DETERMINATION OF DOSES AND CANCER RISK TO PAEDIATRIC AND YOUNG ADULT PATIENTS UNDERGOING PLAIN RADIOGRAPHIC AND FLUOROSCOPIC GUIDED SURGICAL PROCEDURES

A thesis presented to the:

DEPARTMENT OF NUCLEAR SAFETY AND SECURITY

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

UNIVERSITY OF GHANA

BY

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Bsc Diagnostic Radiography (UG, Legon), 2010

In partial fulfillment of the requirement for the award of

MASTER OF PHILOSOPHY DEGREE

IN

RADIATION PROTECTION

JULY, 2015

DECLARATION

This thesis is the result of research undertaken by Hannah Mantebea in the Graduate School of Nuclear and Allied Sciences with exception of references to other people's work which has duly been acknowledged, and was undertaken in accordance with guidance on supervision of thesis laid down by University of Ghana under the supervision of Dr Mary Boadu and Dr J. K. Amoako.

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DEDICATION

This work is dedicated specially to “God Almighty” whose favor and mercy has never ceased to operate in my life and to my Parents Rev. E. G. Mantey and Mrs Janet Mantey for their support and love.

ACKNOWLEDGEMENT

I wish to express my gratitude to the following people who played a major role in the accomplishment of this project. Their support is highly appreciated.

- My supervisors, Dr Mary Boadu and Dr Joseph K. Amoako for their invaluable advice, guidance, encouragement and working tirelessly to go through my write up.
- Prof. Oheneba Boachie - Adjei and the FOCOS surgical team for their warmth reception and support
- Dr Johnson Yeboah for the Monte Carlo code PCXMC 2.0 soft ware
- Mr. Prince Gyekye for guidance in the Monte Carlo code PCXMC operation and advice.
- Mr. Edward Gyasi (SNAS), Mr. Eric Appiah (FOCOS) and Miss Jenifer Ayamga (FOCOS) for their invaluable support and advice.
- Personnel from Dosimetry lab RPI (Philip, Prince and Edith) and Mr. Michael Obeng for their warmth reception and support during TLD readings.
- To my family for their advice and support.
- Finally to the lecturers and my colleagues of Graduate school of Nuclear and Allied Sciences for their comments on this study

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LIST OF ABBREVIATIONS AND SYMBOLS

AEC	Automatic Exposure Control
ALARA	As Low As Reasonably Achievable
BEIR	Biological Effects of Ionizing Radiation
BMI	Body Mass Index
BSS	Basic Safety Standards
DAP	Dose Area Product
DRL	Dose (Diagnostic) Reference Level
E	Effective Dose
EAR	Excess Absolute Risk
ECF	Element Correction Factor
ELL	Expected Length of remaining Life
ERR	Excess Relative Risk
ESD	Entrance Surface (Skin) Dose
FAO	Food and Agriculture Organization
FOCOS	Foundation for Orthopaedics and Complex Spine
FSD	Focus to Skin Distance
GAEC	Ghana Atomic Energy Commission
HSG	Hysterosalpingogram
HVL	Half Value Layer

IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
IM Nailing	Intramedullary Nailing
IV	Intravenous
kV	kilo voltage
LLE	Lost of Life Expectancy
LSS	Life Span Study
mAs	milliampere -second
mGy	milliGray
OLV	Output Linearity Value
PSF	Posterior Spinal Fusion
RBM	Red Bone Marrow
RCF	Reader Correction Factor
REID	Risk of Exposure Induce Death
RPB	Radiation Protection Board
RPI	Radiation Protection Institute
SD	Standard Deviation
SID	Source to Skin Distance
Sv	Sievert

ABSTRACT

Fifty paediatric and young adult patients who underwent plain radiographic and fluoroscopic procedures in the operating theatres of a selected orthopaedic hospital were investigated. Radiation Dose was measured using single chip TLD (LiF) held at the skin surface at the beam entrance site for scoliotic, kyphotic and kyphoscoliotic patients undergoing Posterior Spinal Fusion (single stage), Posterior Spinal Fusion (two stage), Growing Rod and Revision Posterior Spinal Fusion as well as patients undergoing Intramedullary Nailing of the Femur and Osteotomy of the lower Extremity. The radiographic equipment were working at self-consistencies. The readings from the TLD, with patient data and other relevant information from the equipment console were used in Monte Carlo program software (PCMXC 2.0) to estimate organ and effective doses as well as assess cancer risk. Mean effective dose from Posterior Spinal Fusion (single stage), Posterior Spinal Fusion (two stage), Growing Rod, Revision Posterior Spinal Fusion, Nailing of the Femur and Osteotomy of the lower Extremity were found to be7.62 ± 0.84 mSv, 7.48 ± 1.0, 6.82 ± 0.99 mSv, 2.50 ± 0.27 mSv, 0.18 ± 0.09 mSv and 0.001 ± 0.6E4 mSv respectively. The ribs recorded the highest bony organ tissue whiles the breast recorded the highest soft tissue organ dose with Posterior Spinal Fusion (single stage) recording the highest of 25.55±2.81 mGy and 11.49±1.22 mGy. Comparison of paediatric and young adult effective dose showed a higher effective dose in paediatric. Risk of radiation exposure induced cancer death from any cancer were considered for all the procedures and growing rod recorded the highest with 0.0954 % for females and 0.0500% for males. Risk of lung cancer was prevalent in all surgical procedures considered for the study followed by other cancers. However risk of breast cancer was

high in females and risk of colon cancer for males. Paediatric and young adult patients exposure records were recommended to be part of their medical records to aid in consistency of exposure factors and dose optimization especially in case of revision and second stage procedures.

CHAPTER ONE

INTRODUCTION

This chapter gives the background of the study, the statement of the problem, research objectives, relevance and justification and the scope of the research work.

1.1 Background of Study

Fluoroscopy and plain radiography employs the use of x-rays to generate images of the patient body, however, in fluoroscopy, real- time images are produced to enable physicians to look at many body systems, including the skeletal, digestive, urinary, respiratory, and reproductive systems (Hart et al, 2011).

Radiation dose to patient was given only minor consideration during the early days. As the number of examinations performed has increased and data on the long term risks of cancer arising from ionizing radiation exposure has emerged, more attention has been focused on keeping the doses received to a minimum.

For more than a century, x-ray use in diagnosis and treatment has expanded to areas outside the imaging department. Today the most significant use of x-rays has been in interventional procedures and a number of clinical specialties where fluoroscopy or mobile x-rays units are used to guide medical and surgical procedures (ICRP, 2011). Advances in surgical procedures have led to developments in the use of x-ray in operating theatres where mobile radiographic units (fluoroscopic or conventional) are routinely used intra-operatively (Margulis, 2000).

In radiography, x rays passed through the human body are absorbed, causing attenuation of the incident beam. The uniform x-ray beam emitted from the source is modulated as it passes through the human body and these changes are recorded on the film or viewed on monitor (Hart, 2011).

Fluoroscopy may be used alone as a diagnostic procedure, or in combination with other diagnostic or therapeutic media or procedures. The examinations and procedures may include barium x-rays, cardiac catheterization, arthrography (visualization of a joint or joints), lumbar puncture, and placement of intravenous (IV) catheters (hollow tubes inserted into veins or arteries), intravenous pyelogram, hysterosalpingogram (HSG) and biopsies.

Fluoroscopy and plain radiographs are performed to aid in the positioning of medical devices within a patient, to localize sites for surgical excision, or to position the patient for static radiographs (Morrell, 2006). These procedures are often technically difficult, they can involve total exposure times exceeding an hour or more.

A broad range of other fluoroscopically guided procedures have shown considerable growth and the nature of these prolonged fluoroscopic procedures has led to an increase in reports of high skin doses to patients (Mahesh, 2011). Radiation use in fluoroscopy and plain radiographs at small doses have the probability of causing certain types of harm and above some threshold level, damage is apparent, with severity increasing as dose rises above the threshold (Vano, 1998). Cellular damage from ionizing radiation has been reported for the skin, eyes, gonads, and blood, with the most important long-term concern being cytogenetic and chromosomal damage resulting in increased risk of carcinogenesis (Mroz et al., 2008).

Although low doses are used in fluoroscopy and plain radiography as compared to other modalities, in prolonged procedures, the cumulative exposure may result in a relatively high absorbed dose to the patient. Therefore once examination has been justified, it must be optimized by keeping the patients exposure as low as reasonably achievable (ALARA) whiles maintaining useful and correct diagnostic information (Hart et al., 2011).

In order to evaluate the potential for optimization of radiation dose to patient, it is recommended that dosimetry is performed regularly with understanding of the factors that affect patient exposure (ICRP, 1991). According to ICRP (1991), every action that reduces patient dose will reduce staff dose but reverse is not true. For pediatrics and young adults undergoing such procedures, it is of much concern (Sidhu et al., 2009) to optimize their dose due to known additional sensitivity to radiation damage and potentially longer lifetime to which radiation related diseases may manifest (ICRP, 2007). The sensitivity of paediatrics to cancer has been found to be three to five times higher than in adults, hence the importance to estimate and optimize their doses when exposed to ionizing radiation (ICRP, 2007).

There is decrement in Radiation intensity exponentially along the path of the body with only small percentage of entrance radiation exiting the body to form image whiles most of the radiation is absorbed into the body and the rest as scatter. In majority of patients undergoing plain radiographic and fluoroscopy guided procedures, the skin at the beam entrance site typically receives the highest dose than any tissue in the body and therefore the organ at greatest risk for radiation injury (Hall, 2009).

The radiation dose therefore depends on the type of examination, the patient size, the equipment, the technique, and factors best characterized by entrance surface exposure.

The management of patient exposure involves not only measurement of these factors but also clinical monitoring of patient doses (Mahesh M, 2011).

This study assessed paediatric and young adult patient doses at a selected orthopaedic hospital during normal surgical procedures that involve the use of fluoroscopy or plain radiography as a guide specifically in spine and joint related indications.

There are currently a number of methods available for measuring doses to patients. Doses can be measured indirectly using DAP meter or ion chambers mounted on x ray collimator to measure the radiation exposure to the patient or directly by using thermo luminescence dosimeter (TLD) and Photographic film. A more precise direct measurement of the doses to accessible tissues or organs may be obtained using thermo luminescence dosimeters and indirectly with anthropomorphic phantoms.

On the other hand, doses to internal organs may be estimated using Monte-Carlo modeling. This is a computational technique, in which the paths of a large number of photons are tracked in a mathematical model of the human body, and the absorbed dose to each organ is calculated. A commercially available software package like the PCMXC Monte-Carlo code makes it flexible when calculating dose to the patient (Tapiovaara et al., 1997). This code was used in the simulation of the procedures that were computed from the selected orthopaedic surgical facility.

1.2 Problem Statement

There have been increments in the usage of fluoroscopy and plain x-rays in medicine due its easy assessment of dynamic function of the human body and little or non-invasiveness

over other modalities and surgery. The advances of technology in terms of imaging have widened the field of image guidance in several surgical techniques (Gelalis et al., 2011). In Ghana, Studies have been conducted by some researchers (Gyekye et al, 2010, Gyasi et al., 2013) on dose assessment in some radiographic procedures in the imaging department of some selected hospitals. However, radiographic guided procedures outside the imaging department especially in operating theatres and to larger extent pediatrics was not considered in their study. There is little information on doses pediatric patients receive when they undergo radiographic procedures outside the imaging department in the country.

Also, according to ICRP there has been neglect of radiation protection coverage of radiographic machines used outside radiology department and lack of published document on pediatrics undergoing such procedures (ICRP, 2011). Studies conducted by IAEA indicate among non-radiologists and non- cardiologists from over 30 developing countries, there is an almost complete absence of patient dosimetry in such areas (IAEA, 2010). This study therefore, seeks to estimate paediatric and young adult patient's dose during plain radiographic and fluoroscopic guided procedures outside the imaging department and specifically in surgical procedures of a selected facility.

1.2 Objectives

The main aim of the study is to estimate effective and organ dose as well as cancer risk to pediatric and young adult patients undergoing plain radiographic and fluoroscopic guided surgical procedures. The specific objectives of the study are to

- Acquire patient data and technique factors from the fluoroscopic and radiographic machines used for this study and information put into Monte Carlo code (PCXMC) to estimate organ doses and effective doses.
- Acquire direct dose measurement from the patient using thermo luminescence dosimeter.
- Assess radiation risk associated with the dose acquired Monte Carlo code (PCXMC).
- Make appropriate recommendations to optimize doses to pediatrics and young adults undergoing plain radiographic and fluoroscopic guided procedures outside the imaging department specifically in surgery to ensure safety.

