Deanship of Graduate Studies

Al-Quds University

Evaluation of Patient Dose & Associated Risk from Chest Radiography in the West Bank –Palestine

Ahlam Said Mohamad Issa

M.Sc. Thesis

Jerusalem-Palestine

2015/1436

Evaluation of Patient Dose & Associated Risk from Chest Radiography in the West Bank –Palestine

Prepared by

Ahlam Said Mohamad Issa

Supervisor

Dr. Adnan Lahham

A thesis submitted in partial fulfillment of requirements of the degree of Master of Science in Environmental Studies. Department of Applied Earth and Environmental Studies -Faculty of Science and Technology- Al –Quds University

Jerusalem –Palestine

2015/1436

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Deanship of Graduate Studies

Graduate studies \Department of Applied Earth and Environmental Studies

Thesis Approval

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Prepared by: Ahlam Said Mohamad Issa

Registration No. 21210039

Supervisor: Dr. Adnan Lahham

Master thesis submitted and accepted:, Date 3\6\2015

The names and signatures of the examining members are as follows:

1-Head of Committee: Dr. Adnan Lahham   Signature ....

2-Internal Examiner: Dr.Hussein ALMasri   Signature ....

3-External Examiner: Dr.   Adnan Judeh   Signature ....

Jerusalem –Palestine

2014/2015

Dedication

To Beloved Father,

To Beloved Mother,

To Beloved Brothers,

To Beloved Friends &

To Beloved Hometown Palestine.

Ahlam Said Mohamad Issa

Declaration

I certify that this thesis submitted for the degree of Master is the result of my own research, excepts where otherwise acknowledged and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signature:

Name: Ahlam Said Mohamad Issa

Date: 3/6/2015

Acknowledgement

Abstract

The need for using medical examinations is increasing around the world, particularly in diagnostics. One specific country that has shown an increase in the use of radiation in medicine is Palestine. This rapid increase in Palestine is accompanied with a lack of information about the radiation dose received by patients. Moreover, there is a lack of quality control, which should be under taken to get better diagnostic information with minimal X-ray exposure. This study attempts to establish the diagnostic reference levels (DRLs) of patients' doses for the chest radiography in Palestine.

The main focus within this study is to investigate and analyze the factors that affect patient radiation doses from chest radiography in Palestine, which is estimated as 53% of the total number of conventional X-ray examinations. The evaluation of patients' dosage and the associated risk factors were done using Monte Carlo simulations.

The average effective dose was calculated in four major facilities in Palestine for a total of 668 patients. The first is Al – Makassed hospital in Jerusalem; the second and third are located in Hebron; the forth is a digital center in Jerusalem. The effective dose was measured for a computed radiography (CR) machine at the latter. Patient samples were randomly taken from Nov 2014 to Feb 2015. All calculations were done by two commercial Monte Carlo simulation softwares: PCXMC-2.0 and Cal-Dose_X5.0.

The average effective dose was estimated using geometric procedure data, which have been performed on patients. Factors considered include patient's height, weight, age , gender, X-ray tube voltage , electric charge (Milliampere-second), examinations projections (PA, AP, Lateral), filtration thickness in each X-ray machine, anode angle, focal source distance (FSD), and X-ray beam size.

The average effective dose for 668 patients was 0.11 mSv for all chest X-ray examinations and projections in the four hospitals. The average effective dose in AP adult, PA adult, lateral adult, AP pediatric and PA pediatric were 0.14, 0.07,0.33, 0.09 and 0.06 mSv respectively. The calculated Population Dose (S) is (72.67 mSv to 668 men) for the people in the West Bank from the conventional chest X-radiography only. The annual average per capita dose is 2.08×10^{-5} mSv.

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List of Terms and Abbreviations

Abdomen X- ray: is a diagnostic X-ray imaging test to look at organs and structures in the belly area. Organs include the spleen, stomach, and intestines.

Absorbed dose: is a fundamental dose quantity, representing the mean energy imparted to matter per unit mass by ionizing radiation. The SI unit is joules per kilogram and its special name is gray (Gy). The special unit of absorbed dose is the RAD.

Adult: is a human being or other organism that has reached sexual maturity (over 15 years old).

Air kerma-area product (KAP): The air kerma-area product is the integral of the air kerma free-in-air over the area of the X-ray beam in a plane perpendicular to the beam axis.

ALARA: is an acronym for As Low As Reasonably Achievable. This is a radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods.

Angiography: or arteriography is a medical imaging technique used to visualize the inside, or lumen, of blood vessels and organs of the body, with particular interest in the arteries, veins, and the heart chambers. This is traditionally done by injecting a radio-opaque contrast agent into the blood vessel and imaging using X-ray based techniques such as fluoroscopy.

AP: Antero posterior projection, the alternative frontal radiographic projection, used mainly in bedside or portable radiography.

CALDose_X_5.0:CALDose_X − a software tool for the assessment of organ and tissue absorbed doses, effective dose and cancer risks in diagnostic radiology.

Chest X-ray: is a diagnostic X-ray imaging produce image of the heart, lungs, blood vessels, airways, and the bones chest and spine. Chest X-rays can also reveal fluid in or around your lungs or air surrounding a lung.

Coefficient of determination r^2: denoted R^2 or r^2 and pronounced R squared, is a number that indicates how well data fit a statistical model – sometimes simply a line or curve. It is a statistic

Coherent scattering: (also known as unmodified, classical or elastic scattering) is one of three forms of photon interaction which occurs when the energy of the X-ray or gamma photon is small in relation to the ionization energy of the atom. It therefore occurs with low energy radiation.

Incoherent scattering: is a type of scattering phenomenon in physics. The term is most commonly used when referring to the scattering of an electromagnetic wave (usually light or radio frequency) by random fluctuations in a gas of particles (most often electrons)

Collective dose: dose quantity S, (population dose) which is calculated by the sum of all individual effective doses over the time period or during the operation being considered due to ionizing radiation. It can be used to estimate the total health effects of a process or accidental release involving ionizing radiation to an exposed population.

Conventional radiography: Conventional radiography (also known as screen film radiation (SFR)). It is the routine diagnostic X-ray examinations which are used the manual processing techniques and conventional (screen) films.

Computed radiography (CR) system: it is an alternative method to replace the conventional film (screen combination) for digital image acquisition.

Constant Milliampere –second (mAs) value: is a unit of measure used in X-ray imaging, diagnostic imaging, and radiation therapy. This quantity is proportional to the total X-ray energy produced by a given X-ray tube operated at a particular voltage.

Conversion coefficients (CCs): The results of absorbed doses are usually expressed as conversion coefficients (CCs), which are ratios between equivalent dose to organs and tissues at risk and measurable quantities.

CT scan: Computerized tomography (CT scan) — also called CT — combines a series of X-ray views taken from many different angles and computer processing to create cross-sectional images of the bones and soft tissues inside your body.

Digital radiography (DR): is a direct radiography in which a semiconductor based sensor directly converts X- ray energy into electrical signals, hence eliminating the middle step of latent image and image plate reader.

Diagnostic Reference Levels (DRLs): is a level set for standard procedures for groups of standardized patients or a standard phantom. It is strongly recommended that the procedure and equipment are reviewed when this level is consistently exceeded in standard procedures. DRLs were first successfully implemented in relation to conventional X- rays in the 1980s and subsequently developed for application to CT in the 1990s.

Distance from the focus to detector (film) FFD; is the distance between the X-ray source and the film in diagnostic radiography. There are now various possible alternatives: source to image-receptor distance (SID); focus image distance (FID); source receptor distance (SRD); and focus receptor distance (FRD) .

Dose Area Product (DAP): is a quantity used in assessing the radiation risk from diagnostic X-ray examinations and interventional procedures. It is defined as the absorbed dose multiplied by the area irradiated, expressed in gray square centimeters (Gy cm²). (Sometimes is mGy cm² or cGy cm²).

Diagnostic imaging: Diagnostic imaging refers to technology that looks inside the body to help determine the causes of an injury or illness and ensure that a diagnosis is accurate. Radiography is a diagnostic imaging method that uses ionizing radiation to produce an image.

Effective dose: is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body and represents the stochastic health risk, which the probability of cancer induction and genetic effects of ionizing radiation delivered to those body parts.

Entrance Skin Dose (ESD): is the absorbed dose in the skin at a given location on the patient. It includes the backscattered radiation from the patient. It can be measured directly with a dosimeter on the patient or by multiplying the ID with a backscatter factor (B).

Entrance surface air kerma (ESAK): is the air kerma on the central X-ray beam axis at the point where the X-ray beam enters the patient or phantom. The contribution of backscattered radiation is included.

Equivalent dose: The product of absorbed dose in tissue multiplied by a quality factor, and then sometimes multiplied by other necessary modifying factors, to account for the potential for a biological effect resulting from the absorbed dose. It is expressed numerically in rems (traditional units) or sieverts (SI units).

Estimation : the process of finding an estimate, or approximation, which is a value that is usable for some purpose even if input data may be incomplete, uncertain, or unstable.

European Commission: the executive body of the European Union responsible for proposing legislation, implementing decisions, upholding the EU treaties and managing the day-to-day business of the EU.

Half value layer: is the thickness of the material at which the intensity of radiation entering it is reduced by one half. HVL can also be expressed in terms of air kerma rate (AKR), rather than intensity.

HCL (health care levels): a classification of health care service levels by the kind of care given, the number of people served, and the people providing the care. Kinds of health care service levels are primary health care, secondary health care, and tertiary health care.

Health Physics Society: (HPS), formed in 1956, is a scientific organization of professionals who specialize in radiation safety. Its mission is to support its members in the practice of their profession and to promote excellence in the science and practice of radiation safety.

ICRP: The International Commission on Radiological Protection (ICRP) is an independent, international non-governmental organization providing recommendations and guidance on radiation protection. It was founded in 1928 by at the second International Congress of Radiology in Stockholm, Sweden.

Incident air kerma (INAK): (KAI) The incident air kerma is the air kerma from the incident beam on the central X-ray beam axis at the focal spot-to-surface distance, like at the skin-entrance plane. Only the primary radiation incident on the patient or phantom and not the backscattered radiation, is included.

Photon: is an elementary particle, the quantum of light and all other forms of electromagnetic radiation.

Radioactive material: Materials found throughout nature. Like in soil, water, and vegetation. Low levels of uranium, thorium, and their decay products are found everywhere. Some of these materials are ingested with food and water, while others, such as radon, are inhaled.

Internal background: In addition to the cosmic and terrestrial sources, all people also have radioactive potassium-40, carbon- 14, lead-210, and other isotopes inside their bodies from birth.

Interventional fluoroscopy: Interventional radiology (abbreviated IR or VIR for Vascular and Interventional Radiology, also referred to as Surgical Radiology) is an independent medical specialty, which was a sub-specialty of radiology until recently that uses

minimally invasive image-guided procedures to diagnose and treat diseases in nearly every organ system.

Ionizing radiation: is radiation that carries enough energy to liberate electrons from atoms or molecules, thereby ionizing them. Ionizing radiation is composed of energetic subatomic particles, ions or atoms moving at relativistic speeds, and electromagnetic waves on the high-energy end of the electromagnetic spectrum.

International Organization for Standardization (ISO) certificates: quality management systems standards is designed to help organizations ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory requirements related to a product.

Joint Commission International (JCI): certificate provides an evaluation of a clinical program that delivers care to a defined patient population

Lateral projection: a radiographic representation of the body produced by an X-ray beam that travels from the left to the right side of the body, or vice versa. It is a right lateral projection if the right side of the body is adjacent to the cassette and a left lateral projection if the left side is adjacent to it.

Loss of life expectancy (LLE): is a statistical measure of how long a person may live, based on the year of their birth, their current age and other demographic factors including gender.

Low radiation doses; The concept of what constitutes a low dose has been modified considerably over the last 50 years. In 1945 a typical chest X- ray gave a dose of 1 Rem (0.01 Sv) and at least one jurisdiction (UK) went as far as to propose mandating such an X-ray every year. In contrast, in 1987 a proposal of the US Nuclear Regulatory Commission to call a radiation exposure that gave no more than 1 milliRem (0.00001 Sv) to any person "Below Regulatory Concern" was withdrawn after some vocal public opposition. Yet

natural background exposures are a few hundred milliRems or 100 times this amount. Thus "low dose" now means doses as low as, and usually well below background.

Mammography: the process of using low-energy X-rays (usually around 30 kVp) to examine the human breast, which is used as a diagnostic and screening tool. The goal of mammography is the early detection of breast cancer.

Medical exposure: A quantity measures the ionization of air produced by a beam of radiation. It is expressed as coulombs per kilogram of air. It is commonly used to refer to being around a radiation source.

Gray: The international system (SI) unit of radiation dose expressed in terms of absorbed energy per unit mass of tissue. The gray is the unit of absorbed dose and has replaced the rad. 1 gray = 1 Joule/kilogram and also equals 100 rad.

Monte Carlo simulation: are broad classes of computational algorithms that rely on repeated random sampling to obtain numerical results. They are often used in physical and mathematical problems and are most useful when it is difficult or impossible to use other mathematical methods.

Sievert (Sv) :The international system (SI) unit for dose equivalent equal to 1 Joule/kilogram. The sievert has replaced the rem. One sievert is equivalent to100 rem.

National Lung Screening Trial (NLST) in USA: The National Lung Screening Trial (NLST), a cancer screening clinical trial.

Natural sources: Radioactive material is found throughout nature. Detectable amounts occur naturally in soil, rocks, water, air, and vegetation, from which it is inhaled and ingested into the body.

Nuclear medicine: is a medical specialty involving the application of radioactive substances in the diagnosis and treatment of disease.

Posteranterior(PA): X-ray projection, X-ray enters the body from back to front.

Palestinian Health Ministry (PHM): governmental health ministry in West Bank and Gaza strip.

Palestinian Medical Imaging Association (PMIA):nongovernmental organizations to all Palestinian radiographers, it was founded in 1997.

PCXMC: is a computer program for calculating patients' organ doses and the effective dose in medical X-ray examinations. It allows a free adjustment of the X-ray projection and other examination conditions of projection radiography and fluoroscopy.

Pediatric: The branch of medicine that deals with the care of infants and children (less than 15 years) and the treatment of their diseases.

Phantoms: Models which use as human body properties, used by medical researchers.

Philosophical (Truly-random) numbers: it means lack of pattern or predictability in events. A random sequence of events, symbols or steps has no order and does not follow an intelligible pattern or combination.

Photoelectric absorption: the basis of diagnostic radiology. The difference in absorption of X-ray energy by different tissues causes differences in electromagnetic energy arriving at the film.

Plaine X-ray: Projection radiography or plain film radiography is the practice of producing two-dimensional images using X-ray radiation.

Portable: making a radiographic film of a patient confined to bed by taking a movable X-ray machine to the room.

Pulmonary diseases: any condition that affects the blood vessels along the route between the heart and lungs.

Radiation: the emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles which cause ionization.

Radiation protection: Is a general term applied to the profession / science related to protecting man and the environment from Radiation hazards.

Radiosensitive organs: is the relative susceptibility of cells, tissues, organs or organisms to the harmful effect of ionizing radiation.

Radon: the chemical element of atomic number 86, a rare radioactive gas belonging to the noble gas series.

Risk assessment: a systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking.

Risk of exposure-induced cancer death (REID): the lifetime risk of dying of a disease attributable to exposure. These two quantities are not the same, even at low doses.

Stochastic detriment: a random or statistical nature. For an effect to be called stochastic, the probability of it occurring, but not its severity, was regarded as a function of dose without threshold.

Terrestrial background: includes sources that remain external to the body. The major radio nuclides of concern are potassium, uranium and thorium and their decay products.

The LLE/REID: Loss of life expectancy per radiation induced fatal cancer (LLE/REID) the lifetime risks can be assessed with various quantities.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR): was set up by resolution of the United Nations General Assembly in 1955. 21 states are designated to provide scientists to serve as members of the committee which holds formal meetings (sessions) annually and submits a report to the General Assembly. It was established solely to "define precisely the present exposure of the population of the world to ionizing radiation.

Tissue weighting factor: in radiation protection, a factor weighting the equivalent dose in a particular tissue or organ in terms of its relative contribution to the total deleterious effects resulting from uniform irradiation of the whole body

Computational human phantoms: are models of the human body used in computerized analysis. Since the 1960s, the radiological science community has developed and applied these models for ionizing radiation dosimeter studies.

Tube Peak kilo voltage (kVp): is the maximum voltage applied across an X-ray tube. It determines the kinetic energy of the electrons accelerated in the X-ray tube and the peak energy of the X-ray emission spectrum. The actual voltage across the tube may fluctuate.

In Vivo measurements: "within the living"; often not italicized in English, are those in which the effects of various biological entities are tested on whole, living organisms usually animals including humans, and plants as opposed to a partial or dead organism.

Voxel phantoms: A voxel represents a value on a regular grid in three-dimensional space Limitation on stylized phantom.

Chapter I

Medical Radiation Exposure Definition and Utilizations

1.1 Introduction

Medical application of radiation to man is defined as the most significant radiation exposure after the natural sources such as radon. It mainly comes from medical X-ray usage to patients in diagnostic and therapy. The need for using medical X-ray examinations is increasing around the world, particularly in diagnostics (ICRP 103, 2007). Low radiation dose researches indicate that there is an increase in the risk of stochastic detriment from diagnostic X-ray. Therefore, radiation dose to patient must be kept as low as reasonably achievable (ALARA) (European Commission, 1997). Many studies evaluated radiation doses from medical X-ray examinations and risk assessment from their collective doses. It has been found that the effective dose, the basic dose which can be used for risk assessment, is the amount that should be absorbed in radio sensitive organs (ICRP 103, 2007).

One specific country that has shown an increase in the use of medical radiation is Palestine. It is of great importance that standards are followed in order to maintain radiation protection. In Palestine, many doctors and medical professionals are not practicing these protection guidelines and some are not even aware of how grave the risk of medical radiation is. This study will assess patients effective dose, which determines the risk of radiation of chest radiography in the West Bank, and make it as low as possible without losing the quality in order to have a perfect diagnosis.

Many quantities and terminology have been used for specification of medical X-ray doses to patients. Depending on the central beam axis at point where the X-ray beam enters the patient such as the exposure at skin entrance (ESE), the input radiation exposure, the

entrance surface air kerma (ESAK), incident air kerma (EAK). Moreover, if deterministic effects are considered to be a possibility, the absorbed dose is recommended in specific organ or tissue.

Furthermore, for assessing radiation protection, organ dose should be weighted for radiation quality by a radiation weighting factor (W_R). Two quantities have been selected by ICRP. Denoted to Equivalent dose, which is the present weighted absorbed doses by Sievert (Sv), and for representing more than one organ, the effective dose is recommended. The effective dose is defined as the sum of weighted equivalent doses (W_T) in all the tissues and organs of the body (ICRP 103, 2007).

The usage of Diagnostic Reference Levels (DRLs) in medical radiation dose is recommended by the International Commission on Radiological Protection (ICRP) as the first step in the optimization of diagnostic radiography (Medical Council, 2004). Through DRLs application, it is possible to find hospitals where radiation doses are exceptionally high and where practices of radiation protection need to be improved (ICRP 103, 2007).

1.2 Trend in the medical radiation exposure usage around the World

The medical radiation dose increases annually; many countries estimate medical doses and calculate the annual individual dose, which explains the limits, high dose rate, and risk assessment.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published in their report 2008 (sources and effects of ionizing radiation2008), the trend in annual number of diagnostic medical radiological examinations, the annual collective effective dose from diagnostic medical radiological examinations, the annual frequency of diagnostic medical radiological examinations and trend in annual per capita effective dose from diagnostic medical radiological examinations in the world (UNSCEAR, 2008). Figure 1.2.1 shows the trend in the annual

number of diagnostic medical radiological examinations around the world. Figure1.2.2 summarises the trend in the annual collective effective dose (1000 man Sv) from diagnostic medical examinations.
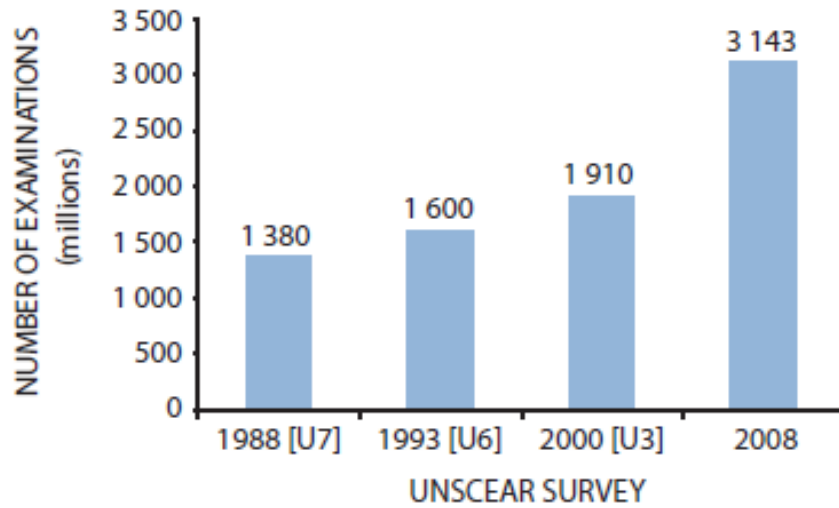
Figure 1.2.1: Trend in the annual number of diagnostic medical radiological examinations (UNSCEAR, 2008)
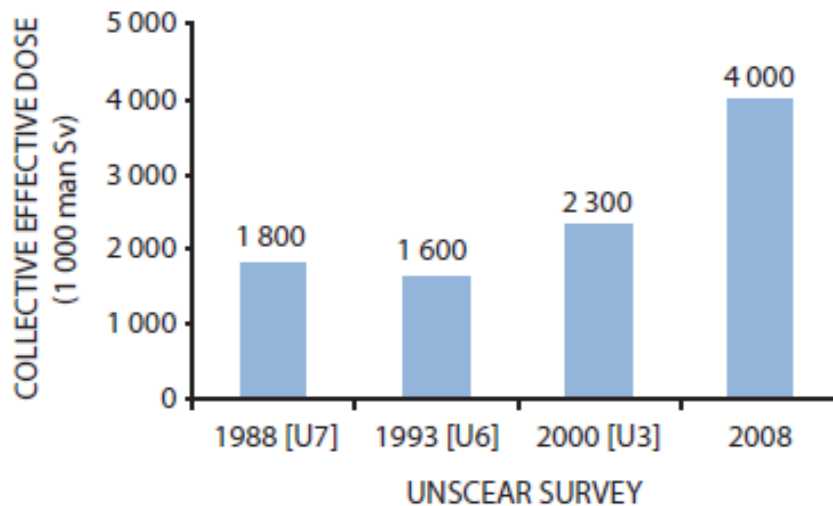
Figure 1.2.2: Trend in the annual collective effective dose (1000 man Sv) from diagnostic medical examinations (UNSCEAR, 2008)

Figure 1.2.3 shows the trend in the annual per capita effective dose (mSv) from diagnostic medical radiological examinations in the world.
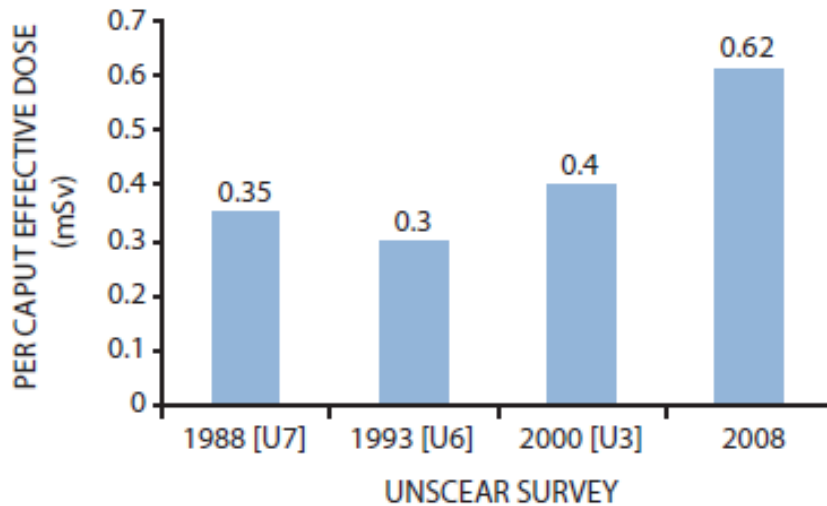
Figure 1.2.3: Trend in the annual per capita effective dose (mSv) from diagnostic medical radiological examinations (UNSCEAR, 2008)

Average effective dose per capita is increasing annually according to high usage of radiological examinations.

