, FKJSH, ALSH 1, ALSH 2 and OAGSH.

4.3.1 Entrance Surface Doses Measured in GROUPS A and B Centres

Table 4.5 shows the Entrance Surface Doses (ESD) of fifteen (15) diagnostic units investigated during the period of this investigation. It presents the results of mean ESD measured and the corresponding standard error of mean (SEM) of GROUP A centres for adult patients. This group (GROUP A) consists of six healthcare centres housing seven x-ray units. Similarly Table 4.6 presents the results of measured ESD for GROUP B centres. The group consists of eight centres in six hospitals. Tables 4.7 and 4.8 present the results of the ESD measurements carried out on paediatric patients during this study at different hospitals of GROUP A and GROUP B. The two tables (Tables 4.7 and 4.8) indicate paucity of data on paediatric patients.

4.3.2 Dose-Area Product Measured in GROUP A and GROUP B Centres

Tables 4.9 and 4.10 present the results of the mean DAP (with standard error on mean) of each centre in GROUPA and GROUP B and the group mean (with standard error on group mean). The tables show that there are limited dose data for abdomen AP and neck AP (in GROUP B), and thigh AP (GROUPS A and B). Besides, there is an indication that relatively higher doses were obtained in ANHS for all procedures. Table 4.11 and Table 4.12 present the results of paediatric patients' DAP for the two groups (GROUPS A and B).

One of the main objectives of dose audit is to identify hospitals delivering excessively high doses (that may increase patient dose burden) and extremely low doses that may reduce the quality of image produced, thereby preventing the required diagnostic information. This is achieved by taking into consideration the allowable tolerance especially when the local audit is carried out. The allowable tolerance helps to establish realistic trigger level for an investigation into causes of high or low doses. To this end Tables 4.13

and 4.14 present results of investigation into units delivering "excessively" high doses and "extremely" low doses in GROUPS A and B centres.

Table 4.5: Mean ESD (mGy) for each centre and corresponding SEM including group mean of GROUP A (adult).

Exam	OAUTHW SEM(R)	FMC SEM(R)	EKSUTH SEM(R)	LTH 1 SEM(R)	LTH 2 SEM(R)	VHS SEM(R)	SDAH SEM(R)	Group mean SEM(N_R)
Chest PA	4.44 (0.79)	5.57 (1.34)	0.50 (0.21)	0.44 (0.062)	4.53 (1.51)	2.22 (0.25)	3.36 (0.74)	3.01 (0.76)
Abdo AP	6.98 (0.67)	3.86 (0.33)	3.44 (1.29)	--	6.19 (1.01)	--	7.89 (4.06)	5.67 (0.87)
Pelvis AP	2.08 (0.24)	5.34 (1.23)	1.11 (0.40)	--	--	--	--	2.84 (1.27)
Lumb AP	8.12 (2.91)	2.29 (0.93)	0.55 (0.09)	4.89 (1.62)	--	2.50 (0.60)	4.43 (1.59)	3.79 (1.08)
Skull AP	5.96 (1.41)	6.42 (1.03)	0.46 (0.40)	2.87 (0.85)	--	-	--	3.93 (1.39)
Knee AP	2.38 (0.007)	2.94 (0.18)	--	0.79 (0.27)	2.78 (0.016)	2.82 (0.11)	0.80 (0.11)	2.09 (0.42)
Neck AP	--	0.63 (0.03)	--	0.86 (0.19)		--	---	0.75** (0.16)
Hand AP	2.36 (0.011)	2.52 (0.004)	0.39 (0.11)		0.47 (0.16)	--	--	1.44 (0.58)
Thigh AP	--	--	--	0.33 (0.019)	---	---	---	**

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.6 : Mean ESD (mGy) for each centre and corresponding SEM including mean of mean of GROUP B (adult).

Exam	TTPC 1 SEM(R))	TTPC 2 SEM(R)	ANHS SEM(R)	AYHS SEM(R)	FKJSH SEM (R)	ALSH 1 SEM(R)	ALSH 2 SEM(R)	OAGSH SEM(R)	Group mean SEM(N_R)
Chest PA	1.01 (0.25)	2.80 (0.43)	**5.95 (1.36)**	0.53 (0.012)	1.05 (0.16)	0.56 (0.069)	1.84 (0.71)	0.49 (0.10)	1.78 (0.66)
Abdo AP	--	1.64 (0.50)	--	--	--	--	--	--	**
Pelvis AP	1.08 (0.35)	---	**5.41 (1.14)**	0.10 (0.02)	4.53 (0.45)	--	---	--	2.71 (1.24)
Lumbar AP	2.53 (0.60)	3.03 (0.46)	--	0.57 (0.075)	**3.38 (2.11)**	---	2.37 (0.19)	0.79 (0.12)	2.11 (0.47)
Skull AP	---	---	**23.82 (9.25) *+**	1.26 (0.014)	--	1.28 (0.11)	--	---	8.79 (7.51)
Knee AP	0.68 (0.18)	---	**3.60 (0.40)**	0.14 (0.001)	0.83 (0.14)	0.057 (0.011)	--	--	1.06 (0.66)
Neck AP	--	--	--	---	--	0.58 (0.02)	--	--	**
Hand AP	0.37 (0.11)	1.83 (0.033)	3.52 (0.009)	0.12 (0.001)	0.75 (0.17)	0.036 (0.012)	--	--	1.10 (0.55)
Thigh AP	--	--	--	0.10 (0.004)	5.77 (1.34)	--	--	--	**

***+ high mAs ** insufficient data, Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP**

Table 4.7 : Mean ESD (mGy) for each centre and corresponding SEM including group mean GROUP A (paediatric)

Exam	OAUTHW SEM(R))	FMC SEM(R)	EKSUTH SEM(R)	LTH 1 SEM(R)	LTH 2 SEM(R)	VHS SEM(R)	SDAH SEM(R)	Group mean SEM(N_R)
Chest PA	3.25 (2.01)	--	0.67 (0.30)	3.34 (2.37)	---	1.60 (0.65)	3.22 (1.65)	2.42 (0.54)
Abdo AP	--	--	--	5.21 (0.12)	2.36 (0.54)	--	--	3.79 (1.43)
Pelvis AP	--	--	--	--	--	--	--	--
Lumbar AP	---	--	0.48 (0.14)	--	--	--	--	**
Skull AP	---	--	4.16 (0.35)	0.29 (0.21)	7.13 (0.46)	--	--	3.86 (1.98)
Knee AP	2.32 (0.001)	--	--	0.72 (0.12)	--	--	--	**
Neck AP	--	--	--	--	--	--	--	--
Hand AP	--	--	2.58 (0.19)	--	2.72 (0.019)	1.30 (0.23)	0.045 (0.011)	1.66 (0.62)
Thigh AP	--	--	--	--	--	--	1.35 (0.82)	**

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.8 : Mean ESD (mGy) for each centre and corresponding SEM including group mean of GROUP B paediatric.

Exam	TTPC 1 SEM(R))	TTPC 2 SEM(R)	ANHS SEM(R)	AYHS SEM(R)	FKJSH SEM (R)	ALSH 1 SEM(R)	ALSH 2 SEM(R)	OAGSH SEM(R)	Group mean SEM(N_R)
Chest PA	0.68 (0.17)	--	--	0.13 (0.0012)	0.56 (0.14)	1.03 (0.32)		0.60 (0.12)	0.60 (0.14)
Abdo AP	--	--	--	--	--	--	--	--	--
Pelvis AP	--	--	--	--	--	--	--	--	--
Lumbar AP	--	--	--	--	--	--	--	0.78 (0.11)	**
Skull AP	1.22 (0.83)	--	--	0.032 (0.0031)	--	0.21 (0.068)	--	4.38 (2.17)	1.46 (1.007)
Knee AP	0.59 (0.20)	--	--	--	--	--	--	--	--
Neck AP	--	--	--	--	--	--	--	--	--
Hand AP	0.56 (0.055)	--	3.39 (0.35)	--	--	--	--	--	** 1.97 (1.48)
Thigh AP	--	--	--	--	--	--	--	--	--

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.9 : Mean DAP (Gy cm^2) for each centre and corresponding SEM including group mean of GROUP A (adult).

Exam	OAUTHW SEM(R))	FMC SEM(R)	EKSUTH SEM(R)	LTH 1 SEM(R)	LTH 2 SEM(R)	VHS SEM(R)	SDAH SEM(R)	Group mean SEM(N_R)
Chest PA	5.56 (1.26)	6.69 (1.99)	0.71 (0.12)	0.58 (0.10)	5.96 (2.38)	2.74 (0.39)	5.08 (1.44)	3.90 (0.96)
Abdo AP	7.94 (0.77)	4.95 (0.45)	6.15 (2.48)	--	5.96 (0.97)	--	7.99 (4.26)	6.60 (0.60)
Pelvis AP	1.94 (0.28)	2.93 (0.70)	0.72 (0.29)	--	--	--	--	1.86 (0.64)
Lumb AP	4.69 (**1.52**)	2.41 (0.59)	0.26 (0.04)	3.05 (1.02)	--	1.46 (0.47)	2.59 (**0**.97)	2.41 (0.61)
Skull AP	3.73 (1.00)	3.53 (0.59)	0.25 (0.28)	1.77 (**0.58**)	--	--	--	2.32 (0.82)
Knee AP	1.79 (0.007)	2.21 (0.14)	--	0.58 (0.0.19)	2.78 (0.019)	1.41 (0.037)	0.50 (0.076)	1.55 (0.36)
Neck AP	--	0.45 (0.02)	--	0.62 (0.14)	--	--	--	0.54 (0.085)
Hand AP	1.42 (0.007)	1.81 (0.05)	0.23 (0.09)	--	0.28 (0.048)	--	--	0.94 (0.47)
Thigh AP	--	--	--	0.26 (0.026)	--	--		**

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.10 : Mean DAP (Gy cm^2) for each centre and corresponding SEM including group mean of GROUP B (adult).

Exam	TTPC 1 SEM(R))	TTPC 2 SEM(R)	ANHS SEM(R)	AYHS SEM(R)	FKJSH SEM (R)	ALSH 1 SEM(R)	ALSH 2 SEM(R)	OAGSH SEM(R)	Group mean SEM(N_R)
Chest PA	1.39 (0.31)	3.32 (0.71)	8.60 (2.33)	0.79 (0.20)	1.32 (0.24)	2.79 (1.22)	0.72 (0.12)	0.45 (0.09)	2.47 (0.95)
Abdo AP	---	1.21 (0.15)	---	---	--	--	--	--	**
Pelvis AP	1.09 (0.37)	---	5.82 (1.55)	0.076 (0.052)	5.55 (0.55)	--	--	--	3.13 (1.49)
Lumbar AP	1.42 (0.36)	1.59 (0.26)	--	0.63 (0.09)	1.80 (1.17)	1.47 (0.16)	--	0.39 (0.13)	1.22 (0.23)
Skull AP	--	--	16.84*+ (7.15)	0.83 (0.22)	---	---	0.74 (0.063)	--	6.14 (5.35)
Knee AP	0.49 (0.13)	--	2.78 (0.11)	0.11 (0.0022)	0.62 (0.10)	0.038 (0.012	--	--	0.81 (0.51)
Neck AP	---	--	--	---	---	---	0.42 (0.015)	--	**
Hand AP	0.22 (0.067)	1.09 (0.019)	2.74 (0.37)	0.097 (0.048)	0.45 (0.10)	0.021 (0.002)	--	--	0.77 (0.42)
Thigh AP	---	---	---	0.12 (0.0041)	5.77 (1.55)	---	---	---	2.95 ** (2.83)

***+ high mAs ** insufficient data, Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP**

Table 4.11 : Mean DAP (Gy cm^2) for each centre and corresponding SEM including group mean of GROUP A (paediatric).

Exam	OAUTHW SEM(R))	FMC SEM(R)	EKSUTH SEM(R)	LTH 1 SEM(R)	LTH 2 SEM(R)	VHS SEM(R)	SDAH SEM(R)	Group mean SEM(N_R)
Chest PA	5.01 (3.82)	--	0.96 (0.44)	4.86 (3.18)	--	2.23 (0.15)	5.99 (3.55)	3.81 (0.95)
Abdo AP	--	--	--	2.75 (0.72)	2.08 (0.49)	--	--	2.42 (0.34)
Pelvis AP	--	--	0.37 (0.11)	--	--	--	--	**
Lumb AP	--	--	--	0.29 (0.64)	--	--	--	**
Skull AP	--	--	2.95 (1.01)	0.46 (0.18)	5.67 (1.45)	--	--	1.77 (0.96)
Knee AP	--	--	--	--	--	--	--	--
Neck AP	--	--	--	--	--	--	--	--
Hand AP	1.74 (0.001)	--	1.89 (0.14)	--	1.63 (0.012)	0.78 (0.12)	0.39 (0.05)	1.29 (0.30)
Thigh AP	--	--	--	--	--	--	0.97 (0.072)	**

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.12 : Mean DAP (Gy cm^2) for each centre and corresponding SEM including group mean of GROUP B (paediatric).

Exam	TTPC 1 SEM(R))	TTPC 2 SEM(R)	ANHS SEM(R)	AYHS SEM(R)	FKJSH SEM (R)	ALSH 1 SEM(R)	ALSH 2 SEM(R)	OAGSH SEM(R)	Mean/mean SEM(N_R)
Chest PA	0.75 (0.25)	--	--	0.12 (0.02)	0.67 (0.09)	0.88 (0.32)	0.43 (0.01)	--	0.57 (0.13)
Abdo AP	--	--	--	--	--	--	--	--	--
Pelvis AP	--	--	--	--	--	--	--	--	--
Lumb AP	--	--	--	--	--	--	--	--	--
Skull AP	1.54 (1.16)	--	--	0.092 (0.013)	--	0.10 (0.029)	--	4.94 (2.82)	1.65 (0.58)
Knee AP	0.42 (0.14)	--	--	--	--	--	--	--	--
Neck AP	--	--	--	--	--	--	--	--	--
Hand AP	0.34 (0.033)	--	2.63 (0.13)	--	--	--	--	--	1.49 (1.15)
Thigh AP	--	--	--	--	--	--	--	--	--

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.13: Investigation into centres with excessively high doses and low doses (GROUP A - ESD).

Hospital	OAUTHW	EKSUTH	EKSUTH	EKSUTH	LTH1	LTH1	LTH2	SDAH	SDAH
Projection	Lumbar AP	Chest PA	Skull AP	Hand AP	Chest PA	Knee AP	Hand AP	Abdo AP	Knee AP
Observation High dose	Yes	--	--	--	--	--	--	Yes	--
Low dose	--	Yes	Yes	Yes	yes	yes	Yes	--	yes

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.14: Investigation into centres with excessively high doses and low doses (GROUP B - ESD).

Hospital	**ANHS**	**ANHS**	**ANHS**	**ANHS**	**ANHS**	**AYHS**	**AYHS**	**ALSH 1**	**OAGSH**
Projection	Chest PA	Pelvis AP	Skull AP	Knee AP	Hand AP	Chest PA	Knee AP	Hand AP	Lumbar AP
Observation / High dose	Yes	Yes	Yes	Yes	Yes	--	--	--	--
Low dose	--	--	--	--	--	Yes	Yes	Yes	Yes

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Comparison of group means obtained in GROUPS A and B centres with the 75th percentile of ALL dose distributions (ESD) and (DAP) for different procedures are presented in Table 4.15 (adult) and Table 4.16 (paediatric) respectively. Dose data on abdomen and neck for adult and paediatric patients are visibly missing in GROUP B data (Tables 4.16 and 4.17).

Comparison of ESD measured in GROUPS A and B centres during local dose audit with results published in UK, USA, and Brazil are shown in Table 4.17. Similarly, a comparison of group mean (DAP) values obtained from the two groups with published data from UK and Iran is presented in Table 4.18. Iran and UK (NRPB) were the few countries included in the comparison because of dearth of published DAP data.

Figure 4.2 gives a comparison of GROUPS A and B mean ESD with mean ESD of other published works from UK (Ireland), UK (RISs), Italy, Slovenia and Brazil. Figure 4.3 gives a comparison of local DAP study in this work with published studies from Nigeria (Akinlade *et al*., 2012), Iran and UK (NRPB). The comparison of data such as done in this study was essential because of the paucity of data on DAP especially in Africa. In Nigeria, the only available data on DAP are those of Akinlade *et al*. (2012).

Table 4.19 and Table 4.20 present the summary of mean and range of exposure factors selected during routine examinations and the associated characteristics of patients examined during the imaging of adult patients and paediatrics respectively at the centres located in GROUPS A and B. The exposure factors include tube potential (kVp), tube load (mAs), focus to skin distance (FSD), and patient characteristics such as: age, thickness (De) otherwise known as patient equivalent diameter (PED) especially for the trunk region derived from patient height and weight. The exception to this is the thickness of the lower extremities (hand and leg). The last column of Table 4.19 contains the published kVp and mAs in NRPB document (Hart *et al*., 2012).Published data for paediatric patients are not available for comparison.

Table 4.15 : Comparison of group mean of GROUP A and B with 75th percentile of ALL distribution of doses (ESD and DAP- adult)

Exam	ESD (mGy)			DAP (Gy cm^2)		
	GROUP A	GROUP B	75th percentile of ALL distribution	GROUP A	GROUPB	75th percentile of ALL distribution
Chest PA	3.01 (0.71)	1.78 (0.66)	2.95	3.90 (0.93)	2.47 (0.95)	3.14
Abdo AP	5.67 (0.87)	--	22.31	6.60 (0.96)	--	28.59
Pelvis AP	2.84 (1.27)	2.71 (1.24)	6.63	1.86(0.64)	3,13(1.49)	4.77
Lumb AP	3.79 (1.08)	2.11 (0.47)	5.87	2.41 (0.61)	1.22 (0.23)	3.20
Skull AP	3.93 (1.39)	8.79 (7.51)	9.04	2.32 (0.82)	6.14 (5.35)	5.06
Knee AP	2.09 (0.42)	1.06 (0.66)	2.78	1.55 (0.36)	0.81 (0.51)	2.09
Neck AP	0.75 (0.16)	--	--	0.54 (0.085)	--	--
Hand AP	1.44 (0.58)	1.10 (0.55)	2.39	0.94 (0.47)	0.77 (0.42)	1.44

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.16 : Comparison of group mean of GROUP A and B with 75th percentile of ALL distribution of doses (ESD and DAP- paediatric)

Exam	ESD (mGy)			DAP (Gy cm^2)		
	GROUP A	GROUP B	75th percentile of ALL distribution	GROUP A	GROUPB	75th percentile. of ALL distribution
Chest PA	2.42 (0.54)	0.60 (0.14)	2.46	3.81 (0.95)	0.57(0.134)	3.97
Abdo AP	3.79 (1.43)	--	--	2.42 (0.34)	--	--
Skull AP	3.86 (1.98)	1.46 (1.01)	3.04	1.77 (0.96)	1.65 (0.57)	2.95
Hand A	1.66 (0.62)	1.97 (1.48)	1.75	1.29 (0.30)	1.49 ()1.15	--

Abdo AP- Abdomen AP, Lumb AP- Lumbar spine AP

Table 4.17: Comparison of GROUPS A and B measured PLRDLs-G (ESD-mGy) with other published works (NDRLs)

Exam	PRDLs-G ESD (mGy)		NDRLs			
	GROUP A (SEM) (N=7)	GROUP B (SEM) (N=8)	UK NDRLs [f] (NRPB)	USA NDRLs [c]	Brazil NDRLs [d]	UK NDRLs [e]
Chest PA	3.01 (0.71)	1.78 (0.66)	0.15	0.25	0.35	0.15
Abdo AP	5.67 (0.87)	--	4.42	4.50	--	4.40
Pelvis AP	2.84 (1.27)	2.71 (1.24)	3.21	--	--	3.90
Lumb AP	3.79 (1.08)	2.11 (0.47)	6.54	5.00	6.6	5.70
Skull AP	3.93 (1.39)	8.79 (7.51)	2.25	--	3.3	1.80
Knee AP	2.09 (0.42)	1.06 (0.66)	--	0.70[b]	--	0.30
Neck AP	0.75 (0.16)	--	--	--	--	--
Hand AP	1.44 (0.58)	1.10 (0.55)	--	0.13[b]	--	0.08[a]

[a]Crawley and Rogers (2000), [b] Huda and Gkanatsios, 1998 (mean ESD- free – in-air for 71 kg adult) , [c]Gray *et al*., 2005, [d] Freitas and Yoshimura, 2009, [e] Charnock *et al*., 2014, [f] Hart *et al*., 2012.

PLRDLs-G : Preliminary Local Reference Dose Levels within each group

Table 4.18: Comparison of GROUP A and B measured PLRDLs-G (DAP -Gy cm^2) with other works (NDRLs)

Exam	PRDLs-G DAP (Gy cm^2)		NDRLs		
	GROUP A (SEM) (N=7)	GROUPB (SEM) (N= 8)	Iran (2014) NDRLs [(b)]	UK NDRLs NRPB [(c)]	UK NDRLs [(d)]
Chest PA	3.90 (0.96)	2.47 (0.95)	0.66	0.11	0.10
Abdo AP	6.60 (0.96)	--	1.64	2.6	2.5
Pelvis AP	1.86(0.64)	3.13 (1.49)	1.64	2.1	2.2
Lumb AP	2.41 (0.61)	1.22 (0.23)	1.02	1.6	1.5
Skull AP	2.32 (0.82)	6.14 (5.35)	0.59	0.78	--
Knee AP	1.55 (0.36)	0.81 (0.51)	--	0.72[a]	--
Neck AP	0.54 (0.085)	--	--	--	--
Hand AP	0.94 (0.47)	0.77 (0.42)	--	0.16[a]	--

[a]Crawley and Rogers, 2000 (UK-Dublin), [b] Shandiz *et al*., 2014,
[c] Hart *et al*., 2007, [d] Hart *et al*., 2012.

PLRDLs-G : Preliminary Local Reference Dose Levels within each group

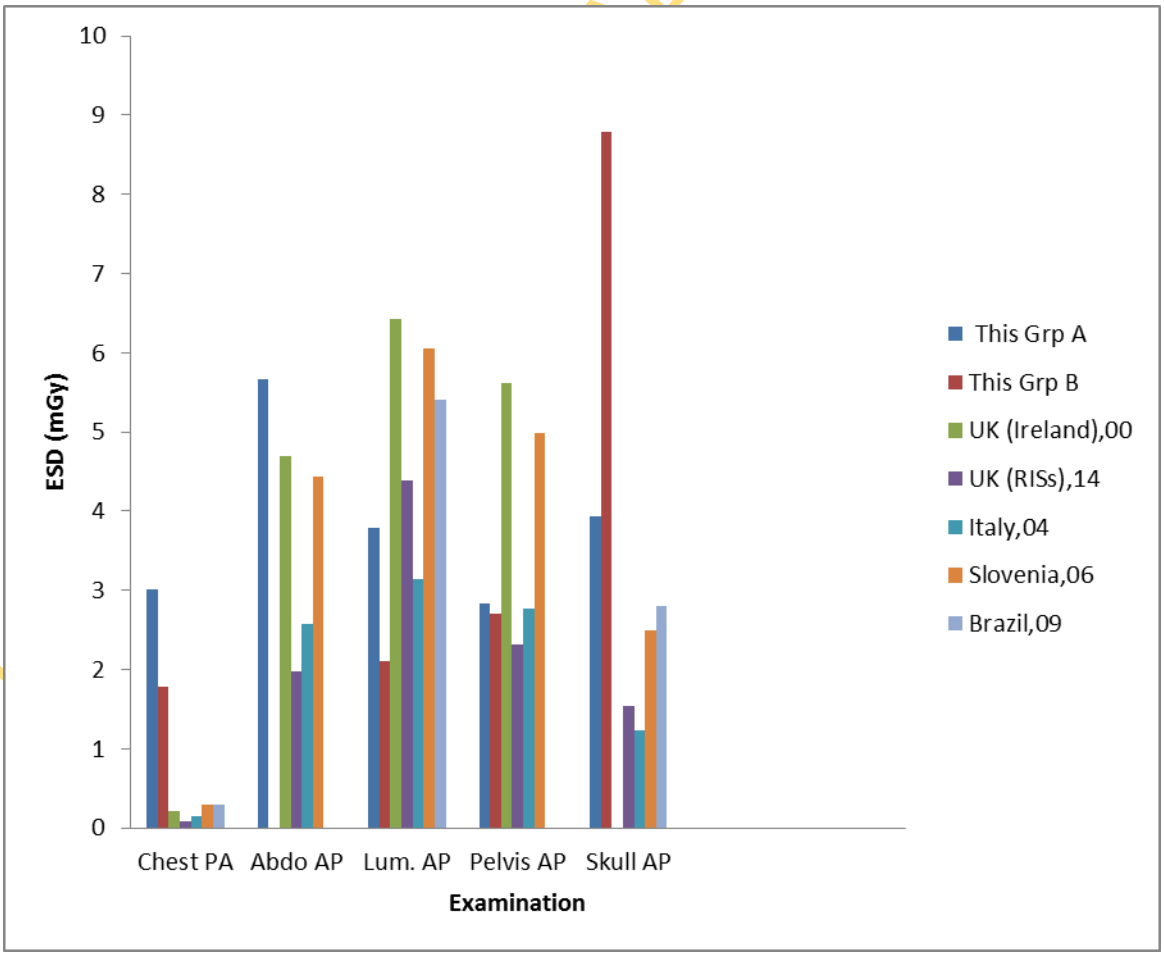
10
9
8
7
6
5
4
3
2
1
0
ESD (mGy)
Chest PA
Abdo AP
Lum. AP
Pelvis AP
Skull AP
Examination
This Grp A
This Grp B
UK (Ireland),00
UK (RISs),14
Italy,04
Slovenia,06
Brazil,09

Figure 4.2: Comparison of GROUPS A and B mean ESD with mean ESD of other published works.

UK (Ireland), 00 = Johnston and Brennan (2000); UK (RISs), 14 = Charnock *et al*., 2014; Italy, 04 = Compagnone *et al*., 2004; Slovenia, 06 = Skrrk *et al*., 2006; Brazil, 09 =Freitas and Yoshimura, 2009

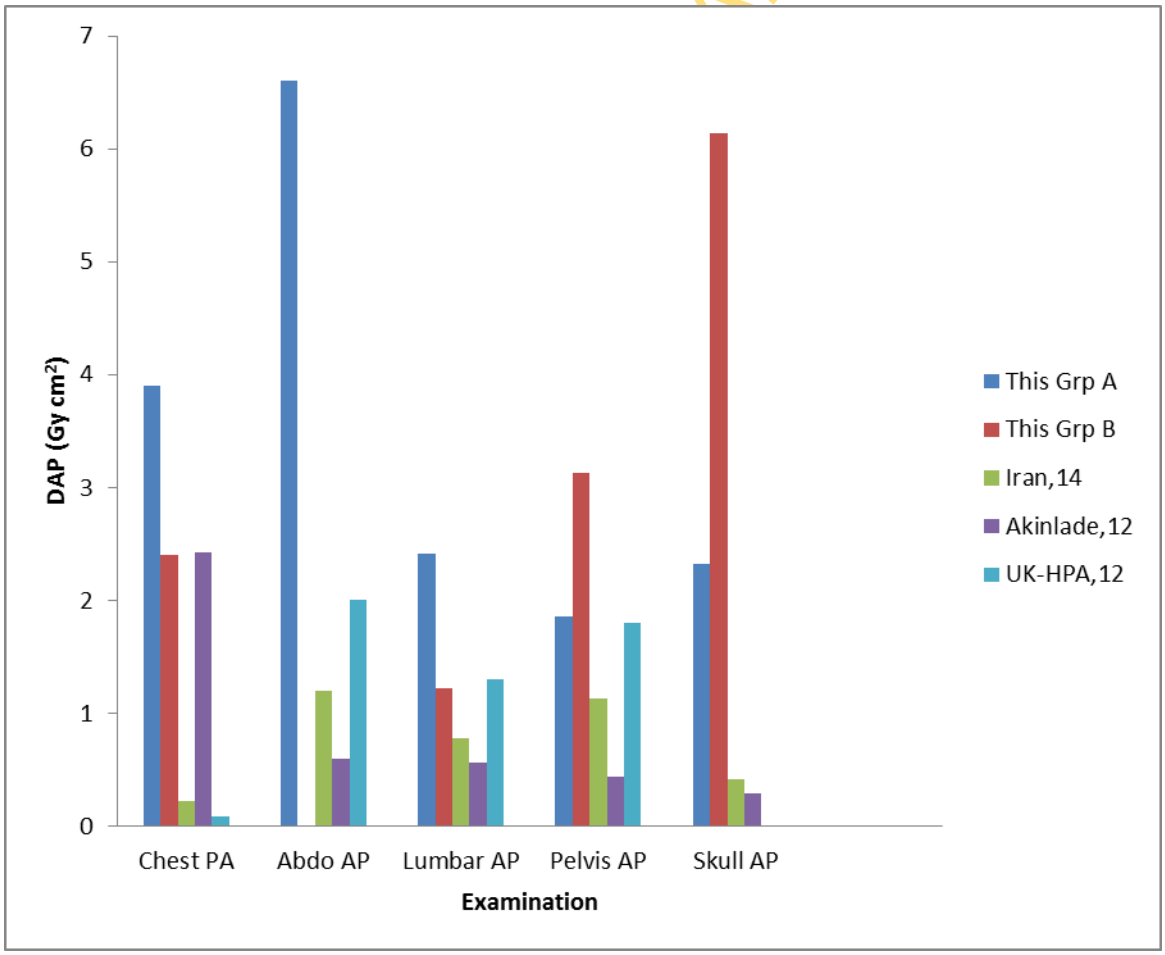

Figure 4.3: Comparison of GROUP A and B mean DAP (Gy cm^2) with mean DAP of other published works

Iran, 14 = Shandiz *et al*., 2014; Akinlade, 12 = Akinlade *et al*., 2012;

UK-HPA =Hart *et al*., 2012.

Table 4.19 Summary of mean and range of patient characteristics and exposure parameters selected for the different examinations in GROUPS A and B (adult) healthcare centres studied

Exam/ Projection	GROUP	No of units (n)	Mean kVp (range)	Mean mAs (range)	Mean FSD (cm) (range)	Mean Age (yr) (range)	Equivalent diameter De (cm) (range)	Mean weight (cm) (range)	kVp(mAs) UK (Hart *et al*. 2012)
Chest PA	A	6	75 (60-77)	26 (3-80)	126 (62-85)	45 (17-86)	22 (17-30)	64 (37-120)	+ 88(65-125)
	B	8	75 (55-96)	24 (5-100)	129 (68-175)	44 (19-90)	23 (17-36)	69 (37-150)	*5(0.3-405)
Abdomen AP	A	5	88 (63-117)	55 (20-125)	81 (68-97)	61 (31-80)	22 (17-25)	63 (40-84)	+76(60-94)
	B	1	91 (85-95)	100 (90-120)	91 (87-96)	56 (45-76)	25 (23-26)	91 (75-100)	*41(1-440)
Pelvis AP	A	3	75 (70-85)	33 (20-63)	86 (63-105)	44 (19-70)	23 (21-27)	72 (60-98)	+75(62-92)
	B	4	80 (50-96)	44 (5-83)	100 (70-125)	59 (22-92)	23 (19-25)	72 (40-93)	*33(1-400)
Lumbar spine AP	A	6	86 (60-117)	62 (23-200)	78 (60-100)	51 (21-78)	23 (20-27)	69 (52-95)	+78 (65-109)
	B	6	85 (63-117)	58 (9-125)	85 (55-150)	48 (20-69)	23 (18-28)	72 (46-105)	*46(1-556)
Skull AP	A	4	73 (67-80)	40 (16-125)	78 (56-122)	43 (27-76)	23 (20-24)	65 (48-77)	+72(69-83)
	B	4	80 (60-94)	58 (15-100)	92 (70-140)	44 (14-63)	22 (19-24)	62 (49-76)	*20(1-246)
Knee AP	A	6	63 (60-102)	13 (6-64)	88 (65-122)	45 (26-82)	15 (9-33)	71 (60-122)	+61(52-68)
	B	6	57 (48-80)	10 (3-32)	86 (63-107)	45 (16-73)	13 (10-25)	67 (47-86)	*4(1-125)
Hand AP	A	4	61 (54-94)	9 (4-32)	82 (67-107)	55 (20-75)	14 (9-25)	59 (50-72)	NA
	B	6	52 (40-86)	10 (3-10)	77 (60-112)	33 (17-78)	10 (5-25)	70 (40-176)	
Thigh AP	A	1	69 (56-79)	23 (20-25)	120 (118-124)	35 (30-46)	22 (20-23)	62 (56-65)	NA
	B	1	61 (57-63)	11 (10-12)	86 (82-87)	28 (20-32)	16 (15-20)	80 (76-83)	

Leg AP	A	4	64 (60-102)	35 (7-80)	85 (60-160)	37 (16-73)	16 (5-33)	69 (40-120)	NA
	B	2	64 (57-94)	23 (7-64)	75 (66-122)	45 (26-73)	13 (12-14)	71 (60-122)	

N/A, Not available for comparison; [+]tube potential (kVp), * tube load (mAs)

Table 4.20: Summary of mean and range of patient characteristics and exposure parameters selected for the different examinations in GROUPS A and B (paediatric) healthcare centres studied

Exam/ Projection	GROUP	No of units (n)	Mean kVp (range)	Mean mAs (range)	Mean FSD(cm) (range)	Mean Age (yr) (range)	Equivalent diameter De (cm) (range)	Mean weight (kg) (range)	kVp(mAs) UK (Hart *et al.*, 2012)
Chest PA	A	5	65 (55-85)	22 (6-48)	91 (69-184)	8 (0-15)	15 (12-18)	22 (5-40)	N/A
	B	3	62 (51-78)	11 (4-24)	115 (67-162)	10 (1-14)	15 (11- 20)	21 (5-55)	
Skull AP	A	3	67 (60-75)	23 (19-30)	95 (90-122)	14 (10-19)	10 (9-12)	26 (23-29)	N/A
	B	2	61 (46-76)	21 (6-64)	89 (60-185)	10 (4-15)	16 (5-18)	27 (8-40)	
Hand AP	A	3	58 (53-60)	15 (4-32)	91 (101-128)	8 (2-12)	11 (7-13)	29 (9-32)	N/A
	B	2	42 (37-45)	4 (2-8)	72 (50-79)	12 (11-14)	10 (8-12)	39 (24-50)	

N/A – Not available for comparison

4. 4 Regional Dose Audit (Entrance surface dose and Dose Area Product)

This section presents the results of the regional dose audit carried out in twelve facilities consisting of fifteen x-ray units investigated in the Southwestern geopolitical zone of Nigeria. Statistical parameters for the overall mean, minimum, maximum, 75th and 80th percentile ESD distributions for adult and paediatric patients are presented in Tables 4.21 and 4.22 respectively. The ratio of maximum to minimum ESD ranged between 26 and 215 in adults, while in paediatrics the range of dose distribution is 10 – 215. Moreover, Table 4.23 and Table 4.24 give the results of mean, median, 75th and 80th percentile overall dose distribution. The range of max/min ratio for adult DAP is 3-57 and the range of paediatric DAP is 8-79. The large values of maximum/minimum ratio observed within and among hospitals indicate wide range of dose variations. The wide dose variation in some instances occurs within the same hospital and in other cases among hospitals as recorded in this study. Figure 4.4 and Figure 4.5 show the results of chest dose distribution among different age groups considered in this study (< 1 to >15 years) for ESD and DAP respectively. Table 4.25 presents the comparison of mean dose (ESD) of male and female with mean overall ESD, 75th percentile, and reference values published in UK (NRPB), Slovenia, Brazil and USA. In addition, Table 4.26 also presents comparison of mean DAP for male and female with mean DAP for all the centres, 75th percentile and published DAP data from UK, Nigeria and Iran. Figures 4.6 and 4.7 present the plots of ESD against the percentile dose distributions for different procedures (in Figure 4.6 - chest PA, lumbar spine AP, pelvis AP, and skull AP, and in Figure 4.7- abdomen AP). Figures 4.8 and 4.9 are the plots of DAP against the percentile dose distributions. The left (lower) and right (upper) arrows shown in Figures 4.6, 4.7, 4.8 and 4.9 indicate the points of investigation. Moreover, Figure 4.6 shows the regions of the graph where investigations are required for dose optimisation and adequacy of image quality. The mean value of the tube voltage (kVp), tube load (mAs), focus to film distance (FSD), equivalent diameter (De) and the corresponding range for all

patients examined are presented in Table 4.27. Comparison of kVp and mAs are made with published values from UK (NRPB-HPA), USA (North America) and Brazil (South America). Adequate data for extremity comparison are not available. Available data on extremity (leg, knee and hand) for comparison are found in the USA. Data for paediatric patients are also included in the table (Table 4.27).

Table 4.21: Statistical parameters for the overall mean, minimum, maximum 75th and 80th percentile ESD (mGy) distributions for different procedures and patient information (Adults).

Exam Type	N	Mean Weight (kg)	Mean age (yr)	Mean ESD (SEM)	Min ESD	Max ESD	Median ESD	75th Percentile ESD	80th Percentile ESD	Max/min
Chest PA	306	67 (37-120)	44.2 (17-90)	2.32 (0.19)	0.019	27.00	1.07	2.95	3.23	147
Abdo AP	20	68 (40-91)	58.7 (31-80)	11.72 (2.67)	1.44	37.42	8.04	22.31	25.71	26
Pelvis AP	35	73 (54-98)	47.9 (19-74)	4.05 (0.54)	0.30	11.43	3.63	6.63	7.53	38
Lumb AP	87	71 (46-105)	51.1 (20-76)	4.74 (0.72)	0.93	38.10	2.66	5.87	6.67	41
Skull AP	32	65 (48-77)	42.9 (19-80)	7.07 (0.67)	1.17	43.19	4.05	9.04	9.93	37
Leg AP	46	69 (40-99)	39.1 (16-82)	1.27 (0.19)	0.02	3.95	0.78	1.51	2.89	197
Knee AP	17	71 (63-87)	57.2 (26-82)	1.59 (0.34)	0.095	4.01	2.12	2.78	2.85	42
Hand AP	45	64 (40-160)	42.7 (19-90)	1.33 (0.19)	0.11	15.11	0.66	2.39	2.51	137
Thigh AP	12	72 (56-80)	30.6 (28-46)	0.50 (0.053)	0.07	15.04	0.67	0.69	0.72	215

Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

Table 4.22: Statistical parameters for the overall mean, minimum, maximum 75th and 80th percentile ESD (mGy) distribution for different procedures and patient information (paediatrics).