1.4 Relevance and Justification

Radiation protection of pediatrics and young adults have come to the consciousness of the public and enlightening groups of professionals (Strauss et al., 2010). For years, monitoring of doses has been concentrated in imaging departments such as Nuclear Medicine and Diagnostic Radiology and Radiotherapy where radiation is frequently used. There has been neglect of other radiation involve specialties such as orthopaedic surgery, neurosurgery, cardiology and neurology. Unfortunately this situation still exists in most countries. It has been established that many National Authorities do not have idea on the number of fluoroscopy and other equipments used in operating theatres (ICRP, 2011). The increase in the use of radiation outside the imaging department and of particular concern fluoroscopy is the potential for causing relatively higher exposures to patient (Sidhu, 2009).

The study therefore will aid in creating awareness to related medical professionals and National Authorities on the use of radiation outside the imaging department to take appropriate decision in the assessment of Dose Reference Levels (DRL) in fluoroscopy and plain radiography.

The research findings will also contribute immensely to the body and knowledge of the subject matter for the international scientific community. Finally, it will provide the needed scientific data on the level of paediatric and young adult patients' doses due to plain radiographic and fluoroscopic surgical procedures in the country.

1.5 Scope of the study

The study covered at least fifty (50) patients undergoing plain radiographic and fluoroscopic guided invasive procedure in the operating theatre below the age of 19 yrs for paediatric group and 19 to 25yrs for young adult group.

The study was conducted in the trauma and orthopedic surgical department of Foundation for Orthopaedic and Complex Spines (FOCOS) hospital in Greater Accra Region of Ghana.

This facility was chosen because it is one of the specialized hospitals in the country that provide comprehensive orthopaedic services including surgical care to adult and paediatric populations in Africa.

CHAPTER TWO

LITERATURE REVIEW

2.1 Radiation Exposure to Humans

Radiation exposure to human is as results of energetic particles or waves passing through space and of more importance its ability to remove electrons (ionization) an atom or molecules , producing free radicals capable to cause cellular damage (Herscovici et al., 2000).

The radiation that human is exposed come from two sources, that which occur naturally and that which is due to the activities of man. The majority of exposure to radiation comes from natural sources contributing to approximately 85% of the exposure to humans (Oddy et al., 2006). The remaining exposure comes from man-made sources with medical x-ray exposure of 11%. Exposure to human can therefore be classified as occupational, public or for the purpose of this study; medical exposures (ICRP, 2001).

2.2 Medical exposures

Radiation exposure to from man-made in the general population is due to its uses in medicine or allied health for diagnostic and therapeutic purpose.

Medical radiation is by far the largest artificial source of population exposure to ionizing radiation, accounting for 90% of all doses from artificial sources (United Nations, 2010). Medical exposure contributes 0.4 mSv to the annual average dose of radiation (>14%) (Parry et al., 1999).

The International Basic Safety Standards defines medical exposure to be exposure incurred by patients as part of their own medical diagnosis or treatment; by persons, other than those occupationally exposed, knowingly while voluntarily helping in the support and comfort of patients; and by volunteers in a programme of biomedical research involving their exposure (FAO et al., 1996).

Radiological protection in medical exposures involve three basic principles including justification; by weighing the diagnostic or therapeutic benefits against radiation detriment and optimization by keeping radiation dose to a minimum to produce required purpose and guidance level (ICRP, 2007)

The risks and benefits of radiation exposure due to medical imaging and other sources must be clearly defined for clinicians and their patients.

2.3 Optimization in medical exposure

A number of techniques exist to reduce radiation exposure to the patient. Though they may sometimes result in some loss of image quality, they should be practiced to the extent that they do not compromise the x-ray procedure. Experience has provided ample evidence that, reasonable selection of conditions, under which ionizing radiation is being used in medicine, can lead to health benefits substantially outweighing the estimated possible deleterious effects.

Medical exposures are intended to provide a direct benefit to the patient and protection optimized to reduce patients dose (ICRP, 1991). According to ICRP publication 105, optimization of protection is "the likelihood of incurring exposures, the number of people

exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors (ICRP, 2007).

Dose optimization as far the study is concern, is possible through appropriate use of the basic features of fluoroscopic and radiographic equipments and intelligent use of dose-reducing technology (Wagner, 2007).

Since stochastic radiation effects, such as carcinogenesis, cannot be ruled out at low levels of exposure, it is prudent to minimize radiation exposure whenever possible. This concept leads to the As-Low-As-Reasonably-Achievable (ALARA) philosophy. X-ray diagnostics is a major source of radiation exposure among the population and is important that x-ray examinations are conducted using techniques that keep the patients' exposure as low as possible.

2.4 Radiation Risk from Medical Exposures

Ionizing radiation remains harmful even at relatively low levels. Ionizing radiation has long been known to increase the risk of cancer and is officially classified as a carcinogen by the International Agency for Research on Cancer (IARC). It is now on the official list of carcinogen by the World Health Organization (IARC., 2011).

Fluoroscopy carries some risks, as do other x-ray procedures. The radiation dose the patient receives varies depending on the individual procedure. Biologic effects resulting from radiation exposure are traditionally divided into stochastic effects and deterministic effects or non stochastic (little, 2003).

Deterministic injuries are commonly caused by radiation that effect exhibits threshold dose below which the effect will not occur whiles stochastic effects increases with

increasing radiation dose. These effects can be severe and clinically overwhelming (Balter et al., 2010) and though commonly referred to as skin injuries, severe deterministic injuries can extend into the subcutaneous fat and muscle (Monaco et al., 2003). Deterministic effect exhibit threshold doses typically at least 10- to 100-fold higher than doses encountered in medical procedures. Thus, there is little or no possibility of an adverse non stochastic effect from exposures in medical procedures. Deterministic effects, such as cell killing and sterility can be more immediate. Such effects are called non stochastic effects. Cataracts, erythema, epilation, and even death are examples of the deterministic effects that can result from high radiation exposures (Mahadevappa, 2011). Stochastic effects do not exhibit a threshold; therefore it is a probability of stochastic effects occurring even at low radiation doses. The stochastic effect that is of importance to the individual exposed to radiation is cancer induction. Stochastic effects, such as mutations, can result in cancer and hereditary effects (ICRP, 2001).

Except in the early period of radiology, when safety measures were few, the emphasis in radiation safety has been on stochastic effects but the recent popularity of prolonged radiation involve procedures has added concern about deterministic effects (Wagner et al., 1994). Radiation risk to pediatrics and young adults is a special problem due to their sensitivity to radiation-induced neoplasm and malignancy, chronic accumulation of delivered doses over many years and vary in size from a few to less to hundreds of pounds (National Academies, 2006).

It has been established that fluoroscopy and x-ray induce cancer and serious injuries to patients. It has also caused cataracts, skin injuries, cancer and death from disease induced by medical fluoroscopy (Koenig et al., 2001a). Observable radiation effects in workers

are commonly caused by the long-term accumulation of radiation dose and in patients; effects are typically caused by the delivery of high radiation doses in a short period of time (Koenig et al., 2001b).

2.5 Fluoroscopy and Fluorographic Procedures

Fluoroscopy is used in a wide variety of examinations and procedures to diagnose or treat patients. X-rays are produced by the x ray tube when a stream of electrons, accelerated to high velocities by a high-voltage supply, collides with the tube's target anode. A set of collimators confines the primary beam to the approximate size and shape of the diagnostic interest. X-rays emerging from the patient carry the image information to the input phosphor of an image intensifier or to a flat-panel digital detector. The energy of the x-rays detected at the input phosphor is emitted as light that causes the photocathode to release electrons. These electrons are accelerated and focused to produce an image on the output screen. All fluoroscopic systems use a camera to scan and transmit the image to a remote display monitor.

Fluoroscopy may be performed to evaluate specific areas of the body, including the bones, muscles, and joints, as well as solid organs, such as the heart, lung, or kidneys. Fluoroscopy is used in many types of examinations and procedures. Procedures that usually involve the use of fluoroscopy are;

- Barium x rays and enemas -to view the gastrointestinal tract;
- Catheter insertion and manipulation -to direct the movement of a catheter through blood vessels, bile ducts or the urinary system;

- Placement of devices within the body, such as stents - to open narrowed or blocked blood vessels;
- Angiograms -to visualize blood vessels and organs; and
- Orthopedic surgery - to guide joint replacements and treatment of fractures.

Fluoroscopic procedures are performed by other subspecialty services, such as gastroenterology, cardiology, and orthopedics.

2.6 Radiation use in Operating Theatre

Certain invasive surgical procedures or operations that involve cutting into and working inside a patient's body take place in operating theatre. This might involve either minimally invasive procedures through small incisions or open surgery where surgeons make larger cuts to reach the internal organs. Complicated operations can last many hours.

The use of fluoroscopy and plain x-rays in surgical procedures has enabled orthopedic surgeons to become technically more proficient. In addition, these surgical procedures tend to have less associated patient morbidity by decreasing operative time and minimizing the area of the operative field.

Mobile fluoroscopy (C- arms) and x-ray (portable x-ray) units are widely used in surgical procedures. The x-ray tube and detector in mobile fluoroscopy are mounted on a wheeled cart with control console, with the generator, viewing monitors and recording devices on a second cart (Morrel, 2006). The C-arm can perform both linear and rotating motions for

optimum positioning with respect to the patient position. Fluorography is usually not done with mobile fluoroscopy since it cannot withstand high tube loading.

The use of mobile C-arm fluoroscopy portable x-rays have expanded, its relative and popularity has grown commensurately. Now, through its relevance to numerous applications and overall convenience, the use of fluoroscopy has become regular, and in some cases indispensable, in the daily clinical practice of orthopaedics (ICRP, 2011). Orthopaedic surgery is a specialty dealing with acute injuries, congenital and acquired disorders and chronic arthritic or overuse conditions of the bones, joints and their associated soft tissues, including ligaments, nerves and muscles. The field of orthopaedics has relied on x-rays for medical imaging since Rontgen's landmark discovery in 1895.

Among other uses that are relevant to the field of orthopaedics, C-arm fluoroscopy and mobile radiographic system facilitate precise use of instrumentation, guides implant placement, and confirms fracture reduction (Singer et al., 2005).

In orthopaedic theatre it can be expected to image different bones whilst pins and plates are used to fix broken bones. Spinal instrumentation using pedicle screws is also commonly used for stabilization of the spine, (Gelalis et al., 2011). Thus, x-rays use for accurate and safe placement of the screw within the confines of the pedicle is of paramount importance for a successful surgery. Mobile fluoroscopic device is an integral part of the standard equipment used in orthopaedic surgery to provide real-time feedback of bone and surgical tool positions. It has been shown that patient exposure can be

reduced (10 times) by adhering to proper radiation safety practices when using C-arm fluoroscopy during surgical procedures (ICRP, 2011).

2.7 Radiation Dose Measurement

In radiology the fundamental quantity used in dose measurement is the absorbed dose to a tissue or organ. It is defined as the energy absorbed per unit mass of tissue, and is given the special unit Gray (Gy). 'Effective' or 'whole body' dose (E) is a measure of the total dose to all the organs of the body, weighted according to their radiation sensitivity (ICRP, 1991).

Mathematically

$$E = \sum_T W_T H_T \quad \text{.....} \quad (2.1)$$

Where

- E : effective dose
- W_T : weighting factor for organ or tissue T
- H_T : equivalent dose in organ or tissue T

There are currently a number of methods available by which one can estimate or measure patient entrance skin dose; they may be classified as direct or indirect methods.

Direct methods involve measurement of skin dose during the procedure by using one of several types of small dosimeters taped to the patient's skin. Indirect methods involve calculation of skin dose from measurements in the beam or from operational factors that affect dose (Geise et al., 1990).

Radiation dose estimation in fluoroscopic procedures has four special developed metrics. These include; peak skin dose, Reference point air kerma (reference dose), kerma-area product (dose-area product), and fluoroscopy time (Miller et al., 2010). Peak skin dose is measured in grays and the highest radiation dose (entrance surface dose) at any part of a patient's skin during a procedure. Fluoroscopy time is a measure of time, not dose. It correlates poorly with other dose metrics (Miller et al., 2004)

Radiation dose to patient is normally measured using a dose-area-product (DAP) meter. The DAP meter is a transmission ionization chamber which can be fitted at the output window of the x ray collimator assembly, so as to intercept the whole of the x-ray beam (Morrell, 2006).