The medical radiation exposure is divided into categories depending on how the X-ray examinations should be done. The National Council on Radiation Protection and Measurements (NCRP) in United States (U.S.) published the medical radiation exposure analysis of the U.S. population which is shown in Figure1.2.4 (NCRP, 2009).
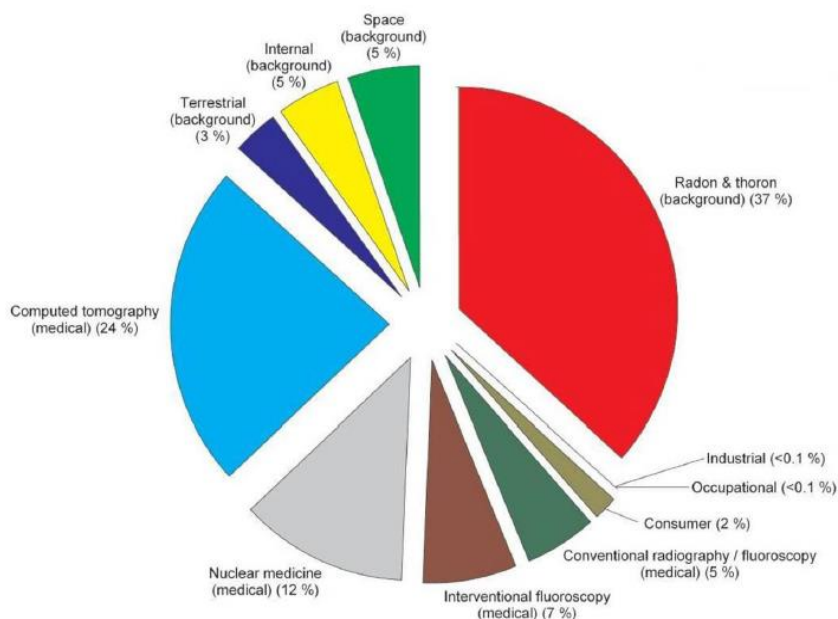
Figure 1.2.4: NCRP Sources of Medical Radiation Exposure _2009 to US population (NCRP, 2009)

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Conventional radiography is represented as main source of medical radiation exposure worldwide, and those examinations have a high value in medical and diagnostic field. Low cost of using X-ray during the recent 100 years has made it a common daily diagnostic tool, but it is important that radiation doses from X-ray examinations are being monitored, and kept at a minimum.   Chest X-ray examination is considered as the most conventional diagnostic radiography examination because it has a high value for solving a wide range of clinical problems. Although recent developments in cross sectional imaging of the thorax exist, particularly computed tomography (CT), this examination provides very important information for diagnosis, treatment, and follows up procedures of many pulmonary diseases. Chest radiography has many advantages over cross sectional imaging, such as lower cost, lower dose, speed of acquisition, and diagnosis (Wouter J.H. Veldkamp, 2009).

1.3 Situation in Palestine

Scientific studies of patients X-ray doses in Palestine are scarce. Practical regulations lack clear instructions for radiation protraction and safety guidelines. The knowledge of radiation protection is quite poor. Doctors and medical professionals in Palestine do not have a clear strategy when it comes to using radiation. Therefore this study is planned to use new statistical approaches and procedures to estimate effective dose for medical examinations in the West Bank. Special consideration will be given to chest X-ray examination doses and the assessment of medical radiation risks.

According to the Palestinian Health Ministry annual report (MOH), Palestinian population is estimated to be around 4,485,459 people at the end of 2013. The population is divided between West Bank, about 2.8 million (61.4%), and about 1.7 million (38.6%) in Gaza Strip (PHIC, 2013). The gender share is about 2.28 million male, and 2.21 million female (PHIC, 2013). The most highly populated city in the West Bank is Hebron, about

15% of the total Palestinian population live there, and the second city is Jerusalem which has about 9.1% of the total average of Palestinian population (PHIC, 2013). The Palestinian society is described as a young society; 3.39% of the total population is less than 15 years old (PHIC, 2013).

Moreover, according to the (MOH) annual report, the total number of the hospitals is 80; 50 hospitals are in the West Bank (about 63%), with about 844 people for each bed (PHIC, 2013). According to the Palestinian Medical Imaging Association (PMIA), in 2013, there are 176 hospitals and medical centers in the West Bank with X-ray departments. About 134 plain X-ray and portable machines can be found in those hospitals and centers (PMIA, 2013).

The total number of utilization of plain X-ray in Palestinian Ministry of Health (MOH) centers and hospitals in 2013, is about (803,913) images in West Bank, which is about 83.5% of the all medical X-ray usage (MOH) (PHIC, 2013). Depending on a sample which was chosen in this research, the estimated chest X-ray number is about 53% of the total plain X-ray. Despite the fact that X-ray radiography is beneficial, the risk from ionization is increasing and can cause many diseases and illnesses, such as cancer, as radiation stochastic effect. Cancer is considered as the second death cause in Palestine. With about 13.3% (PHIC, 2013), the incidence of cancer can be noticed as increasing annually (PHIC, 2013). However, there are no studies explaining reasons for such increase, nor any information about the reasons behind. Risk assessment will be explained in this study in order to get the risk rate from the X-ray examination to each organ.

1.4 Problem statement

This research investigates medical diagnostic radiation exposure in Palestine, which should be considered to get the diagnostic information in better way with minimum X-ray dose. This national survey is to evaluate patients' dose of chest radiographies in the West Bank. Moreover, it analyzes the factors that affect medical radiation doses and estimates the effective dose by Monte Carlo simulations softwares.

1.5 Motivation of the Study

The purpose of this study is to describe the effective dose level received by patients during medical X-ray examinations, and compare it globally. Moreover, to construct the basic DRLs in Palestine.

1.6 Aims and Goals of the Study

1. To estimate the effective dose and organ absorbed dose for patients undergoing chest radiography.

2. To estimate the representative values of effective dose for each type projection of chest radiography (AP/PA/LAT).

3. To keep radiation exposure to patients as low as possible but still compatible with the medical purposes of the examinations.

4. To make risk assessment that will explain the cancer risk to many sensitive organs.

1.7 Summary

Chapter one describes the problem statement and the objectives of this study, with small review of the medical radiation exposure, as the main target of this research for estimating

the effective dose. Moreover, the effective dose describes and recognizes the Palestine conditions in medical imaging profession.

1.8 Thesis Outline

The second chapter discusses the literature review, and similar studies around the world, using Monte Carlo simulating to estimate the effective dose from radiological diagnostic examinations. Chapter III discusses the methodology for effective dose estimation of chest radiography in the West Bank –Palestine, in three selected hospitals, Al Makassed hospital which is located in Jerusalem and two others hospitals in Hebron. Additionally, a few samples from one digital center in Jerusalem are included to check the effective dose from digital CR machines. All calculations are done using Monte Carlo simulation softwares, specifically PCXMC and Cal-Dose_X5.0.

Chapter II

Literature Review

2.1 Theoretical Background

Estimating the effective dose is a solution to get a view of medical radiation exposure to patients. Many previous studies and research tried to estimate the effective dose with different practical theories; however, the common idea is to use Monte Carlo (MC) simulation. Theoretical and practical back-ground will be discussed briefly.

Effective dose was created to provide a new dose quantity related to health due to stochastic effects. In diagnostic radiology, this quantity is used for radiation protection. The relative uncertainty in effective dose estimation from medical exposures for reference patients was found as 40%. It should not be used for individual; rather it will be good for population or group dose (MARTIN, 2007).

Calculations of effective dose in diagnostic radiology have been published in many literatures with various ways of getting the final result. First, it may be calculated by using the Entrance Skin Dose (ESD), entrance surface air Kerma measurements, or Dose Area Product (DAP) estimation. These measurements are easy to get practically. Another way to calculate the effective dose depends on energy imported (ε), entrance skin exposure, half value layer, and X-ray beam area. The effective dose is calculated by conversion factors. It can be calculated for many organs, and examinations (UNSCEAR, 2000). The world wide average effective doses (mSv) to population are shown in Table 2.1.(UNSCEAR, 2000).

Table2.1: Average effective dose to population of diagnostic medical X-ray examinations around the world (UNSCEAR, 2000)

Health care level	Population per physician	Annual number of examinations per 1,000 population	Average annual effective dose to population (mSv)
I II III IV	<1000 1000-3000 3000-10,000 >10,000	920 150 20 <20	1.2 0.14 0.02 <0.02
Worldwide average		330	0.4

It is not practical to conduct in vivo measurements in routine radiological procedures to get organ doses. Monte Carlo simulation solved this issue. Monte Carlo simulation uses phantoms, which are defined as artificial objects, representing a patient, or computer calculations (Lampinen, 2000). The interactions with matter in Monte Carlo simulation area scorned by random numbers, and probabilities are known for each interaction type (Lampinen, 2000).

2.2 Theoretical Background of Effective Dose Calculations

The effective dose was developed by International Commission on Radiological Protection (ICRP) in 1991 , for controlling sources of exposure, and putting the basic, for dose limits, or constraints for workers and public (ICRP 103, 2007). The effective dose, E, is defined as dosimeter parameters, which take into account the doses received by all irradiated radiosensitive organs, and to properly measure the stochastic risks. Effective dose, (E), is recognized with the tissue weighted sum of the equivalent doses in all specified tissues, and organs. Figure 2.2.1 is showing the tissue weighting factors (W_T) which was derived for whole population. The main use for effective dose is for protection

quality, to be used as prospective dose assessment for planning and optimization in radiological protection (ICRP 103, 2007). Effective dose, E, is given by the following two expressions (ICRP 103, 2007):

$$E = \Sigma_T W_T \Sigma_R W_R D_{T,R} \quad or \quad E = \Sigma_T W_T H_T \quad (1)$$

Where: $D_{T,R}$: Absorbed dose in tissue T due to radiation type R.
H_T: The equivalent dose in a tissue or organ; T
W_T or $W_{R,}$: radiation and Tissue weighting factor respectively .

The effective dose determines radiation exposure to whole human body, from external or internal sources. The main idea of the effective dose is to analyze health effects of one organ dose to the entire body dose which are more harmful than the same dose to only portion (organ), which means the dose to the whole body that carries with it the same risk as higher dose to portion of the body. That allows comparison and collection of doses, for whole body or partial body, and for a population at all ages and both sexes, the unit for effective dose is the same as absorbed dose J kg^{-1} or Sievert (Sv) (ICRP 103, 2007), (MARTIN, 2007).
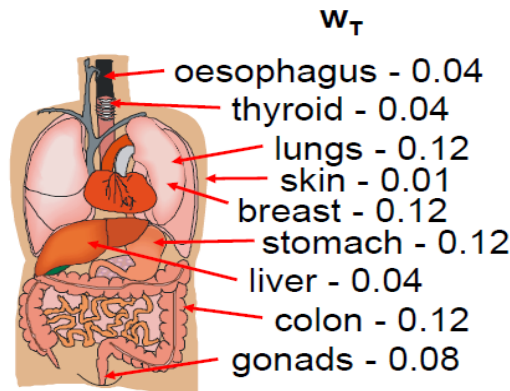
Figure 2.2.1: ICRP Effective dose Tissue Weighting factor W_T derived for whole population (Shrimpton, 2012)

Effective dose is not used for individual dose estimation, and if such individual dose is needed, the basic effective dose should be used individually based on organ dose estimates

for both gender, while the appropriate age, sex, and organ specific risk coefficients should also be taken into consideration (MARTIN, 2007).

Practical measurements of effective dose are extremely difficult. Therefore, the effective dose is generally estimated from conversion factors, which should be taken from routine measurements, which work on appropriate to conditions of exposure; probably this process of calculation is by using Monte Carlo simulation techniques with specific mathematical phantoms (ICRP 103, 2007). Effective dose is the quantity to radiation protection and risk assessment.

2.3 Risk Assessment

The lower doses which are received in conventional radiography, and the possibility that there might be no risks from exposures comparable to external natural radiation background, cannot be neglected, while low doses have a lower limit of uncertainty range in risk estimates extends to zero (HealthPhysicsSociety, 1995). The Health Physics Society recommends that assessments of radiogenatic health risks be limited to dose estimates near and above 100 mSv. In that range, the public risk can be found, and a good support from all scientific research, the important rules in risk assessment are the health risks of radiation exposure can only estimated with reasonable degree of scientific certainty, which are established by regulators for public protection at radiation levels, that are orders of magnitude greater than levels (HealthPhysicsSociety, 1995).

Effective dose can't be used to evaluate the specific sex organs risk from the medical exposure. It means the effective dose is not used to evaluate the female organs dose such as breasts, ovaries, and uterus as specific organs. This is because the effective dose is the average dose for the two sexes. The numerical risks may be derived directly from the organ doses and female specific risk coefficients to get a risk assessment. Table 2.3 shows the

terminology that could be used to describe risks from radiation exposures (MARTIN, 2007).

Estimating radiation risk in the low dose region, the occupational and environmental exposures are extrapolated to the high dose health effects, using a variety of mathematical models, including the linear and no-threshold model (HealthPhysicsSociety, 1995). Cell killing and cell replacement occurs through radiogenatic effects at any dose level, and may be creating a favorable environment for tumor growth. However, in high dose region the probability is too high compared to low dose. High dose is defined as more than 1 Sv, and low doses as less than 100 mSv (HealthPhysicsSociety, 1995).

Table2. 3: Terminology that could be used to describe risks from radiation exposure (MARTIN, 2007)

Effective dose range (mSv)	Level of risk [a]	Proposed risk term	Examples of medial exposures
<0.1	1 in 1 million	Negligible	Radiographs of chest, limbs, neck and teeth
0.1-1	1 in 100000	Minimal	Radiographs of spine , abdomen and pelvis
1-10	1 in 10000	Very low	Barium meals and enemas, CT scans of head , chest and abdomen, nuclear medicine bone scans
10-100	1 in 1000	Low	Double CT scans for contrast enhancement, higher dose interventional radiology procedures
[a] The excess lifetime risk of fatal cancer to a reference adult patient resulting from radiation exposures in the dose ranges could be factor of up to 10 higher or lower than values quoted.			

2.4 Research Studies

Many previous studies make effective dose estimates, based on some Monte Carlo modeling, to make dose assessment for patients in many medical X-ray examinations.

(**Vânia Lucia S. de Oliveira, 2009**)**,** The International Nuclear Atlantic Conference depend on the study which was published in 2009, for   dose assessment in patients

submitted to chest, and skull X-ray examinations, by using PCXMC software to assess organ doses from the diagnostic medical exposure. One hospital was selected in Belo Horizonte, Minas Gerais and, and only one radiology room with one operator, patients were divided to biotype category depend on the geometry of patients. Results of lung doses were 23.5, 33.6, 45.4 μSv in patients whom ordered to A, B, C biotypes small , medium and large. Skull results represented the thyroid gland doses 30.5, 27.6 and 22.3 μSv. It was found that the space of radiological techniques, is permitted of reduce the exposures to patients.

(HyunJi Kim, 2012), This study was done in Korea, Seoul, and supported from the radiation protection dosimeter, and carried out by many sides of medical science in Korea. It used the digital X-ray imaging, to estimates the absorbed organ dose, and effective dose affecting patient health. Approximately 899 patients were examined for screening chest X-ray examinations, using the PCXMC Monte Carlo program simulation. The most important results from that study were the dose per unit ESD which had a tendency to decrease with body mass index (BMI).

(R. Paydar1, 2012), This study was done in Iran on digital chest radiography, to get the effective dose, and ESD dose, using MCNP Monte Carlo code, and adult hermaphrodite mathematical phantom, the effective dose value was found for PA projection in digital chest radiography in some major hospitals. It was found the effective dose higher than the National Diagnostic Reference Level (NDRL). Therefore, the recommendations from that result were that optimization process should be taken to reduce the patient exposure in digital chest radiography**.**

(Toshio Kawasaki, 2012), This study presents the dose data for technical factors in chest radiography of pediatric patients in Japan, with variations of tube voltages kVp, and constant Milliampere –second (mAs) value, and constant distance from the focus to

detector (film) also, that was taken by Monte Carlo simulation software (PCXMC), and by using an in-phantom dose measuring system, this study selected only pediatric patients. The absorbed dose in the lung tissue was found to be from 0.01 to 0.07 mGy, and the effective doses ranged from 0.004 to 0.025 mSv. The main study idea can depend on this publication to be sure that using PCXMC software was extremely useful in effective dose estimates, and measurements.

(Seibert, 2012), This study was done by the National Lung Screening Trial (NLST) in USA, to control trial comparing low dose helical CT, with chest radiography, in the national screening of heavy smokers for detecting early lung cancer. Study period was two years, from 2002 to 2004. This study was done using 53,454 participants, at 33 different sites. The main objective of this study was to determine the effective dose, with individual chest examinations. The total chest X-rays taken was 73.733 in 92 different chest plane imaging systems. The data which were collected from the entrance skin air kerma (ESAK), through estimation from Monte Carlo simulations, while the effective dose was calculated by Monte Carlo software PCXMC. The findings from this study were that the effective dose from the chest X-ray, which were selected in that national screening. In relation to that associated with the previously published NLST low dose from the CT scans conducts during their trial.

(Health Protection Agency Centre for Radiation, 2008), This report from the European Commission is defined as guidance for estimating radiation populations' doses from medical X-ray procedures. The report explains the dose quantities which should be used in any research, and the rules to get the population doses. Also, the report gave the recommendations for the population doses, the needs of population doses, and trends of using those doses. In addition, it gave recommendations for the applications of population doses, like determination of any regional variation, within the same country, through per

capita dose in specific types of X-ray examinations, and comparing the doses value, from the medical X-rays between countries, and any other source of radiation, manmade, industry, nuclear or natural resource.

(I. I. Suliman and F. I. Habbani, 2005), This study included two methods for effective dose calculations and comparison. It was performed in four major hospitals in Khartoum area, Sudan, for eight different X-ray units. The total sample consisted of 325 patients. For this study, two approaches were used. The first approach is by using the Entrance Surface Dose (ESD) and the effective dose values by using Monte Carlo Software, through some parameters of some x-ray examinations. The second approach was using the energy imparted to patients and then calculating the effective dose by conversion factors. Results found were that the effective dose is the best quantity for estimating radiation risk to patients, while the energy imparted could be better estimated using a dose area product meter that relates to the effective dose calculations.

2.6 Summary

Chapter II described the theoretical background of the effective dose estimation and risk assessment. Additionally, a review for important previous studies.

Chapter III
Methodology

3.1 Survey to Data Processing of Analysis Program

This study estimates the effective dose to patients, from chest radiographies in the West Bank –Palestine. According to literature reviews, effective dose has been calculated through several steps. In addition, different models are used in each step to get the effective dose.

Initially, in effective dose calculations, the ESD and the incident air kerma dose have to be estimate from the X-ray tube output parameters. X-ray tube factors are recorded for each patient who undergoing chest X-ray examination. In this study, recorded factors are: Peak Tube Voltage (kVp), Exposure Current -Time Product (mAs), the Focus to Film Distance (FFD), patient age and gender. The ESD was estimated from the X-ray tube geometry parameters by using the following equation (Davies Model) (A.D. Meade, 2003).

$$ESD = O/P \times (KV/80)^2 \times mAs \times 100^2 / FSD^2 \times BSF. \quad (2)$$

O/P is the tube output per mAs measured at a distance of 100cm from the tube focus along the beam axis at 80 kVp, BSF: is a backscatter factor (A.D. Meade, 2003). In this study, the (CALDose_X_5.0) software used to calculate Incident Air Kerma (Ka,i) and the ESD values. The value which was calculated is the incident air kerma (Ka,i) without the back scatter radiation. Figure 3.1 represents the air kerma at the point where the central axis of the X-ray beam enters the patient (ICRU_ 74, 2005) .
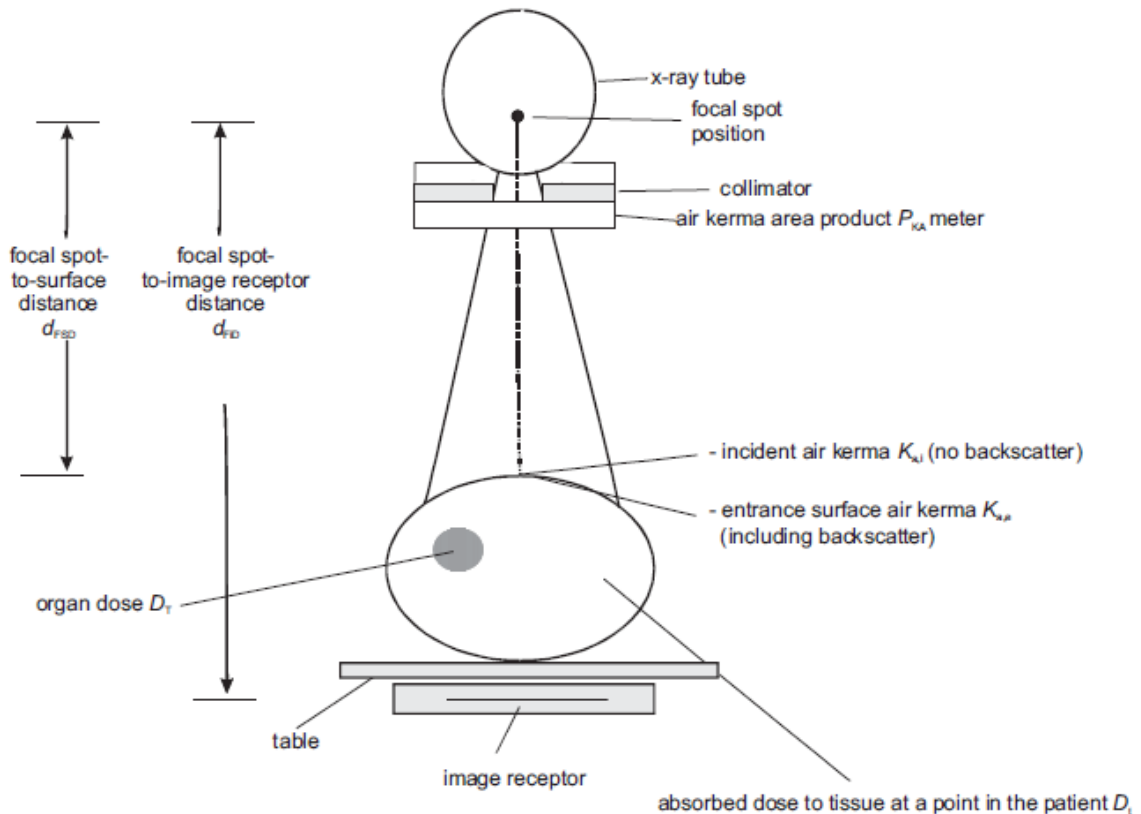
Figuer3.1: Simple exposure arrangement for radiography showing some of the dosimeter, and geometric quantities recommended in ICRU 74 _Report (ICRU_ 74, 2005).

This study relies on the CALDose_X5.0 software to get the Incident Air Kerma (INAK), and PCXMC to get the effective dose and risk assessment. Their properties will be explained later in this chapter. If the ESD will be used in PCXMC, the Back scatter factor (BSF) should be adjusted to the quantities.

3.2 Monte Carlo Simulation Softwares:

Direct experimental patient effective dose measurements are impossible to be done, due to the fact that practical uses of phantom measurements are too hard, expansive and time consuming. The solution is adopting Monte Carlo calculation software to provide an estimation of organ doses in patients undergoing X-ray examinations. Monte Carlo was recognized as the assessment software of conversion factors to calculate the effective dose to patients begun more than 30 years ago (Andreo, 1991). The Monte Carlo usage was

introduced for the first time by Buffon in 1977 to estimate the value of (π) (Lampinen, 2000).

"The use of the Monte Carlo method for organ dose calculation in X-ray diagnostics was introduced by Rosenstein, who used a MIRD based phantom for calculating doses to five organs for adult and pediatric X-ray examinations. Drexler et al. (1984) used the sex-specific phantoms of Kramer et al. (1982) to calculate organ doses in conventional X-ray examinations. Jones et Wall (1985) used their phantom to calculate organ doses in 12 common X-ray examinations. Hart et al. (1994) determined conversion coefficients from entrance surface dose (ESD) and dose-area product (DAP) to organ doses using an improved phantom which included all the organs needed for calculating the effective dose" (Lampinen, 2000).

Depend on Philosophical (Truly-random) numbers, or the calculations of photon transport based on stochastic mathematical simulation of interactions between photons and matter, means that all photons are emitted from a point source into the solid angle specified by the radiation geometry like the focal distance ,and X-ray field dimensions, the random interactions with a phantom according to physical process photoelectric absorption, are coherent scattering and incoherent Compton scattering (B.F.Wall NRPB Chiton, 1996).