Exam Type	N	Mean Weight (kg)	Mean age (yr)	Mean ESD (SEM)	Min ESD	Max ESD	Median ESD	75th Percentile ESD	80th Percentile ESD	Max/min
Chest PA	47	19.0 (4-55)	6.1 (5d-15)	1.99 (0.43)	0.11	15.11	0.81	2.46	2.85	137
Skull AP	24	23 (5-40)	8.1 (5d-15)	2.05 (0.66)	0.07	15.04	1.45	3.04	3.86	215
Hand AP	18	26 (5-50)	7.9 (0.16-14)	1.42 (0.24)	0.26	2.63	1.64	1.73	1.81	10

Table 4.23: Statistical parameters for the overall mean, minimum, maximum 75th and 80th percentile DAP (Gy cm^2) distributions for different procedures and patient information (Adults)

Exam Type	N	Mean Weight (kg)	Mean age (yr)	Mean DAP (SEM)	Min DAP	Max DAP	Median DAP	75th Percentile DAP	80th Percentile DAP	Max/ min
Chest PA	306	67 (37-120)	44.2 (17-90)	3.06 (0.30)	1.009	39.38	1.15	3.14	3.80	39
Abdo AP	20	68 (40-91)	58.7 (31-80)	17.16 (4.96)	1.21	68.61	7.21	28.59	36.29	57
Pelvis AP	35	73 (54-98)	47.9 (19-74)	3.28 (0.47)	1.07	12.51	2.44	4.77	5.83	12
Lumb AP	87	71 (46-105)	51.1 (20-76)	2.72 (0.44)	1.036	24.12	1.40	3.20	3.99	23
Skull AP	32	65 (48-77)	42.9 (19-80)	4.53 (0.052)	0.63	31.79	2.31	5.06	6.27	51
Leg AP	46	69 (40-99)	39.1 (16-82)	1.14 (0.15)	0.057	3.05	0.93	2.04	2.75	54
Knee AP	17	71 (63-87)	57.2 (26-82)	1.53 (0.23)	0.11	3.00	1.89	2.09	2.14	27
Hand AP	45	64 (40-100)	42.7 (19-90)	0.92 (0.13)	0.21	2.85	0.43	1.44	1.81	14
Thigh AP	12	72 (56-80)	30.6 (28-46)	0.18 (0.02)	0.11	0.31	0.23	0.25	0.27	3

Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

Table 4.24: Statistical parameters for the overall mean, minimum, maximum 75th and 80th percentile DAP (Gy cm^2) distributions for different procedures and patient information (paediatric)

Exam Type	N	Mean Weight (kg)	Mean age (yr)	Mean DAP (SEM)	Min DAP	Max DAP	Median DAP	75th Percentile DAP	80th Percentile DAP	Max/min
Chest PA	47	19 (4-55)	6.1 5d--15	3.62 (1.08)	0.47	42.72	0.74	3.97	5.08	79
Skull AP	24	23 (5-40)	8.1 (5d-15)	2.13 (0.82)	0.91	18.79	1.30	2.95	3.23	21
Hand AP	18	26 (5-50)	7.9 (0.16-14)	2.12 (0.18)	0.45	3.58	2.40	2.73	2.74	8

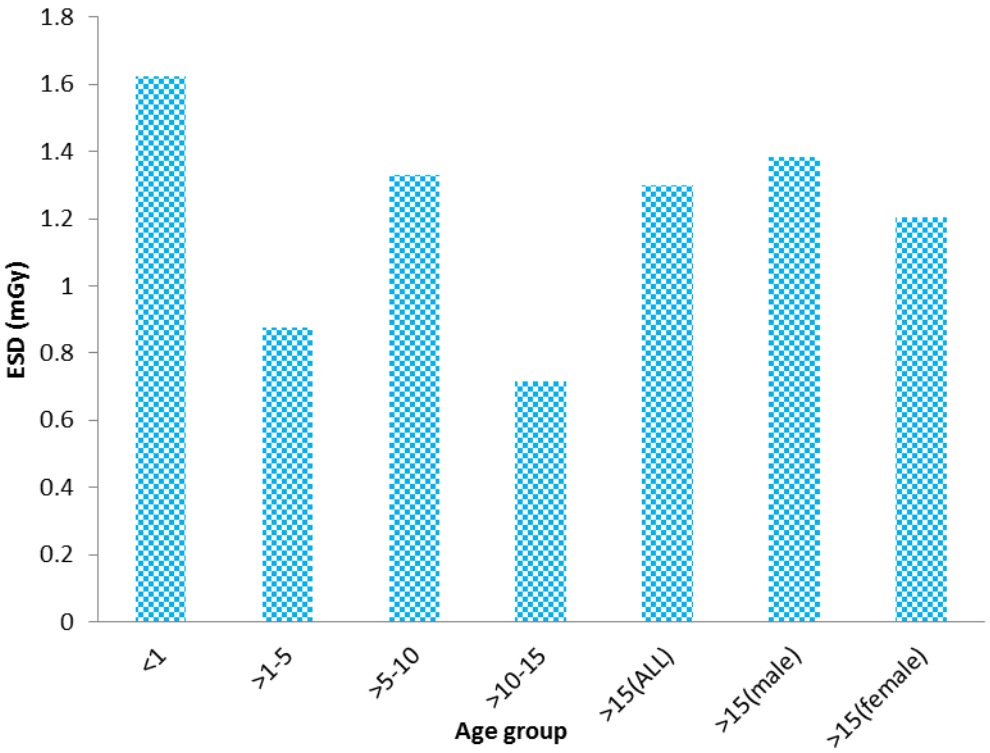

Figure 4.4 Dose distribution among different age groups (Chest PA examination)

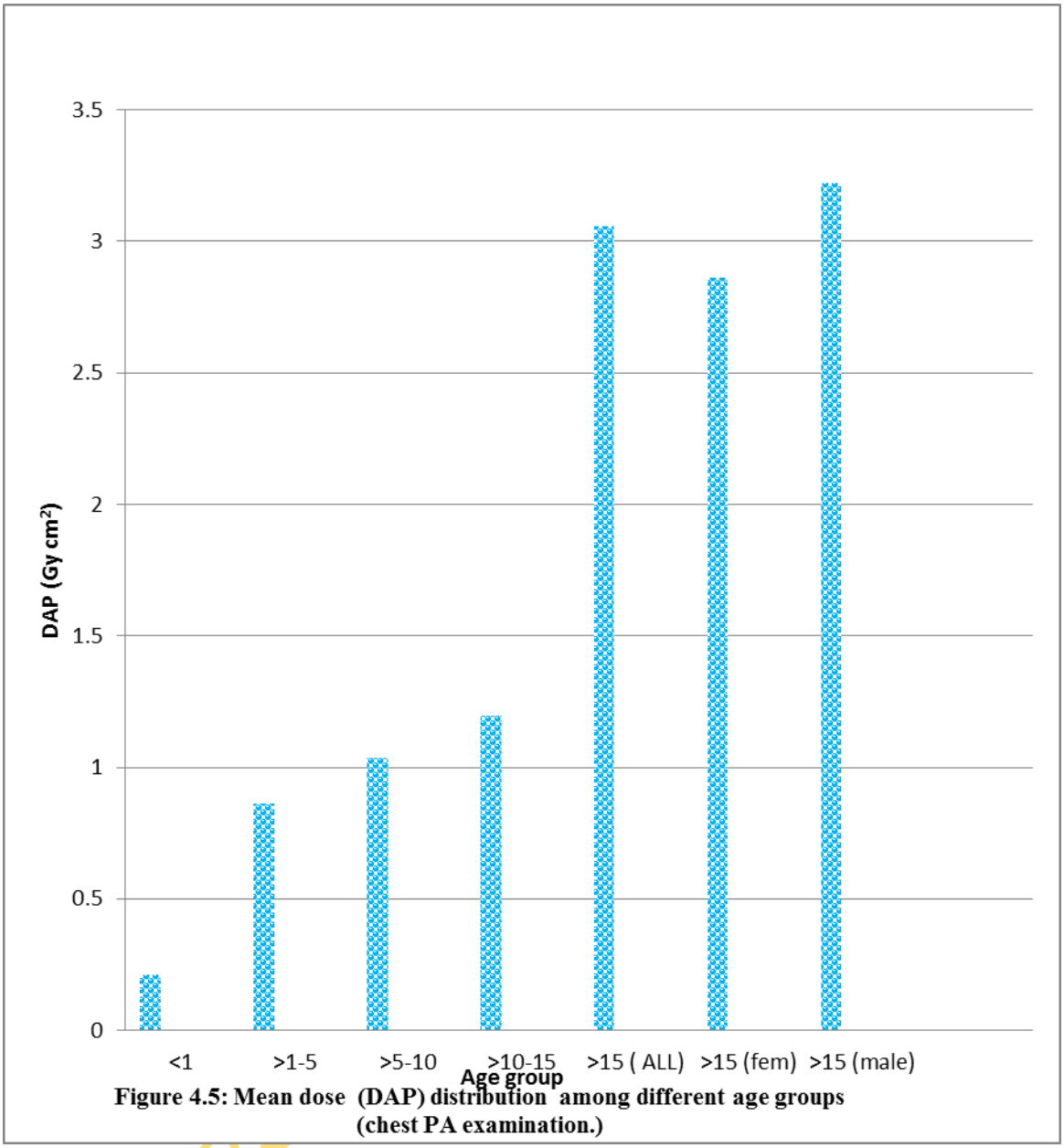

Figure 4.5: Mean dose (DAP) distribution among different age groups (chest PA examination.)

Table 4.25 : Comparison of statistical parameters of male and female ESD (mGy) with ALL (gender based--Adult)

Exam Type	N	Mean age (yr)	**Mean ESD (mGy)	ALL patient ESD (mGy)

			(SEM)	This study Mean ESD	This study 75th perc	NRPB HPA, 2012 (75th per)	Mean ESD from Slovenia (2006)	NDRLs from Brazil (2009)	NDRLs from USA (2005) No BS
Chest PA	156 (m)	42 (17-90)	2.43 ± 0.28 (0.060-27.04)	2.32	2.95	0.15	0.35	0.35	0.25
	150 (f)	46.3 (17-45)	2.19 ± 0.26 (0.019-17.66)						
Abdo AP	10 (m)	63 (38-79)	7.42 ± 2.40 (1.44-21.54)	11.72	22.31	4.40	6.18	--	4.50
	10 (f)	56 (31-80)	15.17 ± 4.52 (2.00-37.42)						
Pelvis AP	21 (m)	44 (19-74)	5.52 ± 0.68 (0.52- 11.48)	4.05	6.63	3.90	5.83	--	--
	14 (f)	55 (35-70)	1.45 ± 0.24 (0.30-2.66)						
Lumb AP	48 (m)	54 (21-76)	6.03 ± 1.37 (0.093-38.10)	4.74	5.87	5.70	7.98	6.60	5.00
	39 (f)	48 (20-73)	3.89 ± 0.68 (0.13-23.88)						
Skull AP	21 (m)	47 (19-80)	8.26 ± 2.39 (1.17-43.19)	7.07	9.04	1.80	2.54	3.30	---
	11 (f)	34 (20-68)	4.31 ± 1.08 1.26 – 11.88						
Leg AP	30 (m)	38 (16-82)	1.25 ± 0.26 (0.022-3.95)	1.27	1.51	0.30	--	--	--
	16 (f)	44 (16-73)	1.18 ± 0.28 (0.11-3.55)						
Hand AP	35 (m)	38 (20-70)	1.42 ± 0.27 (0.036-3.76)	1.33	2.39	--	--	--	--
	10 (f)	61 (19-70)	1.08 ± 0.39 (0.12-2.52)						

+ Represents the thickness of the irradiated region, ** Corrected ESD value, BS= back scatter Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP ** mean value of male and female patients, NRPB-HPA=Hart *et al.*, 2012; Slovenia (2006) = Skrk *et al.* (2006); Brazil (2009) = Freitas and Yoshimura (2009); USA (2005) = Gray *et al.* (2005)

Table 4.26 : Comparison of statistical parameters of male and female DAP (Gy cm^2) with ALL and NDRLs published elsewhere (NRPB-HPA, Nigeria and Iran).

Exam Type	N	Mean age (yr)	**Mean DAP(Gy cm^2) (SEM)	ALL patient DAP (Gy cm^2)				
				This study Mean	This study 75th percentile	NRPB (HPA, 2012)	Mean DAP from Nigeria 2012[g]	Mean DAP and DRLs from Iran (2014)[h]
Chest PA	156 (m)	42 (17-90)	3.22 (0.44)	3.06	3.14	0.1	1.25	0.22
	150 (f)	46 (17-45)	2.87 (0.41)					
Abdo AP	10 (m)	63 (38-79)	8.48 (3.09)	17.16	28.59	2.9	0.56	1.29
	10 (f)	56 (31-80)	24.10 (8.65)					
Pelvis AP	21 (m)	44 (19-74)	4.45 (0.62)	3.28	4.77	2.2	0.46	1.11
	14 (f)	55 (35-70)	1.23 (0.25)					
Lumbar AP	48 (m)	54 (21-76)	3.46 (0.83)	2.72	3.20	1.5	--	0.71
	39 (f)	48 (20-73)	1.89 (0.26)					
Skull AP	21 (m)	47 (19-80)	5.39 (1.78)	4.53	5.06	--	0.34	0.42
	11 (f)	34 (20-68)	2.54 (0.75)					
Leg AP	30 (m)	38 (16-82)	1.19 (0.21)	1.14	2.04	--	--	--
	16 (f)	44 (16-73)	0.95(0.22)					
Hand AP	35 (m)	38 (20-70)	0.97 (0.16)	0.92	1.44	--	--	--
	10 (f)	61 (19-70)	0.74 (0.12)					

[g]Akinlade *et al*., 2012, [h] Shandiz *et al*., 2014. Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

**** mean value of male and female patients**

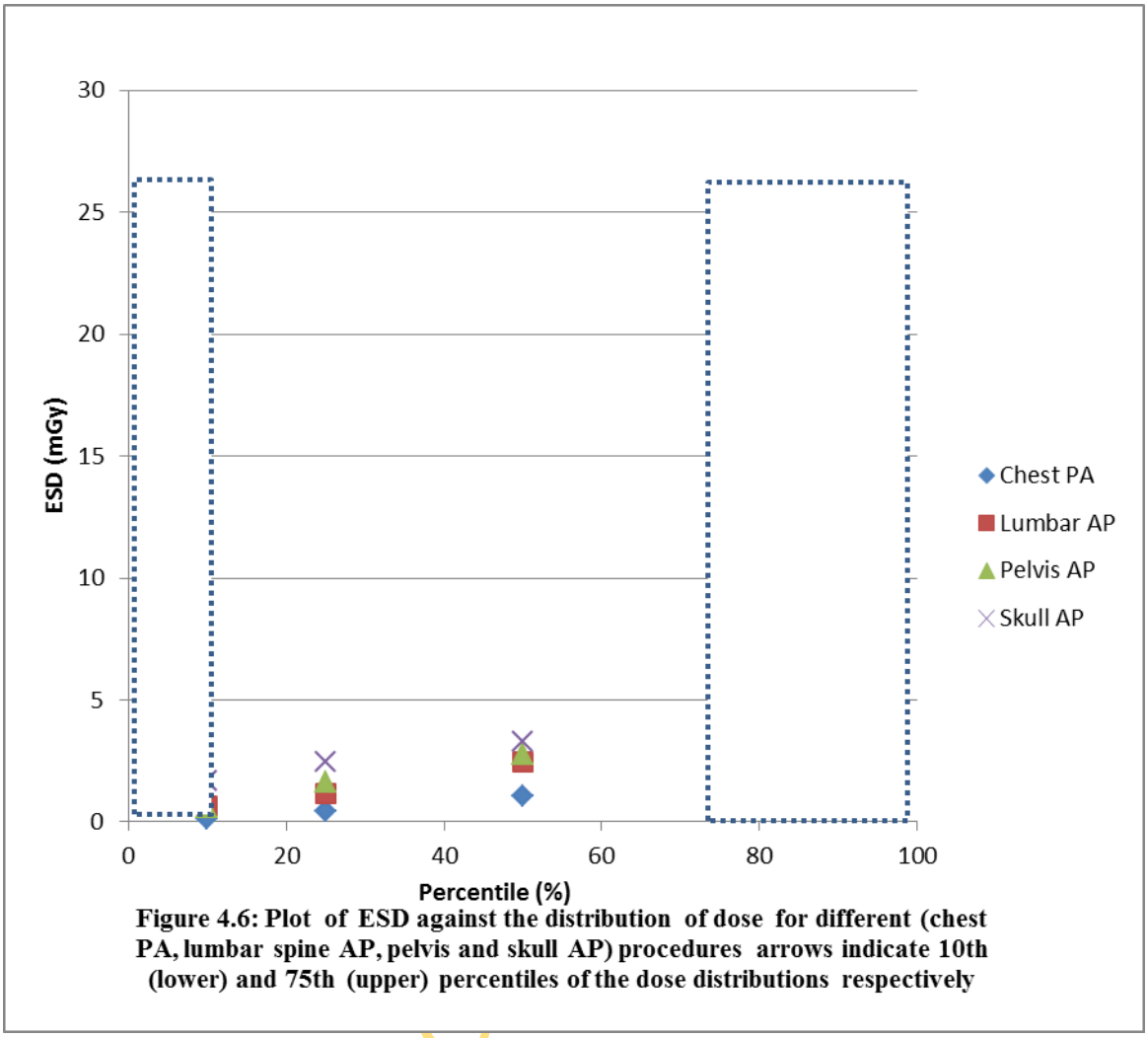

Figure 4.6: Plot of ESD against the distribution of dose for different (chest PA, lumbar spine AP, pelvis and skull AP) procedures arrows indicate 10th (lower) and 75th (upper) percentiles of the dose distributions respectively

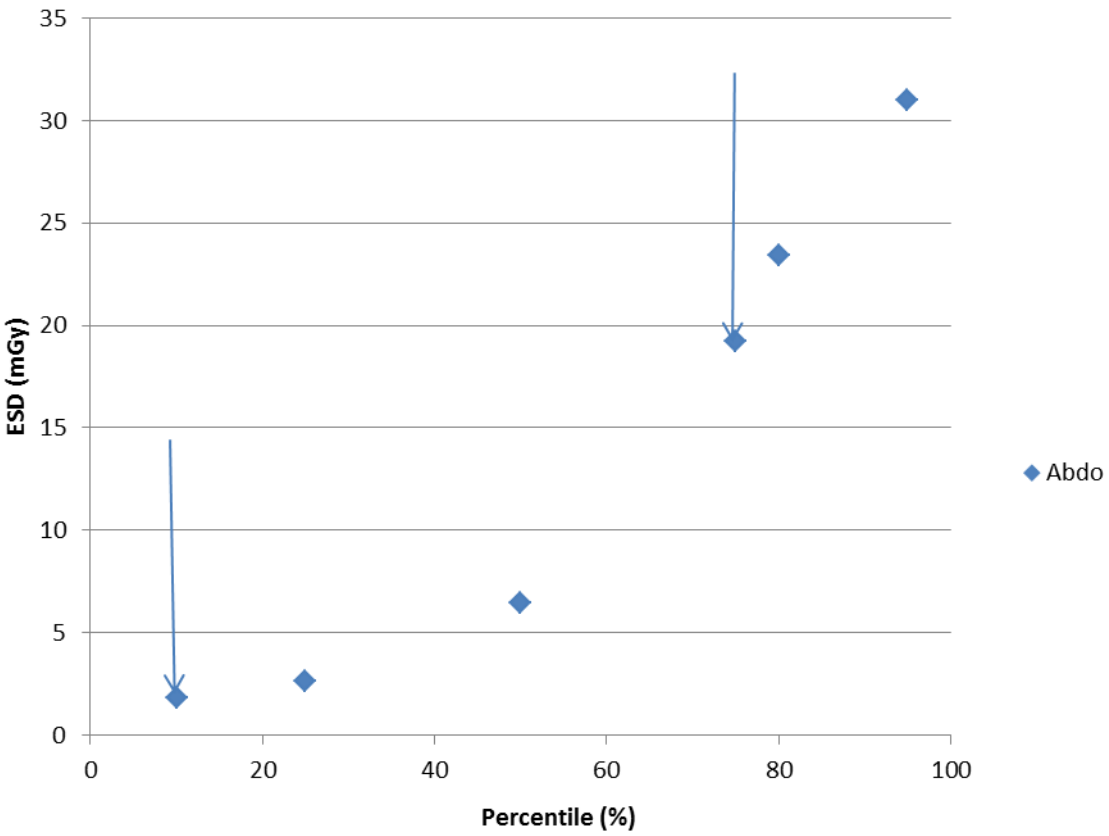

Figure 4.7: Plot of ESD against the distribution of dose for abdomen procedures arrows indicate 10th and 75th percentiles of the dose distributions

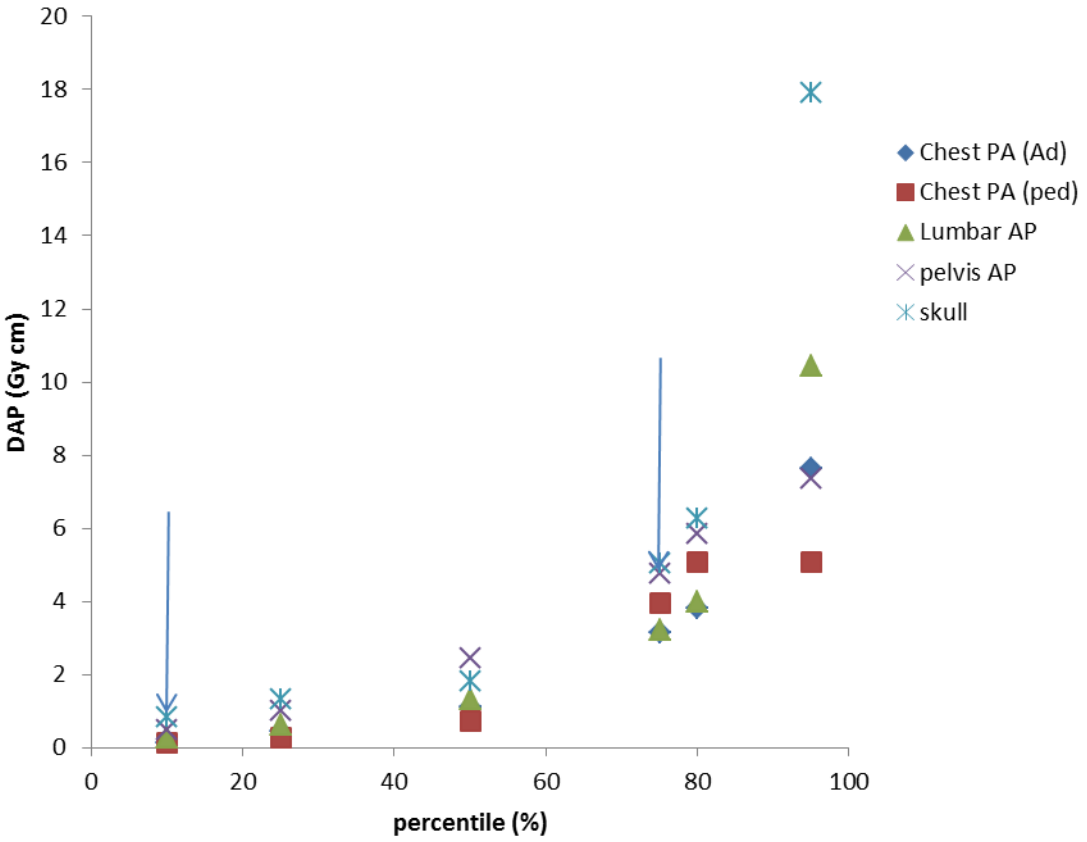

Figure 4.8: Plot of DAP against the distribution of dose for different procedures (chest, lumbar, pelvis and skull) arrows indicate 10th and 75th percentiles of the dose distributions

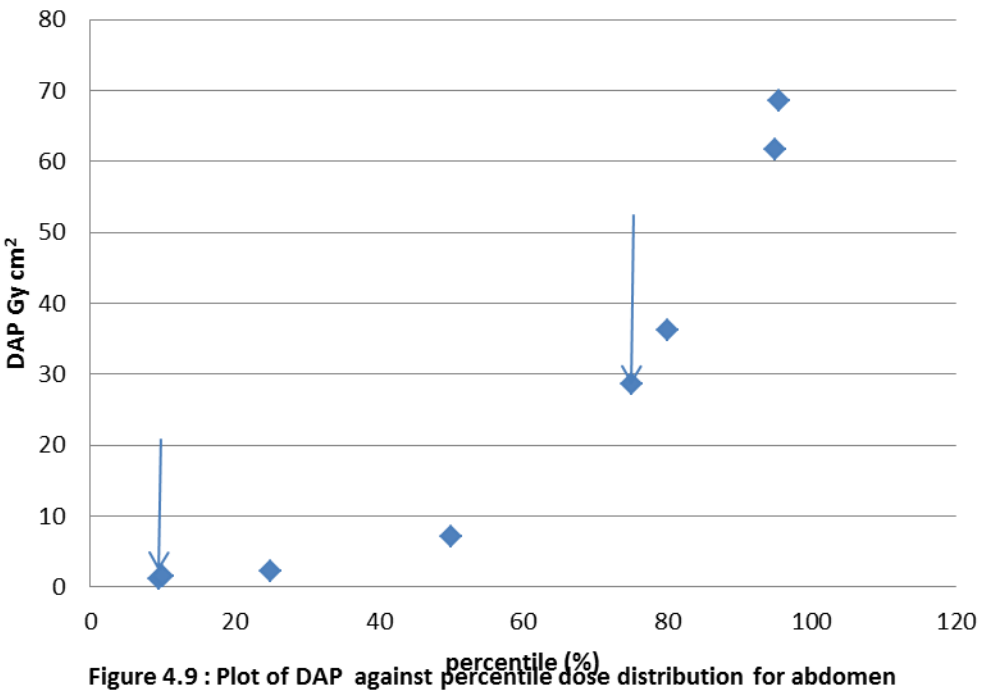

Figure 4.9 : Plot of DAP against percentile dose distribution for abdomen examination, the arrows indicate the 10th and 75th percentiles dose distribution

Table 4.27: Comparison of average exposure factor (kVp, mAs, FSD) settings with others published elsewhere (adult)

Exam Type	Tube Voltage (kVp)	Tube Current (mAs)	FSD (cm)	Average Equivalent diameter (in cm) [D_e]	NRPB (HPA) UK[a]		USA (N. America) [b]		Brazil (S. America)[C]	
					kVp	mAs	kVp	mAs	kVp	mAs
Chest PA	75 (55-185)	25.9 (0.33-100)	125.3 42-185	22.4 (16.8-33.9)	88	5	120	-	77	12
Abdo AP	86 (75-117)	58.1 (20-125)	82.3 68-99	22.4 (17.2-25.4)	76	41	75	-	-	-
Pelvis AP	78 (52-92)	35.7 (5-75)	91.9 63-137	23.3 (19.9-26.9)	75	33	75	-	-	-
Lumb AP	85 (60-117)	62.8 (9-200)	76.8 40-160	23.2 (19.3-28.7)	78	46	75	10.3	70	84
Skull AP	75 (60-85)	44.4 (8-125)	77.6 56-122	22.0 (19.7-24.4)	72	20	80	-	66	59
Leg AP	62 (48-102)	18.7 (3.2-80)	82.4 60-160	12.3 (5-33)	-	-	70	10	-	-
Knee AP	63 (58-80)	9.2 (5-32)	87.8 65-108	13.5 (9-20)	-	-	70	12	-	-
Hand AP	57 (40-94)	9.2 (2.5-32)	78.8 52-107	8.6 (3-18)	-	-	60	4	-	-
Thigh AP	66 (56-75)	17.4 (10-25)	103.3 82-124	23.1 (21.5-23.6)	-	-	-	-	-	-
Chest PA*	61 (44-85)	14 (4-48)	108 (22-85)	14 (11-20)	64-85	1	-	-	71 [c]	11 [c]
Skull AP*	62 (46-76)	18 (4-64)	93 (64-185)	15 (9-18)	60-62[f]	1-12 [f]	-	-	65 [c]	23 [c]

[a] Hart *et al.*, 2012, [b] Gkanatsios and Huda, 1997, [c] Freitas and Yoshimura, 2009, [d] Huda and Gkanatsios, 1998, [f] Compagnone et al., 2004, Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

Table 4.28 presents the mean ESD, estimated effective dose, body mass index (BMI) and De of male and female patients examined in this study for ESD. The dose distribution is

divided into male and female patients. Similarly, Table 4.29 presents the effective dose estimated from DAP for the same set of patients (as in Table 4.28). Most patients irradiated fall within the working class of Nigerians. The exceptions to these include male patients examined during the abdomen AP, and a female patient examined during hand AP examined.

Tables 4.30 and 4.31 present the doses (effective dose) calculated using ESD and DAP and the equivalent chest x-rays (based on 0.05 mSv per examination) and equivalent duration of exposure to nuclear radiation based on 3.0 mSv per yr. The effective doses presented in Tables 4.30 and 4.31 are mean values of effective doses estimated using Orgdose. If the DAP of abdomen AP is taken into consideration, the result of upper bound of Table 4.29 shows an effective dose of 7.28 mSv (abdomen AP), this is equivalent to more than 200 chest radiographs for just one abdomen AP radiograph.

Table 4.28: Statistical parameters for the room mean ESD (mGy), effective dose (mSv)distribution among the hospitals and anthropometrical information of male and female Adults.

Exam Type	N	Mean age (yr)	**Mean ESD (mGy) (SEM)	Effec. dose (mSv)	BMI (kg/m^2)	Equiv. Diameter D_e (cm)
Chest PA	156 (m)	42 (17-90)	2.43 ± 0.28 (0.060-27.04)	0.28 (0.007-3.16)	22.85	22.16
	150 (f)	46 (17-45)	2.19 ± 0.26 (0.019-17.66)	0.27 (0.002-2.06)	25.66	22.71
Abdo AP	10 (m)	63 (38-79)	7.42 ± 2.40 (1.44-21.54)	0.55 (0.19-2.81)	23.23	21.74
	10 (f)	56 (31-80)	15.17 ± 4.52 (2.00-37.42)	1.12 (0.026-2.76)	24.18	23.15
Pelvis AP	21 (m)	44 (19-74)	5.52 ± 0.68 (0.52-11.48)	0.61 (0.57-1.26)	23.25	22.56
	14 (f)	55 (35-70)	1.45 ± 0.24 (0.30-2.66)	0.16 (0.033-0.29)	29.71	24.68
Lumbar AP	48 (m)	54 (21-76)	6.03 ± 1.37 (0.093-38.10)	0.72 (0.0011-4.54)	24.33	22.28
	39 (f)	48 (20-73)	3.89 ± 0.68 (0.13-23.88)	0.46 0.016-2.86	26.36	23.09
Skull AP	21 (m)	47 (19-80)	8.26 ± 2.39 (1.17-43.19)	0.073 (0.011-0.40)	21.77	21.81
	11 (f)	34 (20-68)	4.31 ± 1.08 1.26 – 11.88	0.04 (0.012-0.11)	21.91	22.55
Leg AP	30 (m)	38 (16-82)	1.25 ± 0.26 (0.022-3.95)	--	25.07	11.42+
	16 (f)	44 (16-73)	1.18 ± 0.28 (0.11-3.55)	--	28.42	13.92+
Hand AP	35 (m)	38 (20-70)	1.42 ± 0.27 (0.036-3.76)	--	21.67	8.87+
	10 (f)	61 (19-70)	1.08 ± 0.39 (0.12-2.52)	--	19.75	6.21+

+ represents the thickness of the irradiated region, ** Corrected ESD value.

Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

Table 4.29 : Statistical parameters for the room mean DAP (Gy cm^2) distribution among the hospitals and anthropometrical information of male and female (adults)

Exam Type	N	Mean age (yr)	Mean DAP(Gy cm^2) (SEM)	Effec. dose (mSv)	BMI (kg/m^2)	Equiv. Diameter D_e (cm)
Chest PA	156 (m)	42 (17-90)	3.22 (0.44)	0.44 (0.0052-5.34)	22.85	22.16
	150 (f)	46 (17-45)	2.87 (0.41)	0.39 (0.0012-0.41)	25.66	22.71
Abdo AP	10 (m)	63 (38-79)	8.48 (3.09)	0.89 (0.14-2.93)	23.23	21.74
	10 (f)	56 (31-80)	24.10 (8.65)	2.56 (0.18-7.28)	24.18	23.15
Pelvis AP	21 (m)	44 (19-74)	4.45 (0.62)	0.78 (0.078- 2.20)	23.25	22.56
	14 (f)	55 (35-70)	1.23 (0.25)	0.20 (0.12-0.39)	29.71	24.68
Lumbar AP	48 (m)	54 (21-76)	3.46 (0.83)	0.84 (0.0087-5.86)	24.33	22.28
	39 (f)	48 (20-73)	1.89 (0.26)	0.46 (0.0015-1.69)	26.36	23.09
Skull AP	21 (m)	47 (19-80)	5.39 (1.78)	0.16 (0.021-0.96)	21.77	21.81
	11 (f)	34 (20-68)	2.54 (0.75)	0.078 (0.019-0.24)	21.91	22.55
Leg AP	30 (m)	38 (16-82)	1.19 (0.21)	--	25.07	11.42
	16 (f)	44 (16-73)	0.95 (0.22)	--	28.42	13.92
Hand AP	35 (m)	38 (20-70)	0.97 (0.16)	--	21.67	8.87
	10 (f)	61 (19-70)	0.74 ()	--	19.75	6.21

Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

Table 4.30: Doses ((ESD (mGy), ED (mSv)), equivalent number of chest x-rays and equivalent duration of exposure to natural radiation (ED –calculated according ICRP 103)

Examination	ESD (mGy)	Efective dose (mSv) (ICRP 103)	Equivalent number of chest X-rays +	Equivalent duration of exposure to natural radiation (Week)++
Chest PA	2.32	0.27	5.4	4.7
Abdo AP	11.72	0.86	17.3	15
Pelvis AP	4.05	0.45	13.7	11.8
Lumb AP	4.74	0.55	11.9	10.3
Head AP	7.07	0.21	4.3	3.7
Thigh AP	0.50	0.02	0.4	0.3
Chest PA*	1.99	0.26	4.8	4.2
Head AP*	2.05	0.028	0.6	0.5

*** Paediatric patient, +based on 0.05mSv per chest X-ray, ++ based on 3.0 mSv/year**

Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

Table 4.31 : Doses (DAP (Gy cm^2)), ED (mSv)), equivalent number of chest x-rays and equivalent duration of exposure to natural radiation (ED –calculated according to ICRP 103)

Examination	(DAP (Gy cm^2)	Efective dose (mSv) (ICRP 103)	Equivalent number of chest X-rays $^+$	Equivalent duration of exposure to natural radiation (Week)$^{++}$
Chest PA	3.06	0.42	8.3	7.2
Abdomen AP	17.16	1.82	36.4	31.5
Pelvis AP	3.28	0.52	10.4	9.0
Lumb AP	2.72	0.66	13.2	11.5
Skull AP	4.53	0.14	2.7	2.4
Thigh AP	0.18	0.0.020	0.4	0.3
Chest PA*	3.62	1.04	20.8	18.0
Skull AP*	2.13	0.12	2.2	1.9

*** Paediatric patient +based on 0.05mSv per chest x-ray, ++based on3.0 mSv/year**
Abdo AP-Abdomen AP, Lumb AP-Lumbar spine AP

4.5 Cancer Risk Estimations

In this study organ dose was used to estimate the risk associated with medical exposure in terms of lifetime attributable risk (LAR) and attributable risk fraction. Lifetime attributable risk (LAR) of cancer and attributable risk fraction (ARF) were calculated using models based on patient age and sex. The results of the risk estimation are presented in this section.

Tables 4.32 to 4.41 are the results of the calculated LAR and ARF for both cancer incidence and mortality for 10, 000 of the population: 5-yr old girl (chest PA), 7-yr old boy (chest PA), 42-yr old man (chest PA), 46-yr old woman (chest PA), 44-yr old man (pelvis AP), 55-yr old woman (pelvis AP), 63-yr old man (abdomen AP), 56-yr old woman (abdomen AP), 54 yr old man (lumbar spine AP), and 48 yr old woman (lumbar AP). In Tables 4.32- 4.41, Column 1 indicates the organs within the sites exposed to radiation during patient examination. Column 2 shows the organ doses calculated during irradiation. The third and fourth columns show the expected life attributable risk (incidence and mortality) calculated, while the fifth and sixth columns show the attributable risk fractions (ARF).

An attempt was made to make the results of LAR calculated meaningful; it was extrapolated to the population of Southwestern, Nigeria. The results of extrapolation of data shown in Tables 4.32 to 4.41 are shown in Figures 4.10 to 4.19. The results in Tables 4.32 to 4.41 are based on population of 10, 000, they are extrapolated to the population of 35.5 million people found in the south west geo-political zone of Nigeria (NBS, 2013). The Figures show different types of cancer: Figures 4.10 - 4.13 (lung, breast, easophagus, and stomach, liver); Figures 4.14 - 4.19: (bladder, liver, colon, stomach, lung). Both the numbers of incidences (occurences) and mortality (deaths) resulting from an exposure are shown. The blue bars indicate the incidence rate and the red bars, the mortality rate. The distribution of lifetime attributable risk (LAR), incidence and mortality for all solid cancer based on a population of 35.5 million is presented in Figure 4.20. Ten representative patients of different ages and four procedures were considered. The procedures are: chest (A-D), pelvis (E and F), abdomen (G and H) and lumbar (I and J). Similarly, the blue bars represent the number of expected cancer incidences, and the red bars indicate the number of deaths expected from the exposure.

Figures 4.21- 4.25 present the plots of attributable risk fraction (ARF) against attained age for a girl exposed at age of five. The plots show the distribution of ARF starting from the age when exposed (5 yr) through different attained ages up till 80 years. Figure

4.21 shows the incidence of lung cancer; Figure 4.22 is the plot for the incidence of breast cancer; Figure 4.23 describes the characteristics of the incidence of liver cancer at different attained ages following a single exposure. The ARF (%) plot as against the attained age for the incidence of easophagus cancer is presented in Figure 4.24. The incidence is highest at the age of 60 year. Figure 4.25 is the ARF for incidence of stomach cancer. The ARF decreases gradually to a minimum before rising again beyond 70 years.