Another type of dose measurement particularly to tissue and organs is the use of thermo luminescent dosimeter, scintillation detectors, diodes or radiographic films. Doses to internal organs can be measured directly to accessible organs or phantom to inaccessible organs. Indirectly internal organ doses can be measured using Monte-Carlo modeling (Morrell, 2006).

2.8 Single Chip Dosimetry and Entrance Skin Dose

A TL (thermo luminescence) Dosimetry system with single detector chips is being developed mainly for new or special patient Dosimetry applications. Small chips or sachets containing a thermo luminescent material such as lithium fluoride has been selected for medical Dosimetry applications due to its small physical size and that no cables or auxiliary equipment is required during the dose assessment as well as dose

detection accuracy and dose linearity in the typical diagnostic dose range up to several tens of mGy (DIN, 2005). These TL chips are able to measure entrance surface or skin dose.

The entrance surface dose is defined by the BSS as the absorbed dose in the centre of the field at the surface of entry of radiation for a patient undergoing a radio diagnostic examination, expressed in air and with backscatter.

Entrance skin dose (ESD) is an important parameter in assessing the dose received by a patient in a single radiographic exposure. The European Union has identified this physical quantity as one to be monitored as a diagnostic reference level in the hopes of optimizing patient dose (Muhogora et al., 2001).

2.9 Monte Carlo Method

Several groups have developed software for mathematical simulation of the imaging process. These generally use Monte Carlo modeling. Monte Carlo method (or Monte Carlo simulation) can be used to describe any technique that approximates solutions to quantitative problems through statistical sampling. It is a type of simulation that explicitly and quantitatively represents uncertainties. Monte Carlo method is meant or aimed to solve these problems; to generate sample from a given probabilistic distribution and to estimate expectation of function under this distribution.

In a Monte Carlo simulation, a random value is selected for each of the tasks, based on the range of estimates. The model is calculated based on this random value. The result of the model is recorded, and the process is repeated. A typical Monte Carlo simulation

calculates the model hundreds or thousands of times, each time using different randomly-selected values. When the simulation is complete, a large number of results from the model are made, each based on random input values. These results are used to describe the likelihood, or probability, of reaching various results in the model. Monte Carlo data can be used to calculate doses for any spectrum of interest.

This powerful computational technique follows the histories of hundreds of thousands of photons as they interact with a virtual phantom and then with a model detector. It enables large-scale studies to be performed quickly and easily, comparing many different combinations of imaging parameters. There are now also a small number of commercially available software packages for performing Monte-Carlo dose calculations. These are much more flexible, since they allow the user more control over radiographic parameters such as field size and projection, tube voltage and beam filtration. Examples include 'PCXMC'.

At each interaction point the energy deposition to the organ at that position is calculated and stored for dose calculation. Pseudo random numbers are generated by a multiplicative linear congruential generator, MLCG (16807, 231-1) (Vattulainen et al. 1993), and are used for sampling the initial photon direction, distance between interactions, type of interacting atom, type of interaction and scattering angle (and the corresponding energy loss).

To improve the precision, the photons are constrained not to be absorbed by the photoelectric interaction; instead, the photoelectric absorption has been treated by associating a 'weight' to the photons. This weight, *w*, represents the expected proportion of photons that would have survived absorption in the preceding interactions, and is

reduced in each interaction according to the probability of photo-electric absorption (*p*). At each interaction, an energy deposition of $w \cdot p \cdot E + w \cdot (1-p) \cdot DE$ is made to the organ where the interaction occurs, and the photon weight is reduced to $wnew = wold \cdot (1-p)$. Here, *E* is the photon energy before the interaction and D*E* the energy loss in the scattering interaction.

2.10 Monte Carlo code dose calculation (PCMXC)

Monte Carlo calculation of x radiation transport is based on stochastic mathematical simulation of the interactions between photons and matter, and is the method of dose calculation in PCXMC.

PCXMC is a computer program for calculating patients' organ doses and effective doses in medical x-ray examinations (radiography and fluoroscopy). The doses are calculated in 29 organs and tissues and the program calculates the effective dose with both the present tissue weighting factors of ICRP Publication 103 (ICRP, 2007) and the old tissue weighting factors of ICRP Publication 60 (ICRP, 1991)

The program incorporates adjustable-size paediatric and adult patient models and allows a free choice of the x-ray examination technique. Calculated organ doses can now also be used for the assessment of cancer risk resulting from the radiation exposure. The risk estimates are based on the models of the BEIR VII committee (BEIR, 2006).

Radiation doses in the various organs or tissues in the body cannot be measured directly in patients undergoing x-ray examinations, but they can be calculated with a reasonable accuracy if sufficient data on the x- ray examination technique are available (Tapiovaara et al., 1997).

Organ doses and the effective dose cannot be measured directly in patients undergoing x-ray examinations, and they are difficult and time consuming to obtain by experimental measurements using physical phantoms. However, they can be calculated to a reasonable approximation, provided that sufficient data on the x-ray examination technique are available. Today, such calculations are most often made using the Monte Carlo calculation method, where random numbers are used for simulating the transport of radiation in a complex medium, in this case the human body.(Tapiovaara et al., 2008)

Photons are emitted isotropically from a point source into the solid angle specified by the focal distance and the x-ray field dimensions. The photons are followed while they interact with the phantom according to the probability distributions of the physical processes that they may undergo: photoelectric absorption, coherent (Rayleigh) scattering or incoherent (Compton) scattering (Servomaa, 1998). Other interactions are not considered in PCXMC because the maximum photon energy is limited to 150 keV. This chain of interactions forms the history of an individual photon. A large number of independent photon histories is generated, and estimates of the mean values of energy depositions in the various organs of the phantom are used for calculating the doses in these organs (Tapiovaara et al., 2008)

Radiation and Nuclear Safety Authority, Finland (STUK) first published PC program for X-ray Monte Carlo (PCXMC) in 1997 (Tapiovaara et al. 1997). This program allowed computation of organ doses for patients of different ages and sizes in freely adjustable x-ray projections and other examination conditions that are used in projection radiography and fluoroscopy. Since 1997, the program has been improved in several occasions.

PCXMC versions 1.0–1.5 used slightly modified mathematical phantom models of Cristy (1980). In the present version (PCXMC 2.0) the phantom is still basically the same, but has been updated to the phantom models of Cristy and Eckerman (1987) with some further modifications (modification of the head, correction of some apparent errors in the data of Cristy and Eckerman and inclusion of some new organs: extrathoracic airways, oral mucosa, prostate and salivary glands) These modifications of the phantom enable the calculation of the effective dose using the tissue weighting factors introduced in ICRP Publication 103 (2007). The program is now also able to assess age- and sex-dependent radiation risks. In addition the program calculates the effective dose (the average whole-body dose), and the fraction of the x-ray beam energy that is absorbed in the phantom (ICRP, 1995).

2.11 Radiation Quantities and phantom used in PCMXC

PCXMC calculates the mean values of absorbed doses, averaged over the organ volume. In addition to these organ doses, the program calculates the effective dose for both the present tissue weighting factors w_T (ICRP, 2007) and the old ones (ICRP, 1991). PCXMC also calculates the average absorbed dose in the whole body, and the fraction of the x-ray beam energy that is absorbed in the phantom. In PCXMC, all absorbed doses (and air kerma) are in milligray (mGy).

All organ doses calculated with PCXMC are given in proportion to the incident air kerma ($K_{a,\,i}$) which is measured free-in-air, without backscatter, at the point where the central axis of the x-ray beam enters the patient.

This datum can be calculated from the technique factors [x-ray tube voltage (kV), tube current-time product (mAs), total filtration and focal spot-to-skin distance (FSD)] and measured data of the radiation output of the x-ray source, or it can be obtained from entrance surface air kerma measurements or DAP measurements of actual patient examination. Several phantom models are available for representing the human body in Monte Carlo calculations (Lee et al 2006, Schlattl et al. 2007). The phantoms used in PCXMC version 2.0 are computational hermaphrodite phantoms representing human beings of various ages (new-born, 1, 5, and 10, 15-year-old and adult).

2.12 Diagnostic (Dose) Reference level (DRL)

It is a form of investigation level to identify unusually high levels, which calls for local review if consistently exceeded. In principle, there could be a lower level also.

Diagnostic reference levels apply to medical exposure, not to occupational and public exposure. Their primary value is to identify dose levels that may be unnecessarily high – that is, to identify those situations where it may be possible to reduce dose without compromising the required level of image quality (McCollough, 2010).

Diagnostic reference levels are not for regulatory or commercial purposes, not a dose constraint, and not linked to limits or constraints. The objective of a diagnostic reference level is to help avoid radiation dose to the patient that does not contribute to the clinical purpose of a medical imaging task. The objective of a DRL is to help avoid radiation dose to the patient that does not contribute to the clinical purpose of the image. This is accomplished by comparison between the numerical value of the DRL derived from

relevant regional, national or local data and the mean or other appropriate value observed for a suitable reference group of patients or a suitable reference phantom (Hart et al., 2000).

Diagnostic reference levels are supplements to professional judgment and do not provide a dividing line between good and bad medicine (McCollough, 2010).

Diagnostic Reference Levels are values which are usually easy to measure and have a direct link with patient doses. DRLs can be established using a TLD on the patient's skin to measure entrance surface dose including backscatter. If such doses are found to exceed the corresponding reference dose, possible causes should be investigated and corrective action taken accordingly, unless the unusually high doses could be clinically justified (Hart et al ., 2000)

DRLs are therefore established to aid efficient dose management and to optimize patient doses

2.13 Radiation Risk Assessment

A number of national and international bodies have developed radiation risk models in recent years from which it is possible to calculate the lifetime risks of radiation-induced cancer as a function of the age and sex of the exposed person (BEIR VII, 2006; UNSCEAR, 2006). The BEIR VII committee has derived risk models both for cancer incidence and for cancer mortality. The models take into account the cancer site, sex, age at the exposure and attained age. Risk models are presented for leukaemia, solid cancers in some organs and for all solid cancers combined.

For solid cancers,

$$ERR\ (t,e,D) \text{ or } EAR(t,e,D) = \beta s\ D \exp(\gamma e)\ (t/60a)^{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

For leukemia,

$$ERR(t,e,D) \text{ or } EAR(t,e,D) = \beta s\, D(1+\theta) \exp(\gamma e + \delta \log((t-e)/25a) + \varphi e \log((t-e)/25a)) \quad (2.3)$$

Where,

ERR=excess relative risk

EAR= excess absolute risk

e = age exposure in yrs

t = attained age

D= equivalent dose

Bs, γ, n, φ, δ = fitting parameters of the model

The ICRP models was chosen because they are the most recently published of the others. The risk models are based on incidence data from the life span study (LSS) of the Japanese atomic bomb survivors, with follow up from 1958 to 1998 and with DS02 Dosimetry (ICRP, 2007).

In PCXMC, the BEIR relative and absolute risk models are used. The weighted average dose in the other organs and tissues ("weighted remainder") is considered. This weighted average dose used in the risk estimation of "other solid cancers" is calculated as the weighted average dose in organs and tissues that are not given a direct risk estimate. The weighting is done with the tissue weighting factors of ICRP Publication 103, renormalized such that their sum is equal to one. In effect, this involves the assumption that the relative sensitivities of these organs are in proportion to the tissue weighting factors of ICRP 103.

Effective dose (E) provides a single measure of the dose to a reference person (of average age and gender) that is roughly proportional to the total 'radiation detriment' from stochastic effects associated with the exposure. As defined by ICRP, the 'radiation detriment' takes account of

The life lost from fatal cancers and heritable effects, and the reduced quality of life associated with non-fatal cancers and heritable effects (ICRP, 2007).

Both the clinical benefits and the health risks from the radiation exposure will be dependent, inter alia, on the age and sex of the patient, and so to help the clinician balance one against the other for each patient (Wall et al., 2011).

ICRP has not made any specific recommendations on how to derive radiation risks from medical exposures but it has become common practice to convert estimates of E for particular x-ray examinations to radiation risks using the nominal probability coefficients for fatal cancer or aggregated detriment (with or without the risk of severe hereditary disorders), as published by ICRP (ICRP, 2007).