"For diagnostic radiology dosimeter, the initial photon energy is less than 150 keV range, coefficients of variation are computed as a measure of the reproducibility of the Monte Carlo calculations, and often more than one million photon are followed to reduce the statistical uncertainties to a responsible level, tissue doses are obtained by swimming in each organ all energy depositions, from primary, and scattered photons, and dividing by the total organ mass. Results are the average absorbed dose in the entire organ regardless of the fraction of the organ irritated " (B.F.Wall NRPB Chiton, 1996).

3.3 CALDose_X-5.0 software

CALDose_X-5.0 (Calculation of dose for X-ray diagnosis), is a software tool that provides the possibility to calculate the Incident Air Kerma (IAK, INAK),and Entrance Surface Air Kerma (ESAK), which are two important value measurements in X-ray diagnoses, and important to estimate the effective dose, based on the output of the X-ray equipment (R Kramer1, 2008).

This software uses conversion coefficients (CCs) to assess absorbed and effective doses to organs and tissues in the human body. CALDose_X-5.0 improved its earlier tools, which were mostly based on mathematical MIRD5-type phantoms (R Kramer1, 2008). Improvements include adult posture specific female FASH, and the male MASH phantoms, to get the conversions coefficients (CCs) normalized to the INAK, ESAK, and the kerma area product (KAP), for examinations frequently performed in X-ray diagnosis with the risks of cancer mortality (R Kramer1, 2008).

Recently, CALDose _X developed MAX06 and FAX06 Voxel phantoms, to include various projections, and different X-ray spectra. The main objecting from developing this software are to make these CCs available to the public, and for easy daily routine work by radiological departments of hospitals, health services, educational program, and any other places in need for similar of measurements (R Kramer1, 2008). The assessment of Incident Air Kerma (INAK), ESAK, and organ absorbed doses for X-ray examinations, and exposure conditions are defined by the user by multiplying the CCs, with the value of the corresponding measurable quantity, to get the effective dose according to ICRP 103, and risk assessment for patients (R Kramer1, 2008).

The definitions of the X-ray dose quantities calculated by CALDose_X are:

1. Incident air kerma (INAK): "The incident air kerma is the air kerma from the incident beam on the central X-ray beam axis at the focal spot-to-surface distance, like at the

skin-entrance plane.   Only the primary radiation incident on the patient or phantom and not the backscattered radiation, is included." (ICRU_ 74, 2005).

2. Entrance surface air kerma (ESAK):"The entrance-surface air kerma is the air kerma on the central X-ray beam axis at the point where the X-ray beam enters the patient or phantom. The contribution of backscattered radiation is included." (ICRU_ 74, 2005).

3. Air kerma-area product (KAP): "The air kerma-area product is the integral of the air kerma free-in-air over the area of the X-ray beam in a plane perpendicular to the beam axis." (ICRU_ 74, 2005).These quantities are shown in the Figure 3.3 (R Kramer1, 2008).
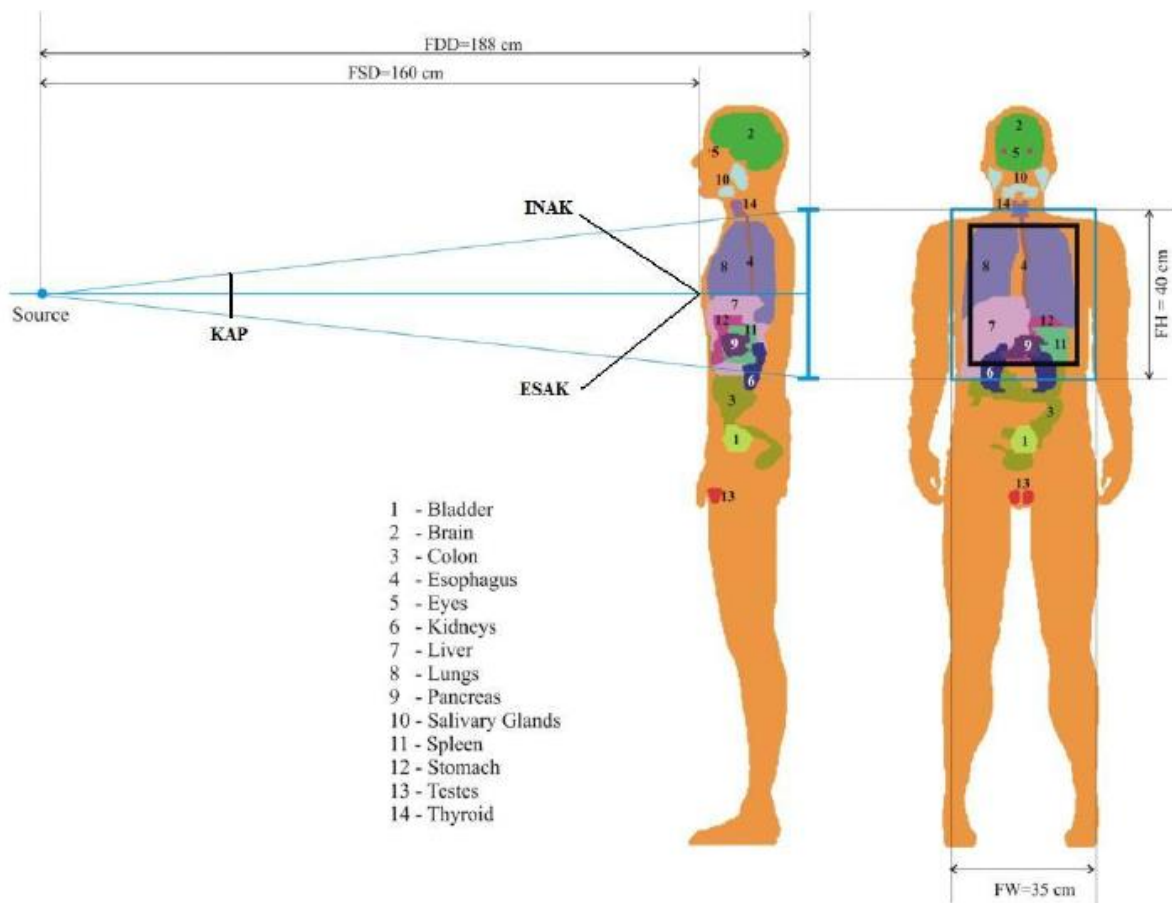
Figuer3.3: Radiographic exposure of the chest of the MAX06 phantom showing some organs of interest and locations to which the normalization quantities INAK, ESAK and KAP refer (R Kramer1, 2008)

The larger square represents the field size at the detector plane, the smaller square represents the field size at the entrance surface (R Kramer1, 2008).

3.4 PCXMC -2.0 Software

PCXMC is a computer program designed by Radiation and Nuclear Safety Authority in Finland (STUK). The first version PCXMC (PC program for X-ray Monte Carlo) was released in 1997 for calculating patient organ dose and estimating effective dose in medical diagnostic X-ray examinations. It allows a free adjustment between the X-ray projections from many X-ray examination types (Tapiovaara M, 2008). The anatomical data on which mathematical hermaphrodite phantom models are based are from Cristy and Echerman (1987), with some modifications and user-adjustable phantom sizes. Also the program has organized doses for patients with different ages and sizes (Tapiovaara M, 2008).

PCXMC calculates and assesses the risk to patients from fatal cancer and medical X-ray examinations. Moreover, the organ doses are calculated for 29 organs and tissues, added to that, the program calculates the effective dose with both old and new tissue weighting factors of ICRP publications60 (1991) and 103 (2007), and the old one from ICRP publication 60 (1991), PCXMC has many properties like free adjustable -size between pediatric, and adult patient models, with free choice of the X-ray technique. The risk assessment of this program is estimated on the risk of death to patients according to radiation -induced cancer, and relating to sex and age -dependent risk model of the BEIR VII committee (Tapiovaara M, 2008).

"The organs and tissues considered in the PCXMC program are: active bone marrow, adrenals, brain, breasts, colon (upper and lower large intestine), extra thoracic airways, gall bladder, heart, kidneys, liver, lungs, lymph nodes, muscle, esophagus, oral mucosa, ovaries, pancreas, prostate, salivary glands, skeleton, skin, small intestine, spleen, stomach,

testicles, thymus, thyroid, urinary bladder and uterus." (Tapiovaara M, 2008). "PCXMC calculates the risk of exposure-induced death for leukemia, cancers in colon, stomach, lung, urinary bladder, prostate, uterus, ovaries, breast, liver, thyroid and for all other solid cancers combined" (Tapiovaara M, 2008).

3.4.1 Basis for PCXMC Dose Calculations

All organ doses calculated by PCXMC are relative to the incident air kerma (Ka,i). In this Monte Carlo method all photons are emitted from a point into the solid angle, which are limited by the focal distance and X-ray field dimensions. Those random interactions with phantom depend on the probability distributions of the physical process (Tapiovaara M, 2008), which are limited by "photoelectric absorption, coherent (Ray leigh) scattering, and in coherent (Compton) scattering."(Tapiovaara M, 2008). At each interaction point, despite the position of the organ, the energy is calculated and stored for dose calculations (Tapiovaara M, 2008).

The maximum photon energy is 150 keV, a large number of independent photon histories is generated, and estimation of the mean value of energy deposition in different organs of the phantom. "This computer program contains, among other data, conversion coefficients for 34 X-ray projections and 40 X-ray spectra; their conversion coefficients have been calculated using Voxel-based adult male and female phantoms" (Tapiovaara M, 2008). "The effective dose is calculated using size-adjustable hermaphrodite phantoms, and organ doses are calculated in reference male and female phantoms. The equivalent organ doses in these two phantoms are averaged, and the effective dose is obtained as a weighted sum of these sex-averaged organ doses" (Tapiovaara M, 2008).

The organs and weighting factors in PCXMC are described in Figure 3.4.1 Below (Tapiovaara M, 2008).

Organ or tissue	Tissue weighting factor w_T (ICRP 103) [7]	Tissue weighting factor w_T (ICRP 60) [8]
Active bone marrow	0.12	0.12
Breasts	0.12	0.05
Colon[1]	0.12	0.12
Lungs	0.12	0.12
Stomach	0.12	0.12
Ovaries (female gonads)[2]	0.08/2	0.20/2
Testicles (male gonads)[2]	0.08/2	0.20/2
Liver	0.04	0.05
Oesophagus	0.04	0.05
Thyroid	0.04	0.05
Urinary bladder	0.04	0.05
Brain	0.01	r
Bone surface[3]	0.01	0.01
Salivary glands	0.01	-
Skin	0.01	0.01
Adrenals	0.12/13	r
Extrathoracic airways[4]	0.12/13	r
Gall bladder	0.12/13	-
Heart	0.12/13	-
Kidneys	0.12/13	r
Lymphatic nodes[5]	0.12/13	-
Muscle[6]	0.12/13	r
Oral mucosa	0.12/13	-
Pancreas	0.12/13	r
Prostate (male)	0.12/26	-
Small intestine	0.12/13	r
Spleen	0.12/13	r
Thymus	0.12/13	r
Uterus (female)	0.12/26	r

[1] The dose in the colon is calculated as the mass-weighted average of the upper large intestine and the lower large intestine.

[2] The dose in the gonads is defined as the average of the doses in the ovaries and testicles. The tissue weighting factor for gonads is presently 0.08 (ICRP Publication 103) and was earlier 0.20 (ICRP Publication 60).

[3] The tissue weighting factor refers to the dose to bone surface. PCXMC approximates this dose using the dose to the whole skeleton (excluding active bone marrow).

[4] In PCXMC only the trachea, pharynx and nasal sinuses are used to represent the extrathoracic airways.

[5] In PCXMC the lymph nodes have not been modelled in the phantom. The dose in lymph nodes is calculated as a weighted average of several surrogate organs (see chapter 3).

[6] In PCXMC, the dose in muscle tissue is calculated as the average dose to the whole phantom, but excluding the other organs and tissues given in this table.

[7] The weighting factors that are shown as the fraction 0.12/13 or 0.12/26 represent the remainder organs of ICRP 103. The new weighting factor for the arithmetic average of the remainder organs is given the tissue weighting factor 0.12. Sex-specific organs have effectively a lower weighting factor than the other remainder organs.

[8] Weighting factors labelled as "−" denote organs that are not included in the calculation of the effective dose according to the old ICRP 60 definition. Weighting factors labelled as "r" belong to the 'remainder tissues' of ICRP Publication 60. The tissue weighting factor of the ICRP 60 remainder is 0.05, and is applied to the mass averaged dose in the remainder organs and tissues. However, if any of these organs receives a dose that is higher than the dose to any of the twelve organs for which a weighting factor is specified, a weighting factor of 0.025 is applied to that tissue or organ and the rest of the weighting factor, 0.025, is applied to the mass averaged dose in the other remainder organs and tissues (ICRP 1991 and 1995).

Figure 3.4.1: The organs and weighting factors in PCXMC (Tapiovaara M, 2008)

The final estimate of the absorption dose at each simulated energy value is obtained as the average of these batches, while the statistical variations are estimated from the standard deviation of that batches (Tapiovaara M, 2008). PCXMC allows the estimation of different radiation quantities like ESK, IAK, KAP, and estimates the incident air kerma by tube current-time product mAs (Tapiovaara M, 2008).

The phantoms which are used in PCXMC can be found in Figure 3.4.2. Patient size transformations in PCXMC are given in Figure 3.4.3(Tapiovaara M, 2008).
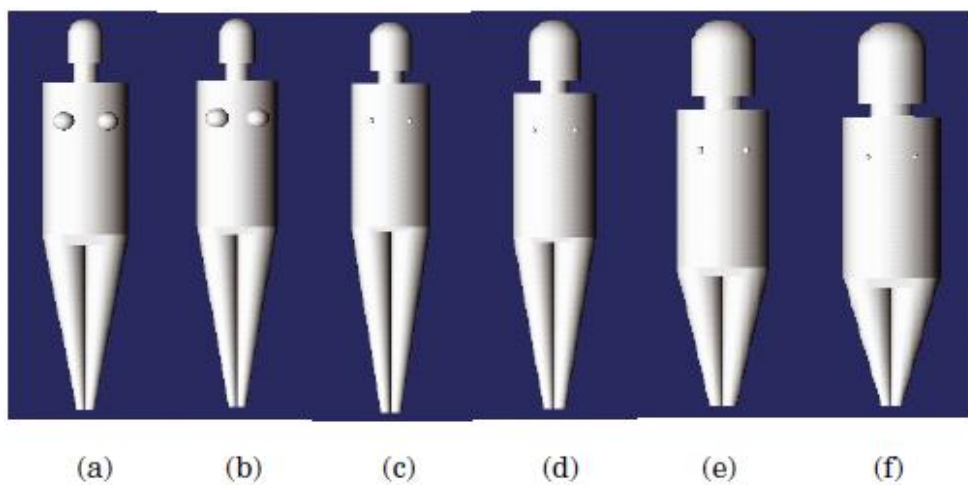
Figure 3.4.2: Phantoms models in PCXMC adults and pediatrics (Tapiovaara M, 2008).
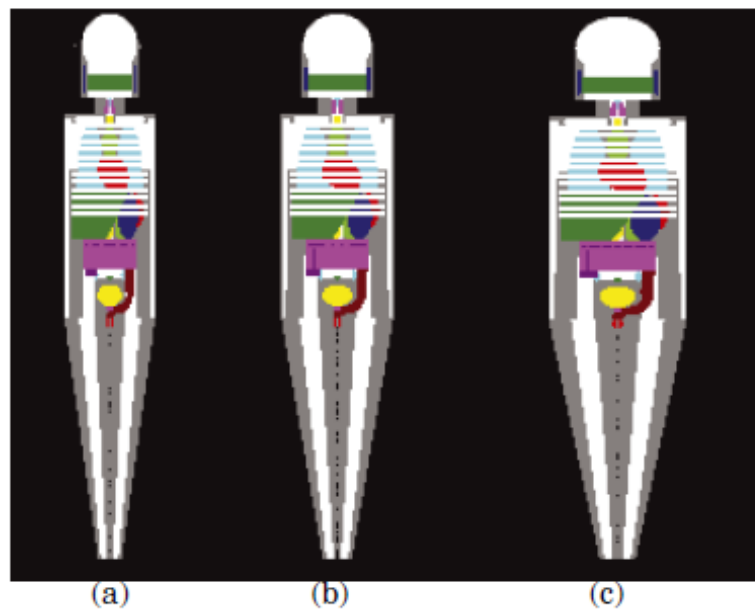
Figure 3.4.3: The patient size transformations in PCXMC (Tapiovaara M, 2008)

The mathematical phantoms in PCXMC are given in Table 3.4.1 (Tapiovaara M, 2008).

Table 3.4.1: The mathematical phantoms in PCXMC (Tapiovaara M, 2008)

Phantoms Age	Weight (Kg)	Total Height (cm)	Trunk Height (cm)	Trunk thickness cm	Trunk width[1] (cm)	Trunk Width[2] (cm)	Leg Length
Newborn	3.40	50.9	21.6	9.8	10.94	12.7	16.8
1 year old	9.20	74.4	30.7	13.0	15.12	17.6	26.5
5 year old	19.0	109.1	40.8	15.0	19.64	22.9	48.0
10 year old	32.4	139.8	50.8	16.8	23.84	27.8	66.0
15 yaer old	56.3	168.1	63.1	19.6	29.66	34.5	78.0
Adult	73.2	178.6	70.0	20.0	34.40	40.0	80.0
[1] Excluding arms		[2] including arms					

3.5 Selected Hospitals

3.5.1 Al Makassed Hospital in Jerusalem (Hospital one)

Al Makassed is considered as reference referral hospital in Jerusalem for all the West Bank and Gaza Strip. It includes many specialization fields. Moreover, it has a Joint Commission International (JCI) and the International Organization for Standardization (ISO) certificates. It has offers a medical residency for physician to become specialists. Therefore, it is defined as educational hospital in the West Bank.

The X-ray department at Al Makassed hospital has two major X-ray rooms, conventional and fluoroscopy examination rooms. It also has three X-ray portable machines for each floor in the hospital, in addition to Computed tomography (CT) machine, Magnetic Resonance Imaging (MRI) machine, and ultrasound machine. It is considered as a major X-ray department in Jerusalem. It accommodates about 34,129 patients for conventional X-ray examinations each year. An average conventional X-ray

examination is estimated about 73% of totals medical X-ray examinations. The average of chest radiography is 53%.

The major X-ray room selected at Al Makassed hospital has Siemens X-ray machine, model no (4303404), with total filtration 2.5 mm Al, anode angle is $12^{o.}$. The second machine is Philips portable X-ray machine, total filtration is 2.5mm Al, and anode angle is 15°. The average exposure factors used in this hospital are summarized in Table 3.5.1 (Al Makassed, 2014).

The patients sample was selected randomly from the 1st Nov. 2014 to the M of Feb.2015. It took about 3 months for registering all patients information. Total patients are 285 from al Makassed hospital in Jerusalem just 267 patients is selected.

Table 3.5.1:   The exposure factors range in Al Makassed Hospital, (Hospital one), for different chest X-ray projections

Exposure factors	PA Adult	PA Pediatric	LAT Adult	AP Adult	AP Pediatric
kV	105-130	99-115	117-133	50-70	40-55
mAs	1-6	0.8-4	4-15	3-15	2-4
FID	180	180	180	100	100

3.5.2 Hospital Two in Hebron

This hospital is defined as a specialty hospital in Hebron for emergency and trauma cases.   It has a major X-ray department for conventional X-ray examinations and fluoroscopy.   Moreover, it has a CT scan department and Ultrasound department.   The X-ray department has one major room for conventional X-ray examinations with Shimadzu X-ray machine; model (R-20). The total filtration is 2.5 mm Al, and anode angle 16°. The second machine is portable Siemens, Polymobil Plus. Total filtration is 3 mm Al, and anode angle is 15°. The range exposure parameters used in hospital two are summarized in table 3.5.2. The average chest radiography constitutes about 36% of the total conventional x-ray examinations.

The patients sample is selected randomly from Oct. 2014 to Jan. 2015. Total of 140 patient data were recorded in this hospital.

Table 3.5.2: The exposure factors range in Hospital two for different chest X-ray examinations projection

Exposure factors	PA Adult	PA Pediatric	LAT Adult	AP Adult	AP Pediatric
kV	80 -95	60-90	85-110	60-75	50-65
mAs	6-8	5-6	12-30	4-10	2-6
FID(cm)	180	180	100	100	100

3.5.3 Hospital Three

The third hospital is located in Hebron. It is considered as the largest hospital in the West Bank. The X-ray department has one conventional X-ray and one fluoroscopy rooms. Additionally, CT scan room and ultrasound machine are found. The average chest radiography is 40%. Only one conventional X-ray room which has Philips X-ray machine was selected, (Industrial X-ray Machine 2003), total filtration is 2.5 mm Al, and anode angle is 15°. The range of exposure factors used in this hospital is summarized in Table 3.5.3. Patients samples were recorded from Nov. 2014 to Jan. 2015. The total selected patients number was 139.

Table: 3.5.3: The exposure factors range in 3rd Hospital for different chest X-ray examination projections

Exposure factors	PA Adult	PA Pediatric	AP Pediatric
kV	70-110	60-75	45-70
mAs	10-27	6-16	6-8
FID	180	180	100

3.3.4 Jerusalem Medical Center

The fourth site was selected to check the effective dose obtained through CR –system. It is a major medical center in Jerusalem. It uses the CR- system since 2010. The X-ray department has one conventional and one fluoroscopy rooms. Additionally, mammography and ultrasound machines are found. One conventional X-ray room was selected. It has a GE (Precision 500D) X-ray machine, with total filtration is 3.5 mm Al, and anode angle is 15°. The exposure factors used in this medical centre are summarized in Table 3.5.4.

Table 3.5.4: The exposure factors range in Jerusalem Medical Center for different chest X-ray examination projections

Exposure factors	PA Adult	PA Pediatric	LAT Adult	AP Pediatric
kV	120-130	90-125	110-133	55-75
mAs	3-8	2.2-6	4-14	2.5-4
FID	180	180	180	100

The samples of patients were selected randomly from Nov. 2014 to Feb. 2015. The total selected patients number is 122.

Chapter IV

Results and Discussion

4. Effective Dose Calculations
4.1 Data Analysis

In this chapter, the mean organs and effective doses to pediatric and adult patients undergoing chest radiographic examination were evaluated in the four hospitals will be shown and discussed respectively. Data for a total of 668 patients were used in this study. The technical parameters used in this study are patient's height, weight, age, gender, and examinations projections (PA, AP, and Lateral). The exposure factors used in this study are X-ray tube voltage (KVp) and electrical charges Milliampere-second (mAs). In addition, the filtration thickness in each X-ray machine, anode angle, focal source distance (FSD), and X-ray beam size is also used. A sample of technical factors used can be found in the appendix.

The average effective dose was calculated for all routine projections of chest radiography in participating hospitals. Furthermore, posterior to anterior (PA) and lateral projections adult chest radiography accounted for over than 69%. Anterior to posterior (AP) projection in pediatric was estimated to be over than 20%, and in adult patients, it accounted for over than 5% of chest X-ray examinations. AP projection for adults was done by portable X-ray machine only for patients who can't stand. The assessment was conducted with a patient position with arms in PA and AP projections and without arms in lateral projection during the effective dose calculation. The PCXMC software calculates the effective dose using tissue weighting factors of ICRP 103 and ICRP 60, and gives the absorbed dose in total body (Tapiovaara M, 2008). Additionally, ESAK dose was calculated by Cal-Dose_X5.0 software.

A. Al Makassed Hospital (Hospital one)

Three hospitals have been chosen for this study. The first site was Al Makassed hospital in Jerusalem. 191 adult patients (92 female and 117 male) participated in this study in all routine adult chest X-ray projections (PA and lateral) and portable chest X-ray projection (AP). Another 76 pediatric patients (35 female and 41 male) were examined in this hospital. The first routine chest X-ray projection in pediatric patients is AP, which was used for kids who can't stand, and the second projection is PA for kids who can stand. The average effective dose and ESAK in Al Maksased hospital for different projections are summarized in Table 4.1.1 and shown in Figure 4.1.1.

High average effective and absorbed doses are found in lateral adult projections because of the use of high mAs and short of FSD (less than 150 cm) compared to PA projection. As a patient stands laterally, the thickness of body increases, therefore, high exposure factors should be used, which results in the production high backscatter radiation and high patients' absorbed dose. High average effective, ESAK and absorbed doses were also found in AP adult procedures which by portable machine.