Table 4.32: Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a ≈ 5 year-old girl after a chest PA radiographic imaging.

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	ARF^{inc} (%)	ARF^{mort} (%)
Lung	0.47	0.0725	0.0712	0.0200	0.0241
Breast	0.12	0.0638	0.0289	0.00890	0.0148
Easophagus	0.16	0.00232	0.00230	0.00460	0.00490
Stomach	0.076	0.0148	0.0102	0.00560	0.00792
Liver	0.15	0.00600	0.00550	0.00510	0.00671
All solid cancer	--	2.245	1.0136	---	----
$ARF_{total}^{inc} = 0.0101$ $ARF_{total}^{mort} = 0.0158$ $ARF_{total}^{in,solid} = 0.0773$ $ARF_{total}^{mort,solid} = 0.0695$					

Table 4.33: Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a ≈ 7-year old boy after a chest PA radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Lung	0.87	0.0699	0.0616	0.00961	0.0102
Breast	0.21	0.0	0.0	0.0	0.0
Easophagus	0.32	0.00797	0.00590	0.00678	0.00512
Stomach	0.17	0.0241	0.0125	0.00487	0.00514
Liver	0.34	0.0293	0.0257	0.0118	0.0151
All solid cancer	--	2.623	1.388	--	--
$ARF_{total}^{inc} = 0.00826$ $ARF_{total}^{mort} = 0.00033$ $ARF_{total}^{in,solid} = 0.0387$ $ARF_{total}^{mort,solid} = 0.00513$					

Table 4.34 : Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a 42-year old man after a chest PA radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Lung	0.945	0.0869	0.0766	0.01170	0.01242
Breast	0.170	0	0	0	0
Easophagus	0.422	0.00591	0.00543	0.004924	0.004611
Stomach	0.206	0.0101	0.00526	0.002024	0.002137
Liver	0.420	0.0122	0.00512	0.004898	0.003026
All solid cancer	--	0.9798	0.5188	--	--
$ARF_{total}^{inc} = 0.00720$ $ARF_{total}^{mort} = 0.0080$ $ARF_{total}^{in,solid} = 0.0469$ $ARF_{total}^{mort,solid} = 0.0144$					

Table 4.35 : Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a 46-year old woman after a chest PA radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Lung	0.797	0.139	0.137	0.0392	0.0464
Breast	0.136	0.00854	0..00385	0.00135	0.00211
Easophagus	0.338	0.00518	0.00505	0.0101	0.0106
Stomach	0.163	0.00849	0.00588	0.00339	0.00466
Liver	0.345	0.00441	0.00409	0.00376	0.00506
All solid cancer	--	1.0065	0.4544	--	--
$ARF_{total}^{inc} = 0.01179$ $ARF_{total}^{mort} = 0.02128$ $ARF_{total}^{in,solid} = 0.03681$ $ARF_{total}^{mort,solid} = 0.03182$					

Table 4.36 : Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a 44-year old man after a pelvis AP radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Bladder	2.51	0.108	0.0411	0.0427	0.0594
Liver	0.092	0.00276	0.00242	0.00110	0.00143
Colon	1.28	0.0941	0.0505	0.02435	0.03168
Stomach	0.15	0.00735	0.00380	0.00147	0.00151
Lung	0.0028	0.000258	0.000226	0.0000347	0.0000366
All solid cancer	--	2.23	1.1785	---	---
$ARF_{total}^{inc} = 0.00999$ $ARF_{total}^{mort} = 0.00778$ $ARF_{total}^{in,solid} = 0.0617$ $ARF_{total}^{mort,solid} = 0.0564$					

Table 4.37: Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a 55- year old woman after a pelvis AP radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	ARF^{inc} (%)	ARF^{mort} (%)
Bladder	0.68	0.0169	0.004766	0.0215	0.0175
Liver	0.026	0.000197	0.000182	0.000174	0.000236
Colon	0.35	0.00557	0.00281	0.00182	0.00202
Stomach	0.041	0.00128	0.000884	0.000541	0.000727
Lung	0.000821	0.00012	0.000119	0.0000358	0.000422
All solid cancer	--	0.3841	0.1734	--	--
$ARF_{total}^{inc} = 0.0000112$ $ARF_{total}^{mort} = 0.00000691$ $ARF_{total}^{in,solid} = 0.0155$ $ARF_{total}^{mort,solid} = 0.0128$					

Table 4.38 : Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a ≈ 63-year old man after an abdomenAP radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	ARF^{inc} (%)	ARF^{mort} (%)
Bladder	3.420	0.0643	0.0245	0.0271	0.0342
Liver	1.425	0.0117	0.0103	0.00587	0.00739
Colon	2.000	0.0478	0.0256	0.0138	0.0168
Stomach	2.560	0.0398	0.0206	0.00864	0.00878
Lung	0.064	0.00391	0.0034	0.000559	0.000583
All solid cancer	--	0.927	0.491	--	--
$ARF_{total}^{inc} = 0.00868$ $ARF_{total}^{mort} = 0.00706$ $ARF_{total}^{in,solid} = 0.0249$ $ARF_{total}^{mort,solid} = 0.0279$					

Table 4.39 : Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a ≈ 56-year old woman after an abdomen AP radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Bladder	8.25	0.206	0.0579	0.261	0.212
Liver	3.55	0.0272	0.0252	0.0241	0.0326
Colon	5.61	0.0893	0.0449	0.0292	0.0324
Stomach	6.21	0.192	0.133	0.0809	0.109
Lung	1.93	0.284	0.278	0.0846	0.0989
All solid cancer	--	4.0185	1.814	--	--
$ARF_{total}^{inc} = 0.0745$ $ARF_{total}^{mort} = 0.0425$ $ARF_{total}^{insolid} = 0.162$ $ARF_{total}^{mortsolid} = 0.135$					

Table 4.40 : Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a ≈ 54-year old man after a lumbar spine AP radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Bladder	1.01	0.0321	0.0122	0.0127	0.0173
Liver	1.36	0.0244	0.0214	0.0103	0.0134
Colon	1.59	0.0763	0.0406	0.0203	0.0256
Stomach	2.33	0.0726	0.0375	0.0149	0.0153
All solid cancer	--	1.540	0.816	--	--
$ARF_{total}^{inc} = 0.00759$ $ARF_{total}^{mort} = 0.0176$ $ARF_{total}^{in,solid} = 0.00433$ $ARF_{total}^{mort,solid} = 0.0394$					

Table 4.41: Lifetime attributable risk of cancer incidence and mortality for 10,000 population and etiologic fraction of cancer incidence and mortality for a ≈ 48 year old woman after a lumbar spine AP radiographic imaging

Organ	Organ dose (mGy)	LAR^{inc}	LAR^{mort}	$ARFi^{nc}$ (%)	ARF^{mort} (%)
Bladder	0.64	0.0238	0.00609	0.0291	0.0224
Liver	0.86	0.0111	0.0102	0.00943	0.0126
Colon	1.01	0.0211	0.0133	0.00481	0.00928
Stomach	1.48	0.0771	0.0533	0.0112	0.00885
All solid cancer	--	1.787	0.807	---	--
$ARF_{total}^{inc} = 0.0172$ $ARF_{total}^{mort} = 0.0219$ $ARF_{total}^{in,solid} = 0.0654$ $ARF_{total}^{mort,solid} = 0.0565$					

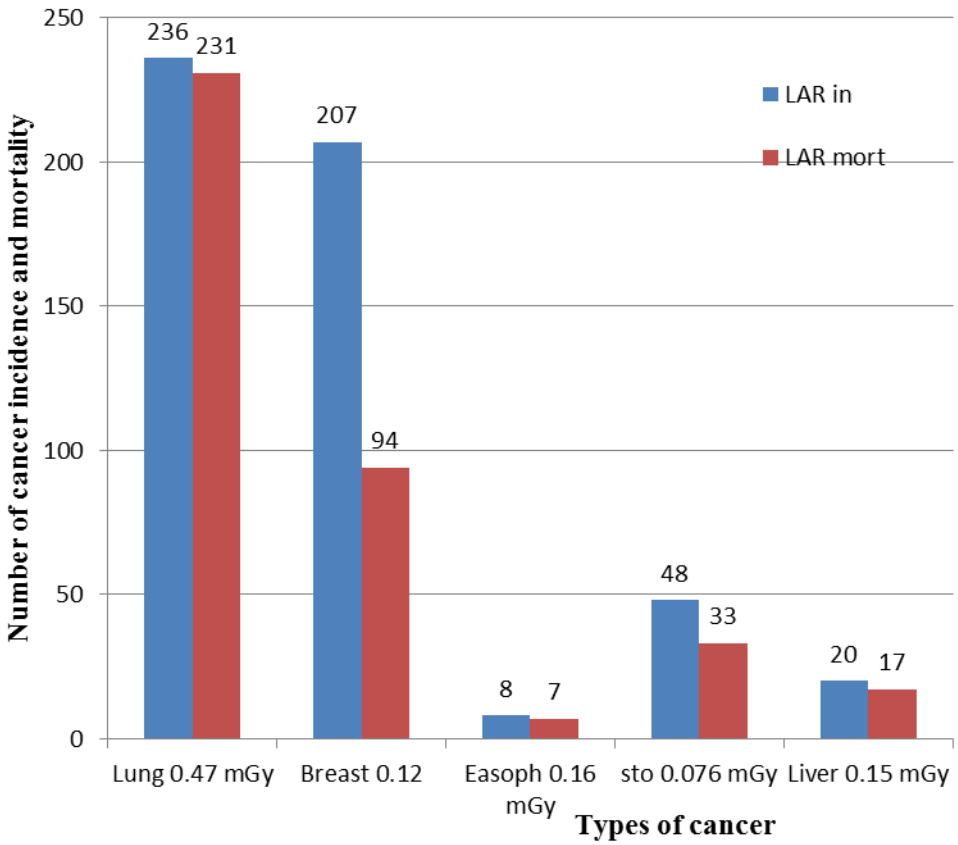

Figure 4.10: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (5 yr old girl chest PA radiograph)

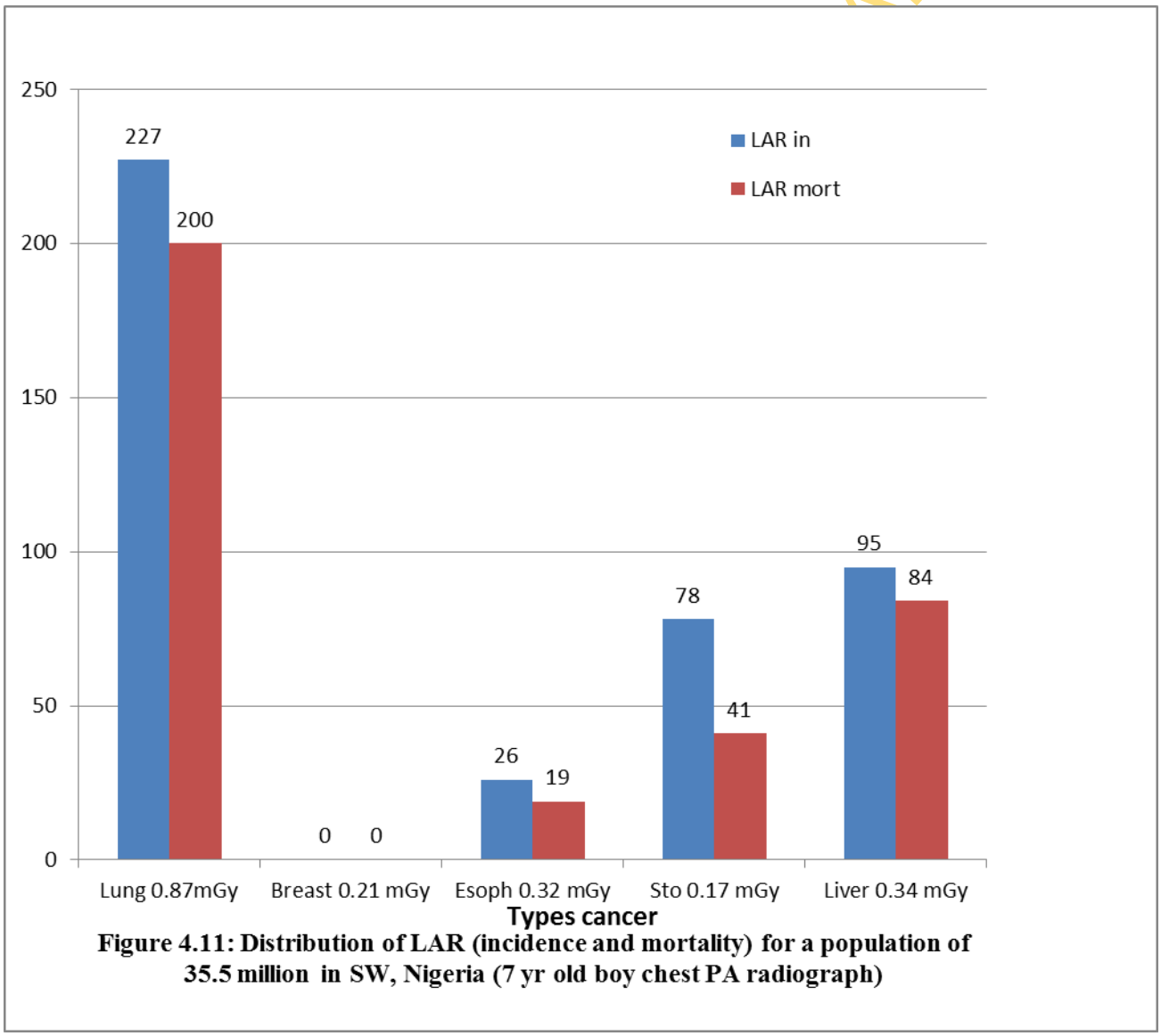

Figure 4.11: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (7 yr old boy chest PA radiograph)

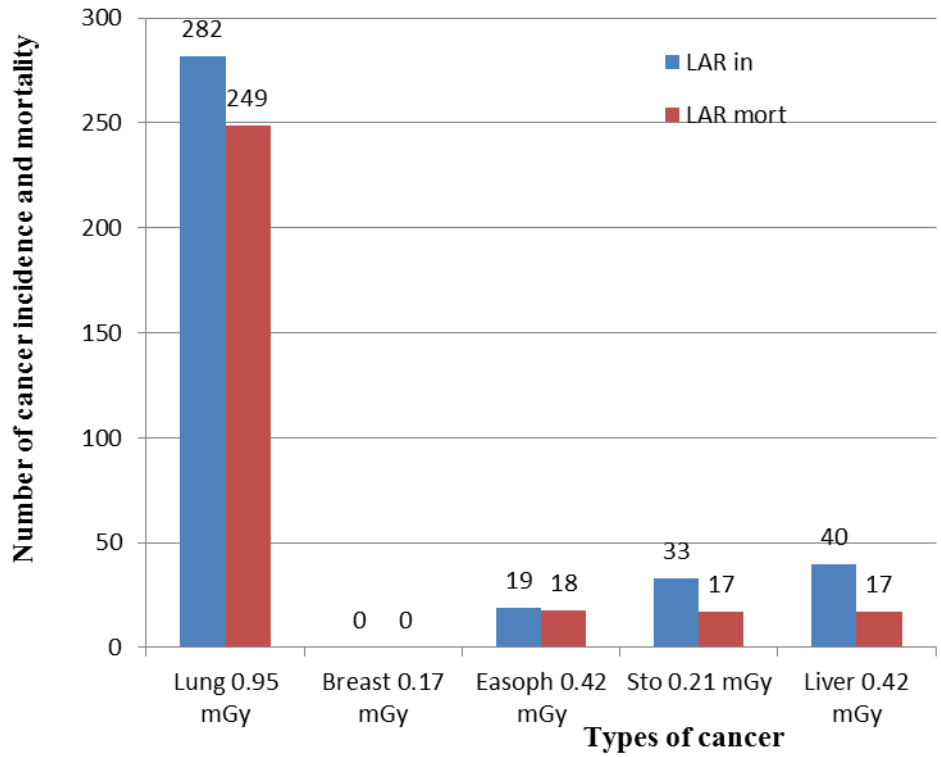

Figure 4.12: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (42 yr old man chest PA radiograph)

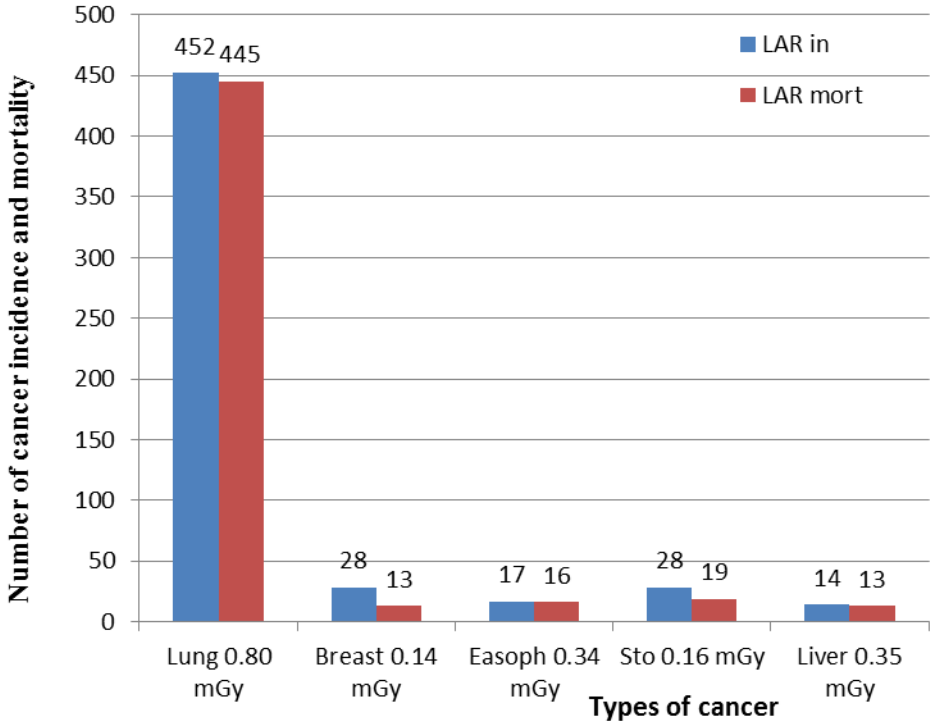

Figure 4.13: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (46 yr old woman chest PA radiograph)

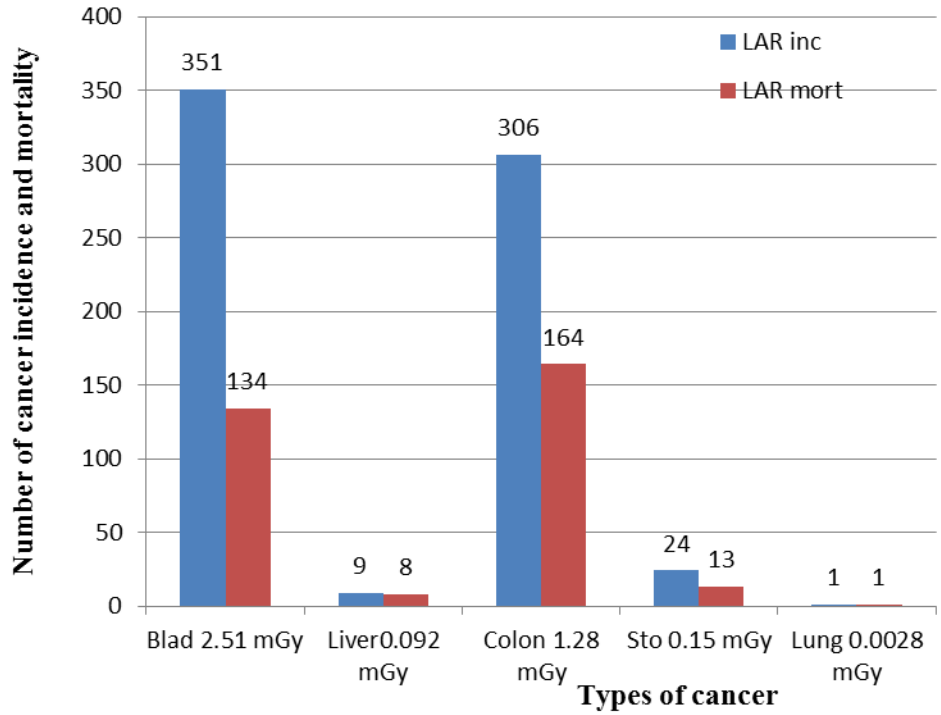

Figure 4.14: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (44 yr old man pelvis AP radiograph)

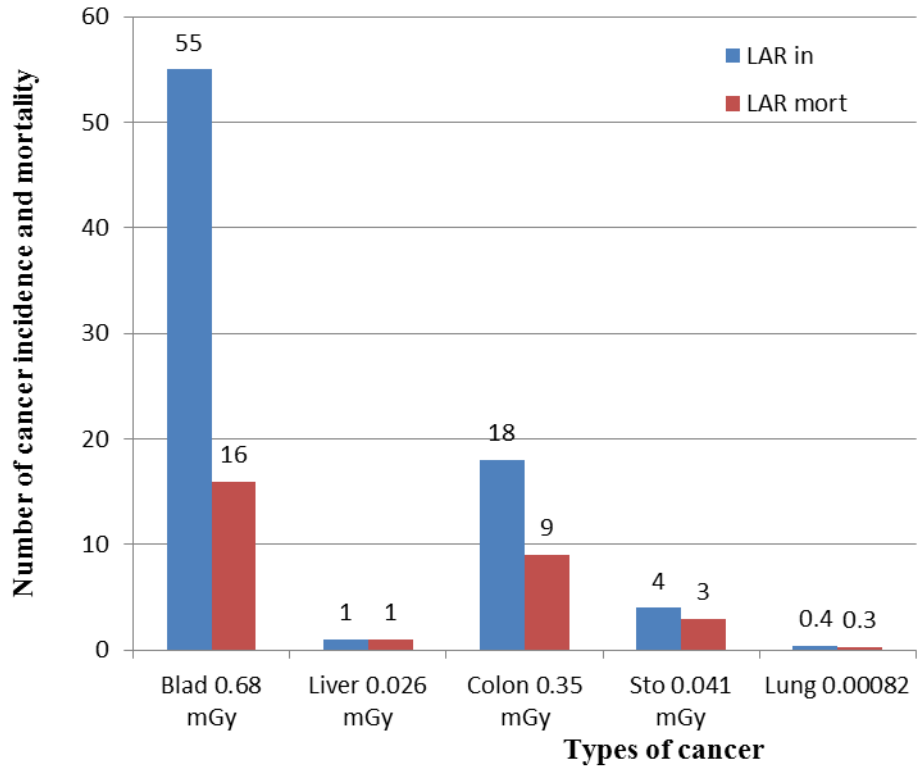

Figure 4.15: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (55 yr old woman pelvis AP radiograph)

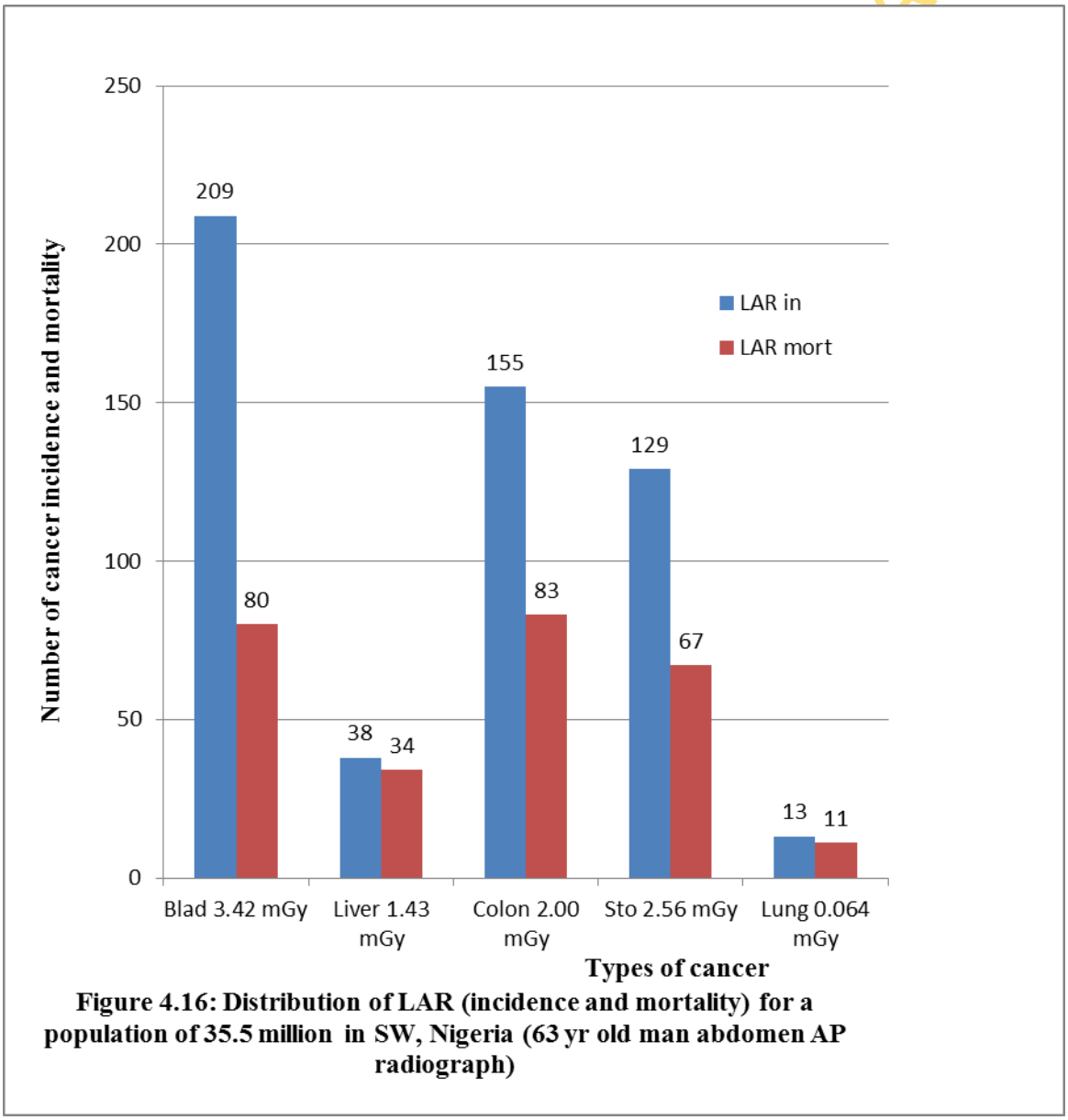

Figure 4.16: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (63 yr old man abdomen AP radiograph)

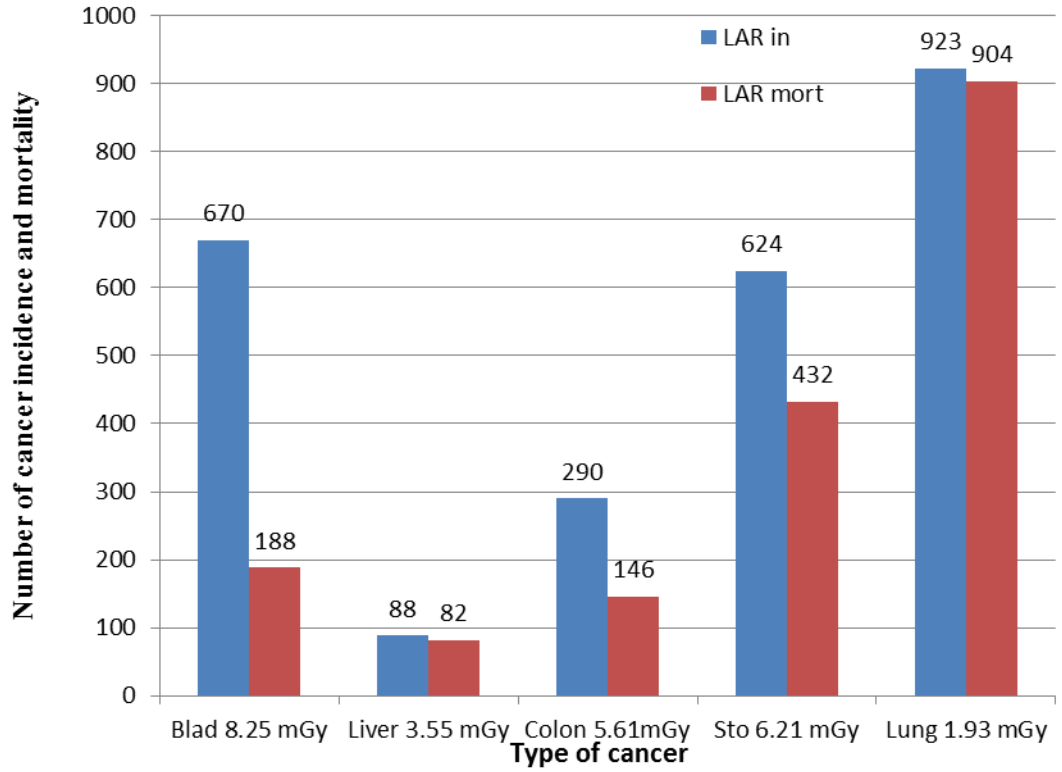

Figure 4.17: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (57 yr old woman abdomen AP radiograph)

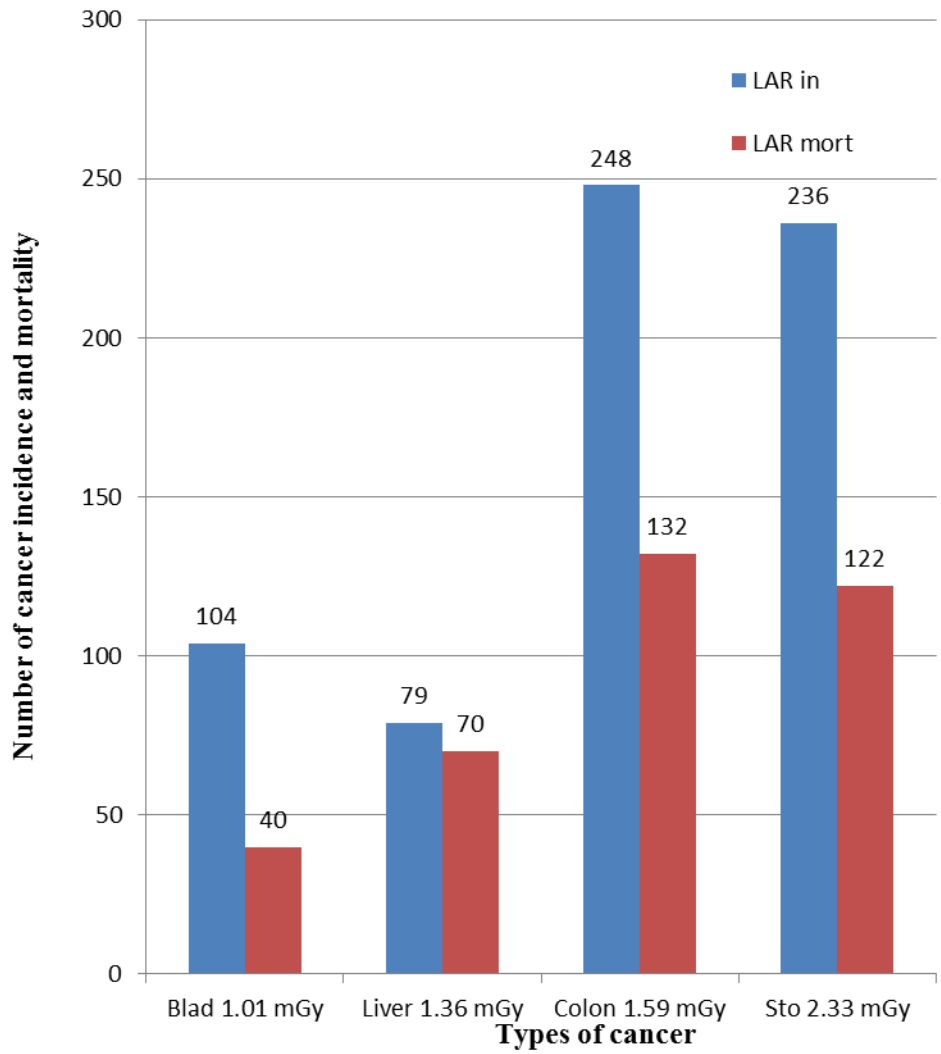

Figure 4.18: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (54 yr old man lumbar spine AP radiograph)

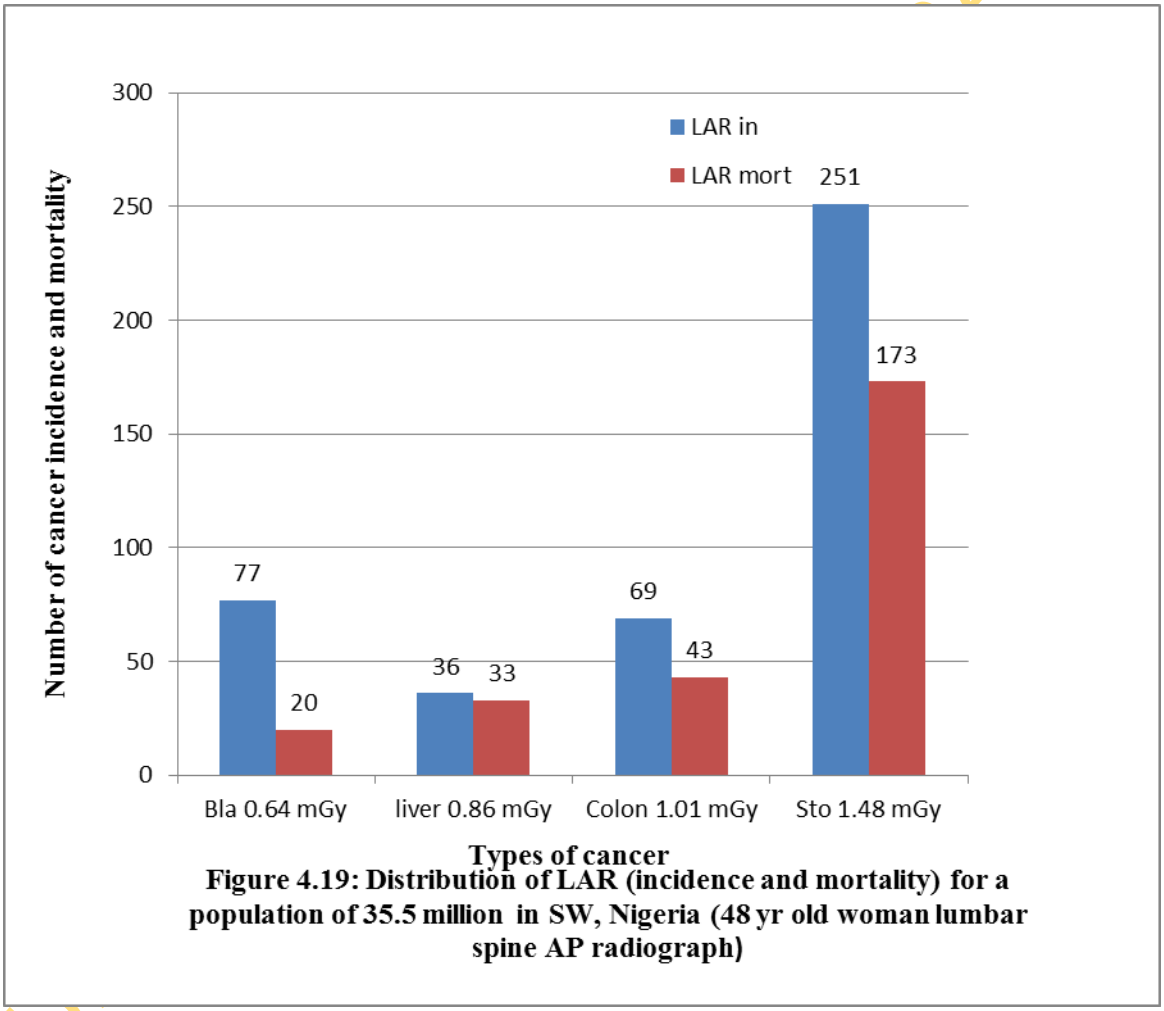

Figure 4.19: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (48 yr old woman lumbar spine AP radiograph)