Organ doses are combined with the corresponding organ-specific risk coefficients to estimate the typical risks of radiation-induced cancer for the x ray examinations as a function of the age and sex of the patient.

Excess relative risk (ERR) and / or excess absolute risk (EAR) models were developed for cancer incidence and mortality as a function of age at exposure and sex, for the following 10 specific organs: breast, lung, stomach, colon, red bone marrow (RBM), bladder, liver, thyroid, esophagus and ovary; and also for the other remaining organs together (ICRP, 2007).

CHAPTER THREE

MATERIALS AND METHOD

3.1 Instrumentation

3.1.1 GE mobile Fluoroscopy C-arm unit

A GE mobile fluoroscopy unit of model OEC 9600 with two display monitors and serial number 62-0510 was used in the study with Aluminum equivalent to be 2.0 mm. It was manufactured in December 1998 by GE company.

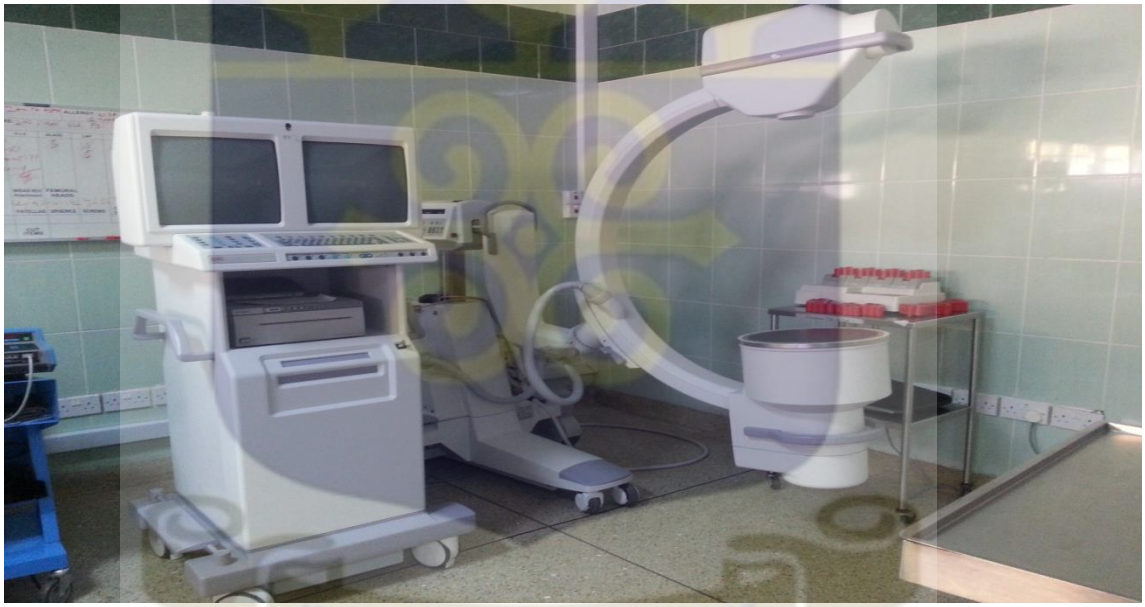

Plate 3.1: Mobile fluoroscopic c arm

3.1.2 GE Portable Plain X-ray Unit

GE Portable x ray Unit model 46-125686G8 with serial number: 2799EX, Maximum Potential: 130 kV, Housing minimum Filtration 0.3 mm. It was manufactured General Electric company in USA in 1995.

Plate 3.2: Mobile x-ray machine

3.1.3 The Thermoluminescent dosimeter (TLD) badge

Effective dose for penetrating radiation is determined by TLD placed on the body. It is comprised of lithium fluoride doped with titanium and magnesium.

Plate 3.3: Single chip TLD in an envelope

3.1.4 The Harshaw TLD 6600 system

The Harshaw TLD 6600 reader system was used to read the TLD chips and the dose received assessed by means of the TLD WinREMS software installed on a dedicated computer interfaced to the reader.

3.1.5 Monte Carlo code PCMXC

Monte Carlo code PCMXC developed by Medical Radiation Laboratory of the Finnish Radiation and Nuclear Safety Authority was used to calculate patient organ and effective doses by imputing recordings of Entrance Surface Dose (ESD) and some parameters from the mobile fluoroscopy and portable plain x ray equipments console. The programme calculates the effective dose with both the present tissue weighting factors of ICRP Publication 103 (2007) and the old tissue weighting factors of ICRP Publication 60 (1991).

3.2 Quality Control Measurement

Quality control measurements were performed to ensure that the x-ray equipments were consistent in their performance. The procedures used have been described below.

3.2.1Tube Output Consistency

The Output consistency of the mobile fluoroscopic (C-arm) and the plain x-ray unit (portable x-ray) were checked using MPD detector (Barracuda) with Ocean software. It was placed at the center of the beam at a distance of 75 cm from the focal spot of the x-

ray tube. The x-ray beam was collimated to the sensitive area of the MPD detector. Different tube current- time was set for a fixed kV and was repeated for kV of 120, 118 and 116 for the C-arms and 60, 70, 80, 90 for the plain portable x-ray unit with varying mAs of 5.0, 4.9, 4.8, and 32, 16, 8 respectively. The software operates by putting values that were recorded divided by the mAs to obtain an output ratio which was later checked for consistency for same kVp. Using the formula $(\max - \min)/(\max + \min)$, the output linearity was obtained from the ratio. Compliance was checked for the values from the acceptance criteria of ≤ 0.1

3.2.2 Half Value Layer

This was done by placing a MPD detector with Ocean software at 75cm at the center of the x-ray beam. The kV was set at120, 118, 116 and 114 for the C-arms and 60, 70, 80, 90 for plain portable x-ray unit with varying mAs of 5.0, 4.9, 4.8, 4.7 4.6 and 32, 16, 8 respectively. The output reading from the MPD detector was recorded after exposure producing appropriate half value layer (in mm) associated with the selected exposure factors. This value was produced based on 50 % the output readings as it fell just below

3.2.3 Tube Potential Accuracy Measurement

Tube voltage and timer accuracy was measured with MPD detector. It was placed 75cm from the focal spot of the x-ray tube exposure parameters were set as that of the tube output consistency. The peak kV reading from the detector after exposures with set parameters was recorded. In addition two other peak voltage readings were recorded with the same exposure parameters. The average was calculated and the percentage error

between the set values on the control console and the measured value with the MPD detector. The deviation percentages were checked with the acceptance criteria of ± 5 %.

3.2.4 Timer Accuracy Measurement

Similar set up for the tube potential accuracy measurement was performed to determine the timer accuracy measurement. Deviation percentages between the measured time and indicated time were calculated and checked for compliance with the acceptance criteria of ± 10 %.

3.3 Data Collection

The Data collected was concentrated on mobile Fluoroscopic C arm and Portable Plain Radiographic machine in operating theatres of an orthopaedic hospital in Greater Accra region of Ghana. The Research Department at the facility approved the study and patient confidentiality by identifying patients with numbers. Patients with ages from birth to 18 yrs were selected for paediatric group and between 18 yrs to 25 yrs for young adults group. The patient selection was made in no particular pattern and included all procedures such as posterior spinal fusion (PSF) with instrumentation and Intramedullary nailing from patients diagnosed of scoliosis, kyphoscoliosis, kyphosis and joint deformities.

The data collection took a period of four months with a total sample size of 50 patients undergoing surgical procedures that uses radiation as a guide.

The procedure is carried out by a surgical team led by senior orthopaedic or neurosurgeon and a radiographer who operates the radiation equipment (C- arm or portable) intermittently to assist in screws, rods and plates placement.

The patients consent and physical parameters such as age, height, sex, BMI and weight were collected when scheduled for surgery. Equipment parameters such as tube voltage, beam on time and current-time product from the equipments console during surgical procedures. Other recorded parameters included part of the body imaged, number of radiographs, projection and image sizes (35 cm x 43 cm, 35 cm x 83 cm and 30.48 cm x 30.48 cm). Source to image distance (SID) which was kept at 100cm and 180cm as well as time taken for procedure completion was also recorded.

Automatic exposure control (AEC) was used in the mobile fluoroscopic c arm and manual parameter selection in the portable radiography machine. Average tube potential (kV) and current time (mAs) was calculated from recorded range. The Data was recorded on a prepared data sheet (Appendix A), compiled and analyzed using Microsoft Excel spreadsheet.

The choice of equipment used for the procedure was surgeon dependent and procedure specific. Events on the rationale behind the use of radiation during the surgical procedure were also recorded for the purpose of optimization.

3.3.1 Radiation Dose Measurement Using Single chip TLD

The TLDs were wrapped in a thin rubber envelope to protect the TLDs from any contamination, and at the same time not to come into view in the final image or produce

any image artifact. The envelope was kept in place at beam entrance site with adhesive tape or cannula tape during the procedure. At least 1 to 3 chips were used during the procedure.

The TLDs were then read using Harshaw 660 reader system at the Radiation Protection Institute (RPI), Ghana Atomic Energy Commission (GAEC). The reader automatically heats the TL material. A photo multiplier measures the TL-light released during the heating of the material from room temperature up to a maximum of 250-400°C. A photomultiplier tube (P.M.T) and an integrating charge measuring system records the information in the form of a glow curve. The glow curve of the TLD is compared and radiation doses deduced.

3.3.1.1 Dose Evaluation from TLD

The dose calibration factor for the dosimeters called Element Correction Factor (ECC) is used as a multiplier with the reader output in nanocoulombs to make the response of each dosimeter comparable to the average response of group dosimeters. The Reader calibration Factor (RCF) is used to convert the raw charge data from the Photomultiplier Tubes (in nC) to Dose D on the TLD card. The Dose is then evaluated by these factors as;

$$Dose = \frac{ECC * charge}{RCF} \quad \text{..... (3.1)}$$

3.3.3 Effective and Organ Dose Estimation Using Monte Carlo code PCMXC

PCXMC is a computer program for calculating patients' organ doses and effective doses in medical x-ray examinations (radiography and fluoroscopy).

Dose calculation in PCMXC is in three stages:

- defining the examination conditions
- performing the Monte Carlo simulation, and
- calculating the organ doses for a specified x ray spectrum and patient input dose.

Based on the stages, the program menu encompasses the Examination data, simulate, *c*ompute doses, and *R*isk assessment for the version used.

Figure 3.1: The main interface of PCXMC

3.3.3.1 The Examination Data interface

The examination Data defines the x-ray examination conditions and the phantom model which will be used in the subsequent Monte Carlo simulation. The patient physical parameters or demographics such as age, height (cm) and weight (kg) was input. Also focus-image distance (which was always 100 cm and 180 cm); 'Xref', 'Yref' and 'Zref' which are the coordinates of an arbitrary point inside the phantom, through which the central axis of the x-ray beam is directed was inserted. The projection angle, the maximum energy in keV (90 in AP projections and 100 in LAT projections) and the number of photons (20,000). The above inputs were used to draw the x ray field and data saved for simulation.