A major reason for such increase is the use of short FSD of less than 80 cm. Additionally, the use of high mAs (8-20) in portable cases, each radiographer selects own exposure factors, which results in wide variations in the average effective dose. Furthermore, in portable radiography, high backscatter radiation is produced, which means high risk to the people who stand around patients.

Table 4.1.1: The Average Effective Dose and ESAK in Al Makassed hospital (Hospital one) for 267 patients from different projections.

Average Doses (mSv)- (mGy)	PA Adult	PA Pediatric	LATL Adult	AP Adult	AP Pediatric
Average effective dose in ICRP103 [mSv]	0.043	0.035	0.12	0.15	0.033
Average effective dose in ICRP60 [mSv]	0.04	0.03	0.1	0.1	0.025
Average absorbed dose in total body (mGy)	0.04	0.03	0.07	0.074	0.017
Average ESAK dose (mGy)	0.28	0.36	1.08	1.16	----------------
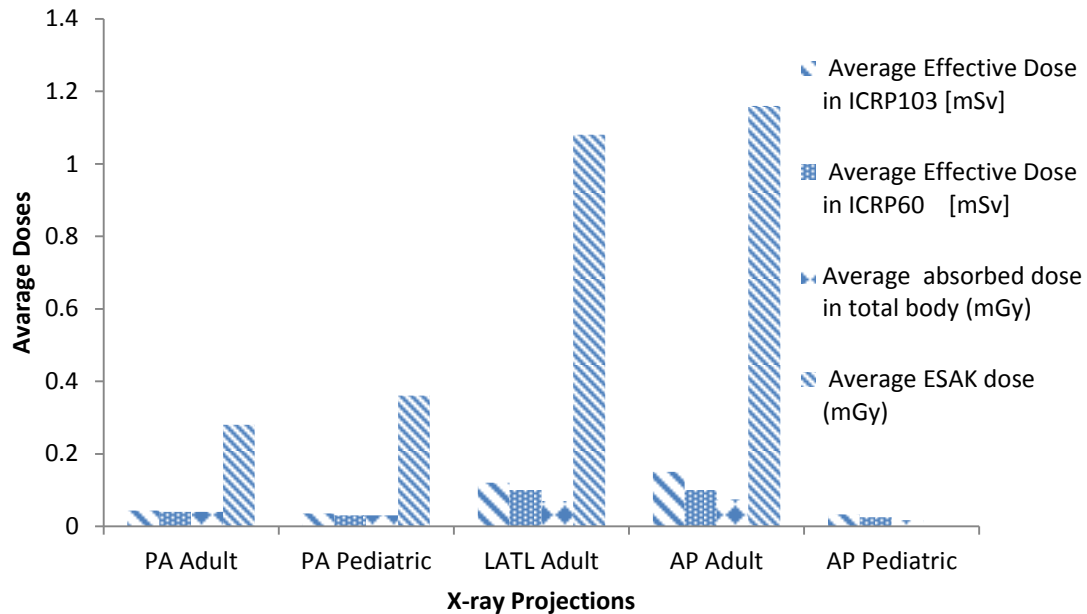
Figure 4.1.1: Results of Effective Dose and ESAK in Al Makassed hospital (Hospital One) from different projections

High average ESAK dose in lateral projection means high of backscatter radiation because the thickness of patient is increasing laterally. ESAK dose combines between the entrance surface air kerma $K_{a,e}$ (free in air) and the backscatter radiation. Therefore, it is high in this case. ESAK dose couldn't be calculated in AP pediatric projection by CALDose_X-5.0 software because the exposure factors are too low (KV) less than 60. As a result, the effective dose was estimated by mAs factor in PCXMC program. Moderate

exposure factors were used in PA adult and pediatric procedures. The average kV is (100-120) and the average mAs is (1-3.5). They produced low average effective and ESAK doses in PA adult and pediatric chest X-ray examinations for hospital one cases.

B. Hospital two

The second major and specialty hospital is located in Hebron. The Radiographers in this hospital were asked to collect data for 300 patients (145 female and 155 male) who were investigated by conventional chest radiography for different projections. Only 140 patients were analyzed to make samples number in four hospitals as the same. Table 4.1.2 summarizes the average effective dose of both tissue weighting factors from ICRP (103 and 60) and ESAK in hospital two. Figure 4.1.2 also shows the average effective dose and ESAK in hospital two for different projections.

High average effective dose and ESAK were found in the lateral and AP adult projections as result of high mAs and short FSD (less than 80cm).   High average ESAK means high of backscatter radiation in all projections, which produces high risks to radiographers and the people around patients.

Table 4.1.2: Average Effective Dose and ESAK in Hospital two for different projections

Average Doses (mGy) – (mSv)	PA Adult	PA Pediatric	LAT Adult	AP Adult	AP Pediatric
Average Effective Dose in ICRP103 [mSv]	0.04	0.08	0.39	0.12	0.019
Average Effective Dose in ICRP60 [mSv]	0.04	0.06	0.28	0.08	0.013
Average absorbed dose in total body (mGy)	0.04	0.05	0.19	0.05	0.008
Average ESAK dose (mGy)	0.4	0.66	5.05	0.88	------
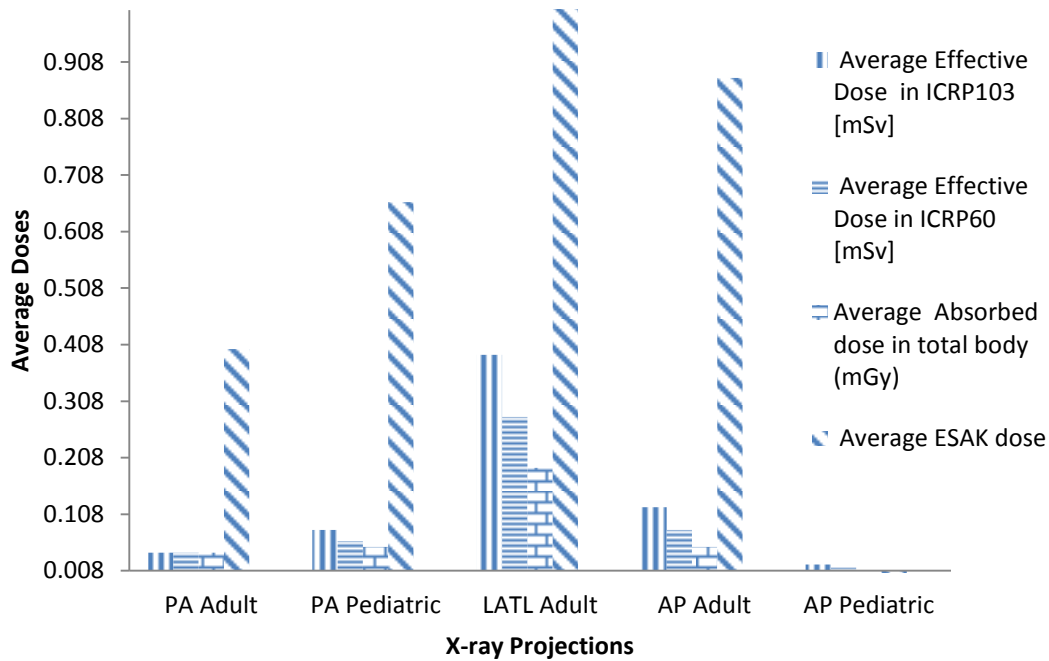
Figure 4.1.2: Average Effective Dose and ESAK in Hospital two for different projection

The highest average ESAK dose is found in lateral projection as a result of short FSD (less than 80 cm), while the correct distance should be (135-145) cm. This kind of mistake incurred by some radiographers increase risks from medical X-ray exposure. Moderate exposure factors were used for PA adult, but high exposure factors were used for pediatric PA. Therefore, the average effective dose for PA pediatric is higher comparing with PA adult. The average exposure factors were used in PA adult about (75-95) kV and (5-6) mAs, and in PA pediatric were (70-85) KV and (5-6) mAs. ESAK couldn't be calculated in AP pediatric projection by CALDose_X-5.0 software because kV value was too low less than (60). Therefore, the effective dose was estimated by mAs factor using PCXMC software.

C. Hospital Three

The third hospital is located in Hebron; it is described as one of the busiest hospital in the West Bank with a large number of patients. A total 185 patients were examined (75 female and 110 male), only 139 patients were selected for this study. Table 4.1.3 summarizes the average effective dose and ESAK in Hospital three for different

projections. Figure 4.1.3 shows average effective dose and ESAK for different projections in hospital three.

Table 4.1.3: Average effective dose and ESAK in Hospital three for different projection

Average Doses (mGy)- (mSv)	PA Adult	PA Pediatric	AP Pediatric
Average Effective Dose in ICRP103 [mSv]	0.11	0.08	0.16
Average Effective Dose in ICRP60 [mSv]	0.102	0.07	0.12
Average absorbed dose in total body (mGy)	0.102	0.07	0.08
Average ESAK dose dose (mGy)	1.06	0.9	0.88

The high average effective dose is found in AP pediatric that result in a usage of high exposures factors mAs and kV, and short FSD less than 80 cm. However, it should be less than this amount. The exposure factors were used in AP pediatric procedure were about 50-70 kV and 4-14 mAs. This large amount of variations of exposure factors comes from different processing technical factors (fixer and developer concentrations in processing machine). According to the information and input data from this hospital, some pediatric patients in AP projection had double X-ray exposure due to repeated cases. As a result, the amounts of exposure parameters are too close to those used for adult patients in the same AP projection.

The highest average effective dose and ESAK were found in PA adult as a result of exposure parameters used (70-100) kV and (10-35) mAs. The use of high mAs and kV directly and strongly affects effective dose measurements. If one of those parameters is low and the other is high the amount of effective dose will be in range. While both of them are high the effective dose increases strongly. This would assist researchers to select suitable exposure factors to be used in chest X-ray examinations for getting the diagnostic information with lower patients' dose.

High average ESAK was found in PA pediatric which is related to high exposure factors used (66-75 kV and 10-20 mAs).   In addition, the number of PA pediatric patients sample in this hospital is too small.   High ESAK average is found in PA adult, PA pediatric and AP pediatric, which means high backscatter radiation to patients, radiographer and people around patients. The lateral projection is not recommended in this hospital. So the result of the lateral average effective dose could not be calculated.
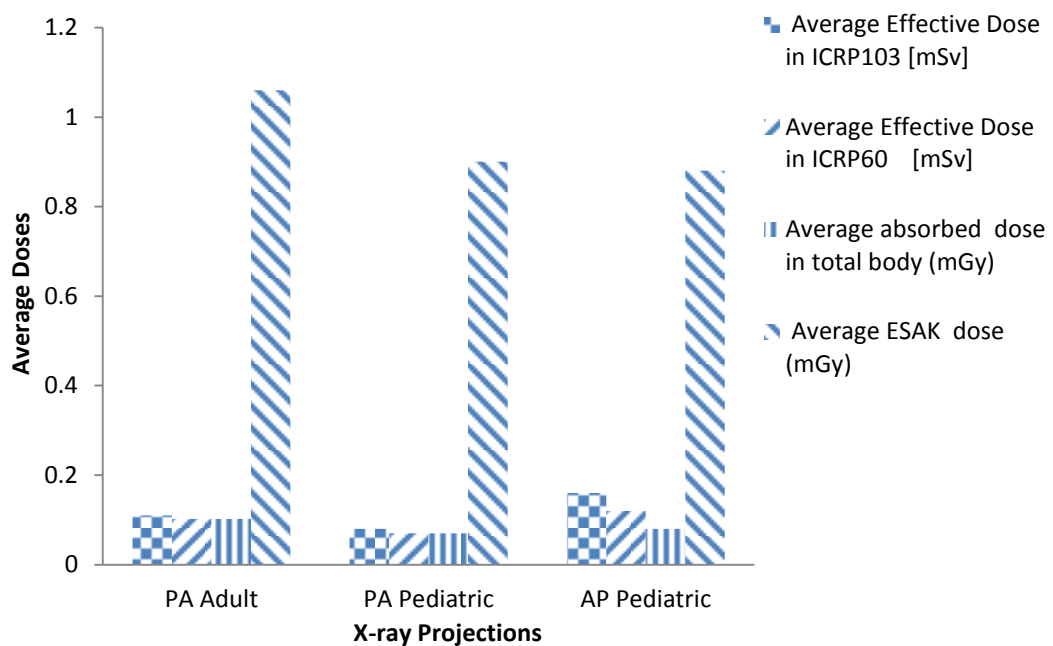
Figure 4.1.3: Average Effective dose and ESAK in Hospital three for different projections

D. Jerusalem Medical Center

A total 122 patients were selected from the fourth site. It is a major medical center in Jerusalem which uses a CR-digital system for medical X-ray examinations. The CR –digital films are recommended for producing good resolution digital images and having more advantages from traditional conventional X-ray processing.   However, a CR- system should be used with high exposure factors comparing with traditionally conventional X-ray system. Using high exposure factors in CR -system connects with lower absorption efficiency in CR phosphor plate with high electronic noise and some

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readout inefficiencies of latent image. Table 4.1.4 summarizes the average effective dose and ESAK in Jerusalem Medical Center for different projections. Figure 4.1.4 shows average effective dose and ESAK in Jerusalem Medical Center for different projection.

Table 4.1.4: Average effective dose and ESAK in Jerusalem Medical Center for different projections

Average Doses (mGy) – (mSv)	PA Adult	PA Pediatric	LATL Adult	AP Pediatric
Average Effective Dose in ICRP103 [mSv]	0.1	0.06	0.14	0.15
Average Effective Dose in ICRP60 [mSv]	0.09	0.05	0.11	0.11
Average Absorbed dose in total body (mGy)	0.08	0.054	0.07	0.075
Average ESAK dose (mGy)	0.63	0.32	1.31	0.65
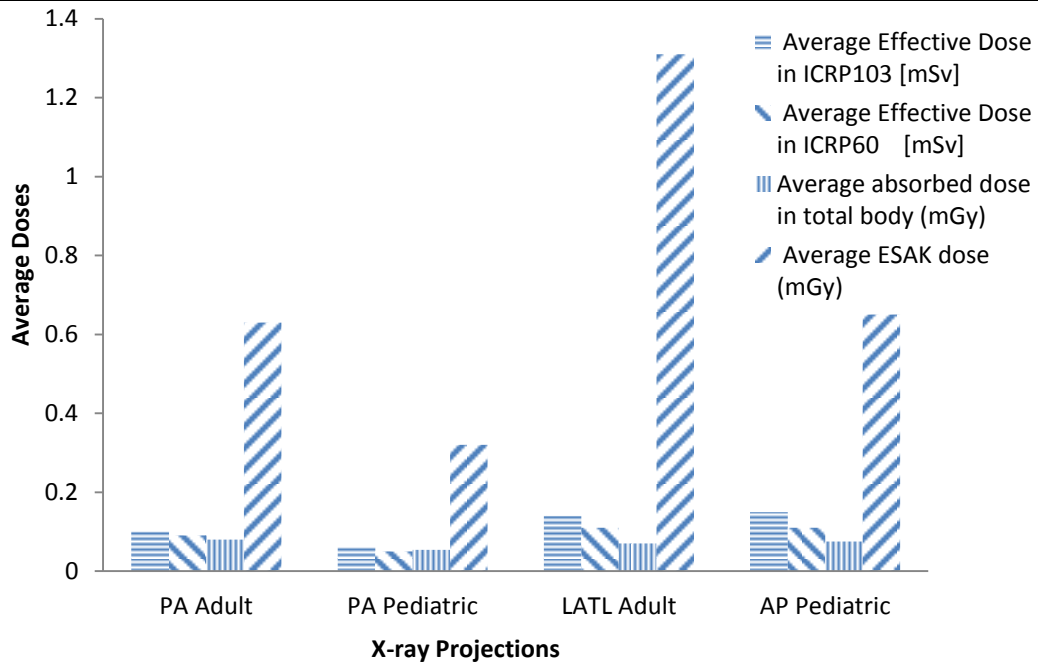
Figure 4.1.4: Average Effective dose and ESAK in Jerusalem Medical Center for different projections

High average effective dose and ESAK is found in AP pediatric and lateral adult projections as a result of short FSD, less than 80 cm in AP pediatric and less than 140 in lateral adult procedures. Additionally, high exposure factors were used in AP pediatric procedures (60-70) kV and (3-7) mAs. Also, the exposure factors in lateral adult

procedures were (120-133) kV and (4-14) mAs. High average ESAK dose can be found in PA adult as a result of high exposure factors (109-133) kV and (3-9.5) mAs.

High average ESAK dose in almost all X-ray projections results from a high exposure factors in CR system, which incurs high risk for radiographers, patients, and people around patients.   Therefore, the radiographer has a responsibility to check suitable exposure factors which give good diagnostic information and quality X-ray images with less medical radiation doses.

To get and investigate the average effective dose and ESAK, these four samples were done in some of the major and most prominent hospitals and medical centers in the West Bank. The following sections in this chapter will discuss and compare these four sites.

4.2 Effective Dose Comparison between different hospitals for different projections

Table 4.2.1 summarizes all average doses for different projection and exposure factors at four hospitals. Figure 4.2.1 shows average effective doses for different projections at four hospitals.

Table 4.2.1: Effective doses and exposure factors Average for different projections at four hospitals

Chest X-ray projections and exposure parameters for each projection	Average effective dose (mSv) and mean exposure parameters in Hospital one	Average effective dose (mSv) and mean exposure parameters in Hospital Two	Average effective dose (mSv) and mean exposure parameters in Hospital Three	Average effective dose (mSv) and mean exposure parameters in CR-medical center	Total Average Effective (mSv) dose to each projection In four sites
AP adult	0.15	0.12	-	-	0.14
Mean kV	50-75	62-74			
Mean mAs	5-15	5-8			
PA Adult	0.04	0.04	0.11	0.1	0.07
Mean kV	100-120	75-95	70-95	109-133	
Mean mAs	1-4	5-6	10-25	3-9.5	
Lateral adult	0.12	0.39	-	0.14	0.33
Mean kV	105-125	88-105		120-133	
Mean mAs	4-12	16-25		4-14	
AP pediatric	0.03	0.02	0.16	0.15	0.09
Mean kV	40-55	55-60	50-70	60-70	
Mean mAs	3-8	2-5	4-14	3-7	
PA pediatric	0.04	0.08	0.08	0.06	0.06
Mean kV	100-115	70-85	66-75	100-125	
Mean mAs	1.3	5-6	10-20	2.8-4	
Total average effective dose for different chest X-ray projections in four hospitals is 0.11 mSv.					
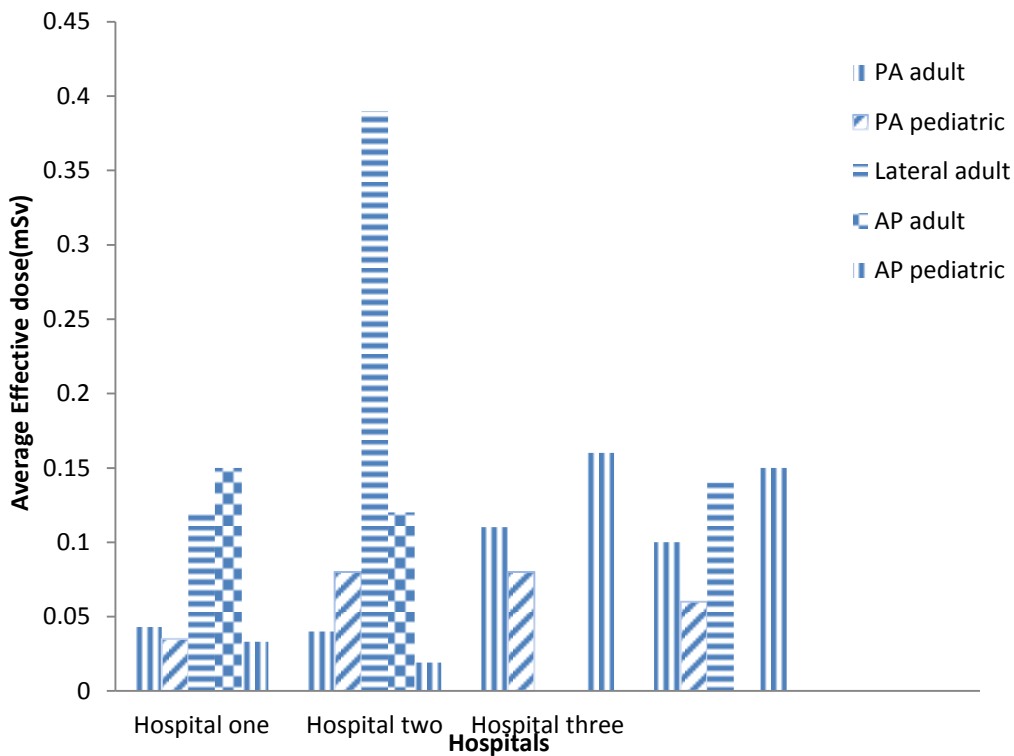
Figure 4.2. 1: Average Effective Doses (mSv) for different projections at Four Hospitals

The highest average effective dose is found in adult lateral projection in hospital two as a result of short FSD (80) cm, which should be increased to 145 cm. The second high average effective dose recorded for AP pediatric projection at hospital three as result of using high exposure factors and short FSD.   The third high average effective dose is found in CR medical center for Jerusalem in AP pediatric projection. The fourth high average effective dose found for AP adult projection in hospital one.

The highest total average patients' doses were recorded in hospital three for different projections, then in Jerusalem CR-medical center. While hospitals one and two have had very close patients doses except in lateral adult projections.

The hospitals are ordered below depending on total average effective doses in different projections:

1- Hospital three

2- CR-medical center

3- Hospital two

4- Hospital one.

The average effective and ESAK doses are respectively ordered according to different projections at four hospitals as below.

Average effective doses:

1- Lateral adult projection

2- AP pediatric projection

3- AP adult projection

4- PA adult

5- PA Pediatric projections

Average ESAK dose:

1- Lateral adult projection

2- AP adult projection

3- PA adult projection

4- PA pediatric projection

5- AP pediatric projection.

The differences in arrangements seen above are result from the ESAK dose is depending on backscatter radiation while the effective dose is depending on the incident air kerma (without backscatter radiation).

The average absorbed doses of total body are ordered according to different projections for four hospitals as:

1- Lateral adult projection

2- AP adult projection

3- PA adult projection

4- PA pediatric projection

5- AP pediatric projection.

The shown result depends on the exposure factors and each X-ray projection. The total absorbed dose for the whole body depends on the total amount of X-ray spectrum reaching body organs.   The standard deviation (SD) gives the variation ranges between the effective dose results. Figure 4.2.2 shows the SD ranges at four hospitals in all projections.
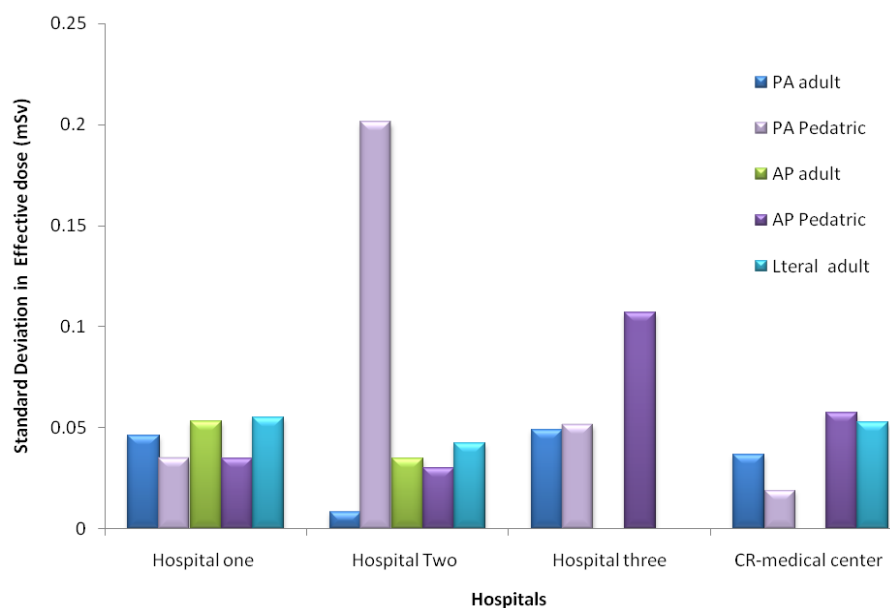
Figure 4.2.2: Standard deviation in effective dose at four hospitals in all projections

The highest SD found in hospital two of PA pediatric projections, which result from the small sample number.   The second higher SD is found in hospital three of AP pediatric, which result of the high variation of exposure factors that were used. Hospital one where it has the high radiographers number gives a high SD in all projections, but it is still near of the total SD range. That means all radiographers use a closed exposure factors.