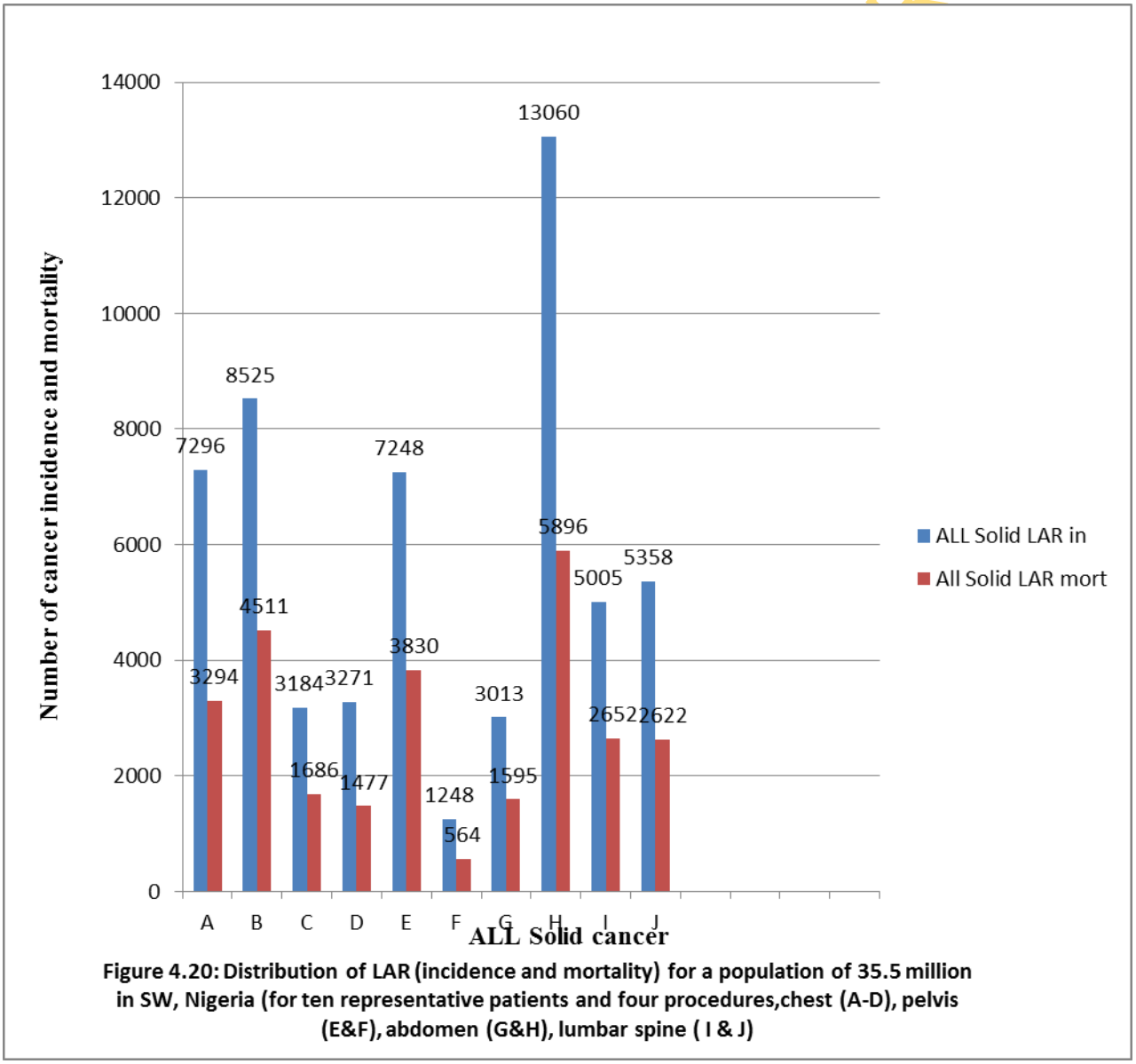

Figure 4.20: Distribution of LAR (incidence and mortality) for a population of 35.5 million in SW, Nigeria (for ten representative patients and four procedures,chest (A-D), pelvis (E&F), abdomen (G&H), lumbar spine (I & J)

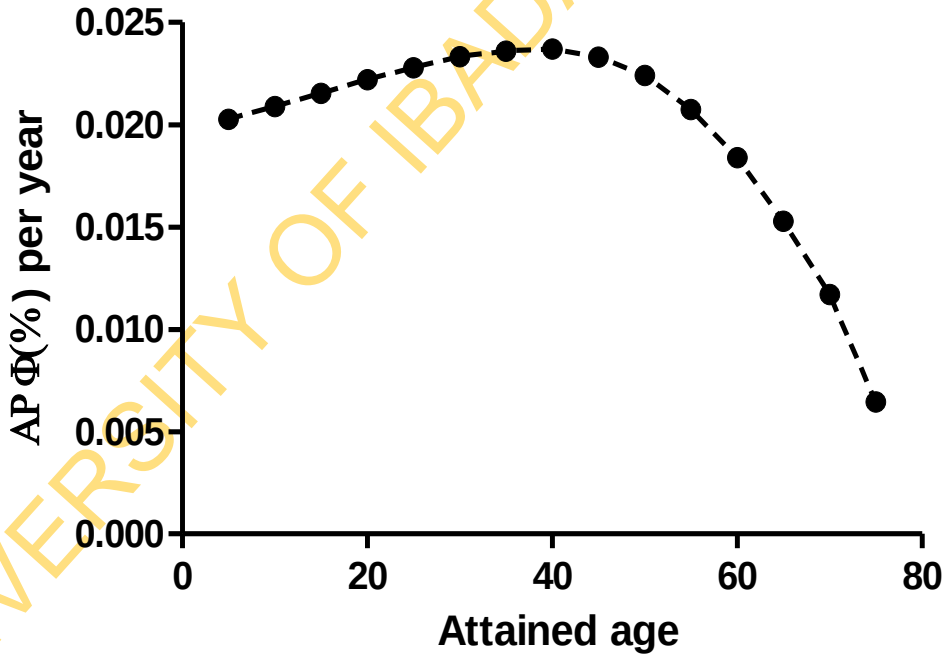

Figure 4.21: Attributable risk fraction for incidence of lung cancer following a single exposure of a 5-year old girl with a dose of 1.32 mGy from a conventional chest radiography

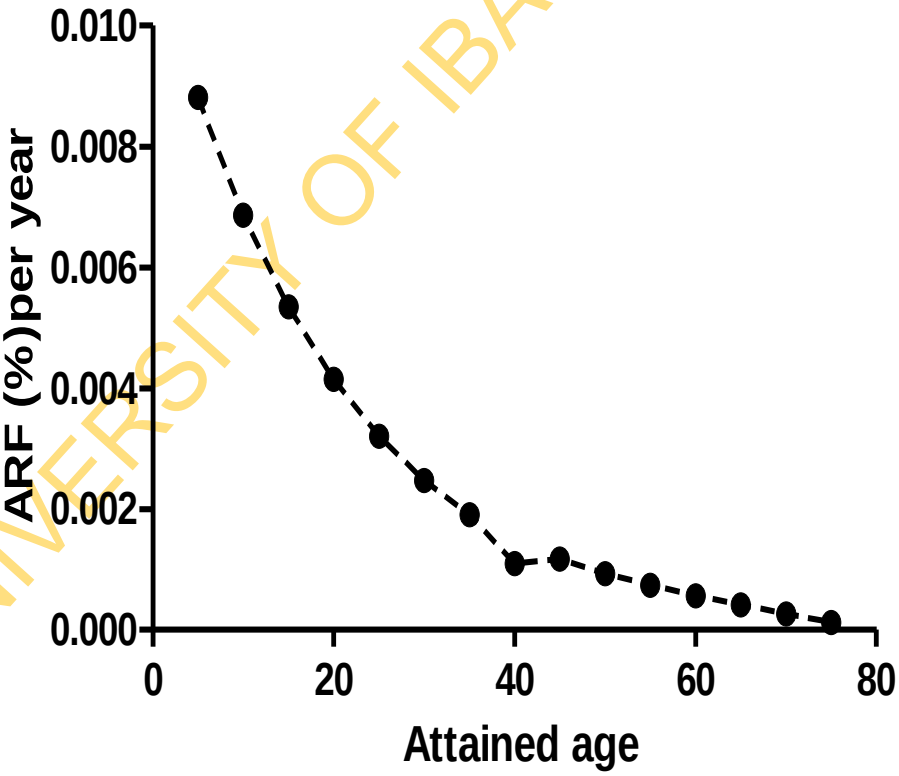

Figure 4.22: Attributable risk fraction for incidence of breast cancer following a single exposure of a 5-year old girl with a dose

of 1.32 mGy from a conventional chest radiography.

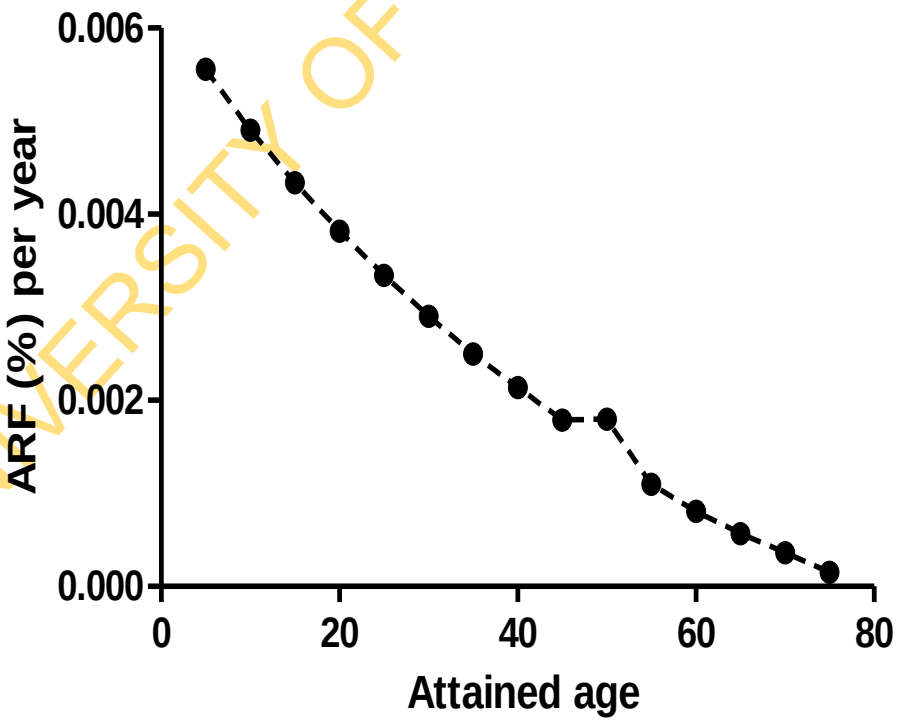

Figure 4.23: Attributable risk fraction for incidence of liver cancer

following a single exposure of a 5-year old girl with a dose of 1.32 mGy from a conventional chest radiography.

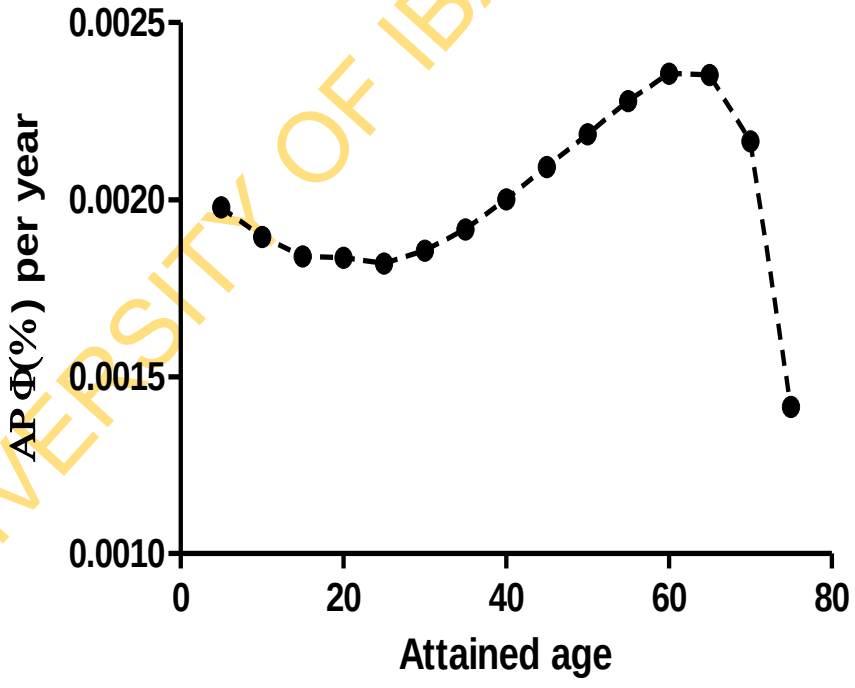

Figure 4.24: Attributable risk fraction for incidence of easophagus cancer following a single exposure of a 5-year old girl with a dose of 1.32 mGy from a conventional chest radiography.

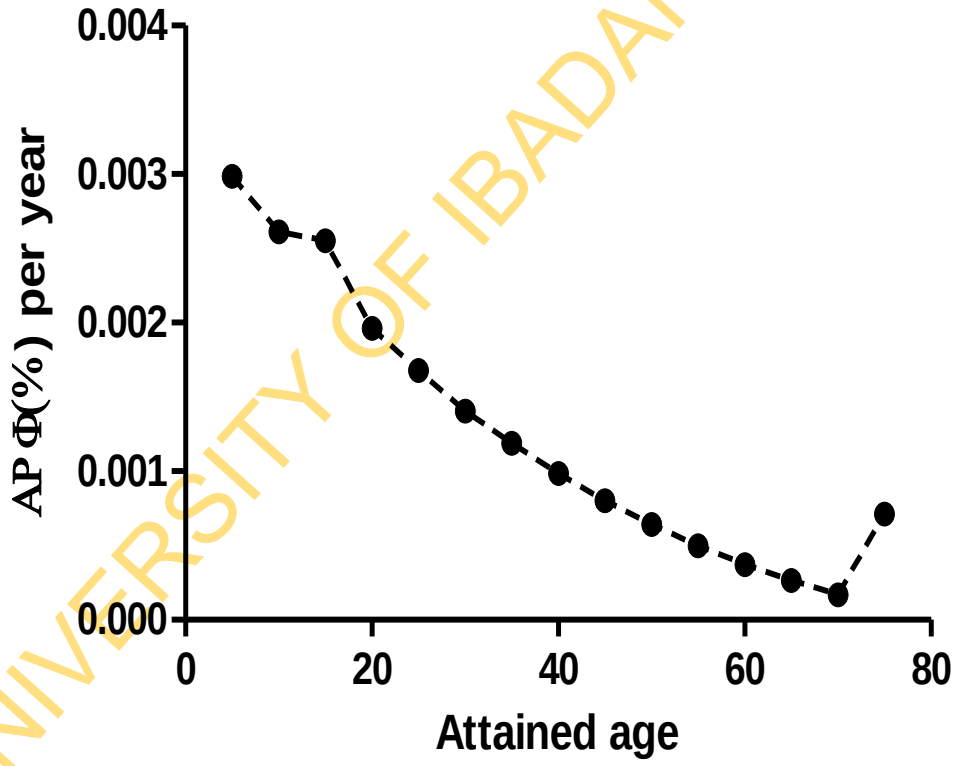

Figure 4.25 Attributable risk fraction for incidence of stomach cancer following a single exposure of a 5-year old girl with a dose of 1.32 mGy from a conventional chest radiography.

4.6 Patient and exposure characteristics

Results of some factors affecting patient dose (patient characteristics, machine parameters) are presented in this section. These include the thickness of the patient (equivalent diameter), weight, height, tube voltage (kVp), tube load (mAs). Results of the relationship between the factors are also presented in the section.

Table 4.42 presents the results of analysis of correlation between patient equivalent diameter (De), and body mass index (BMI). The two parameters could be calculated from patient weight and patient height. Body mass index is patient classification mechanism (underweight, normal weight and overweight) while patient equivalent diameter (De) accounts for patient constitution and shape.

An appropriate linear relationship between patient weight and thickness was established for chest PA (paediatrics), lumbar spine AP, pelvis AP, abdomen AP (adult) and chest PA (adults-male and female). Figures 4.26 – 4.31 show the plots of body thickness against patient weight (kg). The correlations were obtained at 95% confidence interval and $p>0.0001$. The graphs show lines of best fit and worst lines. The relatively low R^2 =0.7532 in Figure 4.26 could be as a result of variability in paediatric patients age (0,1,5,10 and 15 yr) sizes and shapes as shown in Table 3.5. The ages range between <1yr (newborn) to ≤ 15yr (adolescence). Figures 4.30 and 4.31 are the plots of body thickness against body weight of standard male and female. Figure 4.32 presents the results of the application of the expression for patient thickness (chest PA- male) to the selection of mAs during patient exposure. The plot of mAs_{radio} (mAs used by radiographer in imaging patients), and mAs_{model} (the mAs obtained from application of patient thickness model and NRPB standard exposure factors) against patient thickness.

Figure 4.33 is a plot of tube load (mAs) against patient weight (kg). The graph reveals the choice of mAs by twelve hospitals during the study. The recorded low R^2 =0.0066 indicates that radiographers did not consider the patient weight in the choice of mAs. Figure 4.34 presents the plots of tube potential measured (kVmea) against patient weight, while Figure 4.35 presents the plot of tube potential set (kVset) against the patient weight during the routine examination. Figure 4.36 presents the plot of ESD calculated using the real machine kV output (measured with kV meter) against patient equivalent diameter (De). Figures 4.37 and 4.38 present the plots of corrected ESD against the equivalent diameter in chest PA and lumbar spine AP respectively.

Table 4.42: Statistical data of the analysis of correlation between De (cm) and BMI (kg m^{-2})

Exam.	Lumbar AP (Ad) Male	Chest PA (paediatric)	Lumbar AP (Adult) Female	Pelvis AP (Adult) Female	Pelvis AP (Adult) Male	Chest PA (adult)
n pairs	39	45	40	21	12	305
Pearson r	0.9360	0.09390	0.9200	0.9854	0.9646	0.9355
95% CI	0.8801-0.9162	0.02054-0.3771	0.8531-0.9574	0.9632-0.9942	0.8750-0.9903	0.9198-0.9482
P value (2 tailed)	<0.0001	0.0395	<0.0001	<0.0001	<0.0001	<0.0001
Significance of correlation	Yes	**No***	Yes	Yes	Yes	Yes
R^2	0.8761	0.008817	0.8471	0.9711	0.9304	0.8751

*** Low R^2 could be attributed to variability in the ages and sizes of paediatric patients.**

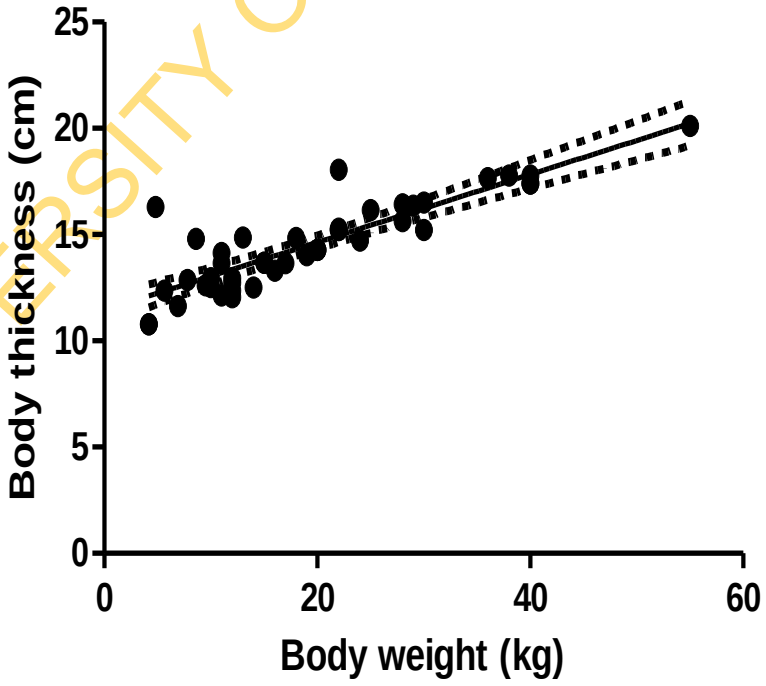

Figure 4.26: Graph of body thickness (cm) versus body weight for chest PA (paediatric) ($R^2 = 0.7532$), equation of t_e (body thickness) versus W (body weight in kg) is $t_{e_{che,PA,Ped}} = 0.16\,W + 11.44$

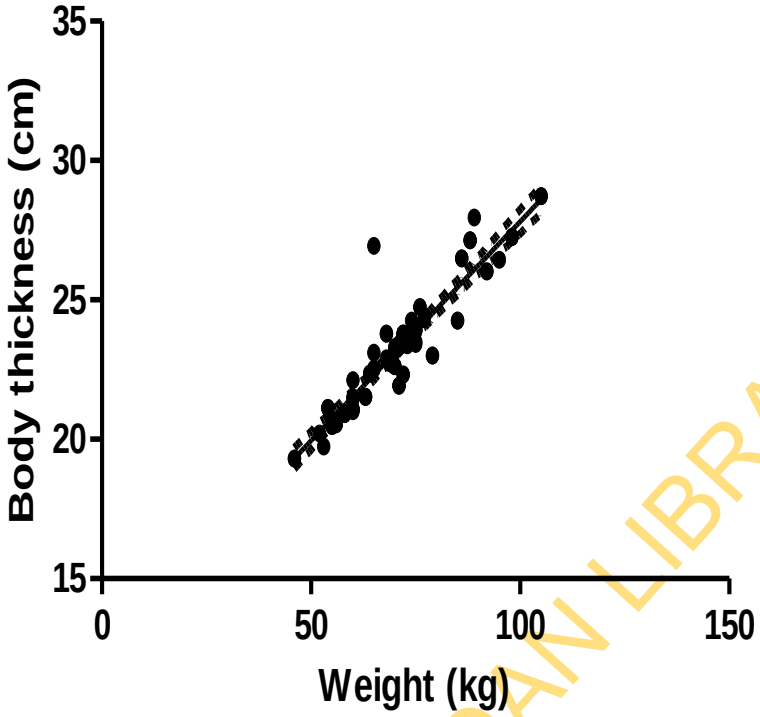

Figure 4.27: Graph of body thickness (cm) versus body weight for Lumbar AP (adult) (R^2 = 0.8649), equation of t_e (body thickness) versus W (body weight in kg) is $t_{e_{lum\ AP\ Ad}} = 0.16W + 12.08$

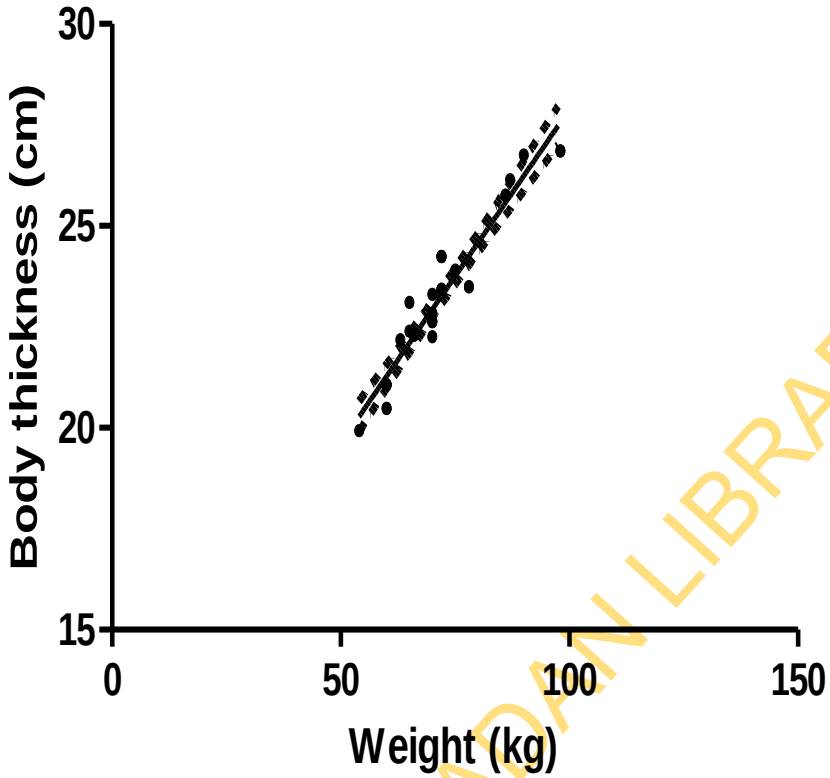

Figure 4.28: Graph of body thickness (cm) versus body weight for pelvis AP (adult) (R^2 = 0.9195), equation of t_e (body thickness) versus W (body weight in kg) is

$$t_{e_{pel,AP,Ad}} = 0.17W + 11.35$$

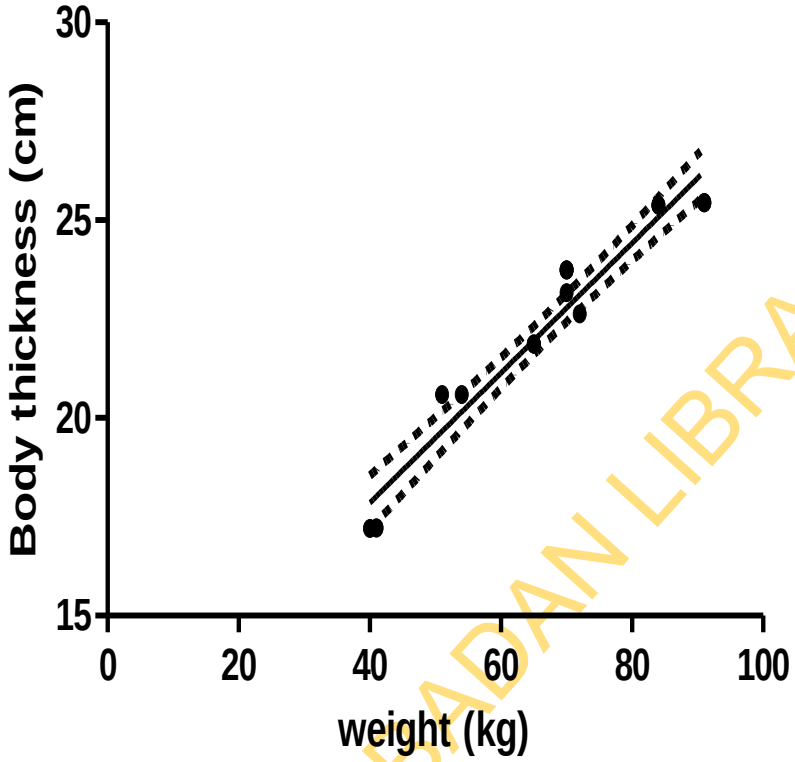

Figure 4.29: Graph of body thickness (cm) versus body weight for abdomen AP (adult) (R^2 = 0.9424), equation of t_e (body thickness) versus W (body weight in kg) is

$$t_{e\,Abd,AP,Ad} = 0.16W + 11.29$$

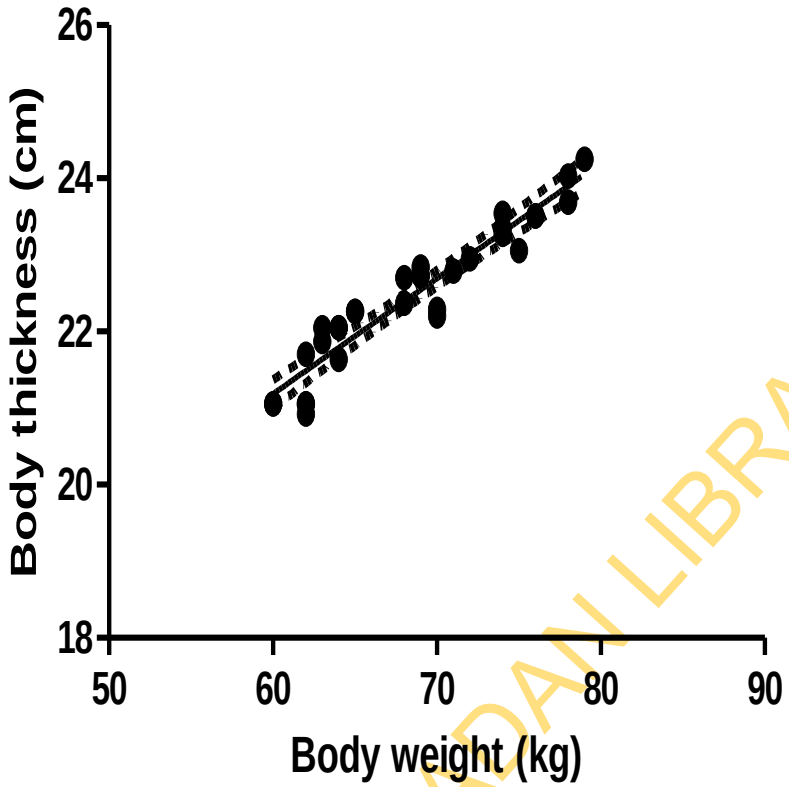

Figure 4.30 Graph of body thickness (cm) versus body weight for chest PA (standard male adult) (R^2 = 0.908), equation of t_e (body thickness) versus W (body weight in kg) is

$$t_{e,ches,PA,\ Ad} = 0.15\,W + 12.14$$

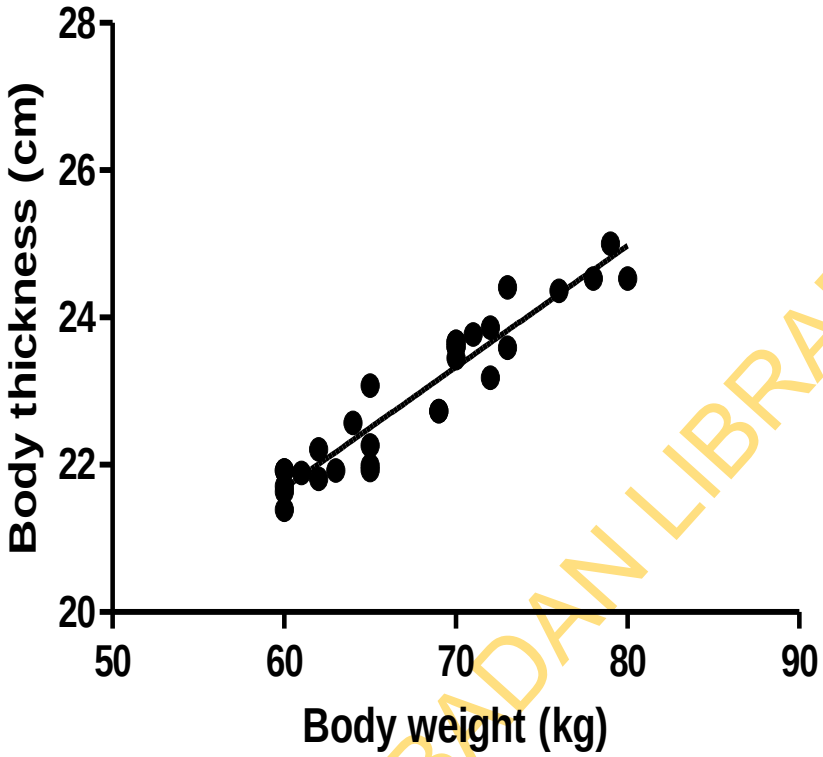

Figure 4.31: Graph of body thickness (cm) versus body weight for chest PA (standard female adult) (R^2 = 0.901), equation of t_e (body thickness) versus W (body weight in kg) is $t_{e_{che,PA,Ad}} = 0.17\,W + 11.79$

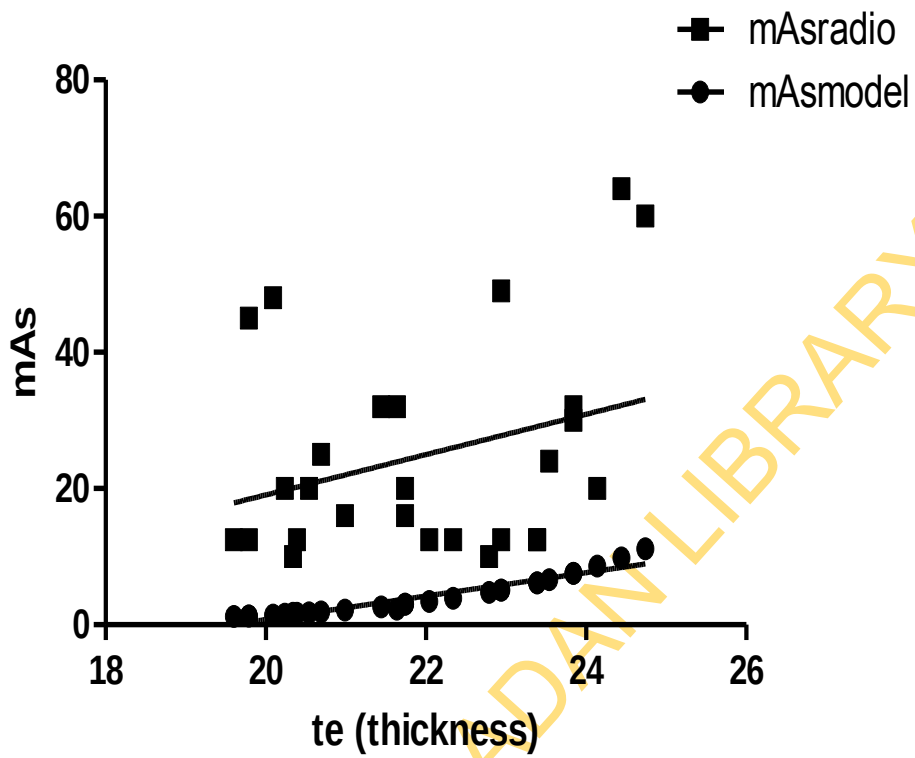

Figure 4.32: comparison of the mAs set using the patient thickness (mAsmodel) obtained in this study and NRPB data and value set by the radiographer (mAsradio) during routine examinations

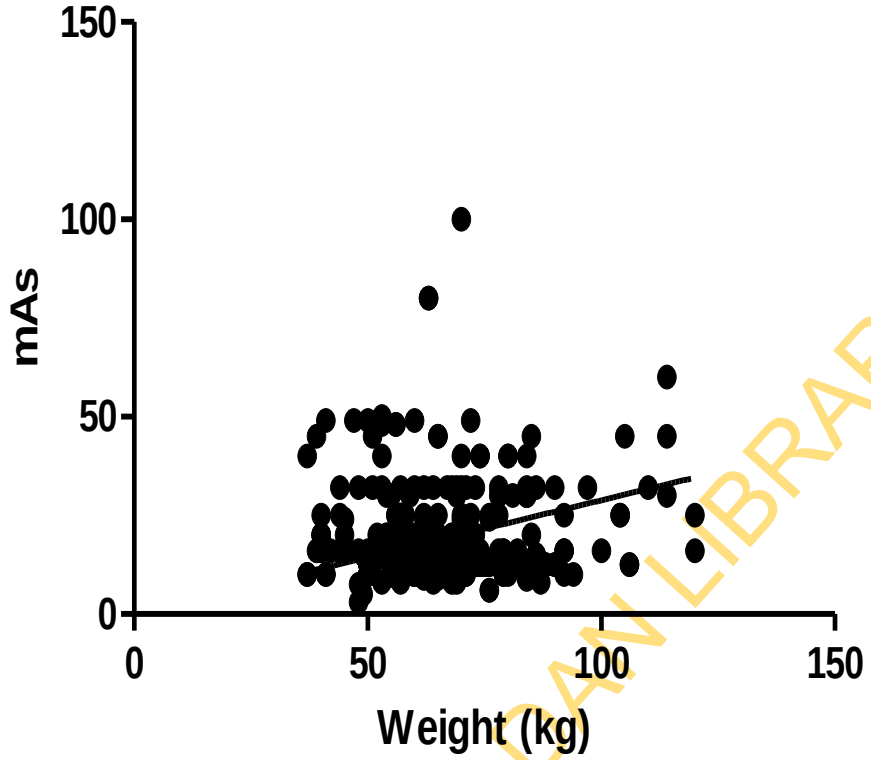

Figure.4.33 Graph of tube load (mAs) versus weight (kg) of adult patient chest for twelve hospitals ($R^2 = 0.0066$).

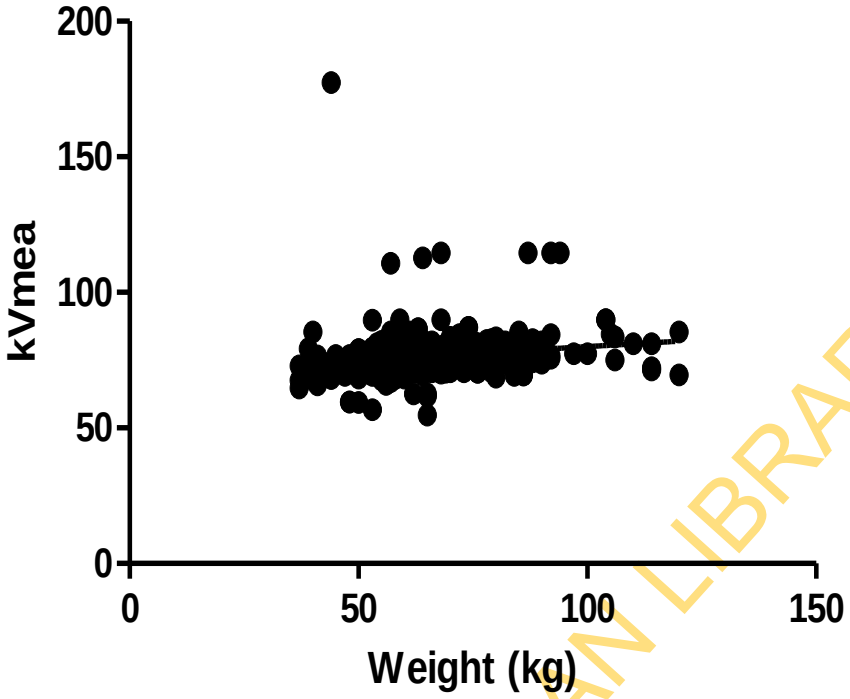

Figure 4.34: Graph of tube potential (kVp-measured) versus weight (kg) of adult patient chest for twelve hospitals ($R^2 = 0.0262$).