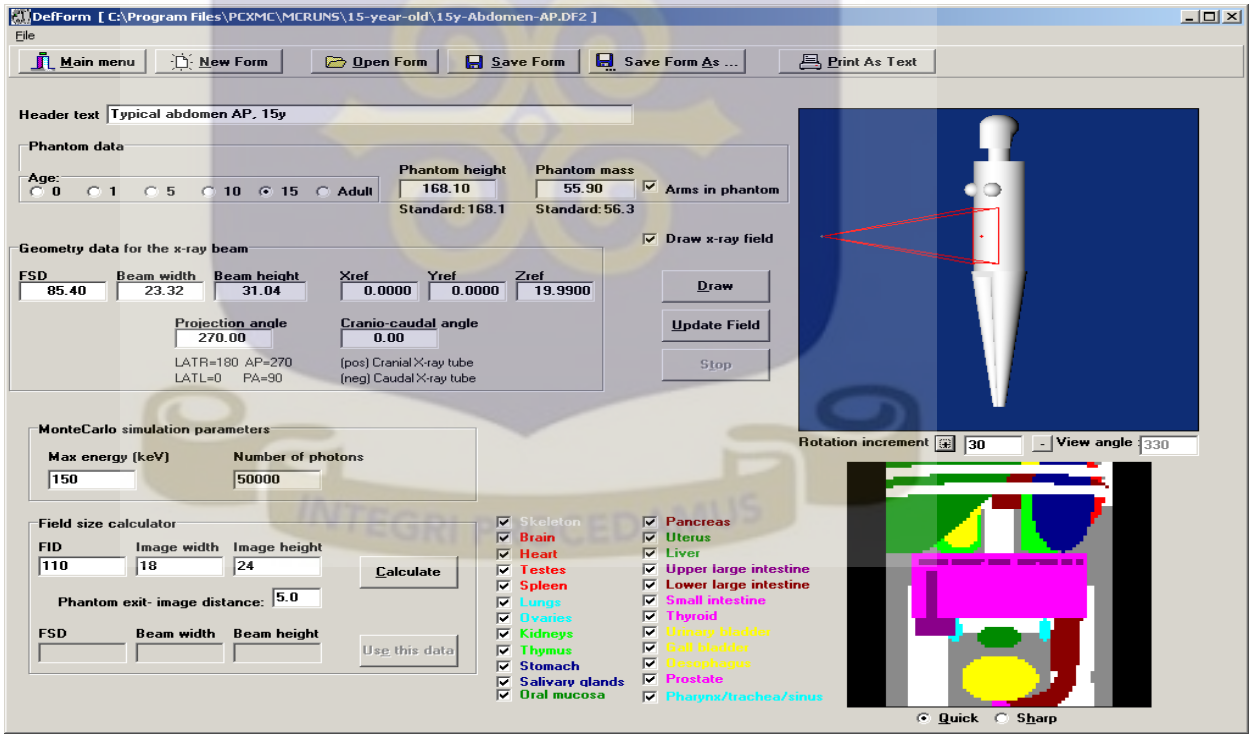

Figure 3.2: Examination data and Patients Information Input Interface of the Monte Carlo Code (PCMXC)

3.3.3.2 Simulation Interface

The simulation interface initiates the actual Monte Carlo simulation. Saved files from the examination data interface can be chosen and with button pressed, the program then simulate these conditions automatically without user interference.

3.3.3.3 Compute Dose Interface

This interface was used in calculating the patient's organ doses in the x ray examination. The saved Monte Carlo simulated data was loaded and the appropriate changes were made in the x ray energy spectrum specified by the x ray tube voltage (kV), anode angle and total filtration. After the spectrum is generated, a displayed form prompting to specify the input dose was done by putting in specifically the, measured air kerma at the phantom entrance point in the centre of the x ray beam (mGy, i.e., incident air kerma) from the TLD.

3.3.3.4 Risk Assessment Interface

This interface is for assessing the risk of radiation-induced cancer death. The program did not assess genetic harm to the Gonads. The equivalent organ dose values were fed either manually or by letting the program sum the organ doses from the selected dose files. Exceptionally high doses were coloured.

In order to assess the risk of radiation-induced cancer death for a given patient, the 'Age', 'Gender' and mortality 'Statistics' (Euro-American: this statistics better suites that of Africans) of the patient is entered. The risk assessment is based on the equivalent doses

of active bone marrow, breast, colon, liver lungs ovaries, prostate, stomach, thyroid, uterus, urinary bladder and 'weighted remainder'. The doses were entered manually from the average organ doses obtained for the individual procedures considered for the study.

After all input data (age, gender, statistics and equivalent organ doses) have been specified, the risk assessment is performed by clicking the 'Calculate risks' button. The risk estimate shows the exposed person's risk of exposure induced cancer death (REID), the expected length of his/her remaining life, the mean loss-of-life (LLE). The window also shows a bar chart of the probability (the site-specific REID value) of various radiation-induced cancers.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Quality Control Measurement

Table 4.1: Summary of Results from Quality Control Measurement for portable plain x-ray unit

Parameter	Range tested	OLV	SD (%)	criteria	Remarks
kV accuracy	(60,70,80,) kVp	-	4.3	SD ≤ ± 6 %	Pass
Output consistency	(60,70,80,) kVp	-	-	mR / mAs should be constant	Pass
Output linearity	(60,70,80,) kVp	0.08	-	OLV < 0.1	Pass
Timer accuracy	(100-25) ms	-	0.3	CV≤ ± 10 %	Pass
HVL at 80kVp = 2.96 mm Al					

SD = standard deviation OLV= output linearity value

The performance criteria of the key equipment parameter for the mobile plain x-ray were found to be within the reference level. The maximum deviation from the indicated voltage on the console was 4.3 % which was acceptable. Tube output was consistent with the output linearity to be 0.005. The measured exposure time deviated from the indicated value 0.3%. The HVL was 2.96 mm Al at 80 kVp which was acceptable as it was not below the limit of 2.3 mm AL at 80 kVp.

Table 4.2: Summary of Results from Quality Control Measurement for mobile fluoroscopic unit

Parameter	Range tested (kVp)	OLV	SD (%)	Criteria	Remarks
kV accuracy	(120,118,116)	-	3.2	SD ≤ ± 6 %	Pass
Output consistency	(120,118,116)	-	-	mR / mAs should be constant	Pass
Output linearity	(120,118,116)	0.1	-	OLV ≤ 0.1	Pass

HVL = 4.56 mm Al at 160 kVp

SD = standard deviation OLV= output linearity value

The performance criteria of the key equipment parameter for the mobile plain x-ray was found to be within the reference level as shown in Table 4.2. The maximum deviation from the indicated voltage on the console was 3.2 % and was acceptable. Tube output was consistent with the output linearity to be 0.1. The HVL was 4.56 mm at 160 kVp which was acceptable as it was below the limit of 2.3 mm Al at 80 kVp.

4.2 Demographic Characteristics

4.2.1 Diagnosis Presented by Patients

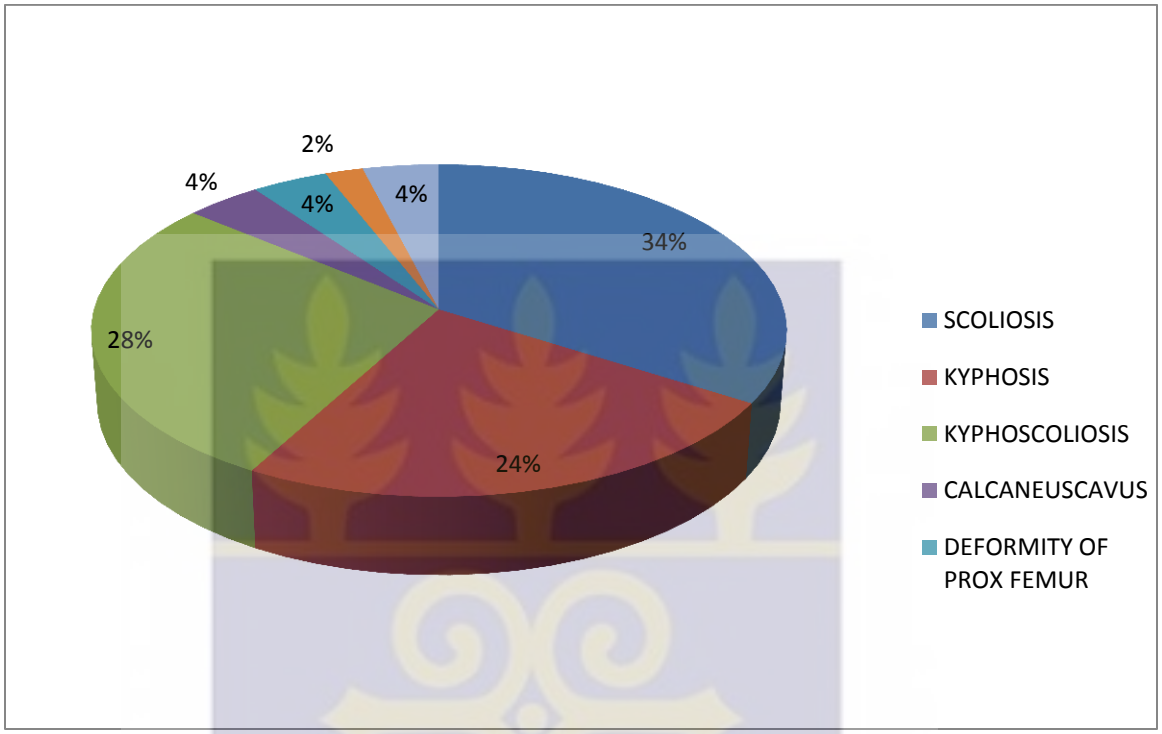

Figure 4.1: Distribution of Diagnosis presented by patients prior to surgery

For surgical procedures, diagnosis play a major role as planning, instrumentation, events and care before, during and after such procedures depends highly on it. Figure 4.1 above, demonstrates the diagnosis or medical condition that was presented by the patients based on which the surgical procedures were done. The conditions were spinal and joint deformities and were expected due to their young age. Scoliosis (idiopathic, early onset, adult scoliosis and congenital) recorded the majority with 34% (n=17) of the patients followed by Kyphoscoliosis with 28% (n=14) and Kyphosis forming 24% (n=12). Post PSF revision, calcaneuscavus and proximal femur deformity also recorded 4% (n=2) each and disc Prolapse with 2% of the patient population.

4.2.2 Patient Group and Respective Mode of Procedures

Table 4.3: Summary of procedures and their respective patient age group and mode of procedure.

Procedure	No. of Patient Age Group		No. of Procedure Mode	
	Paediatric (0-18yrs)	Young Adult (19-25yrs)	Fluoroscopy	Plain Radiography
PSF (Single Stage)	24	7	2	31
PSF (Two Stage)	1	4	0	7
Growing Rod	8	0	1	6
Revision PSF	1	1	0	2
Osteotomy of lower Extremity	2	0	2	0
Intramedullary Nailing of Femur	2	0	2	0
Total	**38**	**12**	**7**	**46**

From Table 4.3, Out of the 50 patients, 38 of them were paediatrics and 12 young adults. 7 patients underwent surgical procedures guided by fluoroscopy and 46 patients using plain x ray as a guide. 2 patients used both x-ray and fluoroscopy as a guide and that was as results of surgeons' decision on the radiography mode to use. The procedures were mostly correctional ones as the medical conditions presented most was abnormalities. Posterior Spinal Fusion (single stage) recorded the highest number of the patient population. Surgical procedures were largely guided by plain x-rays.

4.2.3 Gender Distribution

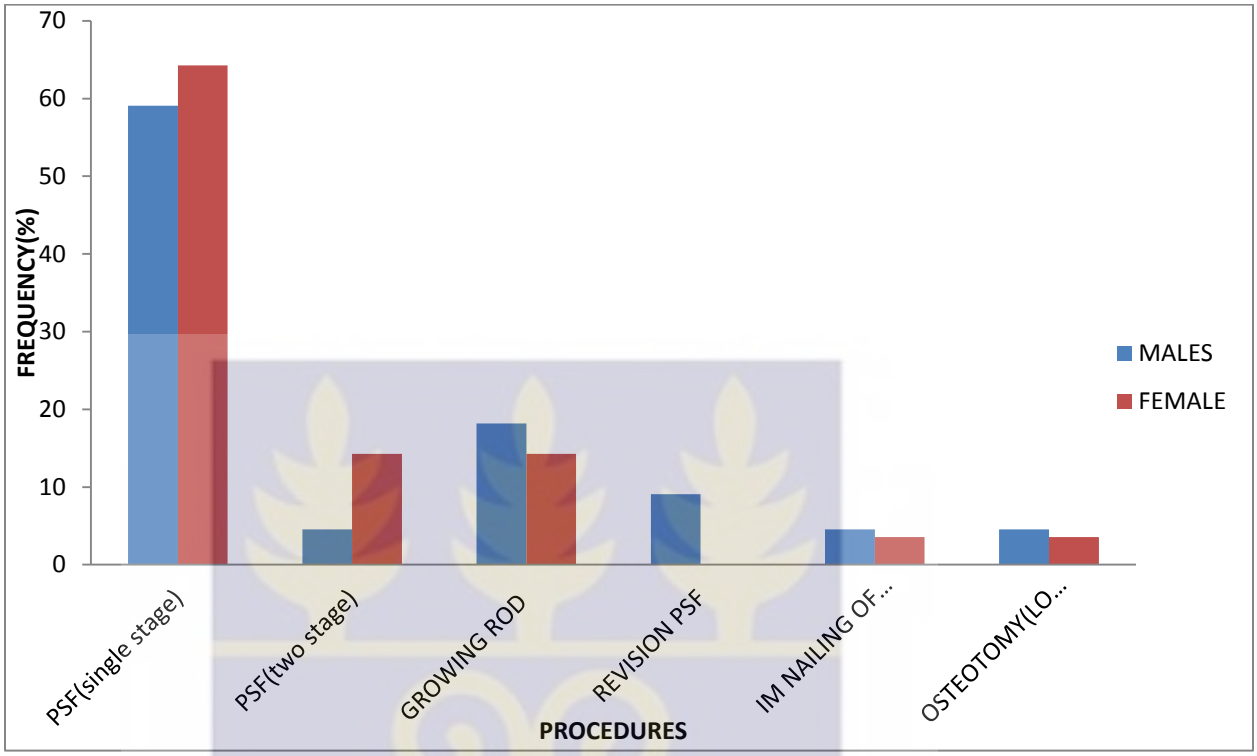

Figure 4.2: Gender Distributions among Patients for Various Surgical Procedures

From Figure 4.2, 59 % (n=13) of the male patients (n=22) used in the study underwent PSF (single stage) with 64 % (n=18) accounting for the female patients (n= 38). Likewise 5 % (n=1) of male and 15 % (n=1) females for PSF (Two stage), 18 % (n=4) males and 14 % (n=4) females for Growing Rod, 5 % (n=1) males and 4 % (n=1) females for both IM Nailing (femur) and Osteotomy (lower extremity). However no female patient was recorded for Revision PSF with 9 % accounting for males. In general, the female population was higher with 56 % corresponding to 38 patients and 44 % males corresponding to 22 patients. Gender consideration is important as it has influence on radiation risk and dose due to sensitivity or vulnerability difference with the sexes.