4.3 Comparison with International Studies

Many studies have estimated the effective dose in many countries. Each country has a specific effective dose reference levels. Those doses are depending on a technical exposure factors, patients' geometry and biological features.

Typical effective dose is found from Chest X-ray in Untied Status about 0.1 mSv (HPS, 2010).   While the NCRP report gives the dose a value of 0.02 mSv in PA projection for adult and about 0.04 mSv in lateral projection (NCRP, 2009). The results obtained in this study for the average effective dose are   in AP adult, PA adult, lateral adult, AP pediatric and PA pediatric were 0.14, 0.07,0.33, 0.09 and 0.06 mSv respectively, and the total effective dose average is ~0.11 mSv. This means it is higher than the values in the

NCRP report, but it still within the range depending on the typical effective dose values in health physics society (HSP) report. The effective dose values in Ireland for chest X-ray examination showed that PA projection was given about 0.3 mSv and gave the lateral chest X-ray about 1.5 mSv (IrishMedicalCouncil, 2004). Results from this study fall in the range of the Irish effective dose values.

The European Guidelines regarding on the estimation of population doses from medical X-ray procedures reports have given the mean typical effective doses for the chest PA and Lateral view depending on exposure level group. Higher exposure group is given the typical effective dose which is about 0.25 mSv, the average exposure group is given it about 0.10 mSv, and the lower exposure group is given it about 0.03mSv. All these quantities are different depending on exposure parameters in many countries of Europe (EUROPEANCOMMISSION, 2008). The results shown in this study are located in an average group which is registered in the European Guidelines.

The typical effective dose is found about 0.014 mSv based on ICRP 60 and ICRP 103 E103/E60 ratio according to the frequency and collective dose for medical and dental X-ray examinations in UK report. That is shown it equal to one (1) mSv (D Hart. B F Wall. M C Hillier, 2008). The results from this study are so near to a previous UK quantities report. The Nordic dose reference levels have given the average of ESD in PA chest X-ray which is about 0.2 mGy and about 0.5 mGy in lateral (Nordic Society forRadiationProtection, 2002). While the ESD and ESAK quantities in this study are higher than the Nordic typical reference doses.

According to the clinical study survey of organ equivalent and effective doses from diagnostic radiology procedures which was done in Canada 2012. The average effective dose from chest X-ray is found to be 0.066 mSv. The range of effective doses is 0.0012-0.33mSv (Ernest K. Osei1, 2012). In comparison to this study, our average effective

doses are higher than the previous quantities in Canada. The higher values may be explained as different exposure factors between places. Furthermore, in Palestine, old equipments are used; lack of radiographers training and lack of standard protocols in the hospitals might be the reason behind such increase.

4.4 Collective Effective Dose Calculations

Population doses have been expressed in terms of the annual collective effective dose (S). This quantity refers to the account of number of people who were exposed to radiation by a particular radiation source, practically (Sofia, 2011).

Population effective dose measure trends in population medical doses with time or when the studies need values of patients' doses collected from different countries. The definition of effective dose population includes all ages, and both sexes on the basis of mean doses to a reference man, and a reference woman.

This is the phantoms are used in PCXMC software or in any Mote Carlo simulation softwares. To get the population dose for people who were exposed to undergo chest X-ray examinations in this study, the population dose (S) should be calculated as below:

Population Dose (S) =

$$= \Sigma_i \textit{ Number of procedures (i) } X \textit{ Average effective dose for procedure (i)} \qquad \textbf{(3)}$$

= 668 (Total number of procedures in this study) X 0.109 mSv (average effective dose for different projections in all hospitals in this study).

S = 72.67 of (668 man mSv) average effective dose to population in the West Bank from the conventional chest X-ray examinations.

Only Al Makassed hospital has annual statics in its radiology department. So the annual average per capita dose in Al Makassed Hospital is found as below:

The annual average per capita dose =

$=$ *Sum of effective doses from all X-ray procedures / Examinations in a year*   **(4)**

$= 0.381$mSv (sum all effective doses of chest X-ray in Al Makassed hospital)/ 18288 (number of chest X-ray examinations in al Makassed hospital in 2014).

$= 2.0833 \times 10^{-5}$mSv annually per capita of the chest X-ray examinations in Al Makassed hospital.

4.5 Statistical analysis for the relations between patients dose and exposure parameters

The collected data in this study showed in this section. Variations in doses between different exposure parameters were statistically significant for all chest X-ray projections. The Pierson correlation was used to investigate the relationship between dose and the exposure factors.

4.5.1 Relationship between the effective dose and the X-ray Tube Voltage (Peak operating Voltage)(KVp)

Sample of patients effective dose and the X-ray tube voltage (kVp) relation is shown in Figure 4.5.1.
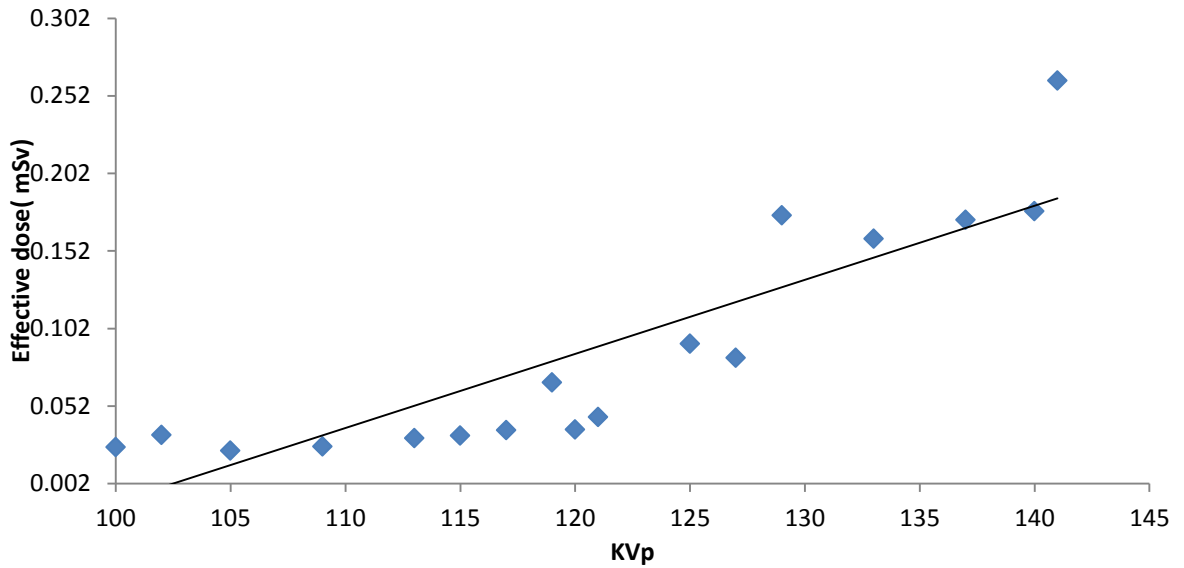
Figure 4.5.1: Relationship between the Effective dose and X-ray Tube Voltage (KVp)

Pierson Correlation (r) is found about 0.527 in this relationship. The descriptive statistics gave the KVp mean equal to 121.8 and average effective dose equal to 0.073mSv. The standard deviation (SD) is found 6.49 for KVp and 0.077mSv in effective dose. Moderate positive correlation was found between those two variables. For example, 99 kVp gives 0.025 mSv of effective dose while in 141 kVp the effective dose is 0.26mSv. Increasing KVp values result in an increase in effective dose but not too high as found in the scatter pointes around the trend line. The X-ray tube voltage is an important exposure factors, but only a significant change in KVp leads to a real change of effective dose value. Increased SD value in KVp is related to high average values.

4.5.2 Relationship between the Incident Air Kerma and milliamp second

Figure 4.5.2 shows the relation between the incident air kerma and milliamp second (mAs). The r value is 0.675. The meanmAsis3.71 and the mean incedent air kerma is 0.4168mGy. The SD of mAs is 2.863 and in incedent air kerma is 0.51901mGy.
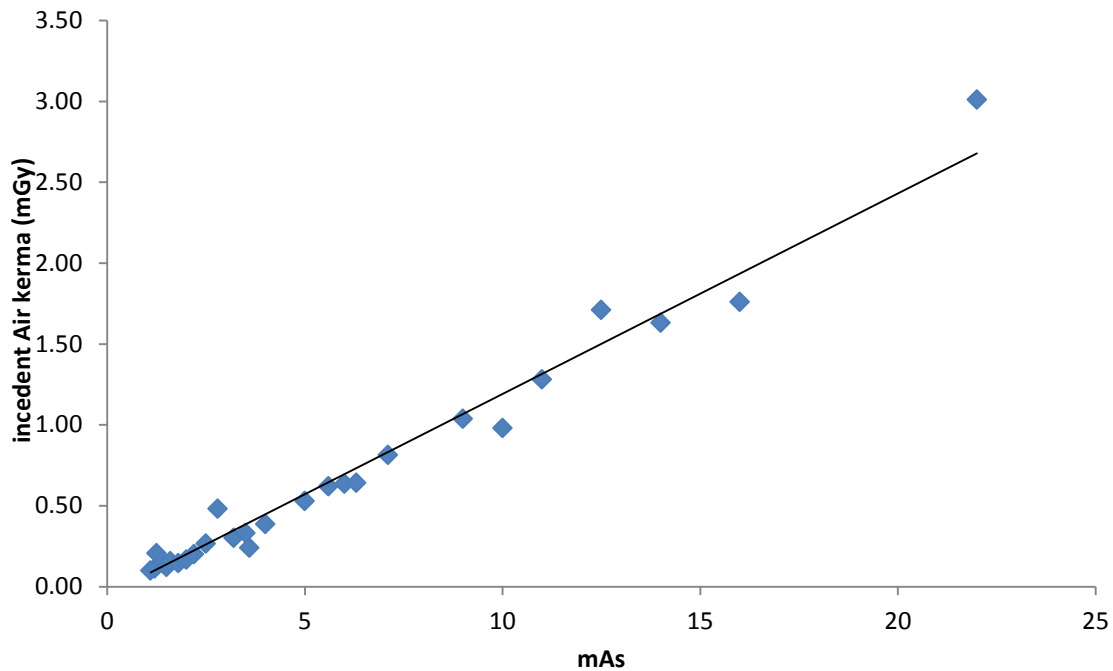
Figure 4.5.2: Relationship between the Incident Air Kerma and milliamp second (mAs)

A strong positive relation is found between Incident Air Kerma and milliamp second (mAs). High value of mAs gives high value of incident air kerma. The directly proportional between incident air kerma and mAs is obvious. A small change of mAs value can give a high incident air kerma value, while the large change in kVp only gives the same change and get a high incedent air kerma. The lower mAs value 1.1 gives 0.10 mGy and the high mAs value 22 gives 3.01 mGy incedent air kerma.

4.5.3 Relationship between effective dose and milliamp second (mAs)

High values of mAs gave high values effective dose. Any change of mAs value leads to a change in effective dose which means that the relation is directly proportional ascending. Figure 4.4.4 shows this relation. The r value is 0.61. The average mAs is3.7123 and the average effective dose is 0.0732mSv. The SD of mAs is 2.86 and in effective dose about 0.07mSv.
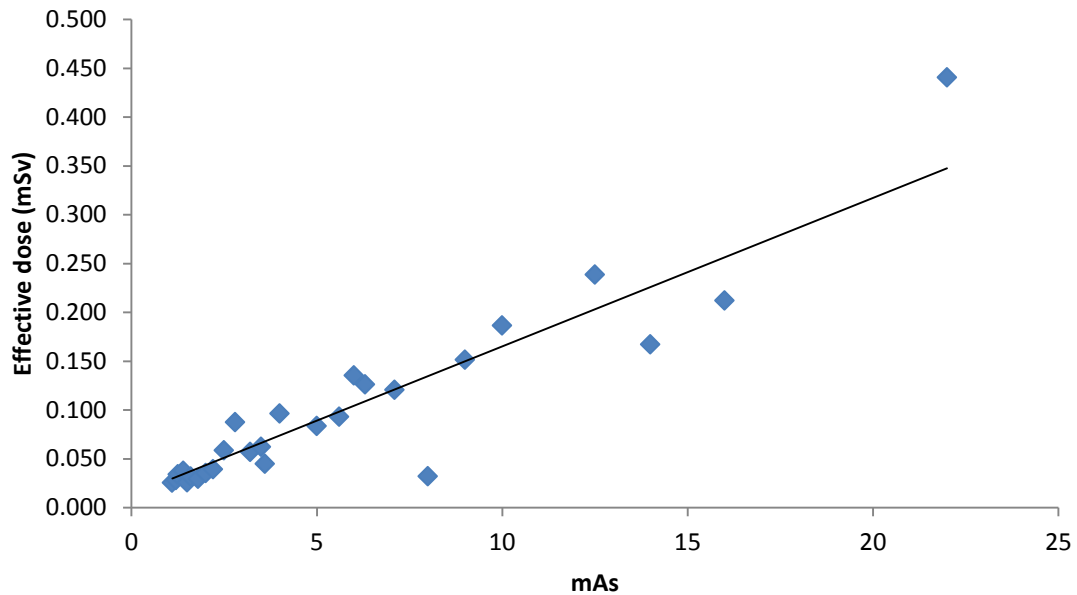
Figure 4.5.3: Relationship between the Effective Dose and milliamp second (mAs)

Strong positive relation is found between mAs and effective dose. It is clear the mAs is the main exposure factors which has the strongest affect on effective dose. Increasing in mAs value leads to high value in effective dose. For example, for 1.1 mAs, the effective dose was 0.026mSv while for 22 mAs the effective dose is 0.441mSv. Some outlier points are found but they were low compared to sample size.

4.5.4 Effect of patients height on effective dose

Patients' biological features are considered important exposure technical determinant factors. Usually the tall patients are highly exposed, especially if the height is combined with high weight. Figure 4.4.5 shows the patients height and the effective dose relation. The r value is 0.162. The average effective dose and high is 0.067 mSv and 167.59 cm respectively. The SD of effective dose is 0.07845mSv and in 8.64 cm in the patients height.
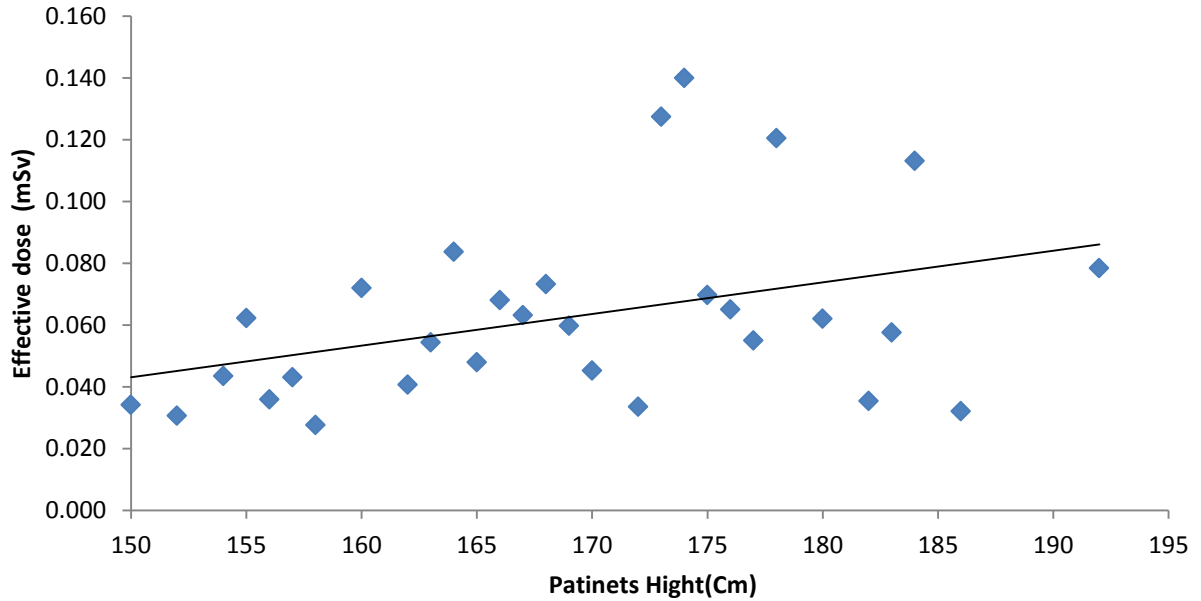
Figure 4.5.4: Effect of Patients Height (cm) on Effective Dose (mSv)

The effect of patients' height on the effective dose is too weak. The scatter plots around the trend line give weak positive relation. The SD of effective dose and height explain this weak relationship. Radiographers use their own exposure factors, so that it is clear in some height points there were different values of effective dose depending of on the used exposure factors.

4.5.5 Effect of patients weight on effective dose

The patients weight is considered to be an essential exposure factors in order to get the quality and the resolution of X-ray examination. Figure 4.4.6 is showing the effective dose and patients' weight relationship. The high - weight needs high exposure techniques to get clear diagnostic X-ray image with good resolution.
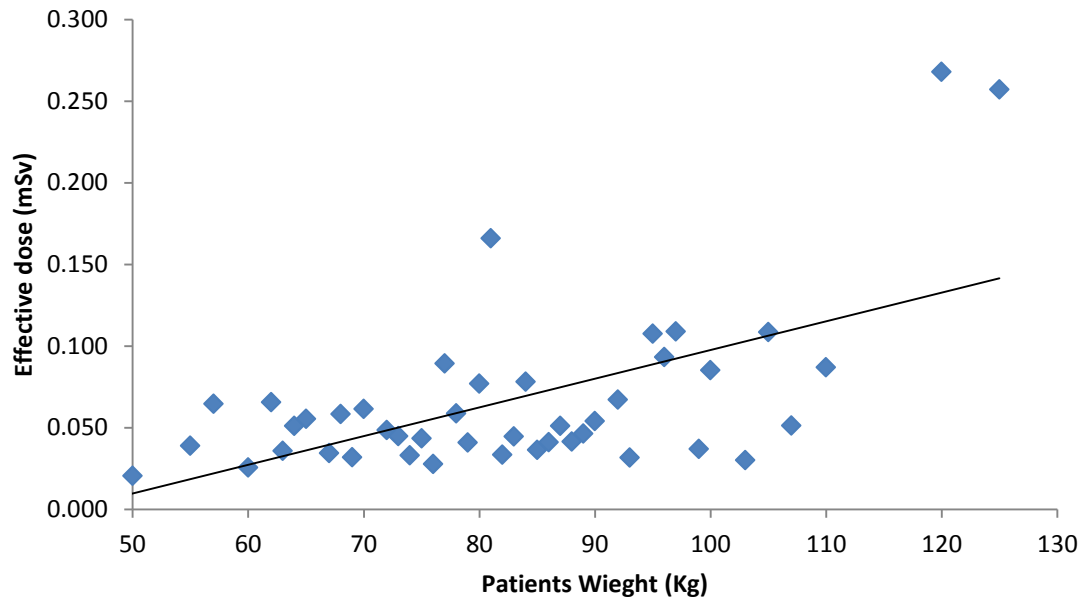
Figure 4.5.5: Effect of Patients weight (kg) on Effective Dose

The effects of patients weight on the effective dose is strongly clear. In figure 4.5.5, the r value is 0.33. The average effective dose is 0.0672 mSv while the average weight is 80.1 kg. The SD values are in effective dose is 0.078 and in the weight is 15.07. Differentiation in the exposure parameters to each radiographer gives this scatter plot shape. While the SD of the effective dose gives the amount of these differentiations in the exposure parameters. For example in weight 85 kg, the effective dose is found 0.026 mSv, and 0.034 mSv in another point according to the exposure parameters that were used.

4.6 Average Radiosensitivity Organs Absorbed Dose for Different Projections in Four Hospitals

4.6.1 Average organs absorbed doses in adult patients PA projections

Moreover, PCXMC calculates some of absorbed doses for radiosensitive organs in human body. Figure 4.6.1 summarises the average organs absorbed doses in adult PA projection. Spleen, lungs and adrenals have the highest average organs absorbed dose in PA projection.
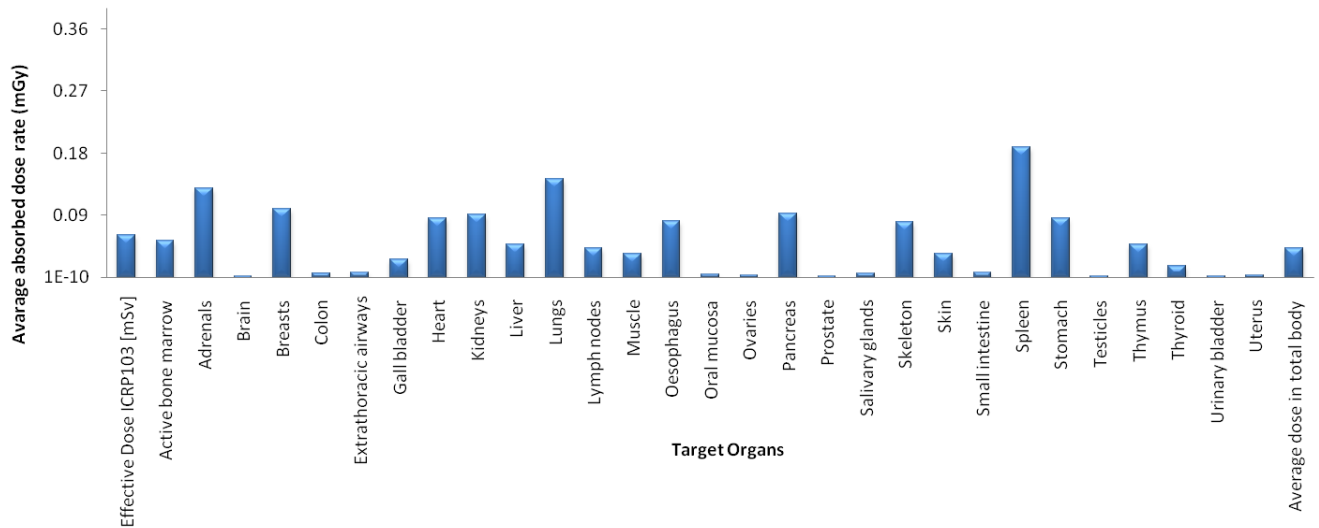
Figure 4.6.1: Average organ absorbed doses in adult patients PA projection

The X-ray beam enters patients from posterior to anterior (from back to front) in PA projection. The average X-ray beam size is about (32.8X32.8) cm that covers all the area of patient chest and back. The Spleen is located beneath the diaphragm, in the upper left quadrant of abdomen inside the range of X-ray beam. Moreover, the adrenals are located at the top of each kidney which means that they are in the range of X-ray beam. Spleen and adrenals are radiosensitive organs because the high activity functions of them to produce hormones in the body. The lung is a sensitive organ which is located in the chest area. It is a complex organ; over 40 types of cell make up the lung. It cannot tolerate large doses of radiation because it has a little regenerative capacity.

4.6.2 Average organs absorbed doses in adult patients AP projection

AP projection is recommended as an alternative procedure for routine PA chest X-ray projection for adult patients who couldn't stand erect. This procedure might be done by portable X-ray machines. Average X-ray beam size is about (31X31) cm. Figure 4.6.2 summarizes average organ absorbed doses for adult patients AP projection.