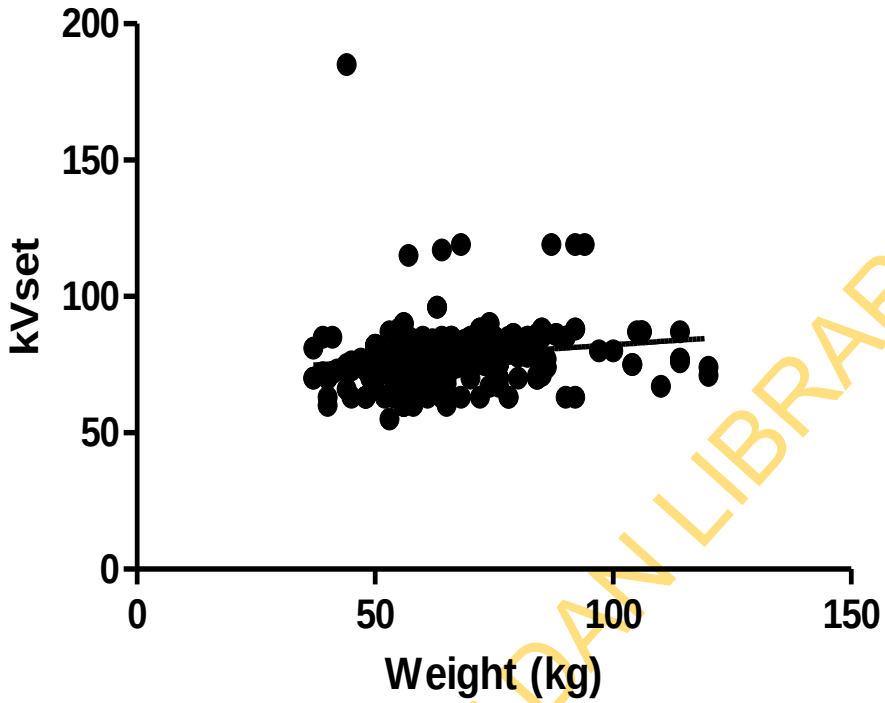

Figure 4.35: Graph of tube potential (kVp-set) versus weight (kg) of adult patient chest) for twelve hospitals ($R^2 = 0.0258$)

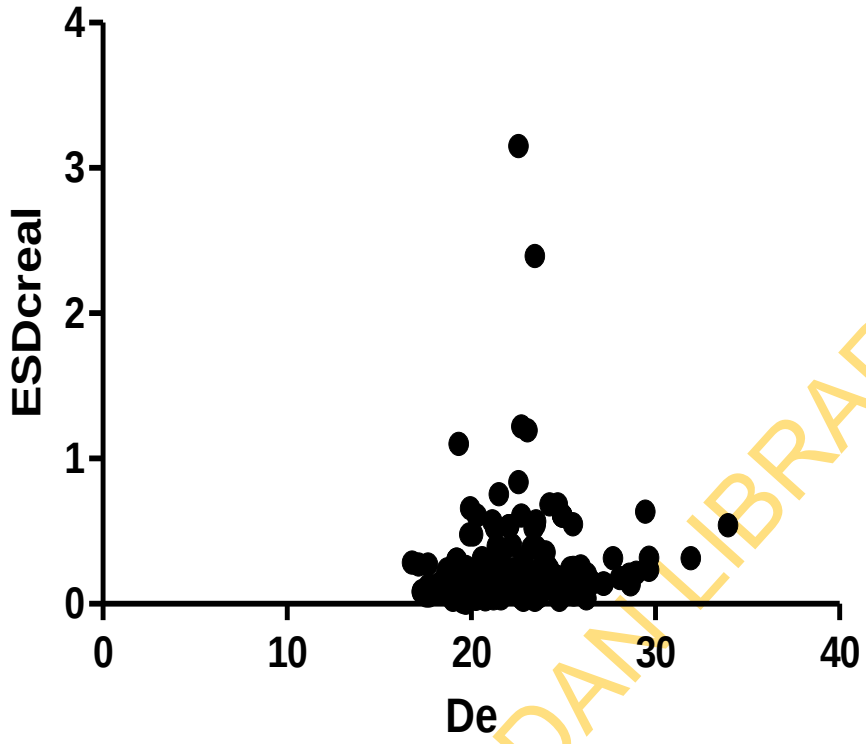

Figure 4.36: Graph of ESDcreal () against equivalent diameter (De) for adult patient (chest, n= 279)

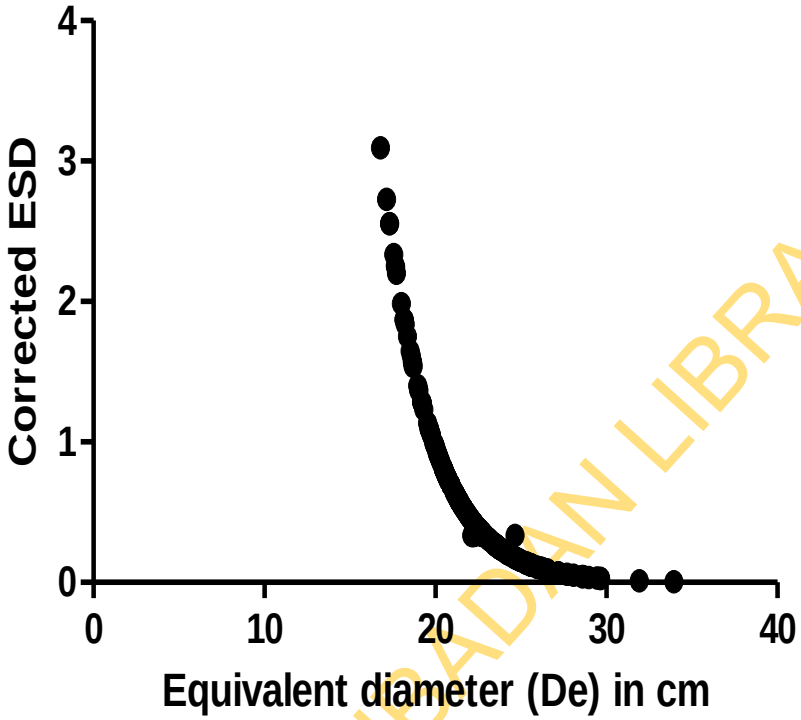

Figure 4.37: Relationship between Corrected ESD and the equivalent diameter (Chest PA-277 patients) with $R^2 = 0.9968$.

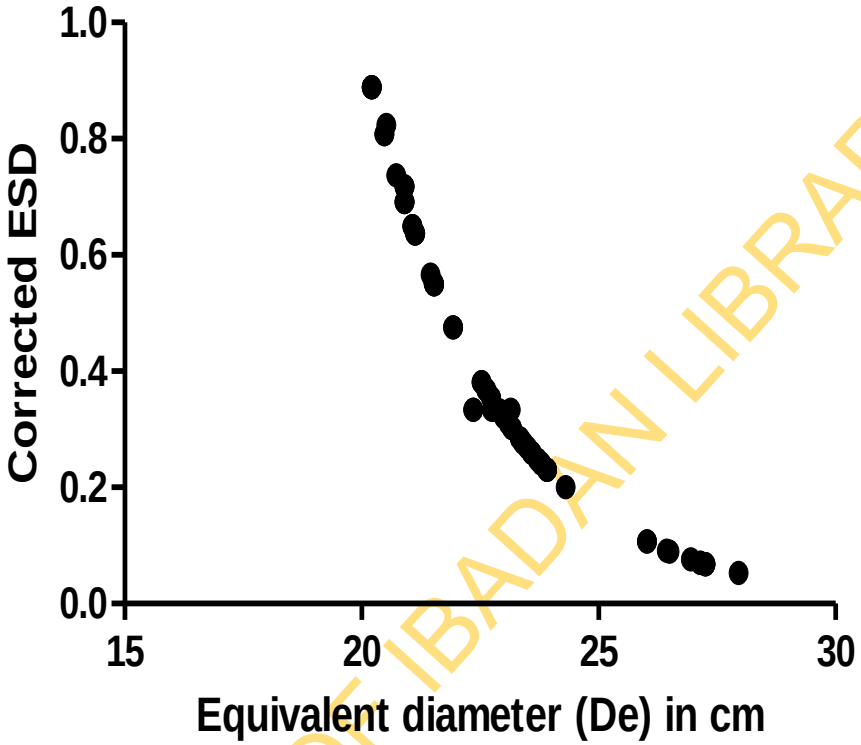

Figure 4.38: Relationship between Corrected ESD and the equivalent diameter (lumbar spine AP-70 patients) with R^2 = 0.9902

CHAPTER FIVE

DISCUSSION

5.1 The Quality Control Tests

It is evident from information presented in Table 3.1 that the diagnostic centres investigated represent different types of existing centres in Southwestern Nigeria. This indicates that the dose audit in this study satisfies the requirement of European Commission guidelines for the determination of guidance levels [it should be based on doses measured in different types of hospitals or clinics and not only in well-equipped hospitals] (EC, 1999). The result of the study is a reflection of the state-of-practice in SW geopolitical zone rather than the state-of-art.

Summary of the quality control (QC) tests carried out at different hospitals and the personnel responsible for the diagnostic examinations are presented in Table 3.2. Some of the staff perform between two and three roles especially in private hospitals. The multiple roles of imaging staff placed additional workload on them, and therefore could have detrimental health effects on them and consequently reduced their efficiency. The radiological staff members (Medical Physicists/Radiation Protection officers) responsible for the quality assurance were in most part not available. The only centre that employed the services of a Medical Physicist was FMC; however, the Medical Physicists were made to perform the roles of Radiographers. The absence of Medical Physicists in eleven out of twelve centres investigated could be the reason for the hospitals not carrying out quality control tests. Only few centres had ever carried out partial quality control tests, perhaps, because of accreditation or certification requirement of Nigerian Nuclear Regulatory Authority (NNRA). Quality assurance (QA) programme is needed to ensure the constancy of image quality in radiography and compliance with acceptable standard of practice. Moreover, QC activities have helped in reducing the number of poor quality images by 40% (Rehani *et al*., 1992), and thus prevent unnecessary doses to patients.

The specific features of machines investigated indicate that only about 27% of the facilities possess charts for matching patient weight and exposure parameters. In the remaining 73% of the centres, the choice of exposure factors is done at the discretion of the Radiographers. In a situation where automatic exposure control (AEC) system is not available to regulate exposure factors in line with the patient size, the choice of exposure factors made at the discretion of the Radiographer without proper matching with patient size could lead to patient of small size being over-exposed and large-sized patient under-

exposed. The trend might lead to poor image with loss of contrast which could consequently lead to repeated imaging, and thus increasing patient doses and cost of films. Failure to adequately match patient weight and exposure factors can lead to patient being unnecessarily exposed or lead to suboptimal image (ICRP, 1982, Huda *et al*., 1996).

5.1.1 Age of Machine and Filtration

The information in Table 3.3 shows that facilities located in VHS (Acoma, Japan), LTH1 and AYHS (GEC Medical) centres, were manufactured some 32, 33 and 41 years ago respectively. The age of machine is one of the factors that affect the output of the machine. Besides, half value layer is a function of x-ray tube age and use. With use, the target's surface pits and becomes coarse, and thereby increases filtration of the tube. Therefore, x-ray tube should be replaced after some years if the whole unit could not be replaced, and HVL needs to be measured annually after the replacement of x-ray tube assembly (AAPM, 1988). Nevertheless, it is interesting to note that the old machines investigated in this study have relatively higher filtrations than the new ones. The filtration of the old machines ranged between 2.2 and 3.0 mm Al. A closer investigation revealed that some of the kVp settings of LTH1 cannot be operated to carry out exposures due to old age. The facility of AYHS tends to stop amidst operation during examinations. Two machines investigated in the work of Akinlade *et al*. (2012): UCH-1974 and OAUTH-1981 are old while two are relatively new: TDC-1998 and NHA-1999.

Another important feature shown in Table 3.3 is the filtration of the machines. The total filtrations of 13 out of 15 the units investigated were recorded. The recorded total filtrations ranged from 0.9 to 3.0 mm Al. From the table (Table 3.3) only 5 units satisfy the minimum filtration requirement of good practice while the remaining 8 (of recorded filtration) fall short of minimum legal standard requirement of 2.5 mm Al (Johnston and Brennan, 2000). Filtration of a machine affects patient dose. The use of filtration below the minimum legal requirement of 2.5 mm Al for peak tube potential values greater than 70 kV (Wade *et al*., 1995) especially the newly installed units could be another factor leading to higher doses in this study. This is because the low doses which are not used for image production are deposited in the body of the patient, thus increasing the dose burden of the patient.

The sizes of filtration used in Nigeria and in this work are examined. The filtrations used in the work of Ogundare *et al*. (2004a) (UCH-2.7, BMSH-1.5, FMC*-2.5 mm Al);

Egbe *et al*. (2008) (GH-2.5, TH-2.6 mm Al); Akinlade *et al*. (2012) (UCH- 2.7; OAUTHC-1.7, TDC-2.7, NHA-1.0 (+ 0.1 mm Cu) mm Al) and this present study show that Hospitals in Nigeria use relatively lower filtration than that used in other developing countries. The average filtration used in this study (is 2.1 mm Al) is less than the mean filtration used in Iran (3.2mm Al). The work of Wade *et al*. (1995), reported that most of the x-ray tubes studied, have their filtrations ranging between 2.5 and 3.5 mm Al. Also the mean filtration in this study is less than the mean filtration reported in Taiwan (2.5 mm Al) (Tung *et al*., 2001). The filtration reported in the work of Suliman *et al*. (2006) ranged between 2.5 and 5.0 mm Al. The work of Suliman and Elshiekh (2008) indicates that, the mean filtration (2.4 mm Al) recorded in another study from Sudan is higher than the mean filtration from Nigeria (this study).

The study of Wade *et al*. (1995) also indicated that a tube fitted with additional 50 µm erbium filters reduced the average dose by 26% with kV and mA kept constant. The introduction of erbium filtration tends to attenuate low energy photons more strongly. It was found to reduce the entrance doses by between 30% and 50% when used, although its advantage over aluminium for reduction of effective dose is less significant (Shrimpton *et al.*, 1986). The study of Wade *et al*. (1995) showed that with the appropriate increase in the filtration and maintaining the kV and mAs, the dose to the patient could be reduced considerably without impairing the quality of radiographic image produced. This could reduce the risk to the patient being examined. The filtrations of different x-ray units recorded in this study are inadequate and require additional filtration to reduce patient's dose to optimal value.

5.1.2 Radiation Output and Patient Dose

Radiation outputs of eleven machines measured range between 0.02146 and 0.6102 mGy $(mAs)^{-1}$. All the outputs were measured at 80 kV and 10 mAs, but different values were obtained in spite of the fact that in certain cases machines were of the same model, filtration and manufactured the same year as indicated in columns 5, 6 and 7 of Table 3.3 (TTPC1 and 2). Because of the importance of radiation output (mGy $(mAs)^{-1}$) in radiography (effects on the patient dose and image quality) it is necessary to carry out regular quality control tests to ensure consistency, and to identify malfunctioning (leakages) tube Suliman *et al*. (2006) so that necessary adjustment of equipment could be done.

Inconsistency in outputs were detected in two of the units (LTH 1 and SDAH) investigated and the managements of the facilities were alerted on the need to take corrective measures.

The plot of radiation output (mGy/mAs) of the machines against different tube potential is presented in Figure 4.1. The graph of output of machines as a function of the tube potential (kV) has been found to assume a polynomial of the form:

$$Output = a_o + a_1 kV + a_2 kV^2 + a_3 kV^3 \quad 5.1$$

Where a_o, a_1, a_2 and a_3 are coefficients of fit, kV is the tube potential.

This (equation 5.1) is in agreement with the form recorded in the earlier study by Boone and Seibert (1997). However, the output of SDAH above 60 kVp deviates slightly from this pattern. This could be as a result of malfunctioning of the x-ray unit above 60 kV. The inconsistency in the output of the machine has the tendency of adversely affecting the image quality (contrast) and patient dose and therefore required urgent technical attention.

5.1.3 Tube Potential and Ripple Factors

The results of the average peak potentials (kVa) and effective peak potentials (kVe) for different centres are presented in Table 4.2. The table reveals small differences between kVa and kVe, indicating that the x-ray units produced ripple factors similar to their typical value or waveform similar to the ideal for their generator type otherwise kVe will be significantly lower than kVa (Rehani, 1995). The negative sign indicates that kVe was greater than kVa.

The results in Table 4.3 were obtained using the measured voltage output of the machines investigated during the quality control test. Theoretically voltage ripples are 13.4 and 3.4 % for 3-phase-6 pulse and 3- phase-12 pulse machines respectively (Bushberg, 1994). The calculated voltage ripple in this study is within the experimentally determined values of 13-25% (for 3-phase-6 pulse) and 3-10% (3-phase-12 pulse) as seen in Table 4.3.

A degree of ripple in kV waveform is demonstrated by inverter type generators (ripple factor of 4.15%) unlike the constant potential system which generates constant potential spectra (ripple factor < 2 %) (Boone and Seibert, 1997). Single-phase generators produce 100% ripple factor in theory; however, due to line capacitance, the complete drop of kV to zero is usually mitigated to some extent.

Moreover, the influence of ripple on the beam quality is measured according to the half value layer (HVL). The HVL of higher kV spectra suffer more due to increased ripple. However, the larger effect of ripple is on the output (mGy/mAs). Boone and Seibert (1997) reported that the output (mGy/mAs) measured at a distance of 1m from the tube is reduced as the ripple factor of the waveform increases. This is as a result of the reduced efficiency of x-rays production at lower applied potential. At lower ripple factor, the severity of the effect on output is not too pronounced. However, high doses are associated with high ripples (Suliman and Elshiekh, 2008).

Table 4.3 shows the coefficients of fit of the relationship between the kV selected on the control console (kV_{set}) and the kV measured (equation 4.2) using QC kit. The linear correlation coefficients and the reproducibility of the machine output for each unit are also tabulated. The knowledge of the equation and the coefficient of fit as recorded in Table 4.3 after each quality control test (QA) of each machine helps to estimate the patient dose using the output of machine, mAs and kV of each x-ray unit.

Table 4.4 gives the results of the quality control tests of some machines investigated during the study. The quality control test was carried out to identify malfunctioning x-ray equipment. The results of the test show that four u (OAUTHW, ALSH, FMC and EKSUTH) of the six x-ray units measured fall within the acceptable limit of 5%, while the coefficient of variation (CV) of two machines (at LTH 1 and SDAH) were found to be higher than the acceptable limit required of good output of x-ray tube. Coefficient of variation serves as a relative measure of dispersion (assesses the degree of dispersion of mean tube potential to its mean value).

The result in Table 4.4 shows that 66.7 % of the tested x-ray units fall within the tolerance limit while the remaining 33.3% are outside the tolerance limit. The results obtained from the variation of the tube potential of the machines found in LTH 1 and SDAH require some adjustment and recalibration to ensure consistency in output of the machines.

5.2 Local Dose Experience (ESD and DAP) in the Groups

Results of entrance surface dose (ESD) for GROUP A and GROUP B centres are presented in Table 4.5 and Table 4.6 respectively with the standard error of mean (SEM) for different examinations. The ranges of ESD measured in GROUP A are: 0.44-5.57; 3.44-7.89; 1.11-5.34; 0.55-8.12; 0.46 – 6.42; 0.79 – 2.94; 0.63-0.86; 0.39-2.52 mGy for chest PA, abdomen AP, pelvis AP, lumbar spine AP, skull AP, knee AP, neck AP and hand AP

respectively. Similarly in GROUP B, the ranges of ESD measured at various centres are: 0.49 -5.95; 0.10 -5.41; 0.57 -3.38; 1.26 -23.82; 0.057 – 3.60; 0.036 -3.52 mGy; for chest PA, pelvis AP, lumbar spine AP, skull AP, knee AP , hand AP and thigh AP respectively. Results of Tables 4.7 and 4.8 indicate that the ranges of ESD for paediatric patient in GROUP A are: 0.67-3.34; 2.36-5.21; 0.29-7.13; 0.72 -2.32; 0.045 – 2.72 mGy for chest PA, abdomen AP; skull AP, knee AP and hand AP respectively. In GROUP B, the ESD for chest AP, skull AP and hand AP range between 0.13-1.03; 0.032-4.38; 0.56 – 3.39 mGy respectively. The ranges of the dose in both adult and paediatric patients show that doses within and among the centres are dispersed. The range factors (RFs), [the ratio of the maximum individual ESD values to minimum individual ESD for the same type of examination] (Ogundare *et al.*, 2004a) of mean ESD (adult) measured among the hospitals in GROUP A are: 12.6 for chest PA, 2.3 for abdomen AP, 4.8 for pelvis AP, 14.8 for lumbar spine AP, 13.9 for skull AP, 3.7 for knee AP, and 6.5 for hand AP. The RFs for GROUP B range between 12.1 and 106.9 for chest PA and hand AP respectively

Despite the fact that ESD is indicative of techniques applied, it does not take into account the effect of field size variation. Entrance surface dose is a point dose while dose-area product takes into account the beam area. Dose area product (DAP) is the appropriate dose index that can be correlated with field size. It is increasingly used as it provides a convenient and accurate method for dose measurement and it is independent of the set-up. In addition, it allows comparison with other studies and effective dose can be deduced as well as the somatic risks. This flexibility emphasizes the possibility of using DAP as a selected dose index for the DRLs (Dougeni *et al*., 2007).

The results of Table 4.9 and Table 4.10 are the dose-area products for both GROUPS A and B (adult). The ranges of DAP measured in GROUP A for different procedures during the examination of adult patients are: 0.58 -6.69 (chest PA); 4.95 – 7.99 (abdomen AP); 0.72 -2.93 (pelvis AP); 0.26-4.69 (lumbar spine AP); 0.25 -3.73 (skull AP); 0.50 -2.78 (knee AP); 0.45- 0.62 (neck AP); 0.23 -1.81 (hand AP) Gy cm^2. Meanwhile, the ranges of adult DAPs for different procedures obtained in GROUP B are: 0.45 – 8.60 (chest AP); 0.076 - 5.82 (pelvis AP); 0.39 -1.80 (lumbar spine AP); 0.74 – 16.84 (skull AP); 0.038 – 2.78 (knee AP); 0.021 – 2.74 (hand AP); 0.12 -5.77 (thigh AP) Gy cm^2. The corresponding RF for DAP (adult) ranges from 19.1 to 76.6 for chest PA and pelvis AP respectively. Table 4.11 indicates that the range of DAP for paediatric patients (GROUP A) in chest PA, abdomen AP, skull AP and hand AP are: 0.96 -5.99; 2.08 – 2.75; 0.46 – 5.67; 0.39 – 1.89 Gy cm^2.

Moreover, the ranges of paediatric DAP (GROUP B) for different procedures are: chest PA (0.12 -0.88); skull AP (0.0092 - 4.94) and hand AP (0.34 -2.63) Gy cm^2.

The results show a wide variation in the mean ESD and DAP for different examinations among various hospitals. It is assumed that the mean value of each hospital in a group is a random variable (Charnock *et al.*, 2013). The results of the RF show a wide variation of doses among hospitals located within the same geographical area. The two units for example in GROUP B: TTPC1 and TTPC 2 (Table 4.6) are located in the same centre, but different doses are obtained for similar examinations (chest PA, lumbar spine AP, hand AP). This shows the nature of dose data.

The differences in dose within the same diagnostic centre could be attributed to different factors such as; the training and experience of the personnel responsible for the exposure of patients, output of the machine, patient size, the choice of exposure factors. It is evident from the results of outputs of facilities in TTPC1 and TTPC 2 that the two machines were manufactured the same year, of the same model, and have the same total filtration, but they have different outputs (0.2069, and 0.3998 mGy/mAs for TTPC1 and TTPC 2 respectively). The wide variations in doses measured within and among centres call for regular dose audit such that any room found delivering excessively high doses is identified so that necessary corrective measures are carried out to prevent undesirable and avoidable patient dose.

In order to determine the current level of patient dose at different diagnostic centres (a cluster of hospitals in a geographical area or within a large hospital with many X-ray rooms), and to determine a subtler and refined typical dose to which the comparison can be made, the centres were grouped. The centres investigated in this study were purposely divided into two groups (GROUPS A and B) based on the location of each group. The comparison of different hospitals in each group will help in detecting facilities delivering excessively high doses. Published guidance on mechanism for establishing a typical dose (local reference diagnostic levels within a group – LRDLs-G) for individual sites (such as GROUPS A and B) indicates that most organizations would only have access to a small number of results in order to establish such values (IPEM, 2004).

5.2.1 Determination of Local Diagnostic Reference Levels within each Group

It is proposed that the group mean of distribution of room mean doses be adopted as local reference value rather than using the third quartile value (or 75th percentile). With this value in place, an investigation is carried out and if the group mean is consistently exceeded by any room, investigation is triggered. In order to make judgment in respect of room mean exceeding group mean (LRDLs-G) value, the degree of uncertainty on the room mean doses must be considered. Consequently, a test of significant variance from the LRDLs-G is based on the standard error of mean (IPEM, 2004; Charnock *et al*., 2013). Two main sources of error associated with the estimation of mean ESD/DAP value are expressed as:

$$< ESD/DAP >= \varepsilon_{meas} + \varepsilon_{random} \qquad 5.2$$

where ε_{meas} is the error of the dosimetric methods, and ε_{random} is the error on the mean ESD/DAP value associated with the sampling procedures (Gastrup, 2004). The error ε_{meas} was estimated to be < 20% in this study. Usually, it is accepted that for random variable a measure of error on the mean value of a sample is given by:

$$\varepsilon_{random} = SEM = \frac{SD}{\sqrt{n}}, \qquad 5.3$$

where SEM is the standard error on the mean, *SD* is the standard deviation, and *n* is the sample size.

Against this background, Tables 4.5 and 4.6 show the results of the mean of each hospital for individual examination and group mean (last columns). The corresponding standard error on mean of each hospital/examination [SEM (R)] and standard error on mean for the group (SEM (N_R)) are presented. The group means of GROUP A (adult) ESD and the corresponding standard error of mean are: 3.01 (0.76), 5.67 (0.87), 2.84 (1.27), 3.79 (1.08),3.93 (1.39),2.09 (0.42), 0.75(0.16), 1.44 (0.58) mGy for chest PA, abdomen AP, pelvis AP, lumbar spine AP, skull AP, knee AP, neck AP and hand AP respectively. In GROUP B (adult), the group means of ESD are: 1.78 (0.66), 2.71 (1.24), 2.11 (0.47), 8.79 (7.51), 1.06 (0.66), 1.10 (0.55) mGy for chest PA, pelvis AP, lumbar spine AP, skull AP, knee AP, and hand AP respectively. This set of results could be regarded as the preliminary local reference diagnostic levels within the group (PLRDLs-G). Insufficient data prevented the determination of group mean for thigh AP (GROUP A), abdomen AP, neck AP, and

thigh AP (GROUP B). As regard ESD of GROUP A, available data in Tables 4.7 and 4.8 show that for paediatric patients, the group means are: 2.42 (0.54), 3.79 (1.43), 3.86 (1.98), 1.66 (0.62) mGy for chest PA, abdomen AP, skull AP respectively. While in GROUP B, the ESD of paediatric patients are: 0.60 (0.60), 1.46 (1.007) mGy for chest PA and skull AP respectively.

Results of Table 4.9 show that the group mean for DAP (adult) and the corresponding standard error of mean for GROUP A are: 3.90 (0.96), 6.60 (0.60), 1.86 (0.64), 2.41 (0.61), 2.32 (0.82), 1.55 (0.36), 0.94 (0.47) Gy cm^2 for chest PA, abdomen AP, pelvis AP, lumbar spine AP, skull AP, knee AP and hand AP respectively. The group means for GROUP B DAP are as follows: 2.47 (0.95), 3.13 (1.49), 1.22 (0.23), 6.14 (5.35), 0.81 (0.51), and 0.77 (0.42) Gy cm^2 for chest PA, pelvis AP, lumbar spine AP, skull AP, knee AP, and hand AP respectively. The group means for GROUP A (paediatric patient) obtained are: 3.81 (0.34), 1.77 (0.96), 1.29 (0.30) Gy cm^2 for chest PA, skull AP and hand AP respectively. The GROUP B paediatric patient's group means are: 0.57 (0.13), 1.65 (0.58) Gy cm^2 for chest PA and skull AP respectively. These values could be regarded as the local diagnostic reference levels within each group (PLRDLs-G).

This is based on the accepted fact that when data from several x-ray rooms are combined, the groups mean forms a local reference value (IPEM, 2004), and it is the standard error on the mean obtained from multiple x-ray rooms [SEM (N_R)] that determines the tolerance limit of each examination. Each room's dose must then be considered to be a random variable. The error of all hospitals [SEM (N_R)] can be expressed as a percentage of group mean for each examination. The results obtained in this study for ESD/examination range from 15% for the abdomen AP examination to 45% for pelvis AP (GROUP A). Moreover in GROUP B, the percentage error on the mean ranged from 22% for lumbar spine AP to 85% for skull AP. The variation recorded in this study for different examinations must have arisen from both the differences in the number of x-ray rooms (n) as well as inherent variations in patient dose values for different types of examinations. The latter element is of most relevance for optimisation studies. The variations indicate that the fundamental nature of radiological process will lead to inherently different variations within a population of x-ray rooms (Charnock *et al*., 2013). An attempt was made at taking care of the differences in patient size and the resulting dose by making the assumption that a patient is a cylinder of water with equivalent diameter, De obtained from the weight and height

measured during the examinations. This helped to standardize the dose data to reference man dose (Hart *et al*., 2000).

5.2.2 Comparison of Doses between Adults and Paediatrics

Tables 4.5 - 4.12 show the performance of each hospital for both adult and paediatric patients. Besides, comparison among hospitals is allowed and between adults and paediatrics. There is a dearth of data on paediatric patients, however available data as indicated in Tables 4.5 and 4.7 (GROUP A, ESD) show that the group mean dose of adult patient is higher than the group mean of paeditric patients in chest PA, abdomen AP, and skull AP procedures by factor of 1.24, 1.50 and 1.02 respectively. However, in hand AP, the group mean of paediatric patients is higher than the dose delivered to the adult patients by a factor of 1.15.

The comparison of DAP for GROUP A shown in Tables 4.9 and 4.11 indicate that the group means for adults are higher than the paediatric group means in chest PA, abdomen AP, and skull AP by factors of 1.02, 2.72, and 1.31 respectively. Similarly, the group mean (ESD) of paediatrics is higher than the group mean for adults by a factor of 1.37 in hand AP. In GROUP B (Tables 4.6 and 4.8), the group means of ESD of adults are higher than the group means doses of paediatric patients in chest PA and skull AP by factor of 2.96 and 6.02 respectively. In case of DAP, comparison of adult and paediatric patients (Tables 4.10 and 4.12) show that it follows the same trend as the ESD. However, for both ESD and DAP, the group mean doses of paediatric patients in hand AP are higher than the adult group mean doses.

The higher paediatric group mean dose as observed in this present study falls short of a good radiological practice. Children are usually considered to be at higher health risk from radiation as they have both an increased opportunity for expression of induced malignancy, and an increased sensitivity for certain forms of cancer (Stather et al., 1988). The trend found in this study requires that investigation into the causes of relatively higher doses in paediatric patients be carried out to a find out the major factors leading to high doses.

In Nigeria the regulations for the management of ionising and non-ionising radiations are outlined in the document of the Nigerian Nuclear Regulatory Authority (NNRA) in line with the International Atomic Energy Agency (IAEA) regulations. However, the regulation for the establishment of guidance levels in diagnostic radiology is

not well defined. This study is an attempt to propose local guidance levels (LRDLs-G). To this end, the results shown in Tables 4.5 – 4.12 for ESD and DAP could be said to be a reflection of the local situation in Southwestern Nigeria. The proposition is in accordance with the published guidance on establishment and use of diagnostic reference levels for medical x-ray examinations by the Institute of Physics and Engineering in Medicine (IPEM, 2004; Wall, 2004). The document indicates that the group mean of the distribution could be taken as the local diagnostic reference levels within the group (LDRLs-G), rather than the third quartile value for at least ten close-to-standard-size adult patients (IPEM, 1992; Charnock *et al*., 2013).

In order to determine the trigger levels (or action levels) and identify the facilities where abnormally high or low doses are delivered, the recommendation of IPEM was adopted. This is based on tolerance limit. The tolerance limit set is based on the standard error on the mean of the patient doses of standard patient (70 ± 5 kg). In this study the doses (ESD and DAP) of patients were standardized using NRPB ESD and DAP normalization factors (Hart *et al*., 2000, Miller *et al*., 2009), therefore this gives room for the application of tolerance limit.

The tolerance limit proposed by the Institute of Physics and Engineering in Medicine (IPEM, 2004) indicates that if the value of a room mean exceeds a group mean value [for a given examination] by more than twice the SEM, the room mean can be taken to exceed the typical dose (group mean) with high degree of confidence. For a given examination in this study, realistic trigger level was established by making certain assumptions:

(1) the mean of mean (group mean) in the last column of Tables 4.5 - 4.12 are taken to be the LRDLs-G with the corresponding SEM(N_R),

(2) each group (GROUP A or B) is considered as a site of multiple rooms or centres (Charnocks *et al*., 2013).

5.2.3 Identification of High and Low Dose Centres

Applying the overall tolerance of LDRLs ± 2 x SEM (N_R) to Table 4.5 and Table 4.6 yields Table 4.13 (for GROUP A/ ESD) and Table 4.14 (GROUP B/ESD) respectively indicating the nature of observationss (either excessively high dose or low quality image (low dose). The centres with high doses that require attention in GROUP A include: OAUTHW (lumbar spine AP); SDAH (abdomen AP) and GROUP B: ANHS (chest PA,

pelvis AP, skull AP, knee AP, hand AP); AYHS (chest PA, knee AP); ALSH1 (hand AP); OAGSH (lumbar spine AP).

Based on the results in Table 4.5 and the observations recorded in Table 4.13, it is evident from Table 4.AP1 (Appendix) column 3 (Lumbar AP-90 mAs, OAUTHW) and column 9 (Abdomen AP-95 mAs, SDAH) that the patients were exposed using high mAs, an indication that further optimisation is needed (Martins, 2007) in Nigeria. The mAs used in lumbar spine AP in this study is less than 150 mAs used in Akinlade *et al*., 2012, who used low FSD (72 cm) in their study. The mean mAs used in UK- (38 mAs) Hart *et al*., (2012) is less than the value used in this study in lumbar spine AP. In abdomen AP, the mAs used in this study is higher than the value used in Akinlade *et al*., 2012 (80 mAs), and in the UK (39 mAs) (Hart *et al*., 2012).

Results of Tables 4.6 and 4.10 (ANHS- skull AP) with a relatively high doses are as a consequence of the use of high mAs. Earlier investigation had indicated that, the common feature of facilities using low tube potential and high mAs with inadequate filtration was high [patient] dose (Johnston and Brennan, 2000). However, in the present study the centres with low doses are EKSUTH (chest PA, skull AP, hand AP); LTH 1 (chest PA, knee AP); LTH 2 (hand AP) in GROUP A and GROUP B: AYHS (chest PA, knee AP, hand AP and lumbar spine AP).

In all the hospitals investigated the issue of screen/film speed was not taken into consideration by Radiographers, therefore its effect on patient dose requires education. Investigation revealed that screen-film speed of 200 is being used in almost all the hospitals in SW, Nigeria, and this must therefore, have led to the increase in patient radiation dose. It is suggested that rare-earth screen-film be adopted in Nigeria because of its ability to reduce patient dose.

Further investigation revealed that the level of knowledge and experience of radiographers is another determinant of the level of patient dose. Regular audit of local patient dose will assist in dose optimisation, a requirement for countries in European Union (EC, 1997). The adoption of an optimisation strategy (national and local DRLs) in the UK has lowered patient doses, as demonstrated by the gradual reduction of NDRLs in UK five-yearly reviews (Hart *et al*., 2012). The 2010 review shows that between 1995 and 2000 there was a mean-dose reduction of average percentage of 16, similar trend was observed between 2000 and 2005. Between 2005 and 2010 an average percentage mean-dose reduction of 5%

was recorded. A higher third quartile average of 10 % reduction was recorded between 2005 and 2010 in UK (Hart *et al*., 2012).

Presently, there appears to be no record of written legal framework supporting dose optimisation in Nigeria, it is currently an "academic exercise". The major concern of the referring Physician, Radiographer, and the Radiologist is high quality image, largely at the expense of patient dose.

5.2.4 Local dose versus Regional Dose (LRDLs-G vs LRDLs-N)

The results of the comparison among local audits, that is, group means of GROUPS A and B (LRDLs-G) and the regional doses (LRDLs-N) obtained from the dose distribution (75^{th} percentile) of all the patients investigated during the period of this study for different examinations are shown in Table 4.15. In part, the results show that comparison of group mean of GROUP A with thatof GROUP B (ESD) indicates that the mean doses delivered to adult patient in GROUP A are greater than the doses to the patients in GROUP B in chest PA, pelvis AP, lumbar spine AP, knee AP, hand AP by factors of 1.69, 1.05, 1.80, 1.97, and 1.31 respectively, while in skull AP, the group mean dose of GROUP B is greater than that of GROUP A by a factor of 2.24. Moreover, for paediatric patients shown in Table 4.16, the groups mean ESD of GROUP A is higher than the group mean (ESD) of GROUP B by factors of 4.03 and 2.64 in chest PA and skull AP respectively. In contrast, for hand AP, the GROUP B means ESD is higher than the GROUP A mean ESD by a factor of 1.19.

Additionally, a comparison of the GROUP A and GROUP B group mean doses (DAP) reveals that the group means DAP of GROUP A higher than the group means (DAP) of GROUP B in chest PA, lumbar spine AP, knee AP and hand AP by factors of 1.58, 1.98, 1.91, 1.22 respectively for adult patients. The doses delivered to GROUP B patients are higher greater than the doses delivered to GROUP A adult patients in pelvis AP and skull AP. As regard paediatric patients (DAP- Table 4.16), the doses received by the patients in GROUP A are higher in chest PA, and skull AP by factors of 6.7 and 1.1 respectively, but GROUP A DAP is lower than that of GROUP B in hand AP.

As regard the comparison of the local audit with the regional 75^{th} percentile dose distribution, Table 4.15 shows that the adult regional dose survey are higher than the local doses (ESD) in abdomen AP, pelvis AP, lumbar spine AP, skull AP, knee AP and hand AP of GROUPS A and B. The ESD of chest PA of GROUP B is less than the regional survey (columns 3 and 4). The regional dose (ESD) survey for paediatric patients (Table 4.16) is

also higher than the local survey in chest PA. However, the local doses are higher than the regional doses in chest PA (GROUP A- adult patients) and hand AP (GROUP A-paediatric patients**).**

The DAP column in the right hand of Table 4.15 shows that the local doses of GROUP A (chest PA), and GROUP B (skull AP) are higher than the regional survey. In a situation where the local dose consistently exceeds the regional survey, investigation as to the causes of higher doses is required. The comparison of each hospital mean with the group mean and comparison of group mean with the regional survey have two-tier advantages; of identifying rooms delivering higher doses and taking corrective measures in the centres delivering higher doses. It is expected that the determined PLRDLs-G be compared with established NDRLs (most importantly within the same country). This is what has been achieved in this work. The results of comparison in this study indicate that local centres studied are not doing too badly in spite of inadequate optimisation process in Nigeria. However, adequate optimisation and monitoring will improve the local situation in Nigeria.

5.2.5 Local Dose (LRDLs-G (ESD)) and Published National Diagnostic Reference Levels

Table 4.17 shows a comparison between the ESD obtained in GROUPS A and B (proposed LRDLs-G) of this study with the published national diagnostic reference levels (NDRLs) in Europe (UK), North America (US), and South America (Brazil) for standard patients. A comparison of the ESDs in this work for the two groups with UK, US, and Brazil reveals that the dose in the present study is higher than those of published NDRLS in other countries in chest PA, abdomen AP and knee AP. Nevertheless, it is noteworthy that doses of pelvis AP, lumbar spine AP are lower than the NDRLs published in UK. This trend is acceptable but does not indicate the best practice since several factors affect patient dose. The comparison shows that there is a dearth of dose data on extremities (hands, legs). This is evident in published report which indicates that an estimated 12.8 million upper extremity x-ray examinations and 15.7 million lower extremity x-ray examinations were performed in the United States in 1980 (NCRP,1989), however effective dose data for extremity x-ray examinations are presently not available for either adult or paediatric patients (Huda and Gkanatsios, 1998). However, in Nigeria Jibiri *et al*. (2013) the dose to the extremities. Data on the dose to extremities is very important because of the effect of ionizing radiation on bone marrow, especially long bones which could lead to leaukemia.