Females are more vulnerable than males and from the results, females recorded the higher population.

4.2.4 Distribution of Age

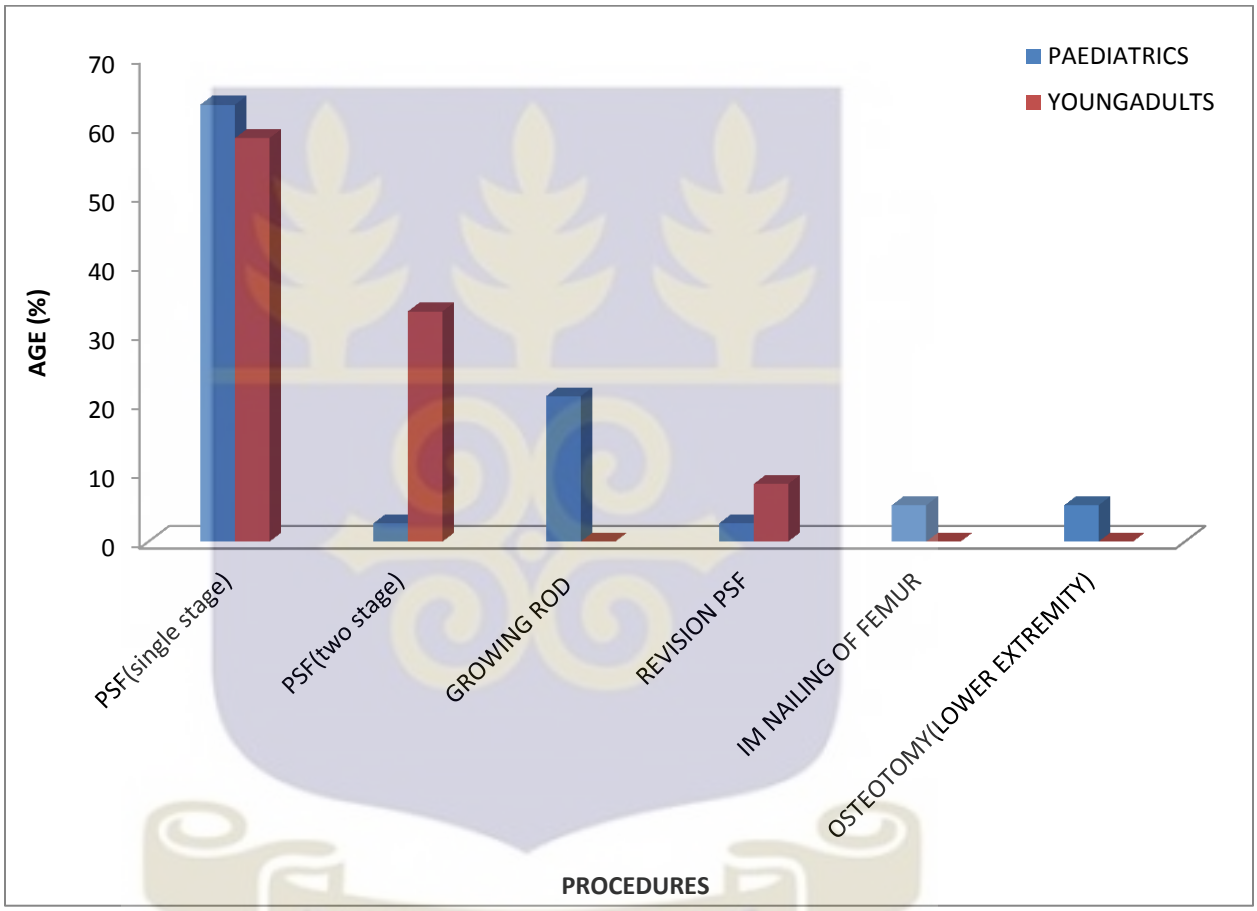

Figure 4.3: Age Distribution among Patients for Various Surgical Procedures Understudy

One of the parameters that aid in decision on the choice of surgical technique (procedure) to be used on patient is age. Also younger aged persons are more sensitive to radiation than older aged persons. As shown in the graph above (Figure 4.3), PSF (Single Stage) recorded 63 % (n=24) of pediatric patients and 58 % (n=7) of young adult patients. Also

PSF (Two stage) recorded 3 % (n=1) of paediatrics and 33 % (n=4) young adult and 3 % (n=1) of paediatrics and 8 % (n=1) of young adult population. However Growing Rod Instrumentation, IM Nailing(femur) and Osteotomy (lower extremity) recorded 0 % of young patients and 21 %, 5 %, 25 % respectively. Growing Rod uses implants that work controlling the spinal deformity while allowing the spine to grow until the child reaches appropriate size for a more permanent solution and therefore recording 0 % for young adults.

4.3 Estimated Mean Organ Doses

4.3.1 Mean Organ Dose for Posterior Spinal Fusion (Single Stage)

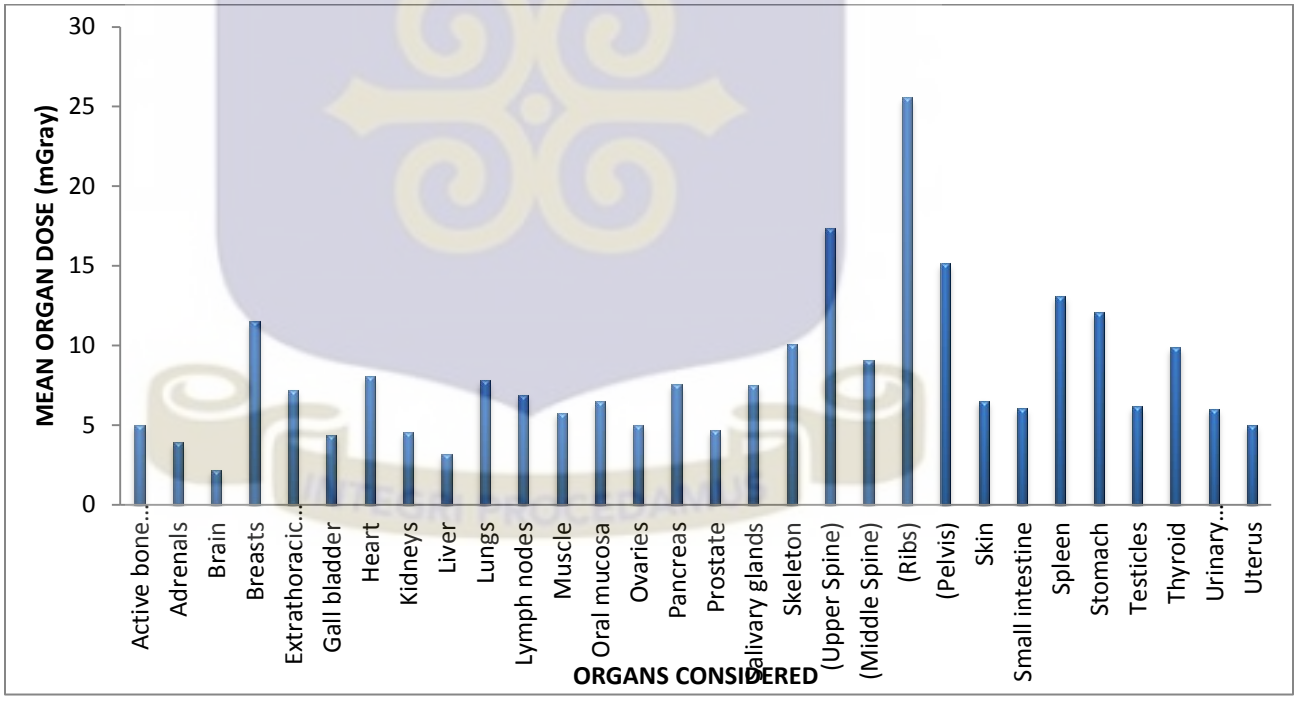

Figure 4.4: Mean Organ Dose Distribution for Posterior Spinal Fusion (PSF) Single Stage and Organs Considered.

As shown in Figure 4.4, the Ribs received the highest dose of 24.15 ± 3.22 mGy for bony organ tissue and the spleen recording the highest soft tissue organ dose of 9.64 ± 2.05 mGy. The breast as one of the sensitive organs and the stomach received the third and second highest soft tissue organ dose of 11.49 ± 1.22 and 12.08 ± 1.27 mGy. This might be as results of the procedure performed in the thoracolumber region of the body and high tissue weighting factor for the above mentioned soft tissue from ICRP 103 (0.12) used in the PCMXC 2.0. Female patients undergoing this surgical procedure are of concern due to the sensitivity of the breast. As a spine procedure and taking the whole spine into consideration, the upper spine received the highest radiation dose of 17.37 ± 2.29 mGy possibly resulting from the smaller size and increase in density along the vertebral column.

4.3.2 Mean Organ Dose for Posterior Spinal Fusion (Two stage)

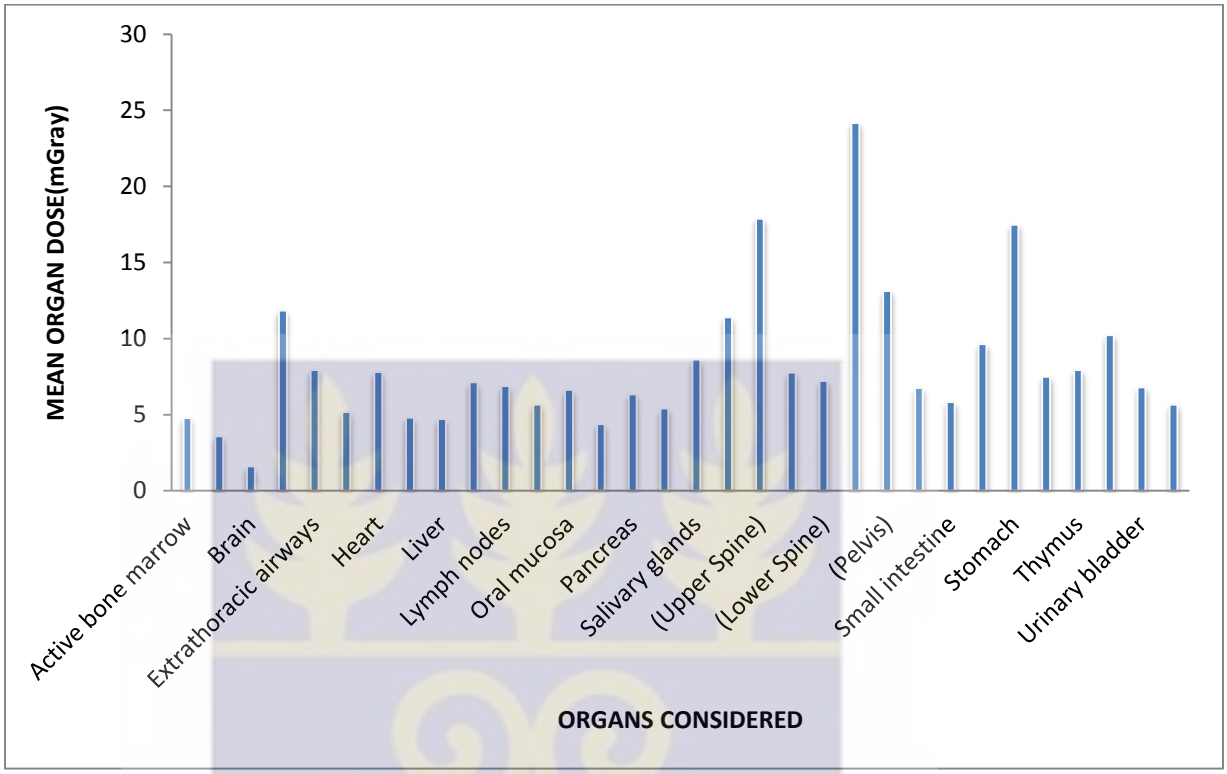

Figure 4.5: Mean Organ Dose Distribution for Posterior Spinal Fusion (PSF) Two Stage and Organs considered

From Figure 4.5, the Ribs received the highest radiation dose of 24.15 ± 3.22 mGy. For the soft tissue organs, the stomach recorded 17.47 ± 1.14 mGy followed by the breast with 11.83 ± 1.30 mGy and the thyroid with 10.22 ± 1.21 mGy which are sensitive organs. The upper spine recorded the second highest bony tissue organ with 17.88 ± 2.78 mGy followed by the pelvis with 13.12 ± 2.07 mGy. This trend of observation was as a result of the above organs position within the thoracolumber region of the patient where the procedure is performed.