The breast receives the highest absorbed dose in this case, while the lung receives the lowest absorbed dose. Breasts, thymus and the heart have received the highest average organs absorbed doses in this case comparing with other projections. It means that the average organs absorbed dose in AP adult projection is too high. So the portable radiography should be done only in critical cases and the doctors should be aware. Breast cancer is the most common women.
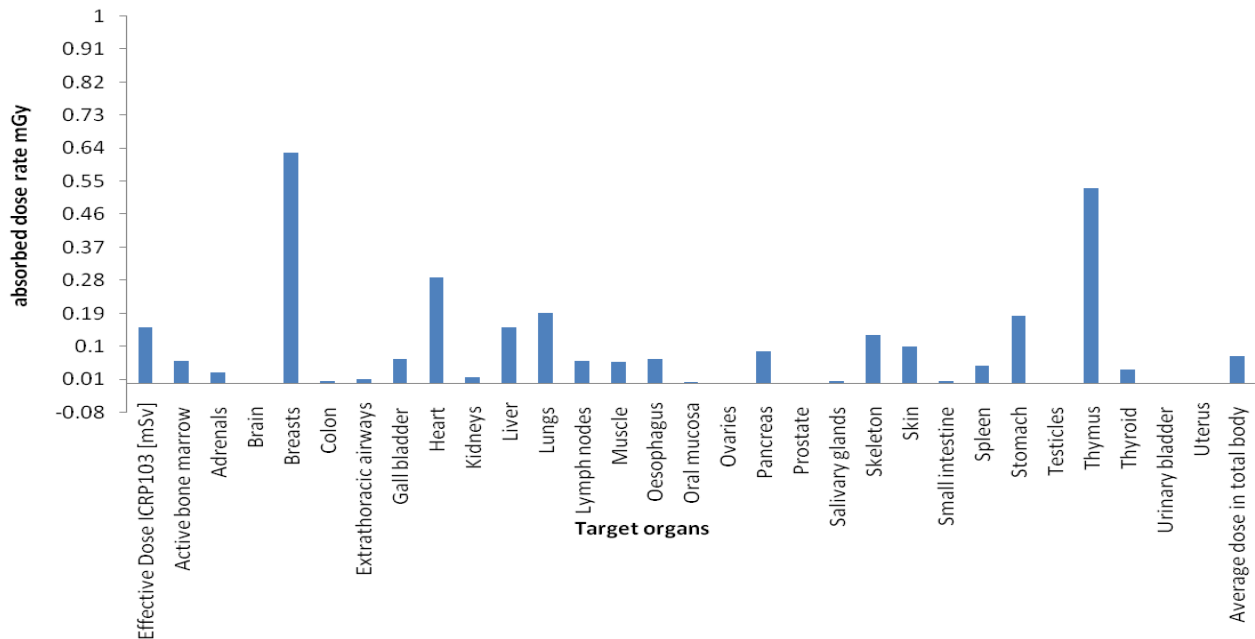
Figuer4.6.2: Average organs absorbed dose in adult Patients AP projection

Cancer risk increases in women who have the BRCA1 and BRCA2 genes. The BRCA proteins are engaged in DNA repair system from damage. These BRCA women carriers might be more sensitive to any ionizing radiation. So the moderate and low radiation exposures should be in minimized as possible.

4.6.3 Average organs adsorbed doses in pediatric patients PA projection

Pediatric patients above 4 years make the chest x-ray examinations in PA projections. Figure 4.6.3 summarieses the average organ absorbed doses in PA projection for pediatric patients. The highest average absorbed dose in PA pediatric is found in lungs then breast and adrenals.
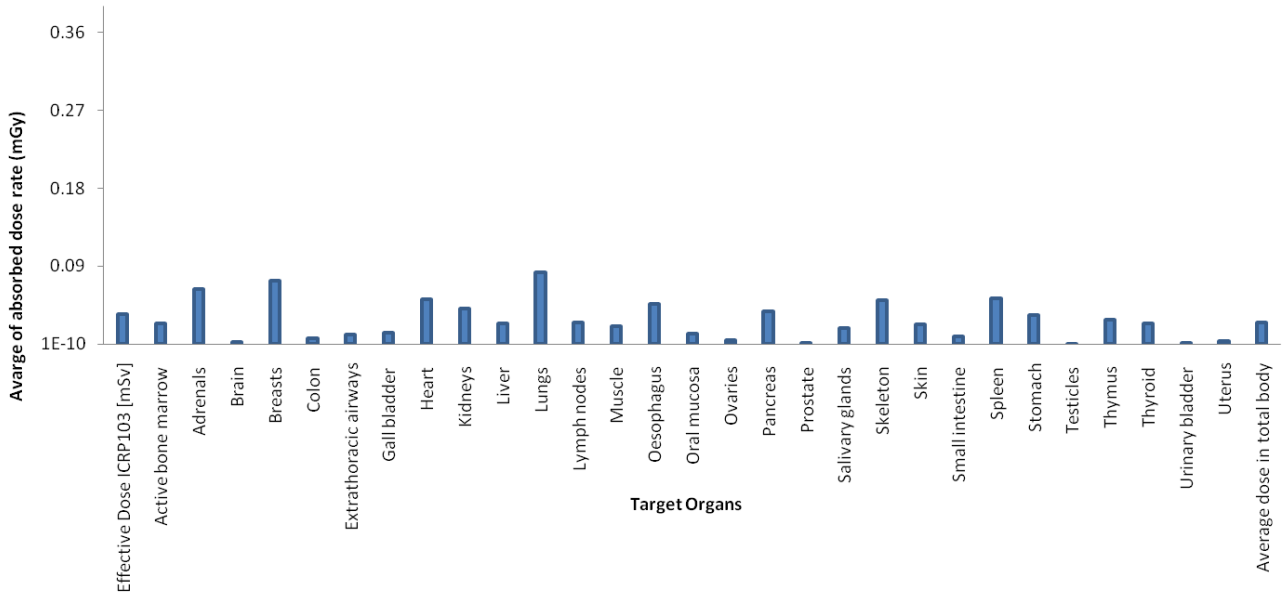
Figure: 4.6.3 Average adsorbed doses in pediatric patients PA projection

Avarege X-ray beam size in PA pedatric is about (23.28 X 22.46)cm. All the chest area is coverd to get the dignostic information. The breats have higher absorbed dose copmaring with spleen in this case which means that the X-ray beam length is short. Therefore, the collamtion should be only as needed to reduce the avarage organ absorbed doses.

4.6.4 Average organs absorbed doses in pediatric patients AP projection

AP projection is the routine chest X-ray examinations in pediatric patients who are below of 4 years old. It has been done by portable machines. Figure 4.6.4 summarieses the average organs absorbed doses in pediatric patients AP projection. The highest average

organs absorbed doses can be found in the breast. Then it is found in thyroid and thymus glands. The average X-ray beam size is about (14.46 X14.87) cm.
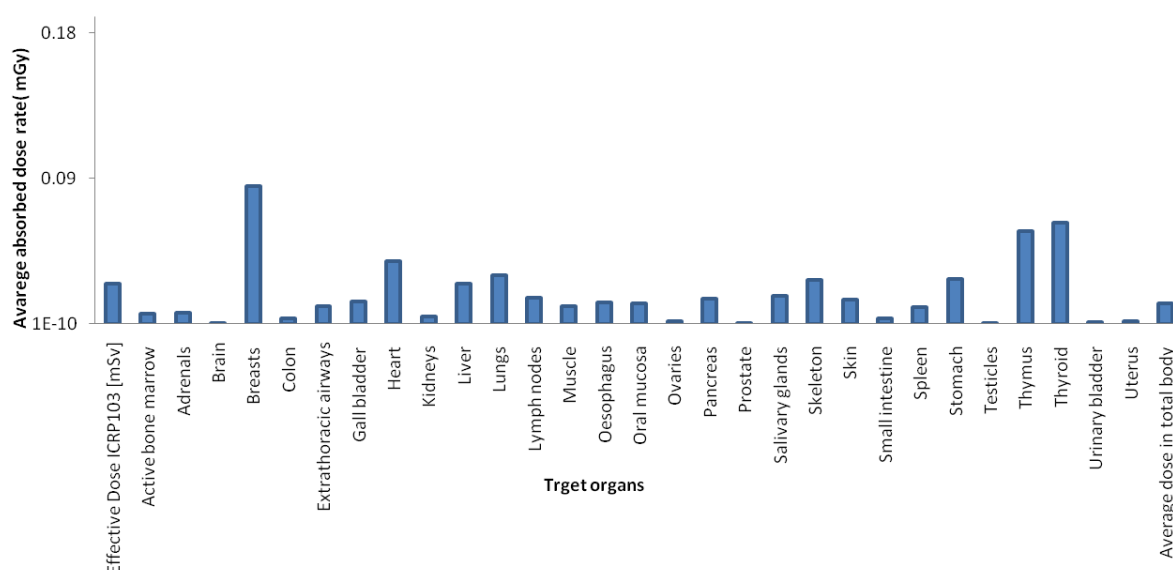
Figure 4.6.4: Average organs absorbed doses in pediatric patients AP projection

The organs which are located in the front side of the body have higher absorbed doses in AP projection (X-ray beams enters from anterior side to posterior side). The thyroid gland is located in front of the throat. It secretes hormones that control metabolism. The thyroid can absorb radiation through ingestion of radioactive material and by external exposure such as during chest X-ray examinations. It means that the developing thyroid (in children) is more susceptible to radiation. So the exposure dose should always be controlled and monitored. Thymus gland is considered to be the most active organ during the neonatal and pre-adolescent periods, and it is very sensitive to radiation.

4.7 Risk assessment calculations

Calculated organ absorbed doses can be used for risk assessment of medical radiation exposure which can induce cancer. The PCXMC software estimates the risk factors which are based on the combined absolute and relative risk models of Committee on the Biological Effects of Ionizing Radiations (BEIR VII) (Tapiovaara M, 2008). This has been

derived by both cancer incidence and second by cancer mortality. They take into consideration the cancer location, sex, and age at exposure and expected attained age. Nowadays, low dose rates and small doses are believed they lead to low a relatively lower cancer risk compared to high dose rates and large doses. This reduction in risk is calculated by the dose and dose rate reduction factor (DDREF) (Tapiovaara M, 2008).

Averages of age -dependent mortality are used for subsequent assessment of lifetime cancer risk, both PCXMC risk models are presented for leukemia and solid cancers in some body organs and for the all solid combined cancers (Tapiovaara M, 2008). The excess risk values are the basis of the lifetime risk estimation. The lifetime risks can be assessed with various quantities. The PCXMC software is using three different quantities to get the risk assessment (Tapiovaara M, 2008):

1- Risk of exposure-induced death (REID)

2- Loss of life expectancy (LLE)

3- Loss of life expectancy per radiation induced fatal cancer (LLE/REID).

"The loss of life expectancy (LLE) is the difference between the expectation of life for a person exposed at a certain age e and of an unexposed person who was alive at that age. LLE/REID describes the average length of life lost per excess cancer death" (Tapiovaara M, 2008). Risk assessment calculations in PCXMC are depending on the Euro-American, Asian mortality and cancer incidence data are from ICRP publication 103. Therefore, the risk calculations in this study used the Euro-American models which are the nearest model for the Middle East behavior especially in the Mediterranean countries. Tables (4.7.1, 4.7.2, 4.7.3, 4.7.4, and 4.7.5) summarize the risk assessment of different patients groups, for different chest X-ray projections. Risk assessments depend on the organs absorbed doses which were calculated in this study. Those patients groups were divided according to sex, age, and the X-ray projections.

Table 4.7.1: Risk Assessment of Age Patients Groups for Different Projections

Risk assessment age groups for different projections	Expected length of remaining life (years)	Risk of exposure-induced cancer death (REID)	Cancer mortality for other causes; not related to this exposure	Loss of life expectancy (LLE) (Hours)	The LLE/REID (years)	Sum of incident air kermas (mGy)	Sum of effective doses (mSv)	Highest REID cancer rates
Neonate Male patients in (AP) Projection	74	0.00%	22.20%	1	32.1	0.13	0.04	lung and other kinds of cancers
Neonate Female Patients in (AP) Projection	79.5	0.0006 %.	18.50%	1.6	28.7	0.06	0.03	Breast cancer
Male Patients Age (1-4) Years AP Projection	73.1	0.0002 %.	22.2 %.	0.6	36.8	0.08	0.02	Lung and other kinds of cancers
Female Patients Age (1-4) Years AP Projection	78.6	0.00%	18.5 %.	1.4	25	0.09	0.03	Breast cancer
Male Patients Age (5-9) years AP Projection	68.3	0.0003 %.	22.2 %.	0.6	24	0.25	0.05	Lung cancer
Female Patients Age (5-9) years AP Projection	73.7	0.0005 %.	18.5 %.	0.8	19.1	0.11	0.02	Breast cancer
Male Patients Age (5-9) years PA Projection	67.3	0.0003 %.	22.2 %.	0.6	24.3	0.13	0.02	Lung cancer
Female Patients Age (5-9) years PA Projection	74.7	0.0003 %.	18.5 %.	0.8	28.9	0.08	0.01	Lung cancer

Table 4.7.2: Risk Assessment of Age Patients Groups for Different Projections

Risk assessment age groups for different projections	Expected length of remaining life (years)	Risk of exposure-induced cancer death (REID)	Cancer mortality for other causes; not related to	Loss of life expectancy (LLE) (Hours)	The LLE/REID (years)	Sum of incident air kermas (mGy)	Sum of effective doses (mSv)	Highest REID cancer rates
Male Patients Age (10-14) years PA Projection	61.4	0.0001 %.	22.2 %.	0.2	23	0.11	0.013	lung cancer
Female Patients Age (10-14) years PA Projection	69.8	0.0003 %.	18.5 %.	0.8	29.7	0.08	0.02	lung cancer
Male Patients Age (15-19) years PA Projection	55.6	0.0001 %.	22.2 %.	0.3	22.9	0.11	0.02	lung and other kinds of cancers
Female Patients Age (15-19) years (PA) Projections	64.8	0.00%	18.5 %.	7.5	30.3	0.95	0.18	lung cancer
Male Patients Age (20-29) years PA Projections	52.8	0.0002 %.	22.2 %.	0.5	22.8	0.15	0.04	lung and leukemia and other kinds of cancers
Male Patients Age (20-29) years Lateral Projections	53.7	0.0003 %.	22.2 %.	0.5	22.1	0.32	0.07	lung cancer, leukemia and other kinds of cancers
Female patients Age (20-29) years PA Projections	54.1	0.0003 %.	18.5 %.	0.8	32.1	0.13	0.02	lung, other kinds of cancers and breast cancer

Table: 4.7.3 Risk Assessment of Age Patients Groups for Different Projections

Risk assessment age groups for different projections	Expected length of remaining life (years)	Risk of exposure-induced cancer death (REID)	Cancer mortality for other causes; not related to	Loss of life expectancy (LLE) (Hours)	The LLE/REID (years)	Sum of incident air kermas (mGy)	Sum of effective doses (mSv)	Highest REID cancer rates
Female Patients Age (20-29) years Lateral Projection	54.1	0.0007 %.	18.5 %.	1.8	31.7	0.43	0.07	lung cancer and breast cancer
Male Patients Age (30-39) years PA Projections	39.5	0.0002 %.	22.2 %.	0.5	21.9	0.2037	0.05	lung cancer, other kinds of cancers and leukemia
Male Patients Age (30-39) years Lateral Projection	41.4	0.0003 %.	22.2 %.	0.6	22	0.5875	0.09	lung cancr, other kinds of cancers and leukemia
Female patients Age (30-39) years PA Projection	47.2	0.0003 %.	18.5 %.	0.8	32.4	0.1513	0.03	lung cancer, other kinds of cancers and breast cancer
Female Patients Age (30-39) years Lateral Projection	47.2	0.0005 %.	18.5 %.	1.4	35.3	0.484	0.06	lung cancer and breast cancer
Male Patients Age (40-49) years PA Projection	33.1	0.00%	22.2 %.	0.4	20.8	0.22	0.05	lung cancer, other kind of cancers and leukemia

Table 4.7.4: Risk Assessment of Age Patients Groups for Different Projections

Risk assessment age groups for different projections	Expected length of remaining life (years)	Risk of exposure-induced cancer death (REID)	Cancer mortality for other causes; not related to	Loss of life expectancy (LLE) (Hours)	The LLE/REID (years)	Sum of incident air kermas (mGy)	Sum of effective doses (mSv)	Highest REID cancer rates
Male Patients Age (40-49) years Lateral Projection	32.2	0.00%	22.2 %.	0.9	20.3	0.92	0.16	lung, other kind of cancer, stomach cancer
Female Patients Age (40-49) years PA Projection	36.8	0.00%	18.5 %.	0.8	30.1	0.18	0.03	lung cancer and other kind of cancers
Female Patients Age(40-49) years Lateral Projection	35.8	0.00%	18.5 %.	1.6	33.6	0.58	0.08	lung cancer and other kind of cancers
Male Patients Age (50-59) years PA Projection	22.7	0.00%	22.2 %.	0.3	17.1	0.19	0.04	lung cancer, other kind of cancers and leukemia
Male Patients (50-59) years Lateral	21.9	0.00%	22.2 %.	0.6	16.4	0.71	0.13	lung cancer, other kind of cancers
Female Patients Age (50-59) years PA Projection	27.7	0.0003 %.	18.5 %.	0.6	24	0.19	0.04	lung cancer, other kind of cancers and leukemia
Female Patients Age (50-59) Lateral Projection	27.7	0.0009 %.	18.50%	2.2	27.3	1.26	0.18	lung cancer, breast cancer and other kind of cancers
Male Patients Age (60-69)years PA Projection	16.6	0.0004 %.	22.2 %.	0.4	12.8	0.39	0.08	lung cancer, leukemia and other kind of cancers

Table 4.7.5: Risk Assessment of Age Patients Groups for Different Projections

Risk assessment age groups for different projections	Expected length of remaining life (years)	Risk of exposure-induced cancer death (REID)	Cancer mortality for other causes; not related to this exposure	Loss of life expectancy (LLE) (Hours)	The LLE/REID (years)	Sum of incident air kermas (mGy)	Sum of effective doses (mSv)	Highest REID cancer rates
Male Patients Age (60-69) years Lateral Projection	15.9	0.00%	22.2 %.	0.6	11.9	1.27	0.22	lung cancer, leukemia and stomach cancer
Female Patients Age (60-69) years PA Projection	18.6	0.0002 %.	18.5 %.	0.3	15	0.17	0.03	lung cancer and other kinds of cancers
Female Patients Age (60-69) years Lateral Projection	20.1	0.0005 %.	18.5 %.	0.8	19.6	0.79	0.1	lung cancer, breast cancer and other kinds of cancers
Male Patients Age (70-79) years PA Projection	9.9	0.00%	22.2 %.	0.1	6.8	0.2	0.05	lung and leukemia
Male Patients Age (70-79) years Lateral Projection	9.9	0.0004 %.	22.2 %.	0.2	6.5	0.83	0.16	lung cancer, leukemia and other kinds of cancers
Female Patients Age (70- 79) years PA Projection	12.3	0.0002 %.	18.5 %.	0.1	7.7	0.19	0.04	lung cancer, leukemia and other kinds of cancers

Table 4.7.6: Risk Assessment of Age Patients Groups for Different Projections

Risk assessment age groups for different projections	Expected length of remaining life (years)	Risk of exposure-induced cancer death (REID)	Cancer mortality for other causes; not related to	Loss of life expectancy (LLE) (Hours)	The LLE/REID (years)	Sum of incident air kermas (mGy)	Sum of effective doses (mSv)	Highest REID cancer rates
Female Patients Age (70-79) years Lateral Projection	12.3	0.00%	18.5 %.	0.5	9.4	1.21	0.17	lung cancer, other kinds of cancers, stomach and leukemia
Male Patients Age (80-89) years PA Projection	5.6	0.00%	22.20%	0	3.1	0.21	0.05	lung cancer, leukemia
Male Patients Age (80-89) years Lateral Projection	7.3	0.0003 %.	22.2 %.	0.1	4.2	0.74	0.15	of lung cancer, leukemia and other kinds of
Female Patients Age (80-89) years PA Projection	7.4	0.0002 %.	18.5 %.	0.1	3.5	0.22	0.04	lung cancer, leukemia and other kinds of cancers
Female Patients Age (80- 89)Years Lateral Projection	6.7	0.0003 %.	18.5 %.	0.1	3.8	0.87	0.13	lung cancer, stomach cancer, leukemia

4.8. Risk assessment comparison between different patients groups for different chest X-ray projections

4.8.1 Risk assessment pediatric patients groups (Neonate -14) Y for different Chest X-ray projections (Male and Female)

The first group in the risk assessment is pediatric patients (male and female) for different chest X-ray projections. Figure 4.8.1 summarizes the risk assessment of some cancer types to the pediatric groups for different chest X-ray projections.
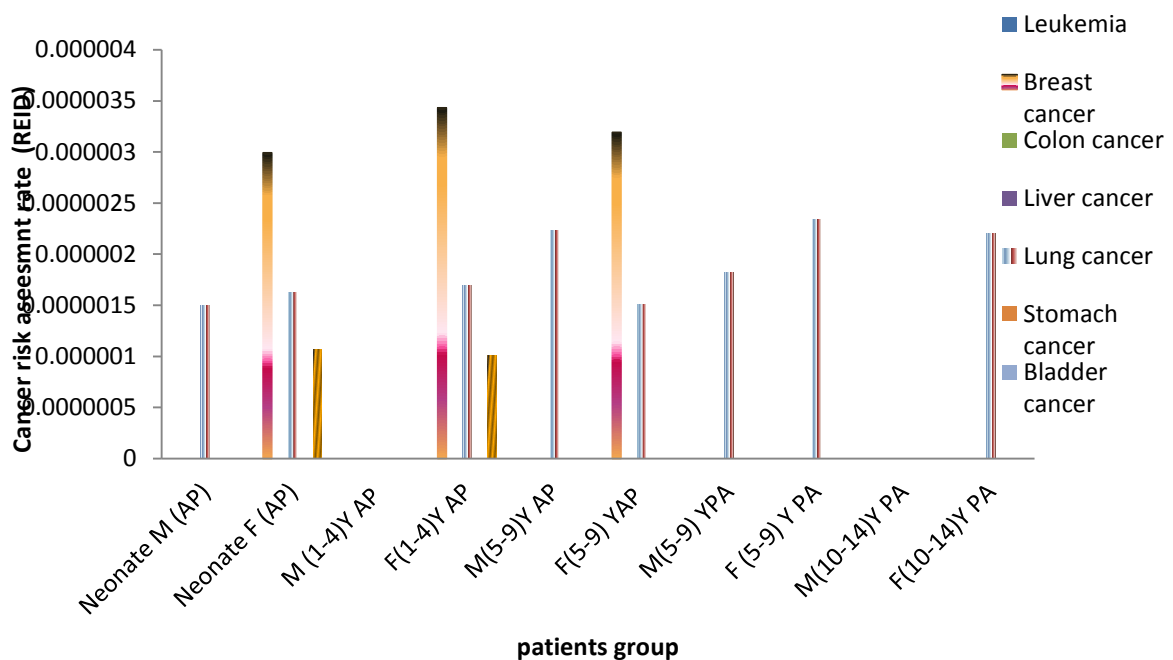
Figure 4.8.1: Risk assessment of some cancer types to the pediatric groups (male and female) for different chest X-ray projections

The figure 4.8.1 shows high average rates in lung cancer in all pediatric groups (projections, age and sex). So the lung has a high absorbed dose in all chest X-ray examinations and projections. Female patient's age groups neonate, (1-4) years and (5-9) years have also a high rate in breast cancer. Female patients age group neonate and (1-4) years have a high rate of other cancers. So that the exposure factors should be decrease as possible, which results in a decrease in these cancer risks especially for pediatric patients.

4.8.2 Risk assessment adult patients age groups (15-59) Y for different chest X-ray projections (male and female)

This group includes the patients age (15-59) years female and males in different chest X-ray projections. Figure 4.8.2 summarizes risk assessment adult patients age groups (15-59) Y for different chest X-ray projections (Male and Female).
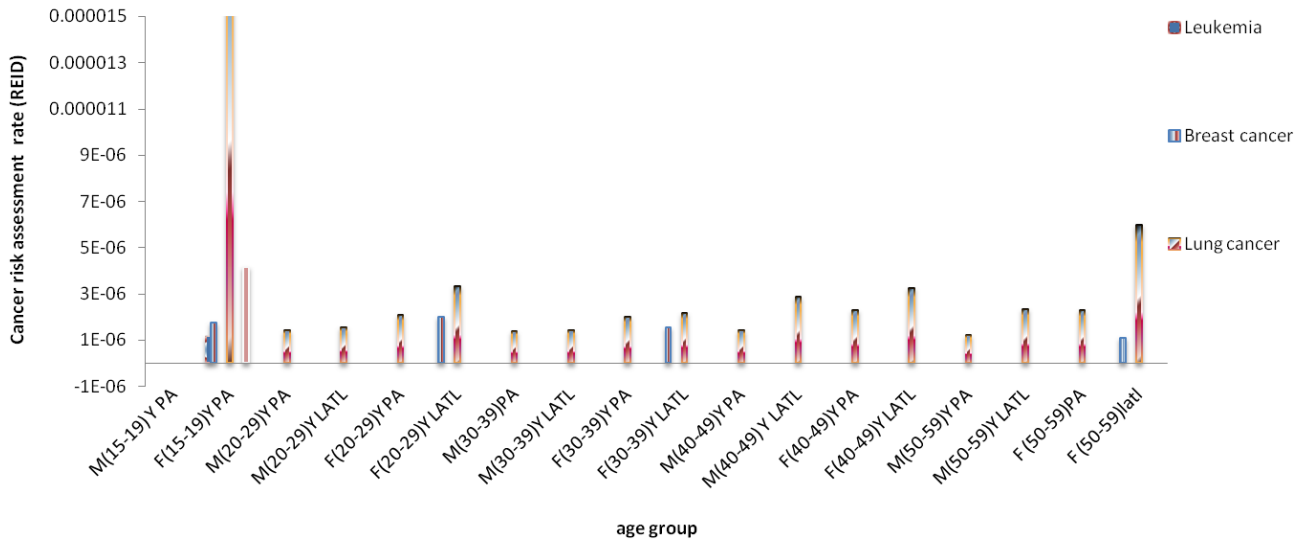
Figure 4.8.2: Risk Assessment Adult Patients age groups (15-59) Y for different chest X-ray projections (Male and Female)

Lung cancer has the highest rate in all groups. High rates of breast and other cancers are more possible in female group (15-19) years. Female ages (20-29) years, (30-39) years and (50-59) years have high rates in breast cancer.