5.2.6 Local Dose (LRDLs –G (DAP)) and Published Doses

Table 4.18 is a comparison of GROUPS A and B dose-area product (DAP) with NDRLs obtained in Iran, and UK. The table indicates that results of hand AP for GROUPS A and B are comparable. Whereas in chest PA, Abdomen AP, pelvis AP (Group B), lumbar spine AP, skull AP and knee AP, LRDLs-G are higher than the published NDRLs DAP. The DAP LRDLs-G proposed in this study is in most cases higher than the published NDRLs. However, in pelvis AP (GROUP A), the DAP measured [1.86 Gy cm^2] is lower than 2.1 Gy cm^2 and 2.2 Gy cm^2 (Hart *et al*., 2012) published NDRLs obtained in UK but comparable with the value measured in Iran.

The possible reason for the trend of the current results being higher than the UK NDRLs could be attributed to the fact that five reviews have been carried out in the UK since 1985. The trend points to the necessity of regular dose measurement and corrective measures applied where necessary in Nigeria.

5.2.7 Local Dose and Other Published Works

A comparison of group mean ESDs obtained in the present study with other works for five different projections (chest PA, Abdomen AP, Lumbar spine AP, Pelvis AP and skull AP) is presented in Figure 4.2. The group mean ESDs obtained in this work in chest PA and skull AP (GROUPS A and B) are substantially higher than the recorded values from any of the countries with which comparisons are being made. The results for pelvis AP are comparable with those of Italy and UK (RIS). The graphical variability of results for different countries reveals the nature of dose data. Generally, the doses received in abdomen AP, lumbar spine AP, pelvis AP and skull AP examinations are relatively higher than the doses received by patients during the chest PA examinations.

The selected exposure factors used in this study which resulted in higher doses recorded in the lower trunk (abdomen area) are attributed to the density and content of the trunk region that required the choice of high kVp and mAs by the Radiographers. Earlier recommendation of Commission of European Community (CEC) study group on Quality Criteria for Radiographic Images suggested that a high kVp with grid be used (CEC, 1990) for such procedures. However, in the survey of Wade *et al*. (1995) it is evident that departments using high kVp techniques were in general giving higher doses than department using low kVp techniques. Their report further indicates that all departments using excessively high doses than the NRPB reference dose were using high kVp. In the current

study almost all the departments investigated used grid during examinations of lower trunk. In addition, they were using film with nominal film-screen speed class of 200. The work of McNeil *et a*l. (1995) showed that mean high doses of almost twice as much were recorded in facilities using screen-film speed of 200 as compared to those using between 200-300 screen-film speeds.

The lumbar spine procedure is the largest contributor to the collective dose to the population in the UK after computed tomography (McNeil *et al*., 1995). This is in agreement with the present study; therefore, it is essential to carefully select technique factors while carrying out the lower trunk examination (lumbar spine). In GROUP B, data on abdomen AP were not available for comparison.

Apparently, there is paucity of data on DAP in the previous dose measurements in Nigeria, Akinlade *et al*. (2012) appears to be the major work published on DAP data. The comparison in Figure 4.3 shows that the results of chest PA (DAP) of GROUP B were comparable with the work of Akinlade *et al*., 2012. A closer investigation shows that they had earlier worked on one of the facilities investigated in this work (TTPC), however the machine on which their investigation was carried out has been replaced, perhaps, for age reason; therefore, this prevents detailed comparison of results. It is quite evident that most of the results of this study are higher than those of Akinlade *et al*. (2012), this could probably be due to the fact that TLD chips were used for ESD measurements in this study, whereas they used indirect method (mathematical computation). In addition, the doses measured in this work were standardized to reference man dose (RMD) using NRPB conversion factors. Doses received by patients undergoing abdomen AP (GROUP A) and skull AP (GROUP B) are relatively higher than doses received by patients examined in Akinlade *et al*. (Nigeria), Iran and UK (Shandiz *et al*., 2014; Hart *et al*., 2012).

5.3 Analysis of Exposure Factors and Patient Data

Tables 4.AP1 and 4.AP2 are the summaries of mean and range of exposure factors selected and patient characteristics (for adult and paediatrics- in each centre) for the examinations in the two groups investigated. Available data indicate that, chest PA is the most frequent examination carried out in Nigeria.

5.3.1 Summary of Age Group of Patients Examined

This study indicates (Tables 4.AP1 and 4.AP2 in Appendix) that most of the patients irradiated during the chest PA examinations are within the working class with mean age range of 33-53. The mean age range for other examinations are; abdomen AP: 45-79; pelvis AP: 34 – 86; lumbar spine AP: 37- 64; skull: 19 – 65; knee AP: 26-68; hand AP: 20-90. The results of this study show that the productive age group is being exposed to ionizing radiation especially in chest PA.

5.3.2 Analysis of Tube Potential (kVp) used

The range of mean tube potentials, kV used across all the hospitals investigated constituting the two groups are; chest PA: 62-97; abdomen AP: 78 – 110; pelvis AP: 65- 87; lumbar spine AP: 65-107; skull AP: 69-88; knee AP: 49-67; hand AP: 50-68 (Tables 4.AP1 and 4.AP2).

In the 2010 report of NRPB-HPA (UK), the following mean and range of tube potentials (kVp) for different examinations (as seen in Table 4.19, last column) are presented: chest PA: 88(65-125); abdomen AP:76 (60-94); pelvis AP: 75(62-90); lumbar spine : 78 (65-109); skull AP: 72 (69-83) and knee AP: 61 (52-68). The range of tube potentials for different examinations used in the present study compared well with the NRPB-HPA, 2010 (UK) review.

The results of Table 4.19 (column 4) further show the comparison of mean kVp used during examinations by the two groups (GROUPS A and B). The comparison shows certain degree of agreement in the tube potentials used by the two groups in chest PA (75, 75); abdomen AP (88, 91); pelvis AP (75, 80); lumbar spine AP (86, 85); and knee AP (63, 57). Comparison of mean kVp values used in this study with the UK data shows that the mean values chosen in pelvis AP, lumbar spine AP, skull AP and knee AP (GROUP A) in this study are comparable with UK value. However, the range of kVp found in UK data in chest PA, abdomen AP, pelvis AP, lumbar spine AP, skull AP and knee AP are wider than the range of values used in the present study.

5.3.3 Analysis of Tube Load (mAs) used

As regard the tube load settings (mAs) -Tables 4.AP1 and 4.AP2, the range across the two groups are chest PA: 0.33-51; abdomen AP: 26-100; pelvis AP: 18-64; lumbar spine AP: 23-117; skull AP: 15-78; knee AP: 5-32 and hand AP: 4-30. The NRPB-HPA exposure settings (mAs-shown in Table 4.19) are: chest AP: 5 (0.3-405); abdomen AP: 41(1-440);

pelvis AP: 33 (1-400); lumbar spine AP: 46 (1-556); skull AP: 20 (1-246); knee AP: 4(1-125).

Comparison of mAs selected between the two groups (seen in Table 4.19) indicate close agreement between the values used in chest PA (26, 24); lumbar spine AP (62, 58); knee AP (13, 10) and hand AP (9, 10). Moreover, it is evident from Table 4.19 (column 5 and column 10) that in all the examinations except pelvis AP (GROUP A), the mAs used in this study are higher than the value used in the UK review. This could be the reason for higher doses recorded in this study. Additionally, the values of FSD used in the two groups are comparable in chest PA, and knee AP. Data on hand (extremity) were not available for comparison.

The ranges of exposure setting in this study (adults) are narrower that the NRPB-HPA 2010 review (Hart et al., 2012). This probably could be attributed to the patient size used in NRPB-HPA investigation and the filtration used. The report of NRPB-HPA indicates a minimum filtration of 2.5 mm Al while in this work the range of filtration of the units investigated is 0.9 – 3.0 mm Al. The choice of appropriate **e**xposure parameters based on the findings and recommendations of this study could lead to future dose reduction in the studied healthcare centres. In addition, regular training and education of personnel involved in medical imaging on the need for and method of dose optimisation are essential.

5.3.4 Analysis of Paediatric Patient Exposure Factors

Exposure parameters of paediatric patients selected during the routine examinations are presented in Table 4.20. Inadequate data in the report of NRPB prevents comparison. However, data available show that the mean kVp found in chest PA and skull AP are comparable, while the value of kVp used in hand AP is higher in GROUP A than in GROUP B by a factor of at least 1.4. Comparison of tube load (mAs) between GROUPS A and B shows that the two values are comparable in skull AP. The mean values of mAs used are relatively lower in GROUP B. The practice of using low mAs could be said to be a good way of achieving lower doses, indicating that there is room for dose reduction in GROUP A using 15 mAs.

5.4 Analysis of Regional Dose Survey in Nigeria

Extensive dose survey of a large country as Nigeria is laborious, capital-intensive and time consuming. Besides, personnel in terms of Medical Physicists/ Radiation and Health Physicists that could go round the six geo-political zones in Nigeria are not readily available. In addition, training of personnel and acquisition of equipment to carry out nation-wide survey is cost intensive. As a result of the aforementioned challenges, it was necessary to expand the scope of this study to include determination of regional diagnostic reference levels in Southwestern Nigeria.This is what the discussion in the following section set out to achieve.

The regional dose (ESD and DAP) survey involving 689 patient shown in Tables 4.21 and 4.22 (for adult and paediatric patients respectively) indicate that the adult patients examined fall within the mean standard weight of 70 ± 10 kg. The range of mean weight recorded in this study for adult patients is 64-73 kg. The mean age of the patients examined is within the age band of the working class of Nigerians. This is in line with the earlier survey carried out at the University College Hospital (UCH), Ibadan (Nigeria) which shows that about 66 % of patients within the age band of 21-60 years (working) are exposed to ionising radiation during the period of ten years (1998-2007), while 19 % of exposed population are paediatrics-0-20 years- (dependant) and 15% are adults (≥61- dependant) (Jibiri *et al*., 2013). The trend reported in this study could be assumed to be the general trend in Nigeria and some other countries in Africa. The DAP results are also shown in Tables 4.23 and 4.24.

Analysis of epidemiological data shows that; for radiation exposure in middle age, most radiation-induced cancer risks do not, as often assumed, decrease with increasing age at exposure. This observation suggests that promotional processes in radiation carcinogenesis become increasingly important as the age at exposure increases. The study concluded that radiation-induced cancer risks after exposure in middle age may be up to twice as high as earlier estimated and could have implications for both occupational exposure and radiological imaging (Shuryak *et al*., 2010). Exposure of the paediatric patients and the working class could pose a serious danger to their health and could also have adverse effects on the family and finance of individuals who incur cancer.

5.4.1 Preliminary Local Reference Dose Levels within Nigeria (PLRDLs-N-ESD)

The mean adult ESD obtained in this study and the corresponding 75th percentile for different procedures during the regional dose survey are shown in Table 4.21 (columns 5 and 9) as follows; chest PA: 2.32 (2.95); abdomen AP: 11.72 (22.31); pelvis AP: 4.05 (6.63); lumbar spine AP: 4.74 (5.87); skull AP: 7.07 (9.04); leg AP: 1.27 (1.51); knee AP : 1.59 (2.78); hand AP: 1.33 (2.39); thigh AP: 0.50 (0.69) mGy. For the paediatric patients (Table 4.22), the regional mean ESD and the percentile are; chest AP: 1.99 (2.46); skull AP: 2.05 (3.04); hand AP: 1.42 (1.73) mGy. The corresponding 80th percentile ESD as suggested by the American Association of Physicists in Medicine-AAPM (Gray *et al.*, 2005) in US for different procedures are also recorded in column 10 of Table 4.21 and 4.22. The 75th percentile could be taken as the preliminary local diagnostic reference levels within Nigeria (PLRDLs-N) for adult and paediatric patients. The mean ESD of adult chest PA is higher than the mean ESD of paediatric chest PA. The mean ESD of adult skull AP is higher than the paediatric skull AP by a factor of 3.45, while the mean ESD of hand AP of adult and paediatric patients are comparable.

5.4.2 Preliminary Local Reference Dose Levels (DAP) within Nigeria (PLRDLs-N)

The results of DAP indicate that overall mean dose and the corresponding 75th percentile values as seen in Table 4.23 for different procedures are as follows; chest PA: 3.06 (3.14); abdomen AP: 17.16 (28.59); pelvis AP:3.28 (4.77); lumbar spine AP: 2.72 (3.20); skull AP: 4.53 (5.06); leg AP:1.14 (2.04); knee AP:1.53 (2.09); hand AP: 0.92 (1.44); thigh AP: 0.18 (0.25). The mean dose-area product and the corresponding 75th percentile of paediatric patients (Table 4.24) are for chest PA, skull AP and hand AP are 3.62 (3.97), 2.13 (2.95), and hand AP 2.12 (2.73) respectively. These values for adults and paediatrics could be regarded as the preliminary local reference dose levels in Nigeria (PLRDLs-N) for DAP. It is clear that in chest PA and hand AP, the mean DAPs of paediatric patient are higher than the mean DAP of adult patients. The differences recorded are 0.56 Gy cm^2 and 1.20 Gy cm^2 for Chest PA and hand AP respectively. The higher dose observed in paediatric patients is undesirable, since it is expected that while examining paediatric patients the exposure factor be carefully selected in order to optimise the paediatric dose. The differences recorded in this study are additional dose burden to paediatric patients. This is an unexpected radiological practice which indicates that doses are not yet being optimised in Nigeria.

In addition, investigations show that both adult and paediatric patients are being examined using the same x-ray facilities and the same personnel (neonates inclusive). This practice could lead to contamination of neonates which contravenes infection control protocol in the neonates units in some countries (Wraith *et al*., 1995). The trend noticed in this study requires a review of the exposure factors used during the examination of paediatric patients, because the risk to children from radiation exposure is greater than the adults (ICRP, 1991). The wide variation in radiation dose recorded in this study was also found in the European survey of paediatric radiology. However, their results indicate that substantial dose reduction could be achieved without loss of image quality (Schneider *et al*., 1993). This is possible through regular review of exposure factors used. It is also expected that special care units be created for neonates (new born) with specially trained personnel to manage it to prevent contamination and enhancement of better imaging.

5.4.3 Dispersion in the Distribution of Doses

The calculated maximum/minimum ratio (or range factor-RF) among different centres studied show a wide variation in ESD (Table 4.21) among different hospitals per procedure (e.g. in chest: PA: RF-142; abdomen AP: RF-26). For different procedures, the RFs calculated range from 26 for abdomen AP to 215 in thigh AP for adults. Similarly, 10 (for hand AP) to 215 (for skull AP) for paediatric patients. The maximum/ minimum ratio of 215 indicates a wide spread in dose distribution for the procedures

The DAP results shown in Table 4.23 and Table 4.24 indicate that the maximum/minimum ratio of doses recorded range from 3 to 57 for adults and 8 to 79 for paediatric patients. A narrower dispersion is found in the DAP results. Similar dispersion was found in the earlier results of Ajayi and Akinwumiju (2000). The variations in the values of doses recorded for the same procedure indicate significant differences in radiological practice among the personnel in the various centres. The trend found in the study, therefore calls for retraining of imaging personnel in Nigeria.

5.4 .4 Distribution of Doses among different Age Groups

Figures 4.4 and 4.5 show the distribution of mean doses (chest PA-ESD and DAP) among different age groups represented in this study. The classification (≤1, >1-5, >5-10 and >10-15) among the paediatrics clearly demonstrate the graphical distribution of doses among the age bands constituting paediatric patients. The ESD dose distribution shows a

higher paediatric patient dose, while a lower DAP dose distribution of paediatric patient is evident. The lower dose recorded in DAP could probably be due to small paediatric patients size. The male adult group has the highest dose distribution for chest PA. This could be attributed to the size of the male adult chest and the size of the film used. The distribution of DAP indicates that the mean dose increases with age of the patient. The distribution in this study is in agreement with some other published DAP dose data (Hart *et al*., 2000; Suliman and Elshiekh, 2008).

A study of dose distribution among different patients such as this is the first step in dose optimisation in diagnostic radiology. The mean dose delivered to the male adult patients is higher than those of female adult patients and for ALL (combination of male and female) adult patients (for the same chest PA) examinations by a factor of 1.12 and 1.05 respectively. Understanding the dose distribution for the same examination helps to determine the extent of the variation: a wide variation would suggest that significant dose reduction is possible with no substantial degradation of image quality (Compagnone *et al*., 2004).

5.4.5 Regional Dose Levels in Nigeria (LRDLs-N) and the Published Values

Comparison of mean ESD and DAP for male and female (separately) patients are made in Tables 4.25 and 4.26 to assess the contribution of each to the overall mean dose. The tables show the sample size (n) of male and female (for adult and paediatric) patients.

The 75th percentile of all ESD obtained in this study (Table 4.25) in chest PA, abdomen AP, pelvis AP, skull AP, and leg AP procedures are higher than the published values of UK, Slovenia, Brazil and USA NDRLs by at least factors that range from 8.4-11.8 for chest PA, 3.3-5.0 for abdomen AP, 1.1-1.7 for pelvis and 2.7-5.0 for skull AP. However, the 75th percentile of the dose in lumbar spine AP examination obtained in this study (5.87 mGy) is comparable with the NRPB-HPA (Hart *et al*., 2012), and USA (Gray *et al*., 2005) published diagnostic reference levels. The lumbar spine AP dose in this present work is lower than the published dose in Slovenia (Skrk *et al*., 2006) and Brazil (Freitas and Yoshimura, 2009). The data from the USA does not include backscatter factor, indicating that low doses can be achieved in Nigeria during diagnostic examinations with the appropriate matching of exposure factors and patient weight. As regards the DAP, comparisons shows that 75th percentile dose distribution in this study is higher in chest PA, abdomen AP, pelvis AP, lumbar spine AP and skull AP. Data on hand AP are not available

for comparison. The paucity of paediatric data prevented comparison with the results from other countries and in Nigeria. Dose-area product (DAP) data are generally not adequate within and outside Nigeria. The 75th percentile result (Table 4.26) of abdomen AP in this study is higher than the published data from UK (Hart *et al*., 2012), Nigeria (Akinlade *et al*., 2012) and Iran (Shandiz *et al*., 2014) by factors of about 9.9, 51.1, and 22.2 respectively. The large variation observed in the present work could be as a result of non-optimisation of dose in Nigeria, lack of adequate dose data, and lack of feedback mechanism in the past surveys in Nigeria.

In their work, Akinlade *et al*. (2012) employed mathematical method for DAP calculation. In addition, NRPB correction factors were applied to the data in this study. The trend found here informs the need for continual review of dose data in Nigeria, creation of national radiation dose database, extensive dose survey and regular feedback after each dose survey. The trend in dose distribution also points to the fact that retraining of personnel on dose optimisation methods and establishment of national diagnostic reference levels (NDRLs) that will serve as benchmark against which future dose data may be compared are needed in Nigeria.

The plots of ESD and DAP against the percentile (10th, 25th, 50th , 75th, 80th, and 95th) dose distribution for chest PA, lumbar AP, pelvis AP, skull AP and abdomen AP shown in Figures 4.6- 4.9 show the regions of the dose distributions needing investigation, either excessively high or extremely low doses. The left arrows indicate the 10th percentile and the right arrows the 75th percentile dose distribution of the examined subjects. Any centre found within the left rectangle (Figure 4.6) requires investigation into the causes of low doses and the hospitals (one quarter of the centre) within the right rectangle also require investigation into the causes of high doses.

5.4.6 Determined Preliminary Action Levels

Radiation doses that are substantially lower than expected may result in poor image quality or inadequate diagnostic information. Radiation dose well below the reference levels may require investigation (ICRP, 2007). The International Atomic Energy Agency recommends the 10th percentile (termed "action levels"-ALs) as opposed to a reference level) as an appropriate action level (AL) at which to initiate an evaluation of image quality (Balter *et al*., 2008). In this study the entrance surface dose (ESD- Figures 4.6 and 4.7) action levels for chest PA, pelvis AP, skull AP, lumbar spine AP and abdomen AP are; 0.42

mGy, 0.61 mGy, 1.66 mGy, 1.16 and 1.85 mGy respectively. Correspondingly, the dose-area product (DAP-Figures 4.8 and 4.9) action levels for chest PA, pelvis AP, skull AP, lumbar spine AP and abdomen AP are; 0.14 Gy cm^2, 0.50 Gy cm^2, 0.83 Gy cm^2, 0.25 Gy cm^2, 1.21 Gy cm^2 respectively. The ESD action levels of paediatric patients for chest PA, skull AP and leg AP are 0.22 mGy, 0.14 mGy and 0.019 mGy respectively. Similarly, the action levels of paediatric DAP for the following projections: chest PA, skull AP and leg AP are 0.13 mGy, 0.039 mGy and 0.37 mGy respectively. The numerical values of AL for different procedures listed above indicate that if the mean dose at a local institution is less than the 10^{th} percentile for the same procedure in the population used to define reference levels, evaluation of image quality should be performed (Balter *et al*., 2008).

In addition, Charnock *et al*., 2013 suggested that some consideration should be given to values that can be considered to be lower than expected, since image quality may be impaired (ICRP, 2007). Poor image quality could lead to loss of diagnostic information which results in the examination being repeated, thus increasing the patient dose burden. A radiographic image provides a representation of the spatial distribution of tissue components as variations in the optical density of film. Image quality can be quantified in terms of the characteristics: contrast, sharpnesss, and noise. Evaluation and diagnosis from image requires structures of interest to be distinguished against the background. However, because the interpretation of the visual image by the radiologist is subjective, the results are likely to vary from one centre to the other. Any attempt to reduce the dose should not bring any detrimental effect to the image quality.

To produce an image on film with an acceptable level of contrast, the exposure must be within a relatively narrow range of doses. The exposure factors used could be optimised through the experience of the radiographers, and the use of exposure charts employed for each x-ray unit. The chart provides a guide to best factors for different examinations for patients of standard build. However, adjustment will need to be made for patients of different sizes (Martins, 2007). The use of education on the appropriate technique for reducing patient dose, coupled with periodic review of doses and sending feedback data to individual departments provide the best way of achieving optimisation (McVey *et al*., 2003 and George *et a*l., 2004).

The right rectangle beyond the 75^{th} percentile (Figure 4.6) indicates the high dose side of the dose distribution. It is important to note that the dose level being referred to as high dose in diagnostic radiology could still be called low level radiation. The BEIR VII

(Biological Effect of Ionising Radiation) report defines low doses as those in the range of near zero up to about 100 mSv (0.1 Sv) of low-LET (deposits less energy in the cell along the radiation path and considered less destructive per radiation track) radiation (National Research Council-NRC, 2002). In the United States of America people are exposed to average annual background radiation levels of about 3 mSv; while exposure from chest x-rays is about 0.1 mSv and exposure from a whole body computerised tomography (CT) scan is about 10 mSv. The follow-up research of the Radiation Effects Research Foundation (RERF) conducted on the survivors of atomic bomb explosions spanning over 50 years found that occurrence of solid cancers increases in proportion to radiation dose. More than 60% of the exposed survivors received a dose of radiation of less than 100 mSv (NRC, 2002). The findings of RERF indicate that exposure of patients to unnecessary radiation dose increases the incidence of detrimental effects.

5.4.7 Selected Exposure Factors, Dose Levels and Image Quality

Comparison of average exposure factors of this study with NRPB-HPA, USA and Brazil presented in Table 4.27 show that the mean tube loads (mAs) used in this study are greater than those used in UK (NRPB), USA and Brazil. The exceptions are found in lumbar spine AP, skull AP (Brazil-adult and paediatric patients). The high doses generally recorded in this study could be attributed to relatively higher mAs used especially in abdomen AP, pelvis AP, lumbar spine AP, and skull AP. Although some of the tube potentials used in this study are to a greater extent comparable with that of the UK , USA and Brazil value (except for chest PA). It is evident that less attention is paid to patient dose; the major preoccupation of physicians and the imaging scientists is the image quality. The use of high mAs leads to the film being overexposed. On the other hand if insufficient mAs is used the film will be underexposed, and therefore, lack photographic density. In either case there is a loss of contrast in the radiographic image and loss of radiographic information could result.

During the study automatic exposure control was only used in the digital unit of ALSH 2. Investigation revealed that during imaging the radiographers selected their exposure parameters at their own discretion. In most cases there were no charts available in the x-ray consoles for matching patient size and exposure parameters. Average patient equivalent diameter of adult patient for the skull and trunk (chest, abdomen, pelvis and thigh) are in the neighbourhood of the value for the standard patient (22.9 cm), that is, in the

range of 22.0 and 23.7 cm. The data on extremities from NRPB-HPA and Brazil are largely inadequate for comparison. The thicknesses of extremities were measured with rules.

5.4.8 Difference between Adult male and female Doses for similar procedures

Gender-based distribution in Table 4.28 (ESD) and (effective dose) show that thigh AP projection is missing (because of small data size (n) involved) from the list of types of examinations. Dose variations were observed between male and female patients. Dose data on entrance surface doses reveal that in chest PA, leg AP and hand AP, the differences between male and female are relatively small. However, the differences between male and female doses recorded in abdomen AP, pelvis AP, lumbar spine AP, skull AP are 7.42, 4.07, 2.14, and 3.95 mGy for adults. The trend is almost similar in adult DAP (Table 4.29); smaller differences are found in chest PA, leg AP and hand AP (0.35, 0.24 and 0.23 Gy cm^2), The differences are more pronounced in abdomen AP, pelvis AP, lumbar spine AP, and skull AP (the differences are 15.62, 3.22, 1.57, and 2.85 Gy cm^2). The difference found in this study among the male and female is as a result of the nature of radiation dose data which are not normally distributed (Miller *et al*., 2009).

The effective dose calculated using ESD data for male and female patients are relatively low (Table 4.28, column 5). The calculated effective doses using the DAP data indicate that the highest mean effective dose obtained is 2.56 mSv, found in abdomen AP (female).

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5.4.9 Estimated Effective Dose and Patient Level of Exposure

Based on the upper bound of the range of effective dose shown in Table 4.28 (column 5) and Table 4.29 (column 5), it is evident that the equivalent number of chest x-rays could be extremely high. For example in chest PA, the upper bound of the ranges are 5.34 mSv (male), abdomen AP (7.28 mSv-female), lumbar AP (5.86 mSv-female) for adult patients; these could result to a large number of chest x-rays.

The effective doses for different examinations were calculated using ESD/ DAP data and OrgDose software based on ICRP 103, ICRP 60, and NRPB data. Effective dose attempts to produce a quantity related to the risk of health detriment for a reference patient in terms of stochastic effects in the long term (ICRP, 1991). Effective dose is useful for comparison of doses from different types of examination in general terms for a reference

patient, and assessing changes in the dose for a reference patient during the process of optimisation.

The comparison of effective dose calculated in this study with the number of chest x-rays and exposure to natural radiation are shown in Tables 4.30 and 4.31. The equivalent number of chest radiographs is based on 0.05 mSv per chest x-ray and the equivalent duration of exposure to natural radiation is based on 3.0 mSv/year. These analyses and comparisons provide insight into what happens during radiographic examination for a referring physician and radiographer on the need to select the appropriate exposure parameters that could assist in dose optimisation.

The results of the equivalent number of chest x-ray examinations calculated from abdomen AP (using DAP data in Table 4.31 row 3) indicates equivalent of 36 chest x-rays per exposure (columns 4) and the corresponding equivalent number of weeks per exposure to natural radiation (column 5) is 32 weeks (more than half of a year, about 62% of a year) of exposure to background radiation. The mean dose received by paediatric patients in chest PA due to an exposure is equivalent to about 21 chest radiographs or 18 weeks of exposure to natural background radiation. The dose-area product provides a better way of presenting a picture of the equivalent chest radiographs and the number of weeks of exposure since it accounts for the beam area. Entrance surface dose is a point dose. The trend of dose results presented in Tables 4.30 and 4.31 informs that the practice of "imaging wisely" and "gently" could be adopted to ensure dose optimisation in Nigeria.

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5.5 Intensifying Screen in Centres Studied and Dose Reduction in Nigeria

The facilities investigated are still using conventional intensifying screens (200 screen film speed) having low absorption coefficient and conversion efficiency as compared to newly developed rare-earth screen (Daniel, 1984). The basic principle in the action of intensifying screen used in films is the utilization of phosphor that converts energy carried by an x-ray photon into visible light which exposes the film. The screens reduce radiation exposure required to produce a diagnostic radiograph (Admassie, 2010). Selection of appropriate screen or intensifying screen with the right speed, results in the usage of lower mAs setting which is advantageous because of the ability to use shorter exposure times. Additionally, patient dose and motion during exposure are reduced especially during paediatric examinations because of shorter exposure time.

The use of rare-earth screen has been shown to be (modern technology) better than the calcium tungstate screen processed under the same condition. Earlier studies showed that the use of rare-earth screen/film combination significantly reduced exposure time, produced radiographs with more mottle than standard screen, and 50% or more reduction in radiation exposure (Daniel, 1984). Therefore, its adoption in Nigeria will prevent excessively high doses and reduce population dose significantly and its attendant cancer risk. Besides, the film processing in most of the centres were done using manual processing, this could affect the quality of image produced when the chemical used has become weak.

5.6 Cancer Incidence and Mortality in the Studied Population

As a result of the limitation of effective dose in quantifying the individual risk, Tables 4.32 - 4.41 present the calculated lifetime attributable risk (LAR) and attributable risk fraction (ARF) based on the ICRP model. The LAR is defined as additional cancer risk above and beyond baseline cancer risk. The tables (Tables 4.32 - 4.41) show the calculated specific cancer incidences (rate of occurence)/ mortality (death rate arising) as well as for all cancers combined. Column 2 of Tables 4.32- 4.41 show the results of organ doses of various organs calculated using DoseCal software. The software employed the measured ESD data for each examination to obtain organ doses. The organ doses estimated, and data from the risk tables (Ivanov *et al*., 2012) were used to determine LAR and ARF for each organ and for the combination of organs in a given body site, say chest. The ARF for the total incidence and mortality are also tabulated as seen in the last row of each table. It is evident from Table 4.33 (7-year old boy) and Table 4.34 (42-year old man) that the values of LAR and consequently ARF for breast cancer are zero. This is an indication that the probability of incurring breast cancer in either male paediatrics or adults is zero. The cancer incidence and mortality estimated in this study are based on a small population of 10,000 people; therefore, low values of LAR (incidence), LAR (mortality), ARF (incidence) and ARF (mortality) were obtained for each organ (Tables 4.32-4.41 – rows 2-5 and columns 3-6) . However, appreciable values were obtained for solid cancer. The results of LAR (incidence) and LAR (mortality) obtained for annual rate of solid cancer using a population of 10,000 are: ≈ Table 4.32 (2, 1); Table 4.33 (3, 1): Table 4.34 (1, 0); Table 4.35 (1, 0); Table 4.36 (2, 1); Table 4.37 (0, 0); Table 4.38 (1, 0); Table 4.39 (4, 2); Table 4.40 (2 , 1); Table 4.41 (2, 1). Based on a population of 10,000 people, the result show that no solid cancer incidence/mortality is expected when a 55 year old woman is exposed during pelvis AP

examination. The highest LAR (incidence) and LAR (mortality) occurrences are recorded during the exposure of 56 year old woman undergoing abdomen AP examination in a population of 10,000 people.

In an attempt to make the results more meaningful, data in Tables 4.32-4.41 were extrapolated to the population of 35.5 million people in the Southwestern (SW) Nigeria. The results are shown in Figures 4.10- 4.19 for different organs.

Four different procedures were extrapolated to a population of 35.5 million, these are chest PA, pelvis AP, abdomen AP and lumbar spine AP. Figures 4.10 – 4.13 show the results of four patients (5-yr old girl, 7-yr old boy, 42-yr old man and 46-yr old woman) who underwent upper trunk (chest PA) medical examinations and received different doses of radiation. In addition, Figures 4.14 and 4.15 included 44 yr old man and 55 yr old woman whose pelvises were examined. Figures 4.16 and 4.17 involved 63 yr old man and 57 yr old woman examined during abdomen AP procedure and finally, Figures 4.17 and 4.18 included 54 yr old man and 48 yr old woman who underwent lumbar spine AP examination.

Figures 4.10 - 4.13 show that the incidence and mortality of lung cancer are generally more pronounced during the chest PA examination. Besides, it is noteworthy from the comparisons of Figure 4.10 (5-yr old girl) and Figure 4.11 (7-yr old boy) that the incidence/mortality of lung cancer for the female (236/231) is greater than for male (227/200) population even at a lower female organ dose of 0.47 mGy as against 0.87 mGy for male. Similar trend is found in Figure 4.12 (42-yr old male) and Figure 4.13 (46-yr old female). It is clear that the incidence/mortality of lung cancer in female exposed to lower dose of 0.80 mGy is higher than male who received dose of 0.95 mGy by factors of 1.6 (incidence) and 1.8 (mortality) respectively. In addition, the mortality rate of lung cancer is higher in female than in male population. This is evident from the comparisons of Figures 4.10 and 4.13 (females) with Figures 4.11 and 4.12 (males).

Another important feature of chest examination as indicated in this study is that, breast cancer incidence/mortality is more pronounced in young female than adult female even at a lower dose. The reason for higher incidence of lung and breast cancer during the chest examination could be attributed to the fact that the two lie in the path of the primary x-ray beam especially in young people with smaller body sizes. Other organs such as liver and stomach are just close by, as a result the incidences are relatively lower than for lung and

breast cancers. These suggest that adequate collimation and shielding be provided during examinations to prevent exposure of organs that are not of great interest during diagnosis.

Owing to the possibility of higher incidence/mortality of lung cancer in female population especially the young (paediatrics), and the increase in carcinogenic effect, it is important to exercise utmost care in the choice of exposure factors and the projection when carrying out chest examinations. In any situation in which alternative imaging technique can be adopted, it is necessary to do so to avoid the use of x-rays. More importantly, in any case where the patient can be adjusted (tilted at an angle) such that examinations can be carried out and the female will not face the beam directly it should be done. Adoption of postero-anterior (PA) is better than antero- posterior (AP) projection when examining a female chest owing to the presence of the breast. Apparently, the location of the organ from the site of exposure is one of the factors that determine the extent of the cancer incidence and its mortality. The study of Kumaresan *et al*. (2011) among Indians indicates that the dose to the patient using the AP view has inferior image quality and is of greater dose than the use of PA view.

With regard to pelvis AP examination, a comparison of Figures 4.14 and 4.15 shows that cancer incidence and mortality in bladder and colon are dose- and site-dependent. The trend therefore, requires that the dose be as low as reasonably achievable without impairing the image quality. Dose delivered to the sensitive organs should be adequately reduced. Figures 4.16 and 4.17 also attest to the fact that the incidence/ mortality is dose-dependent. However, the nature of Figure 4.17 shows that certain organs are more prone to cancer incidence and mortality than others. This is evident in Figure 4.17 which shows that in spite of the fact that, a relatively lower dose of 1.93 mGy is delivered to the lung as against higher dose of 8.25 mGy to the bladder, yet higher annual lung cancer rate of incidence/mortality is still recorded. Although the organs irradiated are relatively farther from the lung, yet the greatest effect is recorded in the lung. This shows that good collimation and shielding are required to prevent nearby organs whose images are not required for a specific diagnosis. Another important characteristic of cancer mortality shown in Figure 4.17 is that certain cancers lead to greater percentage mortality. The percentages of mortality recorded in different organs are: bladder: 21.1%; liver: 93.1%; colon: 50.3%; stomach: 69.2% and lung: 98.5%.

Results of lumbar spine examinations shown in Figures 4.18 and 4.19 indicate that the incidence/mortality of cancer in three out of four organs is dose dependent. However,

those of female with relatively lower dose of 1.48 mGy recorded higher incidence/mortality of stomach cancer. The rate of mortality is also higher in the female subjects in the Southwestern Nigeria. Based on the sensitive nature of the organ (stomach), it is essential to explore other alternative imaging techniques during the examination of the lumbar spine AP of the female patients. Adopting alternative techniques will to a large extent reduce the cancer incidence and mortality among the female subjects. The results shown in Figures 4.18 and 4.19 (stomach cancer) also point to the fact that it is gender dependent, since female with lower doses displayed higher incidence and mortality of stomach cancer than her male counterpart. The difference between the incidence and mortality implies that, it is not all the cancer incidences that might lead to death if detected early and treated; however, it could lead to other deleterious effects

There are other incidences of non-solid cancers such as leukemia (affects blood) and other detrimental effects which reduce the quality of life of individuals in the population studied. Besides, the cost of taking care of the health effects resulting from exposures; it also affects the family and the society finance. Other effects could be in form of cardiovascular diseases and genetic effects.

The distribution of incidences and the corresponding mortality for all solid cancers (lung breast, stomach, liver, bladder, easophagus) for a sample of 10 subjects undergoing four different procedures: chest (subjects A-D); pelvis (subjects E and F); abdomen (subjects G and H); lumbar spine (subjects I and J) are shown in Figure 4.20. The risk of solid cancer for each subject per 10, 000 was extrapolated to a population of 35.5 million. The distribution shows that highest incidence/ mortality is recorded in H (abdomen AP). The calculated annual incidence of solid cancer for H is 13,060 (0.39%) people, while the corresponding mortality rate is 5,896 people from a population of 35.5 million. The mortality rate is less than half of the incidence rate. This is obtained from the examination of a 56 year old female subject who underwent abdomen AP examination. The distribution is closely followed by subject B (chest PA examination) with incidence and mortality being equal to 8,525 (0.24%) and 4,511 respectively. The least recorded is found in pelvis AP (F) with incidence and mortality rate of 1,248 (0.038%) and 564 subjects in a population of 35.5 million. The percentages of mortality emanating from solid cancer range from 45.2 – 53.0 %. The specific numerical information provided in this study would help the referring Physicians, Radiologists and Imaging Staff make the best possible decisions on justification and optimisation of examination.