4.3.3 Mean Organ Dose for Revision Posterior Spinal Fusion

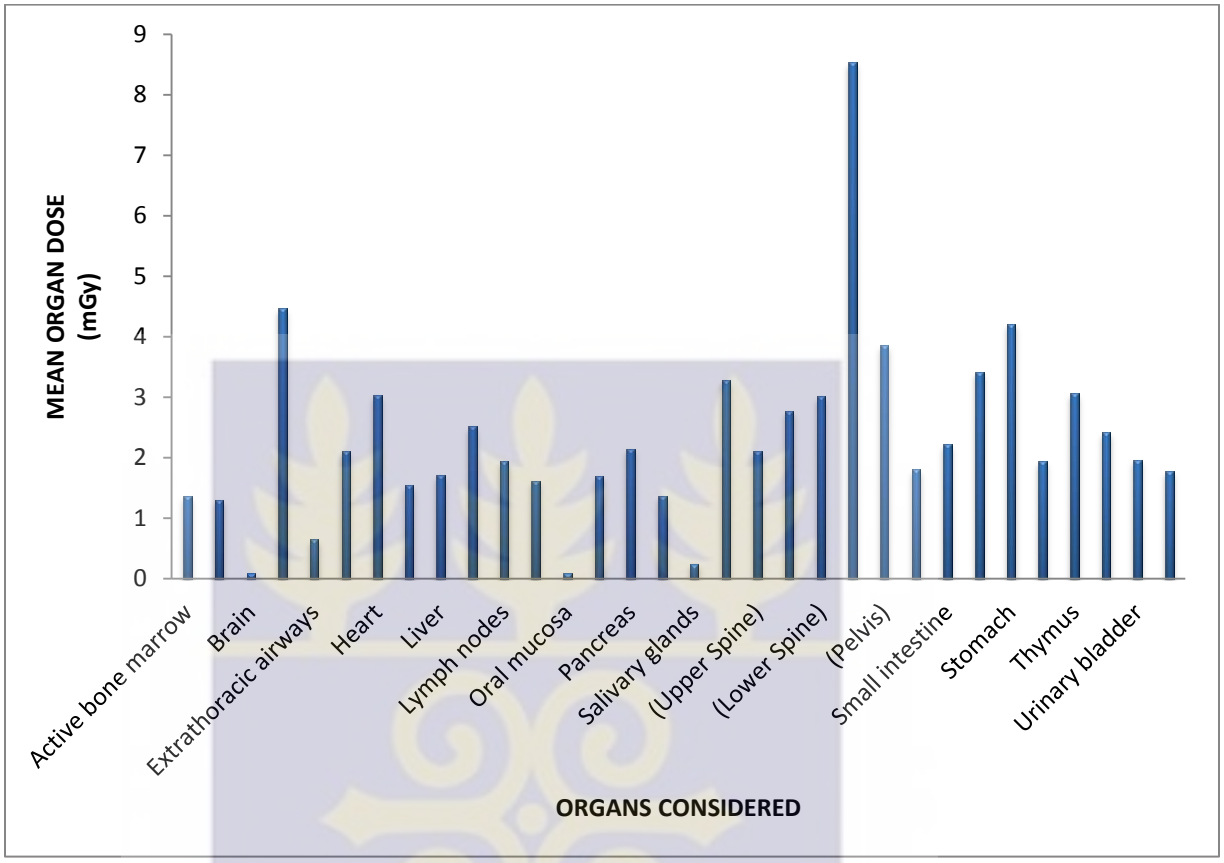

Figure 4.6: Mean Organ Dose Distribution For Revision Posterior Spinal Fusion (PSF) and Organs Considered.

As shown in Figure 4.6, the Ribs received the highest radiation dose of 8.52 ± 0.67 mGy followed by breast with 4.46 ± 0.21 mGy. The stomach and the pelvis followed with 4.21 ± 0.03 mGy and 3.85 ± 0.56 mGy respectively. The gonads (Testicles and ovaries) also received 1.93 ± 1.17 mGy and 0.096 ± 0.019 mGy with ovaries lower than the testicles. The lower spine however received the highest radiation dose of 3.01 ± 0.02 mGy as compared to the upper and middle spine. This however might have resulted from the revision concentrated more to the lower spine region.

4.3.4 Mean Organ Dose for Growing Rod

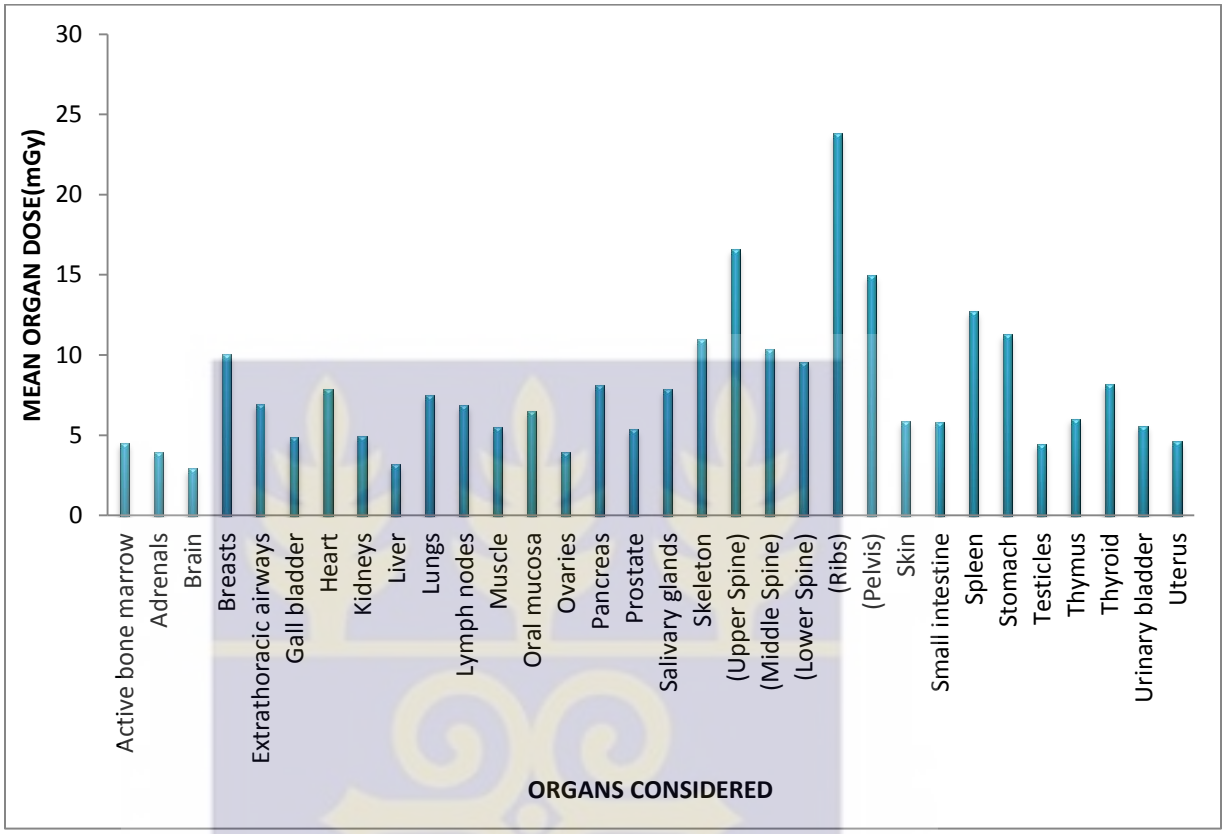

Figure 4.7: Mean Organ Dose Distribution For Growing Rod And Organs Considered.

From Figure 4.7, the Ribs received the highest radiation dose of 23.81 ± 3.84 mGy followed by the upper spine and pelvis with 16.59 ± 3.57 mGy and14.96 ± 2.69 mGy respectively for the bony organs. The spleen however recorded a higher dose for the soft tissue organ dose with 12.72 ± 2.36 mGy, the stomach secondly with 11.29 ± 1.86 mGy and the breast thirdly with 10.04 ± 1.28 mGy. This was as result of the radiation directed towards the thoracic and abdominal region. The Testes recorded 4.44 ± 0.80 mGy higher than the ovaries with 3.93 ± 0.62 mGy accounting for the male and female gonads.

4.3.5 Mean Organ Dose for Intramedullary Nailing of the Femur

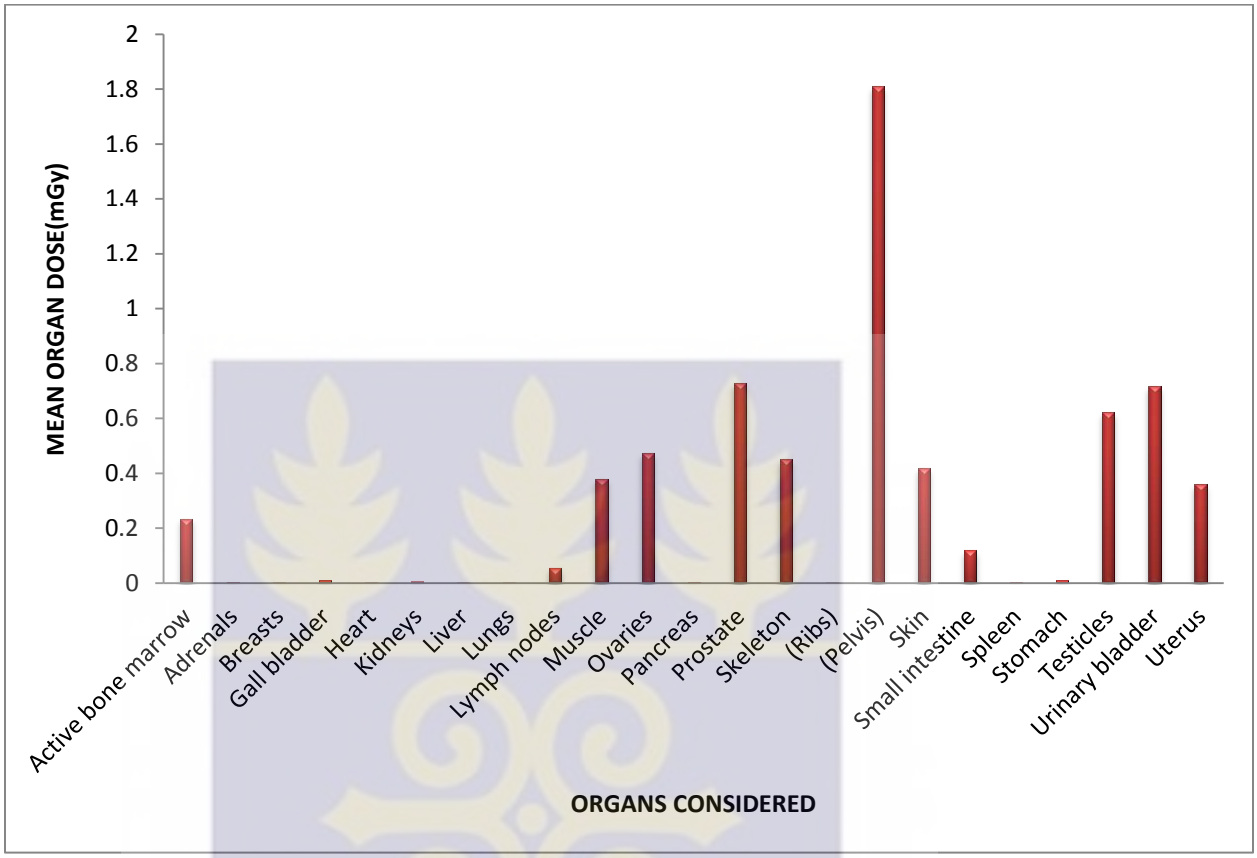

Figure 4. 8: Mean Organ Dose Distribution for Intramedullary (IM) Nailing Of Femur and Organs