Age (20-39) years for females in Palestinian society is crucial because that is the part of time in their lives when they get married and pregnant. So, the exposure factors should be minimized as much as possible and the number of repeated pictures lowered as possible.

4.8.3 Risk assessment adult patients age group (60-89) Y for different chest X-ray projections (Male and Female)

This group includes patients between ages (60-89) years males and females. Older females have lower probability to have certain types of cancer such as breast and ovaries cancer. Figure 4.8.3 shows risk assessment for adult patients age groups (60-89) years for different chest X-ray projections (Male and Female).

Figure 4.8.3 shows high rates of lung cancers for all groups. The highest rate is found in age (70-79) years female lateral projection. More possible risk rate is found in the lateral chest X-ray projection than PA projection, which results from high exposure factors which are used in lateral projections.
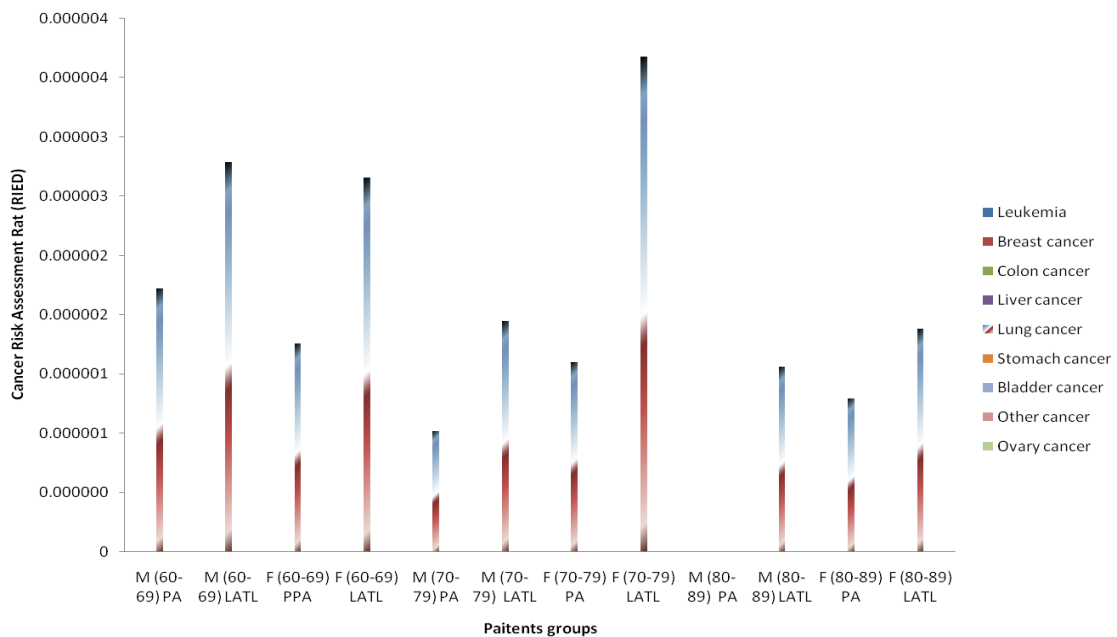
Figure 4.8.3: Risk Assessment Adult Patients Age group (60-89) Y for different Chest X-ray Projections (Male and Female)

The highest risk rate of those three groups (pediatric and adult) for different chest X-ray projections was found in female group (15-19) years PA chest X-ray projection. This has a high rate of lung cancer. The highest rate in breast cancer risk of the three groups was found in female age (1-4) years AP chest X-ray projections. The result of AP projection showed an increase in the absorbed dose of breast tissue. Moreover in all female pediatric

patients AP projections have a high rate of breast cancer. Then it was found in lateral and PA projections respectively.

Lung cancer smoking risk assessment gives about 70% while the chest X-ray examinations risk assessment is too low. Smoking gives about 5% of urban air pollution (Goodarz Danaei, 2005).

4.9 Conclusion and Recommendations

The results obtained in this study for average effective dose from the 668 patients are: ~ 0.11mSv in all chest X-ray examinations and projections for four hospitals. The average effective dose in AP adult, PA adult, lateral adult, AP pediatric and PA pediatric were 0.14, 0.07, 0.33, 0.09 and 0.06 mSv respectively.

Compared to the DRLs around the world, results are in the range of typical effective doses in some countries. However, it is too high compared in other places. The population dose (S) is: ~ 72.67 mSv for 668 patients in the West Bank- Palestine. The annual average dose is: ~ 2.08×10^{-5}mSv annually per capita. The uncertainty in effective dose estimation by PCXMC software is about 40%. The average effective dose error is about 4.96% in this study.

The geometric input data is different from one site to another in this study. A mistake in the procedure parameters directly influences the effective dose. Such as, the short FID has given a high effective dose in lateral projection at hospital two. The mAs value and the FSD are the strongest exposure factors to make a real change in effective dose. The chest X-ray risk assessment found has little important lung cancer in some age groups and sex. Moreover, the other risk factors of lung cancer such as smoking and high radon dose should be considered. Therefore, the exposure factors should be minimally as much as possible. The medical X-ray examinations should be done only by doctor order for specific reasons and as patients needs.

Chest radiography is just one examination from many other conventional X-ray examinations. Our study is a result obtained from medical centers and hospitals in the West Bank. Furthermore, other kinds of conventional X-ray examinations have other factors should be studied in future as soon as possible. A continuation with the same aims of this

study is quite important on other X-ray procedures and examinations, such as CT scan and interventional examinations (fluoroscopy examinations). The DRLs should be applied in Palestine, make it as a standardized reference dose range for all X-ray examinations and projections. It means that medical X-ray researches and the effective dose estimation studies should be supported from the interested people.

For the chest X-ray examinations high kVp and low mAs gives a low average effective dose. A 100 KVp is a perfect starting as a standard of chest X-ray exposure. In addition, a low mAs between (1-4), especially in PA projections for adult is a good choice. While medium kVp with high mAs gives a high average effective dose such as usage of (60kV with 10 mAs). This kind of exposure should be monitored.

The final result has defined the solution for high average effective dose found in some places, by standardization of exposure parameters across all hospitals and medical centers in the West bank.

Educational information should be given to radiographers and universities students to increase the awareness and knowledge of effective dose, risk assessment, radiation protection, getting useful exposure parameters. Radiologists should be included in order to get the aims of radiation quality control. Cal-Dose_X5.0 software is recommended Monte Carlo software, which is easy to download and has been designed for an easy used of the medical radiology staff in their places. It helps to know more about patient doses.

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Appendix (A)

a. Sample of Input Data Effective dose calculations

Hospital	Examination	Projection (AP,PA,LATL, LATR or num.angle)	Oblique angle	Patient number	Patient height (cm), (reference size=0)	Patient weight (kg), (reference size=0))	Patient age (0,1,5,10, 15,30)	X-ray tube voltage (kV)	Filtration (mm Al)	Additional filter (mm Cu)	FSD (cm)	X-ray beam width (cm, at FSD)
A	Skull	AP	0	114	0	0	30	70	4	0	83	15
Al M akasse	Chest	LATL	0	133	162	74	30	129	2.5	0	144.74	28.14
Al M akasse	Chest	PA	0	134	165	65	30	113	2.5	0	155.39	30.22
Al M akasse	Chest	LATL	0	135	165	65	30	125	2.5	0	146.26	28.44
Al M akasse	Chest	PA	0	136	165	65	30	117	2.5	0	155.39	30.22
Al M akasse	Chest	LATL	0	137	165	65	30	121	2.5	0	147.54	28.69
Al M akasse	Chest	PA	0	138	170	79	30	121	2.5	0	153.72	36.72
Al M akasse	Chest	PA	0	139	157	82	30	120	2.5	0	152.42	29.64
Al M akasse	Chest	LATL	0	140	157	82	30	127	2.5	0	141.37	27.49
Al M akasse	Chest	PA	0	141	174	63	30	121	2.5	0	156.22	37.32
Al M akasse	Chest	LATL	0	142	174	63	30	125	2.5	0	147.43	35.22
Al M akasse	Chest	PA	0	143	155	95	30	121	2.5	0	150.56	29.27
Al M akasse	Chest	LATL	0	144	155	95	30	121	2.5	0	138.59	26.95
Al M akasse	Chest	PA	0	145	158	60	30	117	2.5	0	155.75	30.28
Al M akasse	Chest	PA	0	146	166	72	30	105	2.5	0	154.48	36.9
Al M akasse	Chest	LATL	0	147	166	72	30	125	2.5	0	145.96	34.87
Al M akasse	Chest	PA	0	148	184	97	30	121	2.5	0	152.34	36.39
Al M akasse	Chest	LATL	0	149	184	97	30	133	2.5	0	142.99	34.16
Al M akasse	Chest	LATL	0	150	180	80	30	133	2.5	0	144.09	34.42
Al M akasse	Chest	PA	0	151	180	80	30	121	2.5	0	154.23	36.84
Al M akasse	Chest	PA	0	152	162	70	30	117	2.5	0	154.47	30.04
Al M akasse	Chest	LATL	0	153	162	70	30	125	2.5	0	144.53	28.1

X-ray beam height (cm, at FSD)	Xref	Yref	Zref	Arms in phantom (1 or 0)	Input dose quantity (EAK,EE,DAP, EAP or MAS)	Input dose value	ACTUAL AGE	SEX	mAs
20	0	0	89	1	EAK	3.2			
37.32	-0.9034	-8.5881	49.3853	1	EAK	0.13	0.18-42	M	1.4
35.22	-0.9034	-8.5881	49.3853	0	EAK	0.55	0.82-42	M	5
29.27	0.8048	-11.4221	45.0657	1	EAK	0.19	0.27-61	F	2.2
26.95	23.6106	-0.7568	46.1387	0	EAK	0.98	1.47-61	F	10
30.28	0.2735	-8.8247	43.2035	1	EAK	0.11	0.16-23	F	1.4
36.9	1.4364	-9.4621	47.1147	1	EAK	0.15	0.23-59	M	2.2
34.87	-1.6618	-10.2782	46.5402	0	EAK	0.55	0.82-59	M	5
36.39	0.9553	-10.5312	52.2236	1	EAK	0.25	0.37-42	M	2.8
34.16	-1.1184	-11.3402	51.5867	0	EAK	1.11	1.66-42	M	9
34.42	1.5576	-9.5843	51.7113	0	EAK	0.87	1.31-55	M	7.1
36.84	1.5576	-9.5843	51.7113	1	EAK	0.22	0.33-55	M	2.5
30.04	0.2804	-9.4668	46.5402	1	EAK	0.11	0.16-29	F	1.4
28.1	0.2804	-9.4668	46.5402	0	EAK	0.47	0.7-29	F	4.5
36.58	0.8463	-10.1348	46.2633	1	EAK	0.18	0.26-53	M	2.2
34.15	0.8463	-10.1348	46.2633	0	EAK	0.55	0.82-53	M	5
37.32	-0.3115	-8.5852	50.4652	1	EAK	0.18	0.26-22	M	2.2
35.37	-0.3115	-8.5852	50.4652	0	EAK	0.52	0.77-22	M	5
36.45	0.3029	-10.4008	49.6691	1	EAK	0.22	0.33-66	M	2.5
29.62	-0.2665	-10.5276	43.1758	1	EAK	0.18	0.25-53	F	2.2
27.98	-1.0665	-11.3276	45.308	0	EAK	0.52	0.77-53	F	5
37.05	0.8307	-9.1473	45.4118	1	EAK	0.2	0.29-68	M	2.2

Figure 1: Sample of input data for effective dose calculations

b. Sample of Results of Effective dose calculations

Effective Dose ICRP103 [mSv]	Effective Dose ICRP103 Error [%]	Effective Dose ICRP60 [mSv]	Effective Dose ICRP60 Error [%]		Active bone marrow (mGy)	ABM error (%)		Adrenals (mGy)	Adrenals error (%)		Brain (mGy)	Brain error (%)	Breasts (mGy)
0.054121	1	0.03526	1.1		0.089843	0.4		0 NA			0.606891	0.6	0.00148
0.051912	0.7	0.049193	0.8		0.06348	0.4		0.155305	4.5		0.001123	7.8	0.034413
0.156865	1	0.134587	1.1		0.093628	0.7		0.110384	11.3		0.003063	10.4	0.366578
0.048028	0.6	0.047737	0.7		0.06239	0.4		0.225363	4		0.001497	7.2	0.029486
0.167249	0.8	0.11708	0.8		0.070005	0.6		0.050062	15.5		0.002232	9	0.647277
0.053146	0.6	0.050603	0.7		0.068631	0.4		0.189937	4.1		0.000713	8.2	0.03652
0.133143	0.9	0.109328	0.9		0.068424	0.6		0.072021	12.1		0.001067	11.9	0.370886
0.048288	0.6	0.046009	0.8		0.061567	0.4		0.160031	5.4		0.001285	7.5	0.030477
0.030032	0.6	0.029275	0.8		0.037485	0.4		0.133722	4		0.000667	7.7	0.018595
0.038069	0.6	0.036652	0.8		0.045975	0.4		0.13366	4.9		0.000871	6.3	0.028259
0.030904	0.6	0.029772	0.8		0.037439	0.4		0.108625	5		0.000692	6.4	0.02271
0.110857	0.9	0.091548	0.9		0.054603	0.6		0.069365	11.6		0.001191	12.2	0.299445
0.02924	0.6	0.027836	0.7		0.034696	0.5		0.105539	4.4		0.000397	9.4	0.020972
0.042005	0.6	0.039931	0.8		0.052597	0.4		0.139971	5.6		0.000768	10	0.028944
0.136487	1	0.114683	1		0.084377	0.5		0.080136	10.1		0.001255	12.6	0.349203
0.035442	0.6	0.033788	0.7		0.042403	0.4		0.127574	4.7		0.000451	8.3	0.026047
0.039788	0.6	0.03797	0.8		0.045672	0.4		0.158848	4.8		0.000481	7.8	0.030139
0.031755	0.5	0.030365	0.7		0.038189	0.4		0.11502	4.2		0.000545	9.8	0.022128
0.035764	0.5	0.034483	0.7		0.043824	0.4		0.147251	4		0.000628	7.7	0.021971
0.040185	0.5	0.03819	0.7		0.046454	0.5		0.160158	4.3		0.000508	8.7	0.027891
0.025109	0.7	0.024098	1		0.03205	0.4		0.087233	6.7		0.000425	9.8	0.017268
0.039948	0.6	0.03883	0.7		0.049049	0.4		0.172419	4.1		0.000932	7	0.027394

Extrathoracic airways (mGy)	ET airways error (%)	Gall bladder (mGy)	Gall bladder error (%)	Heart (mGy)	Heart error (%)	Kidneys (mGy)	Kidneys error (%)	Liver (mGy)	Liver error (%)	Lungs (mGy)	Lungs Error (%)	Lymph nodes (mGy)	Lymph nodes error (%)	Muscle (mGy)	Muscle error (%)	Oesophagus (mGy)	Oesophagus error (%)	Oral mucosa (mGy)	Oral mucosa error (%)	Ovari (mG
0.498754	4.5	0 NA		0.000514	28.4	0.000002	93.6	0.000144	33.4	0.003211	8.4	0.148836	2.4	0.029028	0.5	0.000987	47.1	1.422769	2.2	
0.001854	19.3	0.007012	7.6	0.034274	1.4	0.015495	2.8	0.029804	1.1	0.085351	0.7	0.017423	1.2	0.014081	0.2	0.044733	2.8	0.000581	22.8	0.00
0.00408	23.9	0.035733	5.5	0.054603	2.2	0.152485	1.8	0.075199	0.8	0.126303	0.9	0.035474	1.3	0.031326	0.2	0.072602	4.2	0.00152	24.8	0.000
0.004123	16.1	0.023514	5.6	0.054559	1.9	0.101721	1.5	0.057384	1.1	0.139005	0.7	0.033224	1.3	0.026592	0.2	0.074722	3.9	0.0018	20.4	0.001
0.012719	16.6	0.014881	11.6	0.17343	2	0.032591	4.1	0.021088	2.6	0.214361	0.8	0.06406	1.6	0.055055	0.3	0.123494	4.6	0.005335	17.1	0.001
0.017855	16.2	0.020886	11.1	0.239631	2	0.045191	4	0.029492	2.5	0.293457	0.7	0.088319	1.5	0.075253	0.3	0.171334	4.5	0.00746	16.6	0.002
0.006785	15.8	0.038886	5.4	0.089565	1.9	0.164304	1.5	0.093492	1.1	0.224971	0.7	0.054283	1.2	0.04309	0.2	0.122673	3.8	0.00301	19.8	0.002
0.00219	17.9	0.009973	5.6	0.0319	1.7	0.034939	2	0.032289	0.9	0.077148	0.7	0.017953	1.1	0.014963	0.2	0.043006	3.4	0.000922	20	0.000
0.005232	14.4	0.008329	8	0.039069	1.9	0.016426	2.7	0.0319	1	0.100098	0.8	0.020848	1.3	0.018335	0.2	0.053374	4	0.001636	18	0.000
0.005232	14.4	0.008329	8	0.039069	1.9	0.016426	2.7	0.0319	1	0.100098	0.8	0.020848	1.3	0.018335	0.2	0.053374	4	0.001636	18	0.000
0.005886	14.4	0.00937	8	0.043952	1.9	0.01848	2.7	0.035887	1	0.11261	0.8	0.023454	1.3	0.020627	0.2	0.060046	4	0.00184	18	0.000
0.003352	19.7	0.007403	8.6	0.040128	1.8	0.015363	2.8	0.035584	1.2	0.092328	0.7	0.019469	1.3	0.018401	0.3	0.050997	3.7	0.001209	20.7	0.000
0.009045	23.8	0.010913	12	0.130534	2	0.017217	4.7	0.019138	2.4	0.142652	1	0.043927	1.6	0.035318	0.3	0.096944	4.7	0.002267	26	0.000
0.002345	20.3	0.005089	9.2	0.028423	1.9	0.011162	2.9	0.025635	1.3	0.067508	0.7	0.013929	1.4	0.013423	0.3	0.036034	3.9	0.00083	22.1	0.000
0.002918	16.9	0.015273	4.8	0.031911	2.5	0.073778	1.4	0.032593	1	0.084885	0.7	0.020488	1.2	0.016283	0.2	0.044385	3.6	0.0011	16.7	0.001
0.003691	16.4	0.026592	4.9	0.038458	2	0.123078	1.5	0.056154	0.9	0.103418	0.8	0.027875	1.3	0.025297	0.2	0.056896	3.7	0.002188	14.2	0.002
0.00253	22.2	0.014429	5.1	0.029832	1.8	0.061945	1.9	0.034132	0.9	0.076077	0.7	0.018947	1.2	0.015241	0.2	0.042285	3.6	0.001054	17.9	0.000
0.006417	14.4	0.028522	5.7	0.052942	2.1	0.127002	1.3	0.067802	1.2	0.137605	0.8	0.035541	1.3	0.032215	0.3	0.074817	3.7	0.003388	16.6	0.002
0.003249	16.7	0.017116	6.1	0.030295	2.1	0.07413	1.5	0.031424	1	0.08123	0.8	0.019746	1.2	0.015733	0.2	0.043018	3	0.001412	14.9	0.00
0.003227	16.8	0.015588	6	0.033942	2.5	0.068194	1.6	0.038318	1.2	0.089086	0.8	0.021661	1.4	0.017764	0.2	0.047106	3.7	0.001377	26.5	0.000
0.006523	23.9	0.014406	9.7	0.11251	2.1	0.027845	3.3	0.013779	2.6	0.133181	0.9	0.041788	1.5	0.034774	0.3	0.084865	4.8	0.003095	21.4	0.002
0.001759	20.4	0.014745	6.3	0.039778	2	0.066327	1.8	0.039803	1	0.105037	0.6	0.023522	1.1	0.017994	0.2	0.050521	3.6	0.001091	22.9	0.000

																			Average dose in total body	Average dose	Absorbed energ fracti
Skin (mGy)	Skin error (%)	Small intestine (mGy)	Small intestine error (%)	Spleen (mGy)	Spleen error	Stomach (mGy)	Stomach error (%)	Testicles (mGy)	Testicles error (%)	Thymus (mGy)	Thymus error (%)	Thyroid (mGy)	Thyroid error (%)	Urinary bladder (mGy)	Urinary bladder error (%)	Uterus (mGy)	Uterus error (%)		(mGy)	dose error (%)	(%)
0.143163	0.9	0 NA		0.000103	100	0.000196	97.9	0 NA		0.004153	91.7	0.043796	16.7	0 NA		0 NA			0.09594	0.2	55.4
0.013222	0.7	0.001142	5.1	0.052582	2.7	0.0149	3.4	0.000003	100	0.01728	9.2	0.004003	14	0.000124	52.7	0.000195	25.7		0.018779	0.1	64.57
0.033907	0.9	0.007618	3.4	0.130854	2	0.04553	2.9	0.000004	100	0.029574	10	0.010005	17.4	0.000485	32.3	0.001655	18.9		0.042834	0.1	59.71
0.024827	0.7	0.00523	3.1	0.135657	2	0.034654	3.2	0.000019	93.4	0.02759	7.8	0.009985	13.4	0.000261	32.1	0.001387	18.8		0.03505	0.1	65.88
0.072244	0.8	0.005602	5	0.282016	2.3	0.149326	2.6	0.000018	100	0.10299	7.6	0.02817	14.3	0.000351	45.8	0.001136	27.1		0.0643	0.2	43.40
0.097496	0.8	0.007829	4.9	0.385991	2.3	0.205047	2.6	0.000026	100	0.142681	7.4	0.039167	14	0.000504	43.7	0.001599	26.4		0.087676	0.2	43.08
0.039681	0.7	0.008655	3	0.219836	2	0.056957	3.1	0.000034	87.2	0.045289	7.7	0.016506	13.2	0.000459	30.7	0.000923	18.3		0.056619	0.1	65.35
0.013758	0.7	0.001823	3.9	0.067529	2.1	0.01715	2.6	0 NA		0.015113	10	0.006699	15.1	0.000064	43.6	0.000689	27.3		0.019908	0.1	63.02
0.018416	0.8	0.001493	5.7	0.05604	2.3	0.015543	3.2	0 NA		0.018636	13	0.010853	10.7	0.00003	46	0.000437	28.2		0.023941	0.1	63.28
0.018416	0.8	0.001493	5.7	0.05604	2.3	0.015543	3.2	0 NA		0.018636	13	0.010853	10.7	0.00003	46	0.000437	28.2		0.023941	0.1	63.28
0.020718	0.8	0.00168	5.7	0.063045	2.3	0.017486	3.2	0 NA		0.020966	13	0.012209	10.7	0.000034	46	0.000492	28.2		0.026933	0.1	63.28
0.018193	0.8	0.001005	6.2	0.05356	3	0.016856	3	0 NA		0.023559	7.9	0.009706	12.2	0.000001	100	0.000344	50.5		0.024706	0.2	59.37
0.039923	1	0.002473	6.5	0.157418	2.8	0.090392	2.9	0 NA		0.074513	9.7	0.014016	15.9	0.000015	98.6	0.000382	44.9		0.03957	0.3	33.46
0.013669	0.9	0.000683	6.6	0.039048	3.2	0.011819	3.2	0 NA		0.01637	8.3	0.006804	13.1	0 NA		0.000247	53.6		0.018157	0.2	60.95
0.016003	0.6	0.003567	4.1	0.082973	1.8	0.020701	3.1	0.000092	92.7	0.013277	9.8	0.006961	16.9	0.000279	28.1	0.001052	15.6		0.02149	0.1	67.29
0.02651	0.8	0.006354	2.8	0.108556	2.3	0.03144	3	0.000024	100	0.015581	10.5	0.012366	13.7	0.000495	32.1	0.001452	21.2		0.03296	0.1	63.26
0.014001	0.9	0.003302	3.2	0.073719	2	0.021309	2.6	0.000045	87.8	0.015044	8.3	0.007871	11.5	0.000165	32.6	0.000748	16.5		0.02207	0.1	64.08
0.034668	0.6	0.005494	3.8	0.139113	2.4	0.037807	2.7	0.000006	100	0.024779	8.5	0.014004	12.4	0.000455	28.3	0.001211	15.7		0.042344	0.1	63.30
0.015281	0.7	0.003812	3	0.077613	1.6	0.020387	3.1	0.000066	98.3	0.01214	9.6	0.007293	9.5	0.000366	22.1	0.000891	16.5		0.020639	0.1	67.08
0.017198	0.9	0.003408	3.5	0.087223	2.5	0.023483	2.7	0.000033	71.7	0.015802	10.3	0.006132	12.1	0.000364	39.6	0.001174	24.5		0.023713	0.1	65.46
0.04484	0.9	0.003974	5.5	0.200124	2	0.110255	2.7	0 NA		0.061284	8.6	0.018584	13.1	0.000374	31.8	0.001098	27.5		0.040865	0.3	39.98
0.017289	0.8	0.002843	3.4	0.093625	2.3	0.023576	3.1	0.000016	100	0.015565	9.3	0.004556	15.7	0.000223	37.3	0.000545	21.8		0.02397	0.1	66.88