5.7 Pattern of Attributable Risk Fraction (ARF) for different Cancers

Figures 4.21 - 4.25 are the plots of ARF against the attained age based on ICRP models. The figures demonstrate the dependence of ARF of lung cancer, breast cancer, liver cancer, easophagus and stomach cancer incidence on the attained age following exposure of a 5 year old girl to a dose of 1.32 mGy from conventional chest x-ray. In Figure 4.21, the ARF_{lung}^{inc} increase steadily until it reaches the highest value in the neighbourhood of 40 years and thereafter the risk fraction decreased gradually at old age. The ARF of incidence of lung cancer at attained age of 40 years is higher than the fraction of incidence at the age of 75years by a factor of about 3.4.

As for the breast cancer, the ARF_{breast}^{inc} decreases steadily with attained age until the age of 40 years, after which a short plateau (40-43 years) was recorded (Figure 4.22). Moreover, the fraction of incidence decreases until it dropped to near zero at old age of 75 years. The characteristics of plot of the ARF_{liver}^{inc} against attained age (Figure 4.23) are similar to the characteristics found in breast cancer, except that the drop in incidence fraction with attained age is not as steep as that of breast and the short plateau occurred at later age of 45-50 years. Similar trend is found in Figure 4.25 (stomach cancer) except that the constant phase occurred between 10-15 years, however, an interesting feature is seen at old age (70 years) where the $ARF_{stomach}^{inc}$ incidence increased sharply.

The feature found in easophagus (Figure 4.24) is quite unique. The ARF_{easoph}^{inc} starts with low incidence of about 0.0020 (of population of 10,000) per year and falls gradually until it reaches the age of 15 years from where a constant (plateau) incidence phase is found between 15 and 25 years. Thereafter, the incidence increases steadily to the highest value at attained age of 65 years where it finally dropped to a low value at age of 75 years. This is an indication that ARF increased from age of 25 to 65year (40 years span). The trend found in this study is in agreement with the one reported in the work of Wall *et al*. (2011). The increase in attributable risk fraction (ARF) incidence at early age is more pronounced in lung cancer (5-40years) and for easophagus cancer, the incidence increased from age of 25-65 years. However, the rates of increase or decrease of risk of cancer incidence vary between the different organs. These trends call for dose optimisation during diagnostic imaging.

5.8 Correlation of Equivalent diameter and Body Mass Index

The present study (Table 4.42) shows strong correlation between De and BMI in adult lumbar spine AP (male and female), chest PA (paediatrics), pelvis AP (male and female) and chest PA. However, extremely weak correlation was recorded in paediatric chest PA. Knowledge of BMI or De of patient is essential during radiographic examinations, since it helps the radiographer to choose the appropriate exposure factors during a specific examination. Correlations between the two parameters indicate that the two parameters can be used to classify patient size and shape (Gibson, 1990) especially the trunk during radiographic examinations. Apparently, De can be used interchangeably with BMI because of strong correlations found between the two patient parameters. It also helps in dose management because effective doses can be greatly controlled if the exposure parameters are selected in line with patient size or size of the exposed body part. Effective dose of overweight subjects can be reduced-to substantial degree in some cases, by orienting the patient such that the thickest fat layer (anterior or posterior) is facing the x-ray tube. (Yanch *et al*., 2009). The low correlation ($R^2 = 0.008817$) recorded in Table 4.42 in paediatric chest PA examination is attributable to the variability in sizes, shapes and ages of patients between 0 and 15 years, this therefore, implies that paediatric patient should be closely monitored during radiographic examinations and be treated according to their age bands instead of collective treatment. The body mass index could be obtained from the weight (w) and height (H) of patient; that is:

$$BMI = {}^{w}/_{H^2} \qquad 5.4$$

Similarly, patient equivalent diameter, De could be calculated from weight and height as shown in equation 3.4. The high coefficient of determination recorded in Table 4.42 for lumbar spine AP (male and female), pelvis AP (male and female) and chest PA for adult patient indicate that BMI and De could be used interchangeably.

The study carried out at the London School of Hygiene and Tropical Medicine, shows that BMI varies from one country to another (BBC, 2012). The average BMI of a Nigerian is 22.88 kg m^{-2} (male =23.98 kg m^{-2}, female = 21.77 kg m^{-2}), this is different from BMI of an American which is 27.82 kg m^{-2} (male = 28.64 kg m^{-2}, female =27.00 kg m^{-2}) or Briton = 26.19 kg m^{-2} (male =27.62 kg m^{-2}, female = 24.76 kg m^{-2}). This implies

that the selection of exposure factors during the examination should be in line with the BMI or De. The use of equivalent patient diameter helps in normalization of the dose of any patient to the reference man's dose and allows inter-comparison of dose values among countries when doses are normalized.

5.9 Models for Estimating Patient Thickness

Owing to the importance of patient size in dose optimisation, an approximate relationship between patient weight and body thickness derived from weight and height is proposed for posteroanterior and anteroposterior projections in Figures 4.26 to 4.29. Equations of body thickness derived from patient equivalent diameter are given in equations 5.5 to 5.8 in Table 5.1 for male and female (combined), paediatric chest PA, lumbar spine AP (adult), pelvis AP (adult), abdomen AP (adult) respectively, where W and t_s are the weight (kg) and thickness (cm) of the patient respectively. Approximate expressions that can be used to determine the standard patient sizes for male and female patients were also etermined from the standard patients whose weights fall within 70 ± 10 kg, these are shown in Figure 4.30 and Figure 4.31. These are shown in equations 5.9 and 5.10 of Table 5.1. The percentage error obtained in the model for standard patient (male chest PA) is about 1.13% while that of standard female is 3.45%. The error could be due to the fact that the standard reference man (weight of 70 kg and D_e=22.9 cm) in the published data is a Caucasian (white man found in the US or Europe), while the model was derived using a Negroid (African found in Southwestern Nigeria).

With these models, the thickness of the indicated projections can be estimated by weighing the patient. Inherent in each expression are the patient height, weight and composition from equivalent diameter (De). The expression for the paediatric patients need refinement to take care of the specific age band and the corresponding weights. The equations were obtained at 95% confidence interval (CI) and p–value, $p < 0.0001$. The coefficient of determination, R^2 ranges from 0.7532 to 0.9424. The low R^2 recorded in paediatric chest PA could be as a result of variation in sizes and ages of various age bands which constitute paediatric patients (0-15 yrs). The models derived are known as Patient Parametric-Exposure Estimation (PPEE) models.

The knowledge of patient size is of utmost importance in radiography as it affects the radiation dose received by patients (most importantly the paediatric patient). Adequate

understanding of patient size helps the radiographer during examination to select the appropriate exposure factors required for large and small patients.

Table 5.1: Patient Parametric-Exposure Estimation model (PPEE) for different procedures and patients

Type of patient	**PPEE Model** (male and female combined)	Equation Number
Paediatric (chest PA)	$t_{e,che,PA,Ped}\ (cm) = (0.16\ W + 11.44)$	5.5
Adult Lumbar Spine AP	$t_{e,lum\ ,AP,Ad}\ (cm) = (0.16W + 12.08)$	5.6
Adult Pelvis AP	$t_{e,pel,AP\ ,Ad}\ (cm) = (0.17W + 11.35),$	5.7
Adult (Abdomen AP)	$t_{e,\ Abd,AP,Ad}\ (cm) = (0.16W + 11.29)$	5.8
	PPEE Model (for standard male or female patient)	
Adult (male) (Chest PA)	$t_{e,male,chest,PA,st\ Ad} = 0.15\ W + 12.14$	5.9
Adult (female) (Chest PA)	$t_{e,female,chest\ PA,st\ Ad} = 0.17\ W + 11.79$	5.10

PPEE =Patient Parametric-Exposure Estimation model

It is clear that more beam energy is absorbed by a larger patient than for a smaller patient; therefore, a larger field size may be required (Chapple, 1998). The study of Ware *et al*. (1999) demonstrates that the energy imparted to adults is a factor of three higher than that for children because of the larger size of adults and increased quantity of x-radiation in milliampere second (mAs). They showed that although the energy imparted to paediatric patients was much lower than to adults, the corresponding effective doses in children were higher. Because of the increased radiation risk in young children, it is important that radiographic technique factors for paediatric patients be carefully evaluated to ensure that the doses are as low as reasonably achievable (ALARA). The infant doses will be directly proportional to the selected quantity of x-radiation, mAs, minimizing this value will reduce doses to patients. The small size of newborn patients, however, should also permit reduction of the x-ray tube potential, which will markedly reduce doses to patients (Ware *et al*., 1999).

5.9.1 Application of Derived Model to Tube Load Selection

Models derived can be used in thesetting of tube load (mAs), an important exposure parameter used during the production of diagnostic image. Optimal exposure is necessary for accurate diagnosis as well as adherence to the ALARA principle (Ching *et al*., 2014). Underexposed image results in low quality image radiograph and may hinder accurate diagnosis. When the film is overexposed, the image quality improves, however, at the expense of patient dose. In order to ensure accurate diagnosis, a well-defined mechanism of exposure adaptation is necessary to allow accurate exposure parameter selection for various kinds of subjects (patients).

In an attempt to apply the patient size-specific model in the choice of tube load (mAs), an approximate simple monochromatic attenuation model (Kotre and Willis, 2003) was adopted, this is given by:

$$mAs_p = mAs_{st}\, e^{-\mu(d_A - d_p)} \qquad 5.11$$

where mAs_p is the tube current- time product per exposure required to produce optimal image, mAs_{st}- standard mAs or tube current-time product per exposure, μ-effective linear attenuation coefficient for the body segment being scanned, d_A= 22.9 cm, standard patient

size, and d_p- the patient thickness. For a male chest examination, the patient thickness d_p in equation 5.9 was used, and mAs_{st} was obtained from the published report of NRPB at constant potential, kV. Different tube loads used during the examinations were obtained with the corresponding weight (kg) and used to obtain the result of Figure 4.32. The figure shows (mAs model) the linear pattern expected if the choices of the tube loads were made based on the patient size. However, a dispersed pattern (mAs radio) was obtained because radiographers did not consider patient thickness in the choice of tube load during examinations.

Figure 4.33 is the plot of mAs as a function of patient weight (kg). This shows a very low coefficient of determination, R^2= 0.0066, and therefore, further reinforces the fact that the choice of tube load was not made based on patient weight. The problem of choosing the tube load could be solved using the model described in this study incorporated into the monochromatic model in form of software as shown in the Appendix (Figure 4.AP1). The software could be coupled to an electrical weighing balance that could give patient thickness and the corresponding tube load immediately a patient steps on the balance.

5. 10 Relationship between Selected Exposure Factors and Patient Weight

The result shown in Figure 4.34 (plot of measured kV against weight) and Figure 4.35 (result of kV set by the radiographer against patient weight) indicate that radiographers in the twelve hospitals represented in the figures did not take into account the weight of the patient while selecting the tube potentials-reason for low coefficient of determination, R^2= 0.0262 (Figure 4.34) and R^2=0.0258 (Figure 4.35).

The poor correlation between techniques factor and the size (weight) of the patient is in part caused by the absence of chart to match patient size (weight) and exposure factor. There was no weighing balance found in any of the centres investigated to measure the weight of patients examined. In any situation where automatic exposure control (AEC) system is not available to regulate the selection of exposure factors, the choice is left to the operator, this leads to the practice of using the same exposure factor for patients of different weights (Huda *et al*., 2000). Failure to account specifically for patient weight during the x-ray examination can lead to patients being unnecessarily exposed (ICRP, 1982) or, if the radiation amount used is too low, it will possibly generate suboptimal image quality (Huda *et al*., 1996). This practice of wrong choice of exposure factor could affect the patient dose and the darkening of the film.

Regular check of the facilities should be undertaken to ascertain that the set kV is within the acceptable limits of the actual output kV required to produce the desired image. With the conventional screen-film radiography, the use of high kVp reduces both patient radiation dose and subject contrast. As a result, the choice of x-ray tube potential needs to be determined by balancing image quality requirements with radiation dose consideration. If significant difference occurs between the set value and the real value (output), it could impair the image quality, contrast and the patient dose. To this end, regular quality control tests of the facilities are required in Nigeria. However, regular quality control tests are impeded by lack of equipment to carry out the tests in Nigeria.

5.11 Relationship between Equivalent Diameter and Entrance Surface Dose

Variations of dose with the equivalent patient diameter are shown in Figure 4.36. The plot of measured ESD against the patient equivalent diameter shows that the doses lie between 17.14 and 33.95 cm, most of the dose values cluster around 22.27cm almost around the size of the standard patient. The low coefficient of determination is attributable to the relatively large population size and certain few high doses around 22.27 cm. Plotting of the dose of certain hospitals against the D_e would have yielded a better correlation between ESD (uncorrected) and D_e. Comparison of Figures 4.37 and Figure 4.38 with Figure 4.36 indicate that the latter assume exponential equation of the form given by:

$$ESD_{corr} = Ae^{-\mu D_e} \qquad 5.12$$

Where μ is the linear attenuation coefficient, A is the initial dose and D_e is the patient equivalent diameter. The relationship shows that the corrected dose received by patient decreases with patient size. Considering the fact that patient dose given by equation 2.17 is the energy imparted per unit mass. Patient dose will generally increase as the size of the patient is reduced because of the lower patient mass and reduced x-ray beam attenuation (Huda *et al*., 1997).

CHAPTER SIX

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

6.1 Conclusion

Radiation doses (ESD, DAP and ED) of patients undergoing common x-ray diagnostic procedures in twelve radiological centres in Southwestern Nigeria together with their exposure parameters have been determined. The present study showed that low filtrations and high mAs are being used in most radiological centres, and adequate quality control tests and feedback mechanisms are not in place in Southwestern Nigeria. The ranges of doses received by both adult and paediatric patients showed that doses within and among centres are dispersed (large spread). The range factors also demonstrated a wide variation in doses received by patients in the centres within the same geographical area indicating that retraining of imaging personnel is required, and regular dose audit is necessary in the country. Centres delivering excessively high doses and extremely low doses were identified and both preliminary local reference dose levels within a group (PLRDLs-G) and within Nigeria (PLRDLs-N) are proposed. Comparison of local doses within the groups (GROUPS A and B : PLRDLs-G) with local dose within Nigeria (regional doses) (PLRDLs-N) showed that, adult regional dose (ESD) is greater than the local dose in abdomen AP, pelvis AP, lumbar spine AP, skull AP, knee AP and hand AP. Moreover, comparison of PLRDLs-G with published national diagnostic reference levels (NDRLs) in United Kingdom, North America, and Brazil showed that ESD of the present study is higher in chest PA, abdomen AP, knee AP examinations. Meanwhile, ESD of pelvis AP and lumbar spine AP are lower than the published reference values. In addition, comparison of the proposed PLRDLs-N with published NDRLs in UK, Slovenia, Brazil and USA showed that, PLRDLs-N (ESDs) in this study are higher in chest PA, abdomen, pelvis PA, skull AP and leg AP. Nevertheless, the result of lumbar spine AP is comparable with published NDRLs in UK and USA indicating that lower doses are feasible in Nigeria with selection of appropriate exposure factors.

It also clear that low filtrations are being used in most facilities investigated in this study, thus leading to high doses in patients. It is important to increase the thickness of the filtration in newly installed facilities in Nigeria. This practice will help in reducing patient dose burden during radiological examinations.

The study indicates that patients examined in Nigeria are at higher health risk than patients examined in the UK because radiological examinations are not yet optimized, and the preoccupation of Radiographers has remained essentially high image quality at the expense of patient dose. The proposed PLRDLs-G and PLRDLs-N are still preliminary and require expansive dose surveys for refinement. The doses measured in this study could be used by NNRA for future policy making and could be an essential part of baseline data for the establishment of national diagnostic reference levels (NDRLs) in Nigeria. The models for estimating patient thickness obtained in this study could serve as a step towards dose optimisation in Nigeria.

6.2 Suggestions for Further Work

The results of this work show that most doses delivered at different centres are relatively higher than the published NDRLs especially the chest PA, abdomen AP and skull AP. Therefore, further research work on methods of reducing patient doses of the identified procedures involving high doses is essential. Generally, there is dearth of data on paediatric dosimetry in Nigeria; this is also an important area requiring extensive further investigations involving many hospitals. The results presented in this work and other published works in Nigeria indicate that low filtrations are being used, therefore, more surveys are needed to substantiate these observations. However, it is important to devise ways of correcting the inadequacy that leads to increase in patient dose. Investigation into reasons why most hospitals are using high mAs is important. Other practical methods of reducing high mAs during diagnostic x-ray examinations could be developed and implemented. This could be achieved by matching different kVp, mAs, filtration, screen-speed and image quality and selecting one that best reduces the doses to the optimal value through computer simulations.

In addition, clinical implementation of the simulated procedures could be carried out. Currently, there is no dose management mechanism in Nigeria; it is therefore imperative to design and implement an online dose registry (database) where each centre could send its quality control test results and exposure factors used during radiographic examinations on regular basis. The online dose registry will help NNRA manage patient

dose in Nigeria, and also help in dose optimisation and determination of national diagnostic reference levels. With the proliferation of x-ray facilities in the country and the increase in the number of x-ray examinations carried out in Nigeria, it is needful for NNRA to design and sponsor an extensive dose monitoring in Nigeria through the use of research students.

6.3 Contributions to Knowledge

The following are the contributions of this work to knowledge:

(1) The study demonstrates the state of radiological practice in Southwestern Nigeria.

(2) Local (PLRDLs-G) and Regional (PLRDLs-N) reference dose levels determined in this study could be used for future policy making by Nigerian Nuclear Regulatory Authority (NNRA) and International Atomic Energy Agency (IAEA).

(3) Both PLRDLs-G and PLRDLs-N obtained could be used for establishing National Diagnostic Reference Levels (NDRLs) in Nigeria.

(4) The feedback (given participating centres) fron this work would assist each healthcares centre studied to improve its radiological practice (dose optimisation).

(5) Rate of cancer incidence/mortality determined in the study will help Physicians to be better informed on the level of patient exposure and the need to adopt alternative imaging techniques during diagnosis instead of using x-rays.

(6) The model (PPEE) derived in the study could be used for dose optimisation in Nigeria and in Africa.

REFERENCES

AAPM American Association of Physicists in Medicine (1988). *Protocols for the Radiation Safety Surveys of Diagnostic Radiological Equipment*. American Institute of Physics, New York, AAPM Report, 25

Admassie, D., Teferi, S., & Hailegenaw, K. (2010). Collective radiation dose from diagnostic x-ray examination in nine public hospitals in Addis Ababa. *Ethiopia. Ethiopian Journal Health Dev*elelopment, 24 (2), 140- 144.

Agba, N.N. (2002). Patient skin dose from diagnostic x-rays at the Federal Medical Centre, Makurdi, Benue State. *Zuma Journal. Of Pure and Applied Sciience*, 4(1), 6-10.

Ahmed, J.V & Daw, H.T .(2014). Cost-benefit analysis and radiation protection. International Atomic Energy Agency Bulletin, vol. 22, NO. 5/6. Retrieved on April 29, 2014.

Ajayi, I.R., & Akinwumiju, A. (2000). Measurement of entrance skin doses to patients in four common diagnostic examinations by thermoluminescence dosimetry in Nigeria. *Radiation Protection Dosimetry*, 87, 217-20.

Akinlade, B.I., Farai, I.P., & Okunade, A.A. (2012). Survey of dose area product received by patients undergoing common radiological examinations in four centres in Nigeria. *Journal of Applied Clinical Medical Physics*, 13(4), 1-9.

Aljundi, I. (2005). Linear interpolation calculator. Available from WeBBusterZ.com.

Anderson-Evans, C.D. (2011). Estimating effective dose from phantom dose measurements in atrial fibrillation ablation procedures and comparison of MOSFET and TLD detectors in a small animal dosimetry setting. Masters Thesis in Medical Physics (Duke University).

Aroua, A., Rickili, H., Stauffer, J-C., Schnyder, P.,Trueb, P.R., and Valley, J.F. (2007). How to set up and apply reference levels in fluoroscopy at a national level. *European Journal of Radiology*, 17, 1621-1633.

Aschan, C. (1999). *Applicability of Thermoluminescent Dosimeters in X-ray Organ Dose Determination and in the Dosimetry of Systemic and Boron Neutron Capture Radiotherapy*. Report Series in Physics, HU-P-D77, University of Helsinki.

Azevedo, A. C. P., Osibote, O.A., and Bocchat, M.C.B. (2006). Paediatric X-ray examinations in Rio de Janeiro. *Physics in Medicine and Biol*ogy, 51, 3723-3732.

Balter, S., Miller, D.L., & Vano, E. (2008). A pilot study exploring the possibility of establishing guidance levels in X-rays directed interventional procedures. *Medical Physics*, 35, 673-680.

BBC British Broadcasting Corporation. (2012).”Where are you on the global fat scale”. Available from http://www.bbc.co.uk/news /health-1877032 #G1A24 H1.58W42C167). Retrieved 2013-12-16.

Beninson, D.J. (1975). Radiation protection standard and their applications. Proceedings of IAEA interregional training course on nuclear power project planning and implementation. AED-CONF.75-769, Karlruhe, Federal Republic of Germany.

BIR British Institute of Radiology (1988). Assurance of Quality in Diagnostic X-ray Department. *British Institute of Radiology*, London.

Boone, J.M., Seibert, J.A. (1997). An accurate method for computer-generating tungsten anode x-ray spectra from 30 to 140 kV. *Medical Physics*, 24(11), 1651-1873.

Brennan, P.C., & Johnston, D. (2002). Irish x-ray department demonstrate varying levels of adherence to European guidelines on good radiographic technique. *British Journal of Radiology*, 75, 243-248.

Brenner, D.J. (2008). Effective dose a flawed concept that could and should be replaced. *British Journal of Radiology*, 84, 521-523.

Brenner, D.J. (2011). *Effective dose a flawed concept that could and should be replaced*. International Commission on Radiological Protection, Washinghton, DC: National Academies Press.

Brenner, D.J. (2012). We can do better than effective dose for estimating or comparing low dose radiation risk. Ann ICRP, 41,124-128.

Broadhead, D.A., Faulkner, K., Rawlings, D.J. and Chapple, C.L (1997). Automated thermoluminescent dosimetry radiographic procedures. *Journal of Radiation Protection*, 17 (1), 17-24.

Bundesamt fur Strahlenchutz (2003). Proclamation of diagnostic reference levels for radiology and nuclear medicine examinations. Retrieved September 26, 2008 from:http://www. bfs.de/ion/medizin/ referezwerte01.pdf.

Burke , K., & Sutton, D. (1997). Optimization and deconvolution of lithium fluoride TLD-100 in diagnostic radiology. *British Journal of Radiology*, 30,23-31.

Bushberg, J.T., Seiberg, J.A., Leidholdt Jr., E.M. & Boone, J.M. (1994). *The essential Physics of Medical Imaging* (1st edition). Williams and Wilkings, USA.

Bushberg, J.T., Seiberg, J.A., Leidholdt Jr., E.M. & . Boone, J.M. (2002). The Essential Physics of Medical Imaging (1st edition). Lippincott Williams and Wilkings Williams, USA.

CEC Commission of the European communities (1996). European Guidelines on Quality Criteria for Diagnostic Radiographic Images. Report EUR 16260EN. The Commision.

Chapple, C-L., Faulkner, K., Lee, R. J. & Hunter, E.W. (1992). Results of a survey to paediatric patients undergoing less common radiological examinations. *British Journal of Radiology*. 65, 225-231.

Chapple, C-L., Faulkner, K & Hunter, .E. W. (1994). Energy imparted to neonate in a special care baby unit. *British Journal of Radiology*, 67, 366-370.

Chapple, C-L., Broadhead, D.A., & Faulkner, K. (1995). A phantom-based method of deriving typical patient doses from measurement of dose-area product on populations of patient. *British Journal of Radiology*, 68, 1083-1086.

Chapple, C.L. (1998). *The Optimization of radiation dose in pediatric radiology*. Ph D thesis, University of Newcastle, Newcastle University Library-09826506, MED Thesis L6425.1998:1-254.

Charnock, P., Moores, B.M., & Wilde, R. (2013). Establishing local and regional DRLs by means of electronic radiographical X-ray examination records. *Radiation Protection Dosimetry*, 157 (1), 710-721.

Ching, W., Robinson, J., & McEntee, M. (2014). Patient-based radiographic exposure factor selection: a systematic review. Australian Instituteof Radiology. *Journal of Medical Radiation Science*, 61, 176-190.

Chougule, A. (2005). Reference doses in radiological imaging. *Polish Journal of Medical Physics and Engineering*, 11 (2), 115-126.

Ciraj-Bjelac, O. Arandjic, D., Kosutic, D. & Lazarevic, D. (2007). An assessment of scattered radiation during fluoroscopic procedures in diagnostic radiology. *Nuclear Technology & Radiation Protection*, 3, 204-208.

Compagnone, G., Pagan, L., & Bergamini, C. (2004). Local diagnostic reference levels in standard x-ray examinations. *Radiation Protection Dosimetry*, 113(1), 54-63.

Compagnone, G., Pagan L., & Bergamini, C. (2005). Effective dose calculations in conventional diagnostic x-ray examinations for adult and paediatric patients in large Italian hospital. *Radiation Protection Dosimetry*, 114 (1-3), 164-167.

Contento, G., Malisan, M.R., Pandovani, R. (1998). A comparison of diagnostic radiology practice and patient exposures in Britain, France and Italy. *British. Journal of Radiology*, 61(1), 2-10.

Cook, J.V., Kyriou, J.C., Pettet, A., Fitzgerald, M.C., Shah, K., Pablot, S.M. (2001). Key factors in the optimisation of paediatric x-ray practice. *British Journal Radiology*,74, 1032-1040.

Crawley, M.T., & Rogers, A.T. (2000). Dose-area product measurements in a range of common orthopaedic procedures and their possible use in establishing local diagnostic reference levels. *British Journal of Radiology*, 70, 740-744.

CRCPD Conference of Radiation Control Programme Directors- CRCPD .(2003). Patient exposure and dose guide (Franfort).

Daniel, P. (1984). Plain radiography with rare earth screen comparison with calcium tungstate screen. *AJR.*, 143, 1335-1338.

Davies, M., McCallum, H., White, G., Brown, J. & Hlem, M. (1997). Patient dose audit in diagnostic radiography using custom designed software. *Radiography*, 3,17-25.

Diaconescu, C., & Iacob, O. (2002). Survey of Diagnostic paediatric radiology and the resulted collective effective dose (2000 y).*The Journal of Preventive Medicine.*10 (3), 3-9.

Dougeni, E.D., Delis, A.B., Karatza, A.A., Kalogero, P., Skiadopoulas, S.G., Mantagos, S.P. & Panayiotakis, G.S. (2007). Dose and image quality optimisation in neonatal radiography. *British Journal of Radiology*, 80, 807-815.

EC European Commission. (1997). Quality criteria for computed tomography: working document. Publication EUR 16262. Brussel, Belgium: European Commission.

EC European Commission (1999). Guidance on diagnostic reference levels (DRLs) for medical exposures. Radiation Protection 109. Issued by the Director –General Environmental, Nuclear Safety and Civil Protection.

EC European Commission (2008a). European guidance on estimating population doses from medical X-ray procedures. Brussels: Directorate General for Energy and transport; Radiation Protection No. 154.

Edmonds, K.D. (2009). Diagnostic reference levels as a quality assurance tool. *The Radiographer*, 56 (3), 32-37.

Egbe, N.O., Nyang, S.O., Ibeagwa, O.B., & Chiaghanam,W.E. (2008). Peadiatric radiography entrance doses for some routine procedures in three hospitals within eastern Nigeria. *Journal of Medical Physics*, 33(1), 20-34.

Egbe, N.O., Inyang, S.O.; Eduwem, D.U. and Ama, I. (2009a). Doses and image quality for chest radiographs in three Nigerian hospitals. *European Journal of Radiography*: 1 (1), 30-36.

Egbe, N.O., Chiaghanam, W.E., Azogor, W.E. & Inyang, S.O. (2009b). A baseline study of entrance dose and image quality for lumbar spine radiography in Calabar, Nigeria. *Radiography*, 15 (4), 306-312.

Esen, N.U., & Obed, R.I. **(**2012). Doses received by patient during thorax x-ray examinations. *Iranian Journal Medical Physics*, Article 4, 9 (4), 245-251.

EU European Union (1997). Council directived97/43 Euratom of 30 June (1997) on health protection of individuals against the dangers of ionising radiation in relation tomedical exposure. Official Journal of the European Communities, 1997.

Farai , I. P., & Obed, R.I. (2001). Occupational radiation protection dosimetry in Nigeria. *Radiation Protection Dosimetry*, 95, 53-58.

Faulkner, F. & Corbett, R.H. (1998). Reference doses and quality in medical imaging. *British Journal of. Radiology*,71, 1001-1002.

Freitas, M.B., Yoshimura, E.M. (2009). Diagnostic reference levels for the most radiological examinations carried out in *Brazil. Rev Panam Salud Publica.*, 25 (2), 95-104.

Friberg, E.G., Widmark, A. & Hauge, I.H.R. (2007). National collection of local diagnostic reference levels in Norway and their role in optimisation of x-ray examinations. Norwagian radiation protection Authority, Osteras, Norway. Retrieved from http://www.nrpa.no/applications/system/publish/view/showLink.asp?ips=1&archive

Gastrup, H. (2004). Estimating and combining uncertainties. In 8th International ITEA Instrumentation Workshop, Park Plaza Hotel and Conference Centre, Lancaster, CA.

Geijer, H. (2001). Radiation dose and image quality in diagnostic radiology. Linkoping University Medical dissertation no. 76, 1-76.

George, J., Eatough, J.P., Mountford, P.J., Kollier, C.J., Oxtoby, J., & Frain, G. (2004) Patient dose optimisation in plain radiography based on standard exposure factors. *British Journal of Radiology*,77, 858-863.

Gibson, R.S. (1990). *Principles of nutritional assessment*. New York: Oxford University Press; 172-182.

Gkanatsios, N.A., & Huda, W. (1997). Computation of energy imparted in diagnostic radiology. *Medical Physics*, 24(4), 571-579.

Gonzalez, L., Vano, E. & Ruiz, M.J. (1995). Radiation doses to paediatric patients undergoing micturating cystourethrography examinations and potential reduction by radiation protection optimization. *British Journal of Radiology*, 68 (807), 291-95.

Gonzalez, L., Fernadez, R., Ziraldo, V., Vano, E. & Ortega, R. (2004). Reference level for patient dose in dental skull lateral teleradiography. *British Journal Radiology*, 77, 735-739.

Gray, J.E., Archer, B.R., Butler, P.F., Hobbs, B.B., Mettler, F.A., Pizzutiello, R.J., Schueler, B.A., Strauss, K. J., Suleiman, O.H., Yaffe, M. J .(2005). Reference values for diagnostic radiology; *Radiology*, 235 (2), 354-358.

Hadnadjev, D.R., Arandjic, D.D., Stojanovic, S.S., Ciraj-Bjelac, O.F., Bojovic, P.M., & Nkovic, J.S. (2012). Patient doses in computed tomography:an assessment of local diagnostic reference levels in a large teaching hospital. *Nuclear. Technology & Radiation Protection*, 27(3), 305-310.

Halato, M.A., Suliman, I.I., Kafi, S.T., Ahmed., Sid Ahamed, F.A., Ibrahim, Z. & Suliman, M.F. (2008). Radiation Physics & protection Conference, 11-19 November, 2008, Nasr City-Cairo, Egypt.

Hambali, A.S., Ng, K.H., Abdullahi, B.J.J., Wang, H.B., Jamal, N., Spelic, D.C., Suleiman, O.H. (2009). Entrance surface dose and image quality: comparison of adult chest and abdominal x-ray examinations in general practioner clinics, public and private hospitals in Malaysia. *Radiation Protection Dosimetry*.

Hart, D., Hillier, M.C., Wall, B.F., Shrimpon & Bungay, D. (1996). *Dose to patient from medical X-ray examination in the UK-1995 Review*. National Radiological Protection Board. Publication NRPB-R289.

Hart, D, Wall, B.F., Shrimpton, P.C., Dance, D.R. (2000). The establishment of reference doses in paediatric radiology as a function of patient size. *Radiation Protection Dosimetry*, 90 (1-2), 235-238.

Hart, D., Hillier, M.C., Wall, B.F. (2002). Doses to patients from medical x-ray examination in the UK-2002 fourth review, Chilton, United Kingdom: *National Radiological Protection Board*; NRPB-W4.

Hart, D., Hillier, M.C., Wall, B.F. (2007). *Doses to patients from radiographic and fluoroscopic X-ray imaging procedures in the UK-2005 review*. HPA-RPA-029. Chilton, UK: HPA.

Hart, D. Hillier, M.C., Shrimpton, P.C. (2012). *Doses to patients from radiographic and fluoroscopic x-ray imaging procedures in UK-2010 review*. Health Protection Agency (HPA-CRCE-034). HPA Centre for Radiation, Chemical and Environmental Hazards, ISBN: 978-085951-716-4.

Hendra, I.R.F. (1986). *A systematic approach to quality assurance in medical diagnostic imaging*. In quality assurance in medical imaging. Bristol: Institute of Physics, 1-14.

Hendrick, R.E. (2010). Radiation dose and cancer risks from breast imaging studies. *Radiology*, 257 (1), 246-253.

Holm, L-E., & Leitz, W. (2002). *The Swedish Radiation Protection Authority's regulations and general advice on diagnostic standard doses and reference levels within medical x-ray diagnostics.* Stockholm, Sweden: Swedish Radiation Protection Authority, SSI FS: 2.

Huda, W., Slone, R.M., Belden, C.J., Williams, J.L., Cumming, W.A. & Palmer, K.C. (1996). Mottle on Computed Radiographs of the chest in paediatric imaging. *Radiology*, 199: 249-252.

Huda, W. & Gkanatsios, N.A. (1997). Effective dose and energy imparted in diagnostic radiology. *Medical Physics*, 24 (8), 1311-1316.

Huda, W., Antherton, J.V., Ware, D.E..,Cumming, W.A. (1997). An approach for the estimation of effective radiation dose at CT in paediatric patients. *Radiology*, 2003, 417-422.

Huda, W., Gkanatsios, A. (1998). Radiation dosimetry for extremity radiographs. *Health Physics*, 75 (5), 492-499.

Huda, W., Nickoloff, E.L., & Boone, J.M. (2008). Overview of patient dosimetry in diagnostic radiology in the USA for the past 50 years. *Medical Physics*, 35 (12), 5713-28.

Huda, W., Scalzetti, E.M. & Levin, G. (2000). Technique factor and image quality as a functions of patients weight at abdominal CT. *Journal of Medical Physics*, 27 (2), 430-435.

Hussain, A.M. and Oresegun M.O. (2006). Health risk assessment of doses to patients' eyes from dental x-ray examination. *Nigerian Journal of Physics*: 18 (2): 235-240.

IAEA International Atomic Energy Agency. (1996). *International basic standards for protection against ionising radiation and for the safety of radiation source*. IAEA safety series No. 115 (Vienna: IAEA).

ICRU International Commission on Radiation Units and Measurement (1970). Radiation dosimetry: x-ray generated at potentials of 150 kV Report 17 (ICRU Publication, Washington, DC, USA).

ICRP International Commission on Radiological Protection (1982). Protection of the patient in diagnostic radiology,: No. 3. In *Anns of International Commission on Radiological Protection* (No. 2/3). Oxford, England: Pergamon.

ICRP International Commission on Radiological Protection (1991). 1990 Recommendation of *International Commission on Radiological Protection*. ICRP Publication 60 Oxford. Pergamon Press.

ICRP International Commission on Radiological Protection (1996). ICRP Publication 73 (Annals of the ICRP Vol 26 No. 2) Radiological Protection and Safety in Medicine; Pergamon Press, Oxford.

ICRP International Commission on Radiological Protection (1996). Radiological Protection and Safety in Medicine., ICRP Publication 73, Ann., 26 (2).

ICRP International Commission on Radiological Protection (2007). ICRP recommendations of the *International Commission on Radiological Protection* ICRP Report 103.Elsevier Ltd..

ICRP International Commission on Radiological Protection (2007a). The 2007 Recommendations of the *International Commission on Radiological Protection*. Elsivier; ICRP Publication 103; *Ann ICRP*, 37 (2-4) (Amsterdam:Elsevier).

IPEM Institute of Physics and Engineering in Medicine (1992). IPEM/NRPB/CoR. Nationalprotocol for patient dose measurement in diagnostic radiology. Chilton, UK: NRPB.

IPEM Institute of Physics in Engineering and Medicine (2004). Guidance on establishment and the use of diagnostic reference levels for medical X-ray examinations. *Institute of Physics in Medicine*, New York.

IPSM Institute of Physical Sciences in Medicine (1992). National Protocol for patient for patient dose measurement in diagnostic radiology. *Dosimetry Working Party of the Institute of Physical Sciences in Medicine (IPSM), York*.

IRSN Institute de Radioprotection et de Surete Nuclaire (2004). Diagnostic reference levels for radiology and nuclear medicine. Available from: http://nrd.irsn.org/about2.php [Accessed 26 September, 2008.] IRSN.

Ivanov, V.K., Tsyb, A.F., Mettler, F.A., Menyaylo, A.N. & Kashcheev, V.V. (2012). Methodology for estimating cancer risks of diagnostic medical exposure: with an example of the risks associated with computed tomography. *Health Physics*, 103 (6), 732-738.

Izewskwa, J., & Rajan, G. (2013). *Radiation. dosimeters*. Division of Human Health, International Atomic Energy Agency, Vienna. Retrieved on February 6, 2013 from www.naweb.iaea.org/.../chapter3,

Jibiri, N.N. & Oguntade, G.T. (2007). Genetically significant dose assessments of occupationally exposed individuals involved in industrial and medical radiographic procedures in certain establishments in Nigeria. *Nuclear Technology & Radiation Protection*, 2, 53-56.

Jibiri, N.N, Akano, A.A., & Olowookere,C.J. (2013). Population exposure to ionizing radiation from radiology examination in a large Nigeria hospital (UCH) between 1998 and 2007: Necessity of dose data on the extremity examination. *Journal of the Nigerian Association of Mathematical Physics*, 25(2), 189-198.

Jibiri, N.N., & Adewale, A.A. (2014). Estimation of radiation dose to the lens of eyes of patient undergoing Cranial Computed Tomography (CT) in a Teaching Hospital in Osun State, Nigeria. *International Journal of Radiaiont Research*, 12(1), 53-60.