Figure2:Sample of Effective dose calcations results

c. Sample of Calculated Data

Name	Date modified	Type	Size
70-79 M LAT	2/19/2015 10:36 PM	Text Document	6 KB
70-79 M PA	2/19/2015 10:30 PM	Text Document	6 KB
60-69 F LAT	2/19/2015 10:01 PM	Text Document	6 KB
60-69 F PA	2/19/2015 9:58 PM	Text Document	6 KB
60-69 M LAT	2/19/2015 9:57 PM	Text Document	6 KB
60-69 M PA	2/19/2015 9:55 PM	Text Document	6 KB
50-59 F LATL	2/19/2015 8:17 PM	Text Document	6 KB
50-59 F PA	2/19/2015 8:14 PM	Text Document	6 KB
50-59 M LAT	2/19/2015 8:12 PM	Text Document	6 KB
50-59 M PA	2/19/2015 8:10 PM	Text Document	6 KB
40-49 F LAT	2/19/2015 7:31 PM	Text Document	6 KB
40-49 F PA	2/19/2015 7:28 PM	Text Document	6 KB
40-49 M LAT	2/19/2015 7:25 PM	Text Document	6 KB
40-49 M PA	2/19/2015 7:22 PM	Text Document	6 KB
30-39 F LATL	2/19/2015 6:21 PM	Text Document	6 KB
30-39 PA F	2/19/2015 6:19 PM	Text Document	6 KB
30-39 M LATL	2/19/2015 6:15 PM	Text Document	6 KB
PA 30-39 M	2/19/2015 6:13 PM	Text Document	6 KB
20-29 F LAT	2/19/2015 5:42 PM	Text Document	6 KB
20-29 F PA	2/19/2015 5:39 PM	Text Document	6 KB
20-29 M LATL	2/19/2015 5:36 PM	Text Document	6 KB

Name	Date modified	Type	Size
Chest _AP_A_225_mydata.df2	2/10/2015 11:25 PM	DF2 File	2 KB
Chest _AP_A_225_mydata.en2	2/10/2015 11:25 PM	EN2 File	19 KB
Chest _AP_A_225_mydata.mG2	2/10/2015 11:25 PM	MG2 File	5 KB
Chest _AP_A_226_mydata.df2	2/10/2015 11:25 PM	DF2 File	2 KB
Chest _AP_A_226_mydata.en2	2/10/2015 11:26 PM	EN2 File	19 KB
Chest _AP_A_226_mydata.mG2	2/10/2015 11:26 PM	MG2 File	5 KB
Chest _AP_A_227_mydata.df2	2/10/2015 11:26 PM	DF2 File	2 KB
Chest _AP_A_227_mydata.en2	2/10/2015 11:26 PM	EN2 File	19 KB
Chest _AP_A_227_mydata.mG2	2/10/2015 11:26 PM	MG2 File	5 KB
Chest _AP_A_228_mydata.df2	2/10/2015 11:26 PM	DF2 File	2 KB
Chest _AP_A_228_mydata.en2	2/10/2015 11:26 PM	EN2 File	19 KB
Chest _AP_A_228_mydata.mG2	2/10/2015 11:26 PM	MG2 File	5 KB
Chest _AP_A_229_mydata.df2	2/10/2015 11:26 PM	DF2 File	2 KB
Chest _AP_A_229_mydata.en2	2/10/2015 11:26 PM	EN2 File	19 KB
Chest _AP_A_229_mydata.mG2	2/10/2015 11:26 PM	MG2 File	5 KB
Chest _AP_A_230_mydata.df2	2/10/2015 11:26 PM	DF2 File	2 KB
Chest _AP_A_230_mydata.en2	2/10/2015 11:26 PM	EN2 File	19 KB
Chest _AP_A_230_mydata.mG2	2/10/2015 11:26 PM	MG2 File	5 KB
Chest _AP_A_231_mydata.df2	2/10/2015 11:55 PM	DF2 File	2 KB
Chest _AP_A_231_mydata.en2	2/10/2015 11:55 PM	EN2 File	19 KB
Chest _AP_A_231_mydata.mG2	2/10/2015 11:55 PM	MG2 File	5 KB

Figure3: Sample of calculated data in PCXMC -2.0 software

Appendix (B)

a. Sample of Risk Assessment Data

```
PCXMC 2.0 - Radiation risk assessment:


Stochastic radiation risks
      Euro-American mortality data
      33.0 year-old female
      Expected length of remaining life 47.2 years
      Risk of exposure-induced cancer death (REID): 0.000465 %
      (Cancer mortality for other causes; not related to this exposure:  18.5 %)

                   Cancer type        REID
                      leukemia    1.88E-5 %
                 breast cancer   0.000154 %
                  colon cancer    4.76E-7 %
                  liver cancer    1.33E-6 %
                   lung cancer   0.000215 %
                  ovary cancer    7.32E-8 %
                stomach cancer    1.44E-5 %
                bladder cancer     1.1E-8 %
                  other cancer    6.14E-5 %



      Loss of life expectancy (LLE):    1.4 hours
      LLE/REID                        :   35.3 years




      PCXMC dose files used in the risk estimate
        30-39  F LATL.mG2
        The sum of incident air kermas in those dose files is: 0.484 mGy
        The sum of effective doses in those dose files is: 0.06376 mSv
```

```
The above risk estimate is based on doses (mSv):
            Active bone marrow        0.03929
            Breasts (women)           0.2282
                      Colon        0.001333
                      Liver         0.01258
                      Lungs         0.1048
            Ovaries (women)        0.000339
            Prostate (men)                0
                    Stomach        0.04773
                    Thyroid         0.1176
            Uterus (women)          0.00086
            Urinary bladder            4E-5
            Weighted remainder      0.05283

Sum of doses in the above dose files (mGy):
```

Figure 1: Sample of Risk Assessment data which were calculated in PCXMC -2.0 software

b. Sample of OrgansAbsorbed Doses

```
       Weighted remainder      0.05283

Sum of doses in the above dose files (mGy):
         Active bone marrow       0.039291
                  Adrenals        0.030231
                     Brain        0.001898
                   Breasts        0.228197
    Colon (Large intestine)       0.001333
     (Upper large intestine)      0.001919
     (Lower large intestine)      0.000558
       Extrathoracic airways      0.030035
              Gall bladder        0.006367
                     Heart        0.118676
                   Kidneys        0.005579
                     Liver        0.012579
                     Lungs        0.104845
               Lymph nodes        0.034242
                    Muscle        0.030111
                Oesophagus        0.054318
               Oral mucosa        0.005705
                   Ovaries        0.000339
                  Pancreas        0.033227
                  Prostate        0.000000
            Salivary glands       0.008911
                  Skeleton        0.113343
                    (Skull)       0.009404
             (Upper Spine)        0.079229
            (Middle Spine)        0.084461
             (Lower Spine)        0.006887
                 (Scapulae)       0.245290
                (Clavicles)       0.304243
                     (Ribs)       0.301264
          (Upper arm bones)       0.727113
         (Middle arm bones)       0.515935
          (Lower arm bones)       0.002593
                   (Pelvis)       0.000680
          (Upper leg bones)       0.000040
         (Middle leg bones)       0.000000
          (Lower leg bones)       0.000000
                      Skin        0.048635
            Small intestine       0.001366
                    Spleen        0.056678
                   Stomach        0.047733
                 Testicles        0.000093
                    Thymus        0.088385
```

```
                   Thyroid        0.117567
          Urinary bladder        0.000040
                    Uterus        0.000860
      Average dose in total body    0.052826
   Effective dose ICRP60  (mSv)     0.046921
   Effective dose ICRP103 (mSv)     0.063764
```

Figure 2: Sample of organs absorbed doses were calculated in PCXMC-2.0 software

Appendix (C)

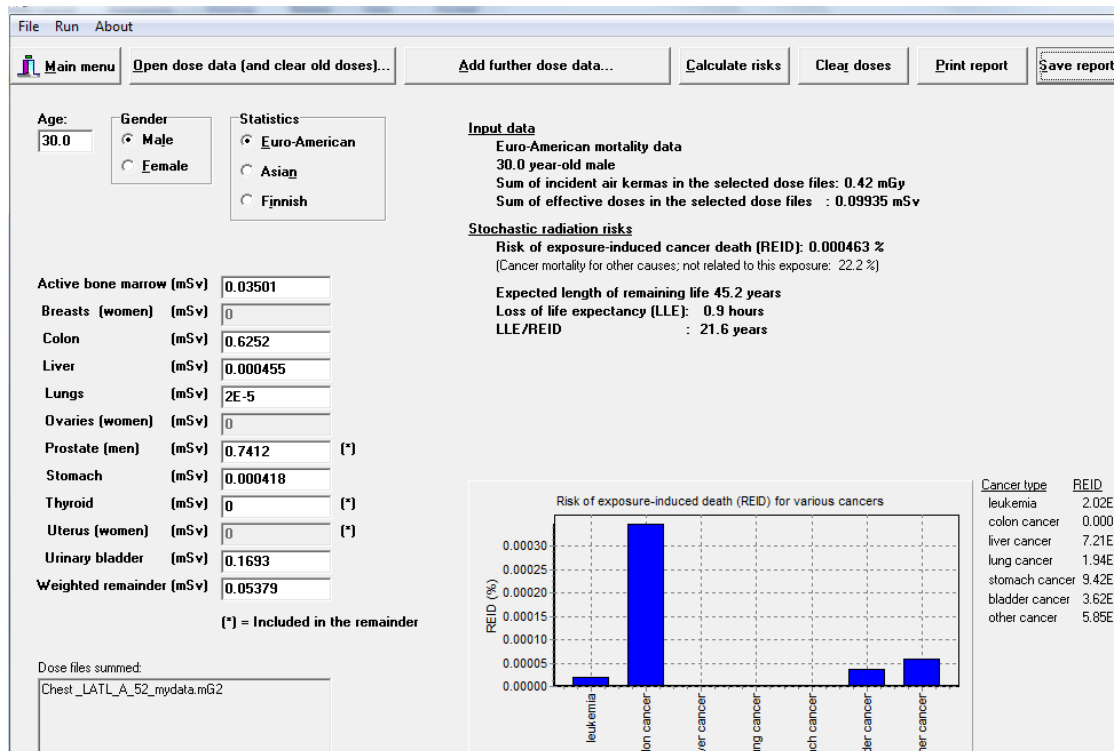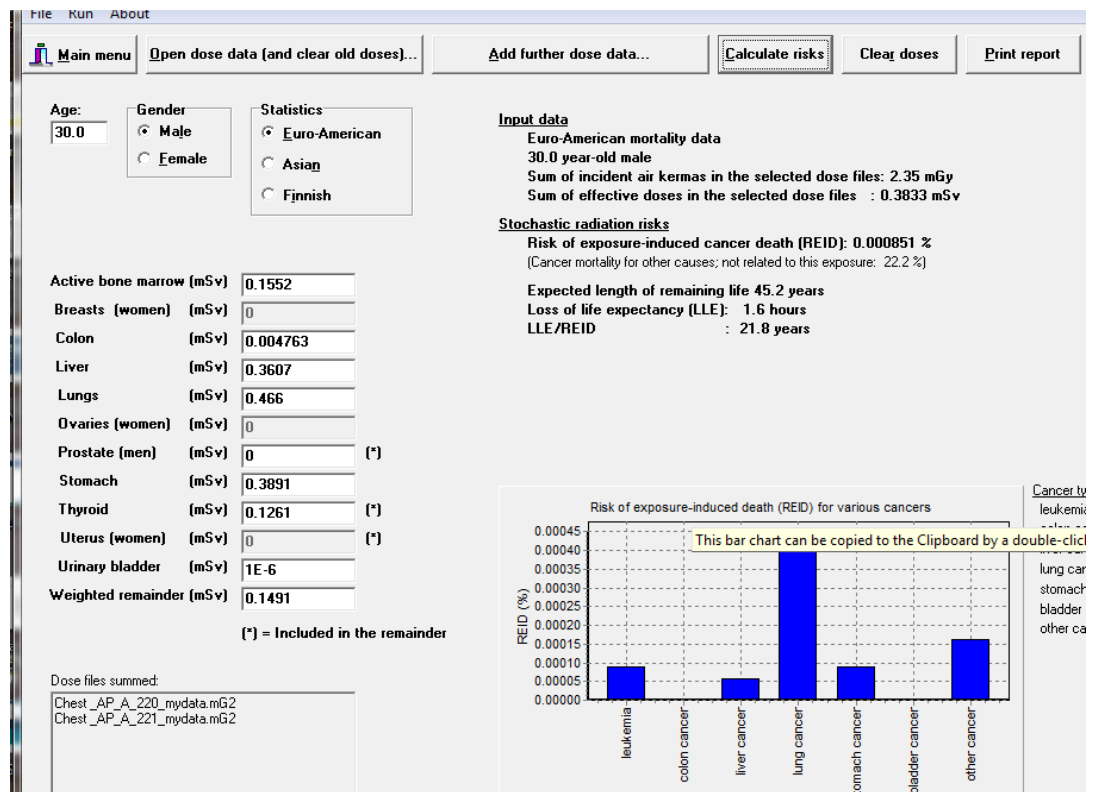### a.PCXMC -2.0 software in Risk Assessment calculations

Figure 1: PCXMC -2.0 software in risk assessment calculations

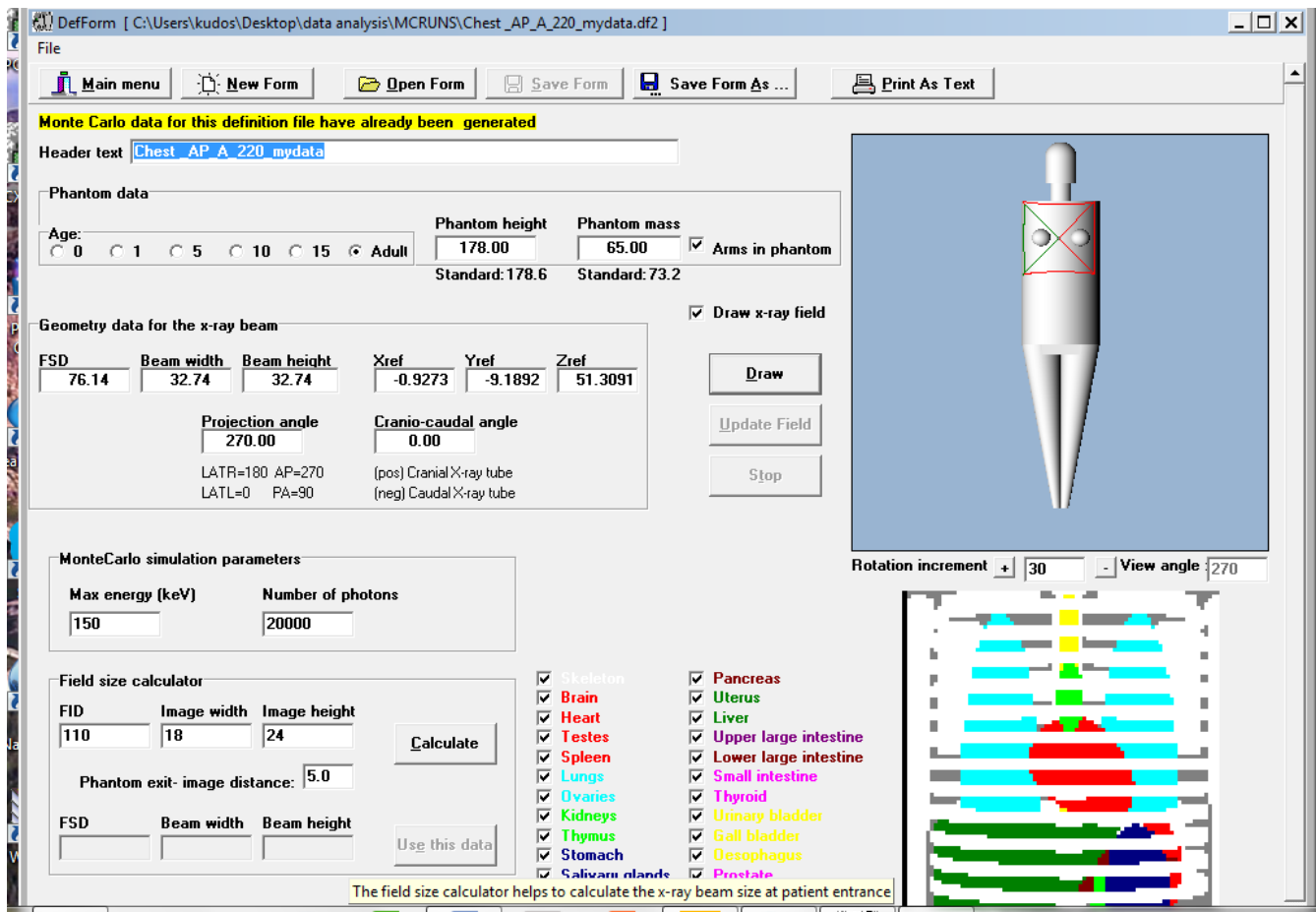## b.PCXMC -2.0 software (Effective dose calculations)

Figure 2: PCXMC -2.0 Software in Effective dose calculations

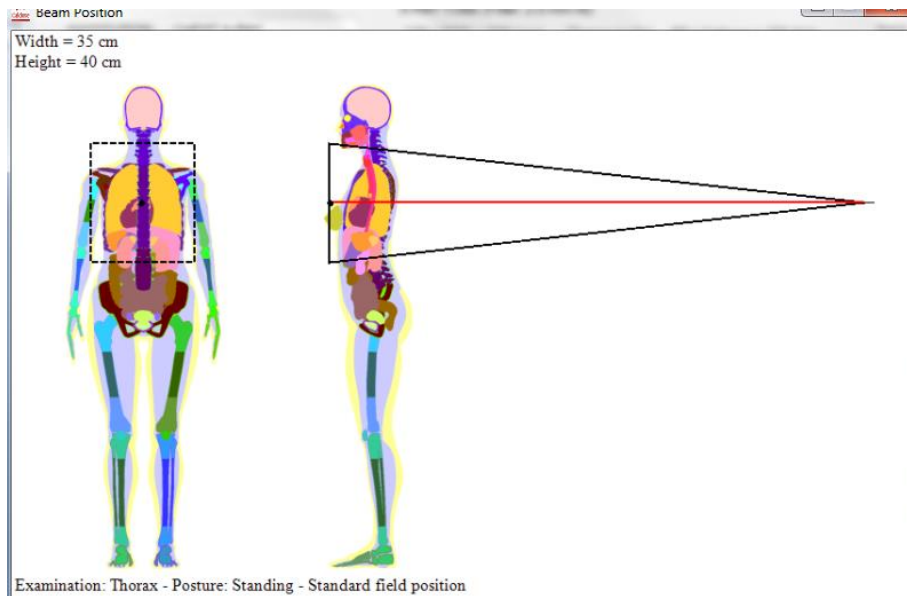## c.CALDose_X-5.0 software (ESAK and Incident Air Kerma calculations)

Figure 3: CALDose_X-5.0 software in ESAK and Incident Air Kerma calculations for chest X-ray examinations

دراسة استقصائية لقياس كمية الأشعة وتقدير الخطر منها من فحص الصدر الشعاعي في الضفة الغربية

اعداد الطالبه : احلام سعيد محمد عيسى

اشراف الدكتور : عدنان اللحام

الملخص

الحاجة إلى استخدام الفحوصات الطبية بالاشعة السينية التشخيصية في تزايد في جميع أنحاء العالم، ومن اهم البلدان التي يلاحظ بها هذا التزايد السريع هي فلسطين وبالتحديد الضفه الغربيه التي ازداد وتضاعف بها عدد المراكز الطبية للاشعة السينية في الاونة الاخيرة بشكل ملحوظ. ولكن مع زياده الاستخدام يخشى ان يكون هناك بعض التجاوزات في كمية الاشعة التي يتعرض لها المرضى وذلك نتيجه لعدم وجود دراسات اعطت كمية الاشعة المسموح بها وكميه الجرعه الفعاله Effective Dose بالإضافة إلى معدل الجرعة التي يتلقاها السكان نتيجه لتعرضهم للاشعة السينية في المجالات الطبية فلا يوجد اي معلومات عن الجرعة المرجعية (DRL).

الفكرة الرئيسية في هذه الدراسة هو التحقق من معدل وكمية الجرعات الإشعاعية في التصوير الشعاعي للصدر في الضفة الغربية وفي فلسطين الذي يقدر بحوالي 53٪ من معدل الفحوصات التقليدية للاشعة السينية . اجريت هذه الدراسه باستخدام مبدأ المحاكاه Monte Carlo (simulation).

اجريت هذه الدراسه في عدد من مستشفيات الضفة على 668 مريض واهمها المستشفى الرئيسي الذي تم اختياره بصفته المستشفى التعليمي والمرجعي في الضفة الغربية هو مستشفى الجمعية الخيرية الاسلاميه المقاصد الذي يقع في القدس. وإلى جانب هذا المستشفى تم اختيار مستشفيين اثنين آخرين في مدينه الخليل، إضافة إلى أن عينة صغيرة من مركز في مدينه القدس يستخدم التصوير الشعاعي ولكن بالتصوير الرقمي CR، للتحقق من كميه الجرعة الفعالة في آلات CR الرقمية الحديثة. تم اخذ العينات من المرضى بشكل عشوائي في الفترة الواقعة ما بين شهرتشرين الثاني من عام 2014 الى شهرشباط من العام 2015 . تمت كافة الحسابات باعتماد مبدا المحاكاة الرقمي عن طريق تقنية (Monte Carlo simulation) في برنامجيين رئيسسن وهما ال PCXMC-2. و Cal-Dose_X5.0. وهما برناماجين للمحاكه متوفرين بشكل تجاري.

تم حساب متوسط الجرعة الفعالة باستخدام بيانات هندسية اخذت من العينات في المستشفيات على المرضى اثناء القيام بفحص الصدر بالاشعة السينية وهي طول المريض ووزنه والعمر والجنس ، كمية الطاقة والجهد (كيلو فولت) KV p ، ميلي أمبير في الثانية (mA.s)، ومسارات الاشعة كافة في الفحوصات (Lateral ،AP ،PA). بالإضافة إلى ذلك سمك الترشيح في كل جهاز الأشعة

السينية، وزاوية الأنود، والمسافة بين المصدر والمريض (FSD)، ارتفاع وعرض حزمة الاشعة. وقد كانت النتائج التي وجدت كالتالي: معدل الجرعه الفعاله ل 668 مريض الذين شملتهم هذه الدراسه حوالي mSv 0.11 ملي سيفرت في كافه انواع التصوير الشعاعي للصدر في المستشفيات الاربعه ومقسمه حسب الفئات التاليه للبالغين lateral , PA, AP حيث كانت 0.07, 0.14 , 0.33 ملي سيفرت بالترتيب وايضا للصغارفي PA, AP حيث كانت0.06,0.09 ملي سيفرت بالترتيب ومعدل الجرعة التي يتلقاها السكان من عدد مرضى 668 هو 72.67 ملي سيفرت. والمتوسط السنوي للفرد الواحد في الضفة الغربية هو (2.08 X 10⁻⁵ mSv) ملي سيفرت سنويا للفرد الواحد.