Johnston, D.A., & Brennan, P.C. (2000). Reference dose levels for patient undergoing common diagnostic x-ray examinations in Irish hospitals. *British Journal of Radiology*, 73, 396-402.

Kepler, K., Filippova, I., Lintrop, M., & Servomaa, A. (2002). Paediatric patient dosimetry `as part of quality assurance programme of radiology in Estonia. Retrieved from http://www.ut.ee/BM/public at s,oon, d.htm on 20 October, 2005.

Kiljunen, T, Jarvinen, H., & Savolainen, S. (2007). Diagnostic reference levels for thorax X-ray examinations of paediatric patients. *British Journal of Radiology*, 80, 452-459.

Kobayasi, M., Asada, Y., Matsubara, K., Matsunaga, Y., Kawaguchi, A., Katada, K., Toyama., H., Koshida, K., & Suzuki, S. (2014). Evaluation of organ doses and effective dose according to the ICRP reference male/female phantom and the modified impact CT patient dosimetry. *Journal of Applied Clinical Medical Physics*, 15(5), 246-256.

Kotre, C & Willis, P. (2013). A method for systematic selection of technique factors in paediatric CT. *The British Journal of Radiology*, 76 (2003), 51-56.

Kron, T. (1995). Thermoluminescence Dosimetry and its Application in Medicine-part 2: History and Applications.Australas. *Phys. Eng. Sci*. Med., 17, 175-199.

Kumaresan, M., Kumar, J., Biju, K., Choubey, A., & Kantharia, S. (2011). Measur ment of entrance skin dose and estimation of organ dose during paediatric chest radiography. *Health Physics*, 100 (6), 654-657.

Kyriou, J.C., Fitzgerald, M., Pettet, A., Cook, J.V., & Pablot, S.M. (1996). A comparison of dose and techniques between specialist and non-specialist centres in the diagnostic x-ray imaging of children. *British Journal of Radiology*, 69, 437-50.

Kyriou, J.C., Newey, V & Fitzgerald, M.C. (2000). Patient doses in diagnostic radiology at the touch of a button.London UK: The Radiological Protection Centre, St George's Hospital.

Lee, J.S., Kim, Y.H., Yoon, S.J., & Kang B.C. (2010). Reference dose levels for dental panoramic radiography in Gwangju South Korea. *Radiation Protection Dosimetry*, 142 (2-4), 184-90.

Lindskoug, B.A.(1992). The Reference Man in Diagnostic Radiology. *British Journal of.Radiology*, 65, 431-437.

Maccia, C., Ariche-Cohen, M., Nadeau, X. & Severo, C. (1996). The 1991 CEC trial on quality criteria for diagnostic radiographic images. *Radiation Protection Dosimetry*, 57 (1-4), 111-117.

Martins, C.J., Farqouhar, B., Stockdale, E. & Macdonald, S. (1994). A study of the relationship between patient dose and size in paediatric radiology. *British Journal of Radiology*, 67, 864-871.

Martin, C.J. (2007). Optimization in general radiography. *Biomedical Imaging and Interventional Journal*, 3 (2), 1-14.

Martins, C.J., Le Heron, J., Borras, C, Sookpeng, S., & Ramirez, G. (2013). Approaches to aspects of optimization of protection in diagnostic radiology in six continents. *Journal of Radiological Protection*, 33, 711-34.

McCollough, C.H. (2010). Diagnostic reference levels. Image wisely [internet]. (November):1-6. Available on www.imagewisely.org.

McNeil, E.A. Peach, D.E., & Temperton, D.H. (1995). Comparison of entrance surface doses and radiographic techniques in West Midland (UK) with CEC Criteria, specifically for lateral lumbar spine radiographs. *Radiation Protection Dosimetry*, 57 (1-4), 437-440.

McParland, B.J., Gorka, W., Lee, R., Lewall, D.B. & Omojola, M.F. (1996). Radiology in neonatal intensive care unit: dose reduction and image quality. *British Journal of Radiology*, 69 (826), 929-937.

McParland, B.J. (1998). Entrance skin dose estimates derived from dose- area product measurement in interventional radiological procedures. *British Journal of Radiology*, 71, 1288-1295.

McVey, G., Sandborg, M., Dance, D.R. (2003). Study and optimisation of lumbar spine x-ray imaging systems. *British Journal of Radiology*, 76 (9), 177-188.

Meric, N., Bor, D., Buget, N., Ozikirli, M. (1998). The use of Monte Carlo Technique for determination of tissue air ratio (TAR) in diagnostic radiology. *Physica Medica*, 39, 14(1).

Mettler, F.A. Jr., Bhargavan, M., Faulkner, K. (2009). Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources- 1950-2007. *Radiology*, 253 (2), 520-531.

Mgbenu, E.N., Inyang, A.E., Agu, M.N., Osuwa, J.C .and Ebong, I.D.U. (1995). *Modern Physics*. Spectrum books Limited, Ibadan, Nigeria.

Miller, D., Kwon, D., & Bonavia, G.H. (2009). Reference levels for patient radiation doses in interventional radiology: proposed initial values for US practice. *Radiology*, 253 (3), 753- 764.

Mohammadain, K.E.M., da Rosa, L.A.R., Azevedo, A.C.P., Guebel, M.R.N., Boechat, M.C.B. & Habani, F.I. (2004). Dose evaluation for paediatric chest x-ray examinations in Brazil and Sudan: low dose and reliable examinations can be achieved in developing countries. *Physics in Medicine and Biology*, 49, 1017-1031.

Montgomery, A., Martins, C.J. (2000). A study of the application of paediatric reference levels. *British Journal of Radiology*, 73, 1083-1090.

Muhogora, W.E. & Nyanda, A.M. (2001). The potential for reduction of radiation doses to patient undergoing some common X-ray examinations in Tanzania. *Radiation Protection Dosimetry*, 94 (4), 381-384.

Myer M.J. (1993). *Genetic and somatic effects of ionising radiation and to assess their risks*. Wotton, R. (Eds). Postgraduate Medical Sciences- Radiation of patient (pp. 19-33). Cambridge University Press.

NBS National Bureau of Statistics (2013). Population of Soutwestern Nigeria.

NCRP National Council on Radiation Protection and Measurements (1989).Exposures of the US population from diagnostic medical radiation: recommendation of the National Council on Radiological Protection and Measurements. Report No. 100. *National Council on Radiological Protection and Measurements*.

Ng, K.H., Rassiah, P., Wang, H.B., Hambali, A.S., Muthuvelu, P., & Lee, H.P. (1998). Doses to patients in routine X-rays examinations in Malaysia. *British Journal of Radiology*, 71, 654-660.

Nickoloff, E.L., Lu, Z.F., Dutta, A.K. & So, J.C. (2008). Radiation dose descriptor: BERT, COD, DAP, and other strange creatures. *Radiographics*, 28(5), 1439-1450.

NNRA, Nigerian Nuclear Regulatory Authority (2015). Regulation for Radiation Safety in Nuclear Medicine. Retrieved on 12/10/2015 at www.nnra. gov.ng/ radiological safety; 1-63.

NOHSC National Occupational Health and Safety Commission (1995). Recommedation for limiting exposure to ionising radiation. National Occupational Health and Safety Commission NOHSC: 3022 (1995). On Radiological Protection Publication 26 Oxford, England. Pergamon.

NRC Nuclear Regulatory Commission (1995). Notices, Instruction and Report to workers; Inspection and Investigations. Nuclear Regulatory Commission (NRC) 10 CFR. Washington, DC.

NRC National Research Council (2002). BEIR VII: Health risks from exposure to low level of ionising radiation. National Academies Press, United States of America.

NRL-C5 National Radiation Laboratory 5. (2010). *Code of staff practice for the use of X-ray in medical diagnosis.* NRC.C5 version 1.3 ISSN 0110-9316.

NRPB National Radiological Protection Board (1988). Health effect models developed from the 1988 UNSCEAR Report. NRPB-R226. London: HMSO.

NRPB-RCR National Radiological Protection Board & Royal College of Radiographers (1990). *Patient dose reductionin diagnostic radiology*. Document of the NRPB, 1 . 3 (London: HMSO).

NRPB National Radiological Protection Board (1992). *Dosimetry working party of the Institute of physical Sciences in Medicine- national protocol for patient dose measurement in diagnostic radiology*. National Radiological Protection Board (NRPB).

Nyathi, T., Nethwadzi, L.C., Mabhengu, T., Pule, M. L., & van der Merwe, D.G. (2009). Patient dose audit for patient undergoing six common radiography examinations: potential dose reference levels. *The South African Radiographer*, 47 (2), 9-13.

Obed, R.I., Ademola, A.K., Adewoyin, K., & Okunade, O.A. (2007). Doses to patients during routine x-ray examinations of chest, skull, abdomen, pelvis in nine selected hospitals in Nigeria. *Research Journal of Medical Science*, 1(4), 209-214.

Ogundare, F.O., Oni, O.M., & Balogun, F.A. (2002). Measurement of X-ray Absorbed Doses to Dental Patients in Two Dental X-ray Units in Nigeria. *Radiation Protection Dosimetry*, 102 (4), 355-358.

Ogundare, F.O., Uche, C.Z., & Balogun, F.A. (2004a). Radiological parameters and radiation doses of patients undergoing abdomen, pelvis and lumbar spine x-ray examinations in three Nigerian hospitals *British Journal of Radiology*, 77, 934-940.

Ogundare, F.O., Ajibola, C.L., & Balogun, F.A. (2004b). Survey of radiological techniques and doses of children undergoing some common x-ray examinations in three hospitals in Nigeria. *Medical Physics*, 31(3), 521-524.

Ogunsehinde, A.O., Adeniran, S.A.M., Obed, R.I,, Akinlade, B.I. and Ogundare, F.O. (2002). Comparison of entrance surface doses of some x-ray examinations with CEC reference doses. *Radiation Protection Dosimetry*, 98, 231-4.

Olowookere, C.J., Obed, R.I., Oluwafisoye, P.A., & Vincent, U.E. (2008). Medical/ Health Physicist: missing Component of Nigeria Radiological Crew. *Journal of Advancement in Medical and Pharmaceutical Sciences*, 2 (4): 83 – 89.

Oritz, P., Maccia C., & Padovani, R. (1995). Results of the IAEA-CEC coordinated research. Programme on radiation doses in diagnostic radiology and methods for reduction. *Radiation Protection Dosimetry*, 57, 95-99.

Osei, E.K., & Darko, J. (2013). A survey of organ equivalent and effective doses from diagnostic radiology procedures. *ISRN Radiology* (Hindawi publishing Corporation).Vol. 2013 : 1-9.

Osibote, A.O., Azevedo. A.C.P., Carlvaho, A.C.P., Khoury, H.J., Olivera, S.R., Silva, M.O., & Marchon, C. (2007). Patients exposure and imaging quality in chest radiographs: a critical evaluation. Radiol Bras. 40(2), 119-122.

Parry, R.A., Sharon, A., Glaze, M.S., & Benjamin, R.A. (1999). The AAPM/ RSNA Physics Tutorial for Residents: Typical patient radiation doses in diagnostic radiology. *Radiographics*, 19, 1289-1302.

Persliden, J. Petterson, H.B., & Falth-Magnusson, K. (1996). Radiation dose at small intestinal biopsies in children: results of a national study. *Acta Radiol*., 34, 92-98.

Preston, D.L., Ron, E., Tokuoka, S., Funamoto, S., Nishi, N., Soda, M., Mabuchi, K., & Kodama, K. (2007). Solid Cancer incidence in Atomic Bomb Survivor: 1958-1998. *Radiat Res*., 168:1-64.

Ramsdale , M.L., Peet, D., Hollaway, P. and Rust, A. (2001). *Patient dose survey and the use of local and national diagnostic reference levels.* In: proceeding of the International Conference on Radiological protection of patient in diagnostic and interventional radiology, nuclear medicine and radiotherapy. Malaga, March 2001; IAEA-CSP-7/P, 434-439.

Rannikko, S. Ermakov, I., Lampieinen, J.S., Toivonen, M., Karila, K.T.K., & Chervjakov, A, (1997). Computing patient doses of x-ray examinations using a patient size- and sex-adjustable phantom. *British Journal of Radiology*, 70, 708-718.

Rehani, M. M., Arun Kumar, L.S., & Barry, M. (1992). Quality assurance in diagnostic radiology. *Indian Journal of Radiological Imaging*, 2, 259-263.

Rehani, M.M., Kaul, R., Kumar, P., & Berry, M. (1995) Does bridging the gap between knowledge and practice help?-Example of patient dose reduction in radiology.*Journal of Medical Physics*, 20.

Robinson, A. (1990). *Radiation Protection and Patient doses in diagnostic radiology*, In: Grainger & Allison's (eds). Diagnostic Radiology: A Textbook of Medical Imaging (Churchill Livingstone, NewYork: 169-189).

Samara, E.T., Aroua, A., Bochud, F.O., Ott, B., Theiler, T., Treier, R., Trueb, P.R., Vander, J., & Verdum, F.R. (2012). Exposure of the Swiss Population by medical x-rays: 2008 review. *Health Physics*, 102 (3), 265-270.

Santos, J., Foley, S., Paulo, G., McEntee, M.F., & Rainford, L. (2014). The establishment of computed tomography diagnostic reference levels in Portugal. *Radiation Protection Dosimetry*, 158 (3), 307-317.

Scanff, P., Donadieu, J., Pirard, P., & Aubert, B., (2008). Population exposure to ionizing radiation from medical examinations in France. *British Journal of Radiology*, 81, 204-213.

Schandorf, C. & Tetteh, G.K. (1998). Analysis of dose and dose distribution for patients undergoing selected X-ray diagnostic procedures in Ghana. *Radiation Protection Dosimetry*, 76 (4), 249-245.

Schauer, D.A. & Linton, O.W. (2009). National Council on Radiation Protection and measurements Report shows substantial exposure to increase. *Radiology*, 253(2) 293-296.

Scheneider, K., Kohn, M.M., Bakowski, C., Stein, E., Freidhof, C., & Horwitz, A.E. (1993). Impact of radiographic imaging criteria on dose and image quality in infants in and EC-wide survey. *Radiation Protection Dosimetry*, 49:73-6.

Shandiz, M.S., Toosi, M.T.B., Farsi, S., & Yaghobi, K. (2014). Local reference dose evaluation in conventional radiography examinations in Iran. *Journal of Applied Clinical Medical Physics*, 15(2), 303-310.

Sherifat, I. & Olarinoye, I.O. (2009). Patient entrance skin doses at Minna and Ibadan for common diagnostic radiological examinations. *Bayero Journal of Pure and Applied Sciences*, 2(1), 1-5.

Shrimpton, P.C., Wall, B.F., & Fisher, E.S. (1981). The tissue-equivalence of Alderson Rando anthropomorphic phantom for x-rays of diagnostic qualities. *Physics in Medicine and Biology*, 26 (1), 133-139.

Shrimpton, P.C., & Wall, B.F. (1986).National survey of doses to patients undergoing a selection of routine x-ray examinations in English hospitals, Report NRPB-R200 (National Radiological Protection Board, Didcot).

Shuryak, I., Rainer, K., Sachs, R.K., Brener, D.J. (2010). Cancer risks after radiation exposure in middle age. *J Natl. Cancer Inst*., 102, 1628-1636.

Skrk, D., Zdesar, U., & Zontar, D. (2006). Diagnostic reference levels for x-ray examinations in Slovenia. *Radiol Oncol*., 40(3), 189-95.

Smith-Bindman, R., Lipson, J., Marcus, R., Kim, K., Mehesh, M., Gould, R., Berrington de Gonzalez, A., & Miglioretti, D.L. (2009). Radiation Dose Associated with Computed Tomography Examinations and the associated Lifetime Attributable Risk of Cancer. *Arch Intern Med.*, 69 (22), 2078-2086.

Sonawane, A.U., Shirva, V.K. & Pradhan, A.S. (2009). Estimation of skin entrance doses (SEDs) for common medical x-ray diagnostic examinations in India and proposed diagnostic reference levels (DRLs). *Radiation Protection Dosimetry*., 138 (2), 129-136.

Sprawls, J.P. (1993). *Physical principles of medical imaging* (3rd ed.). Aspen publishers Inc. Gaithersburg, Maryland, 165-167.

Stather, J.W., Muirhead, C.R., Edward, A.A., Hamson. I.D., Lloyd, D.C. & Wood, N.R. (1988). Health effects developed from the 1988 UNSCEAR report. National Radiological protection Board Report-R226 (HMSO, London).

Suliman, I.I., Abbas, H.I., & Habbani, F.I. (2006). Entrance surface doses to patient undergoing selected diagnostic x-ray examinations in Sudan. *Radiation Protection Dosimetry*, 123 (2), 209-214.

Suliman, I.I., & Elshiekh, H.A (2008) Radiation doses from some common pediatric x-ray examinations in Sudan. *Radiation Protection Dosimetry*, 132 (1), 64-72.

Theocharopoulos, N., Perisinakis, K., Damilakis, J. Varveris, H. & Gourtsoyiannis, N. (2002). Comparison of four methods for assessing patient effective dose from radiological examinations. *Medical Physics*, 29 (9), 2070-2079.

Harsaw (2001). TLD Reader Manual. Saint- Gobin crystals and detectors, radiation measurement products, Model 3500 Manual TLD Reader with WinREMS, Operators Manual, USA.

Toosi, M..T.B & Akbari, F. (2012). Diagnostic reference level arising from dental panoramic radiography. *Iranian Journal of Medical Physics*, 9(3):161-167.

Toosi, M.T.B & Malekzadeh, M. (2013). Local diagnostic reference levels for common paediatric x-ray examinations in Khorazan Razavi Province, Iran. *Iranian Journal of Medical Physics* 11 (4):301-307.

Tootel, A.K., Scczepura, K., Hogg, P. (2014). Comparison of effective dose and lifetime risk of cancer incidence of CT attenuation correction acquisitions and radiopharmaceutical administration for myocardial perfusion imaging.*British Journal of Radiology*. 86, 1-8.

Tsapaki, V., Tsalafoutas, I.A., Chinofoti, I., Karageorgi, A., Carinou, E., Kamenopoulou,, V., Yakoumakis, E.N. & Koulentianos, E.D. (2007). Radiation doses to patients undergoing standard radiographic examinations: a comparison between two methods.*British Journal of Radiology*, 80, 107-112.

Tung, C.J., Tsai, H.Y., & Lo, S.H. (2001). Determination of guidance levels of dose for diagnostic radiography in Taiwan. *Medical Physics*, 28(5), 850-857.

UNSCEAR United Nations Scientific Committee on Effects of Atomic Radiation (1993). Sources and effects of ionising radiation. United Nation Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly. New York: United Nations.

UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation. (2000). Sources and effect of ionising Radiation. Report to the General Assembly, with scientific annexes.

UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation (2010). UNSCEAR 2008 Report Vol I: Sources of ionising radiation. New York: United Nations.

Vano, E.G., Gonzalez, L., Fernandez, J.M., Guibelalde, E. (1995). Patient dose values interventional radiology. *Br J. Radiol*, 68:1215-1220.

Victoreen (1989). Instruction Manual of NERO^{TM} Model 6000 M. Victoreen INC, U.S.A

Wade, J.P., Goldstone, K.E., & Dendy, P.P. (1995). Patient dose measurement and dose reduction in East Anglia (UK). *Radiation Protection Dosimetry*, 57(1-4), 445-448.

Wagner, L.K., Lester., R.G., & Saldana., L.R. (1997). *Exposure of the pregnant patient to diagnostic radiations: a guide to medical management*. 2nd Madison Wis: Medical Physics Publishing.

Wall, B.F. (1996). How to assess the dose to the patient in diagnostic radiology. Ninth International Congress of the International Radiation Protection Association, Vienna, Austria April 14-19,1996.

Wall, B.F. (2000). Diagnostic reference levels-the way forward. *British Journal of Radiol*ogy, 74, 785-788.

Wall, B.F. (2004). Diagnostic reference levels in the x-ray department. *Eur Radiol Syllabus*, 14, 66-73.

Wall, B.F., Haylock, R., Jansen, J.T.M., Hillier, M.C., Hart, D., & Shrimpton, P.C. (2011). *Radiation risk from medical x-ray examinations as a function of the age and sex of a patient*. Report HPA-028. Chilton, UK: Health Protection Agency.

Ware, D.E., Huda, W., Mergo, P.J., & Litwiller, A.L. (1999). Radiation effective doses to patients undergoing abdominal CT examinations. *Radiology*, 210, 645-650.

Warren-Forward, H.M., & Millan, J.S. (1995). Optimisation of Radiological technique for chest Radiography. *British. Journal of Radiology*, 68(1), 12-19.

West, M. (1993). *The principle of quality assurance and quality control applied to equipment and techniques*. In postgraduate medical science, radiation protection of patient. Wotton, R. (edit) Cambridge University press, 49-57.

Wotton, R. (1993). *Nature of ionising radiation and its interaction with tissue*: in Postgraduate medical science radiation protection of patient. Cambridge University Press: 7-17.

Wraith, C.E., Martin, C.J., Stockdale, E.J.N., McDonald, S., & Farquhar, B. (1995). An investigation into techniques for reducing doses from neo-natal radiographic examinations. *British Journal of Radiology*. 68, 1074-1082.

Yanch J.C., Behrman, R.H., Hendricks, M.J., & McCall, J.H. (2009) Increased radiation dose to overweight and obese patients from radiographic examination. *Radiology*, 252 (1), 128-137.

Yasuda, H. (2009). Effective dose measured with a life size human phantom in low earth orbit mission. *J.Radiat. Res*., 50 (2), 89-96.

APPENDICES

(A1) Comparison of local survey in this study with NDRLs set in UK (NRPB-HPA) and in the US (table shows hospitals with mean ESD below the NDRLS)

Exam.	Sources of NDRLs	Group A Hospitals (ESD in mGy)	Group B Hospitals (ESD in mGy)	Percentage Below NDRLs
Chest PA	UK(NRPB-HPA)-(0.15 mGy) USA (0.25 mGy)	Higher doses than NDRLs	Higher doses than NDRLs	NGP
Abdomen AP	UK (NRPB-HPA)-(4.40 mGy) USA (4.50)	EKSUTH(3.44), FMC (3.86)	TTPC 2 (1.64)	(20%) NGP
Pelvis AP	UK (NRPB-HPA)-(3.90 mGy)	OAUTH (2.08), EKSUTH (1.11)	TTPC 1(1.08), AYHS (0.10)	(27 %) NGP
Lumbar AP	UK (NRPB-HPA)- (5.70 mGy) USA (5.00 mGy)	FMC (2.29), EKSUTH (0.55), LTH1(4.89), VHS(2.50), SDAH (4.43)	ALSH2(2.37), TTPC1(2.53), OAGSH (0.79), TTPC2(3.03), AYSH (0.57), FKJSH (3.38)	Higher percentage of the hospitals are below NDRLs (73%) GP
Skull AP	UK (NRPB-HPA)-(1.80 mGy)	EKSUTH (0.46)	AYHS (1.26), ALSH (1.28)	Few hospitals are below NDRLs (20%) NGP

GP – Good Practice, NGP- Not Good Practice

(A2) Comparison of local survey in this study with NDRLs set in UK (NRPB-HPA) (table shows hospitals with mean ESD below the NDRLS)

Exam.	**Sources of NDRLs**	**Group A Hospitals (DAP in Gy cm^2)**	**Group B Hospitals (DAP in Gy cm^2)**	**Percentage of centres below NDRLs**
Chest PA	UK (NRPB-HPA)- (0.10 Gy cm^2)	Higher doses than NDRLs, in all	Higher doses than NDRLs , in all	---
Abdomen AP	UK (NRPB-HPA)- (2.90 Gy cm^2)	Higher doses than NDRLs	TTPC 2 (1.21)	13%
Pelvis AP	UK (NRPB-HPA)- (2.20 Gy cm^2)	OAUTHW(1.94), EKSUTH (0.72)	TTPC 1(1.09), AYHS (0.076)	27%
Lumbar AP	UK (NRPB-HPA)- (1.50 Gy cm^2)	EKSUTH (0.26), VHS (1.46)	TTPC1(1.42), ALSH(1.47), AYSH(0.63), OAGSH (0.39)	40%
Skull AP	No data for comparison	No data for comparison	No data for comparison	No data for comparison

Table 4.AP1: Summary of mean (range) exposure factors used during examination and adult patient characteristics of GROUP A Health Care Centres

Exam	Parameters	OAUTHW	FMC	EKSUTH	LTH1	LTH2	VHS	SDAH
Chest PA	kVp	72(60-80)	97(68-177)	74(70-78)	66(60-75)	72(63-86)	64(60-80)	82(61-96)
	mAs	29 (10-40)	24 (8-40)	19(16-32)	21(16-32)	8(3-9)	31(24-32)	49(10-80)
	FSD (cm)	126 (88-153)	141 (50-159)	128(90-167)	122(57-167)	156(126-185)	84(42-150)	126(60-163)
	Age (yrs)	53 (23-80)	51(22-80)	44(25-78)	44(17-86)	49(23-57)	47(17-85)	33(17-70)
	De (cm)	22 (19-26)	23(19-25)	20(18-25)	23(18-30)	23(19-26)	22(19-26)	21(17-24)
	Weight (kg)	65 (48-86)	69 (40-100)	58(39-84)	67(40-120)	67(48-84)	63(42-86)	57(37-85)
Abdo AP	kVp	82(78-88)	87(85-90)	78(75-81)	--	81(63-86)	--	110(102-117)
	mAs	54(50-63)	40	26(20-32)	--	61(51-71)	--	**95(64-125)**
	FSD (cm)	85(74-97)	69(68-70)	74(70-78)	--	89(81-94)	--	**88(82-90)**
	Age (yrs)	79()	59(38-80)	45(31-53)	--	60()	--	63(58-73)
	De (cm)	22()	21	21(17-25)	--	24 ()	--	23(22-24)
	Weight (kg)	65()	53(50-54)	58(40-84)	--	70 ()	--	71(70-72)
Pelvis AP	kVp	73(70-85)	78(75-85)	76(75-78)	--	--	--	--
	mAs	44(40-63)	30(25-32)	24(20-32)	--	--	--	--
	FSD (cm)	97(90-105)	81(63-103)	81(78-83)	--	--	--	--
	Age (yrs)	57(35-70)	34(19-51)	41(32-50)	--	--	--	--
	De (cm)	24(24-27)	24(22-27)	22(21-23)	--	--	--	--
	Weight (kg)	77(72-90)	78(63-98)	61(60-70)	--	--	--	--
Lumbar AP	kVp	83(80-85)	94(90-100)	89	82(71-95)	--	77(60-80)	88(70-117)
	mAs	**90(40-160)**	44(40-50)	45	117(40-200)	--	26(23-32)	49(16-100)
	FSD (cm)	**66(60-70)**	61(40-70)	122	78(60-97)	--	59(50-68)	83(62-100)
	Age (yrs)	53(48-60)	64(44-78)	43	37(31-42)	--	47(21-65)	60(40-73)
	De (cm)	24(22-27)	22(20-24)	24	21(20-22)	--	23 (20-24)	24(21-26)
	Weight (kg)	74(60-88)	62(52-68)	74	59(54-63)	--	70(53-85)	75(60-95)
Skull AP	kVp	75(72-80)	78(75-80)	69()	71(67-80)	--	--	--
	mAs	30(25-40)	30(16-40)	22(8-40)	78(40-125)	--	--	--
	FSD (cm)	85(74-92)	84(87-122)	80(73-83)	64(56-67)	--	--	--
	Age (yrs)	47(43-50)	40(31-76)	45(27-68)	38(20-75)	--	--	--
	De (cm)	22(21-23)	23(22-23)	23(21-24)	22(20-24)	--	--	--
	Weight (kg)	65(58-72)	68(65-70)	70(52-77)	58(48-77)	--	--	--
Knee AP	kVp	59()	66(60-80)	--	63()	61()	60 constant	67(63-102)
	mAs	6()	8(6-16)	--	10()	5	32 constant	14(7-64)
	FSD (cm)	91(87-91)	80(65-105)	--	108()	100	71(68-74)	80(66-122)
	Age (yrs)	46(45-47)	68(45-82)	--	42()	26	43(32-53)	47(26-73)
	De (cm)	14(13-15)	15(9-30)	--	12()	23	13(12-14)	13(5-33)
	Weight (kg)	78()	73(65-87)	--	63()	68	71(60-83)	71(66-122)
Neck AP	kVp	--	75()	--	67(56-75)	--	--	--
	mAs	--	25()	--	37(20-50)	--	--	--
	FSD (cm)	--	77()	--	64(50-72)	--	--	--
	Age (yrs)	--	72()	--	51(41-74)	--	--	--
	De (cm)	--	14()	--	19(14-30)	--	--	--
	Weight (kg)	--	53()	--	71(57-85)	--	--	--
Skull AP	kVp	58(54-62)	55()	68(60-75)	--	--	--	63(57-94)
	mAs	5(4-6)	5()	19(5-32)	--	--	--	8(6-12)
	FSD (cm)	90(78-107)	79()	82(78-87)	--	--	--	76(57-94)

	Age (yrs)	42(27-70)	90()	39(20-57)	--	--	--	50(21-75)
	De (cm)	11(9-13)	7()	22(21-23)	--	--	--	8(5-14)
	Weight (kg)	65(60-72)	47()	65(58-71)	--	--	--	58(50-70)

Abdo - abdomen

Table 4.AP2: Summary of mean (range) exposure factors used during examination and adult patient characteristics of GROUP B Health Care Centers

Exam	Parameters	TTPC 1	TTPC 2	ANHS	AYHS	FKJSH	ALSH 1	ALSH 2	OAGHS
Chest PA	kVp	78 (74-88)	79 (68-87)	71 (72-96)	76 (55-87)	70 (60-86)	82 (70-80)	83 (84-90)	62 (60-62)
	mAs	25 (8-60)	21 (12-45)	28 (5-100)	27 (8-50)	51 (5-80)	12 (10-16)	0.33 ()	25 (20-32)
	FSD (cm)	116 (60-154)	109 (48-138)	125 (120-128)	106 (101-112)	157(66-172)	124 (111-136)	123 (119-126)	173 (170-175)
	Age (yrs)	48 (26-70)	48 (30-70)	40 (22-50)	44 (22-73)	43 (19-90)	40 (19-65)	43 (22-65)	47(41-54)
	De (cm)	23 (17-36)	24 (20-34)	22 (19-25)	21 (20-25)	23 (18-31)	22 (17-29)	22 (18-27)	25 (24-26)
	Weight (kg)	75 (39-150)	71 (58-105)	68 (49-84)	59 (50-84)	72 (41-117)	66 (66-106)	63 (37-92)	79 (70-85)
Abdo AP	kVp	--	91 (85-95)	--	--	--	--	--	--
	mAs	--	100 (90-120)	--	--	--	--	--	--
	FSD (cm)	--	91 (87-96)	--	--	--	--	--	--
	Age (yrs)	--	56 (45-76)	--	--	--	--	--	--
	De (cm)	--	25 (23-26)	--	--	--	--	--	--
	Weight (kg)	--	91 (75-100)	--	--	--	--	--	--
Pelvis AP	kVp	65 (50-73)	--	80 (72-96)	87 (60-100)	86 (82-92)	--	--	--
	mAs	43(8-75)	--	18 (5-30)	50 (40-83)	64 ()	--	--	--
	FSD (cm)	86(80-96)	--	93 (72-137)	111 (70-125)	111 (106-113)	--	--	--
	Age (yrs)	62(58-69)	--	44 (22-57)	44 (31-67)	86 (82-92)	--	--	--
	De (cm)	23 (22-29)	--	22 (19-23)	25 (22-27)	21 ()	--	--	--
	Weight (kg)	70 (65-75)	--	67 (54-72)	86 (40-93)	66 ()	--	--	--
Lumbar AP	kVp	86 (75-96)	80 (70-95)	--	82 (79-90)	107 (94-117)	--	91 (65-120)	65(63-66)
	mAs	64 (9-90)	66 (12-90)	--	56 (32-90)	108 (80-125)	--	23 (19-25)	33 (25-40)
	FSD (cm)	73 (55-75)	76 (55-122)	--	72 (67-78)	115 (98-150)	--	97 (82-115)	77 (75-78)
	Age (yrs)	46 (27-67)	56 (34-69)	--	47 (30-63)	42 (32-42)	--	40 (20-60)	56 ()
	De (cm)	23 (22-24)	24 (21-28)	--	23 (22-25)	26 (22-28)	--	20 (18-24)	24 ()
	Weight (kg)	69 (55-75)	76 (58-98)	--	71 (64-76)	89 (72-105)	--	51 (46-56)	74 ()
Skull AP	kVp	--	--	78 (75-80)	88 (65-94)	--	--	83 (60-100)	72 (63-81)
	mAs	--	--	75 (15-100)	64 (50-75)	--	--	15 (10-22)	77 (64-80)
	FSD (cm)	--	--	68 (64-73)	76 (70-96)	--	--	85 (60-95)	137 (33-140)
	Age (yrs)	--	--	65 (49-50)	28 (20-63)	--	--	19 (14-30)	65 ()
	De (cm)	--	--	22 (20-23)	22 (19-24)	--	--	21 (19-23)	24 ()
	Weight (kg)	--	--	65 (54-76)	60 (49-75)	--	--	60 (57-69)	63 ()
Knee AP	kVp	55 (48-63)	--	60 (55-70)	57 (50-72)	63 (59-72)	--	56 (50-80)	49 (48-50)
	mAs	5 (4-6)	--	20 (10-30)	8 (5-12)	14 (5-32)	--	8 (5-11)	5 (3-6)
	FSD (cm)	79 (67-88)	--	84 (70-107)	91 (67-105)	88 (8-89)	--	82 (63-76)	92 (90-94)
	Age (yrs)	33 (29-38)	--	28 (16-45)	60 (45-73)	54 (26-68)	--	47 (30-58)	45 (39-50)
	De (cm)	18 (9-17)	--	22 (21-25)	10 (7-13)	11 (10-12)	--	10 (9-12)	9 (7-10)
	Weight (kg)	70 (53-84)	--	65 (47-71)	60 (48-72)	64 (66-68)	--		80 (74-86)
Hand	kVp	51 (40-65)	53 (50-79)	53 (45-55)	52 (45-60)	52 (47-59)	--	50 (45-86)	

AP									
	mAs	5 (4-6)	4 (3-10)	30 (constant)	10 (5-60)	5 (4-7)	--	7 (5-12)	
	FSD (cm)	48 (22-86)	53 (50-70)	87 (85-89)	97 (90-106)	94 (76-105)	--	82 (60-112)	
	Age (yrs)	26 (20-32)	20 (17-25)	49 (47-58)	50 (22-78)	30 (19-53)	--	20 (18-35)	
	De (cm)	9 (6-15)	7 (5-10)	23 (20-25)	6 (3-10)	8 (3-14)	--	6 (4-10)	
	Weight (kg)	70 (66-7636)	71 (55-90)	76 (60-80)	48 (40-56)	95 (54-176)	--	58 (20-60)	

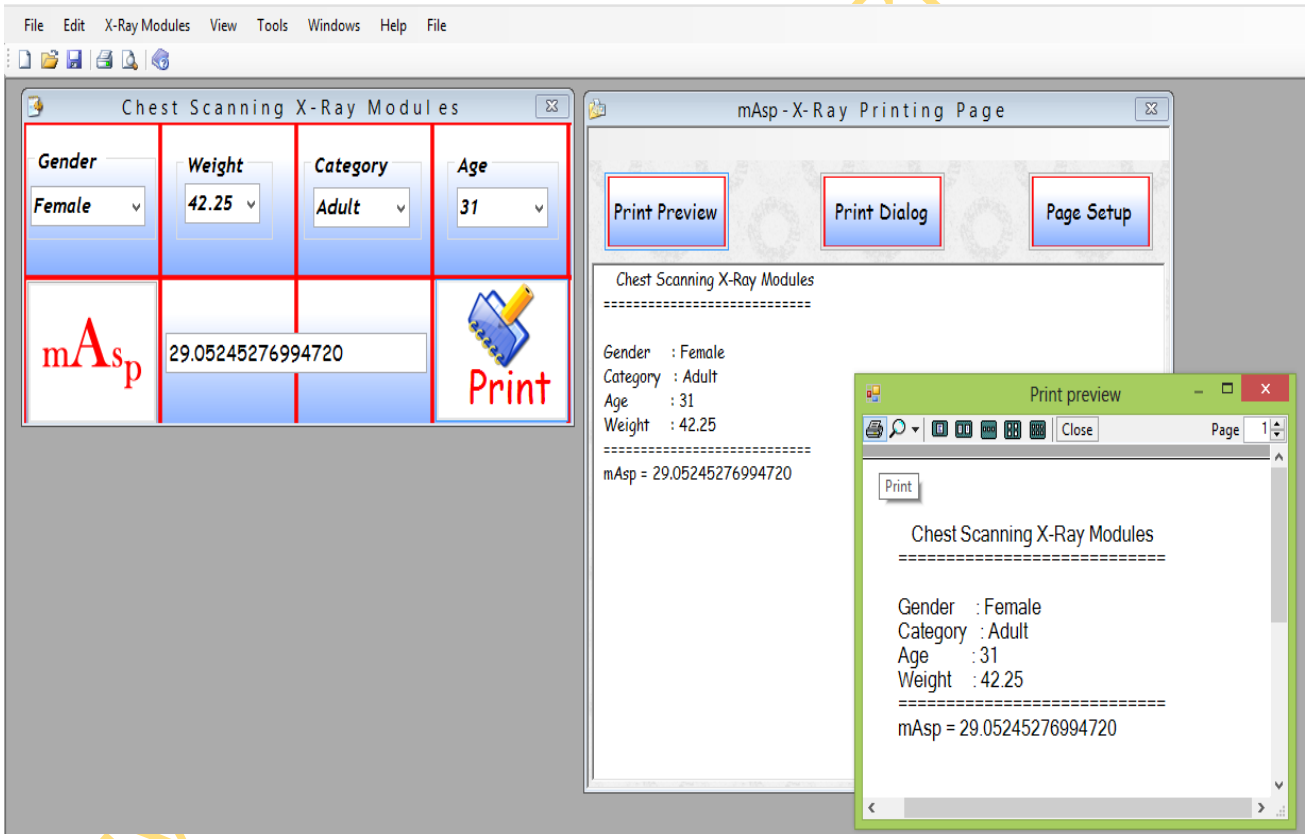

Figure 4.AP1: Showing the front end of PPEE model software for selecting tube load based on patient thickness