From Figure 4.8, pelvis received the highest radiation dose of 1.80 ± 0.96 mGy. The prostate received the second highest radiation dose of 0.72 ± 5.13E-06 mGy followed by the urinary bladder with 0.71 ± 0.35 mGy and the gonads (Testicles and Ovaries) receiving 0.62 ± 0.22 and 0.47 ± 3.34E-05 mGy respectively. This trend of observation was as a result of the procedure performed around the pelvic region and therefore radiation directed towards that area. However organs like the breast, stomach and spleen recorded a negligible radiation dose. This might resulted from the fact that the surgical procedure was performed around the pelvic region and such organs were distal from the procedure site.

4.3.6 Mean Organ Dose for Osteotomy of lower Extremity

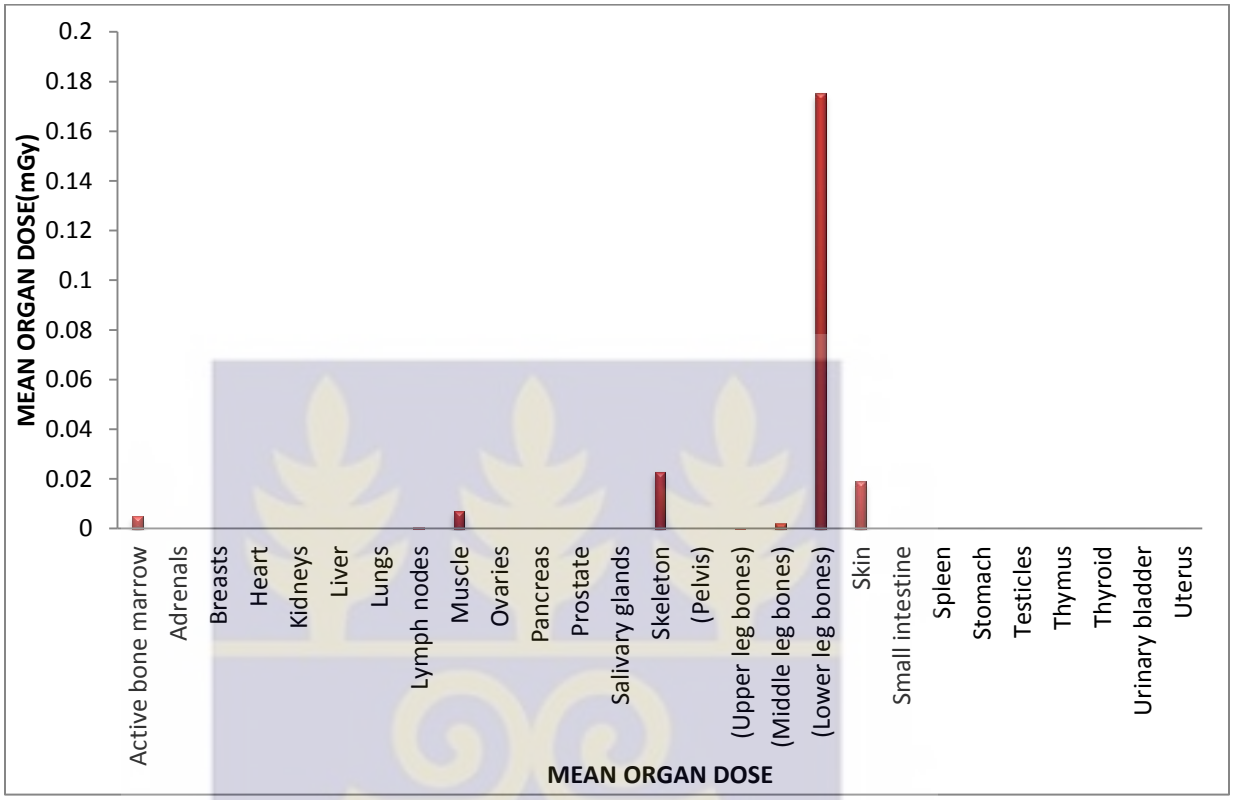

Figure 4.9: Mean Organ Dose Distribution for Osteotomy of the Lower Extremity and Organs

From Figure 4.9, the lower leg bones recorded the highest radiation dose with 0.17 ± 0.08 mGy followed by the skeleton with 0.02 ± 0.14 mGy. The skin received the third highest radiation dose of mGy followed by the muscle and the active bone marrow with 0.007 ± 0.003 mGy and 0.004 ± 0.003 mGy respectively. The sensitive organs like the gonads and other internal organs recorded a negligible dose. This was however expected as procedure was done at the lower extremity. The gonads and other internal organs received a negligible doses resulting from distal position of their anatomical site to the site of the surgical procedure.

4.4 Comparison on Number of Radiographs from Procedures

4.4.1 Mean Number of Radiographs from specific Procedure

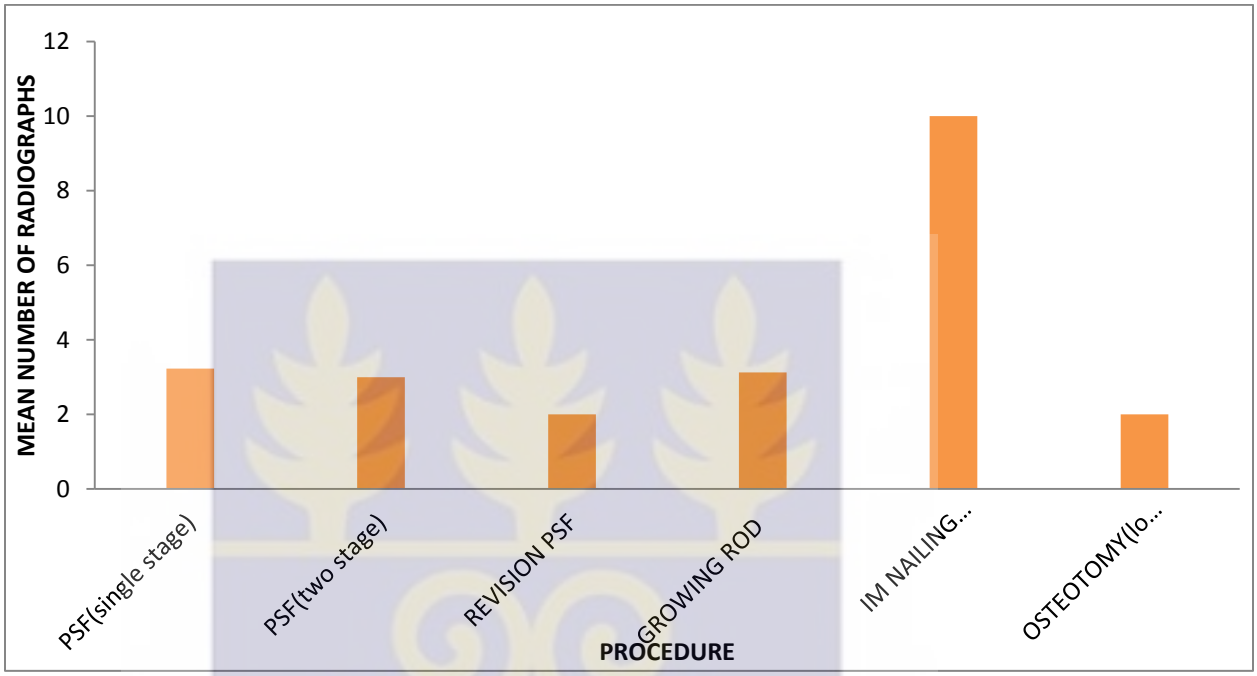

Figure 4.10: Number of Radiographs taken per patient for specific procedures

From Figure 4.10, the number of images taken per patient was higher in IM Nailing of Femur. This observation was as a result of aiding in position of guide wires and strategic placement of screws to prevent interference with nails by the surgeon. The spine procedures (PSF single stage, PSF two stage and Growing Rod) recorded an average of 3 radiographs per patient for a procedure. Revision PSF however recorded an average of 2 radiographs which might be as results of patient coming in for procedure with an existing instrumentation but with a complication.

4.4.2 Mean Number of Radiographs from Spinal Procedure (Plain x ray guided)

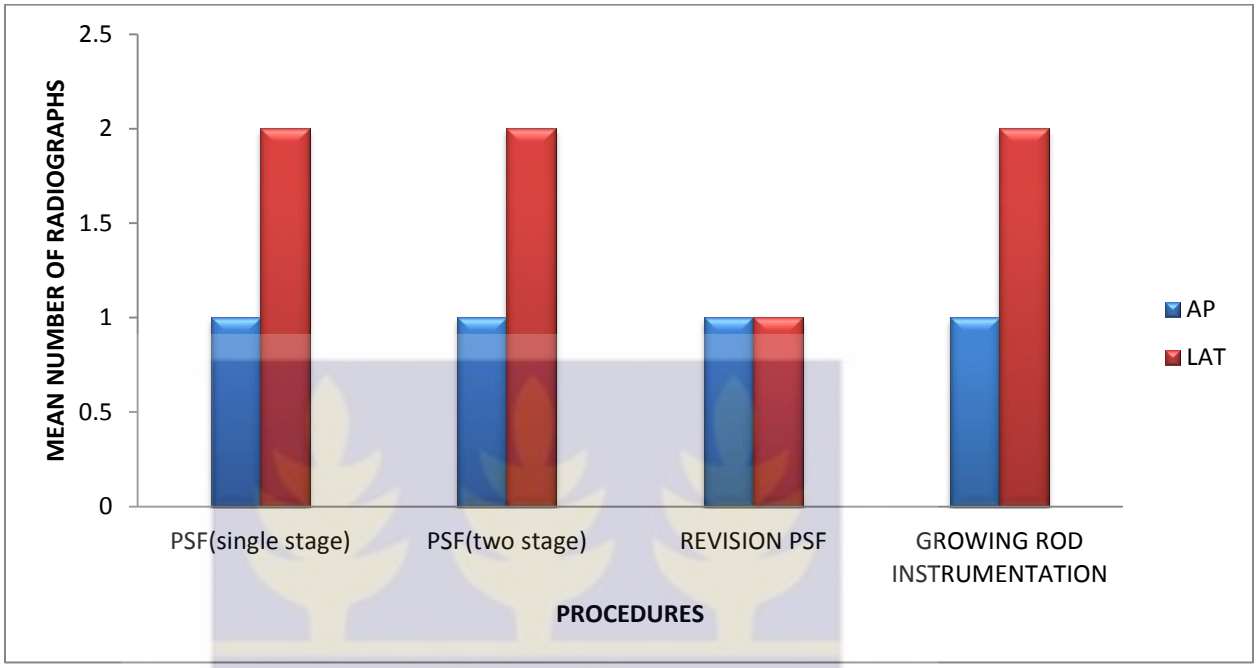

Figure 4.11: Number of radiographs from spinal procedures per patient

Radiographic projections influence equipment exposure factor selection which in turn influences the radiation exposure. AP view is normally associated with lower exposure as compared to Lateral view.

As shown in the graph above (Figure 4.11), each procedure recorded at least an AP radiograph and an average of 2 radiographs for lateral projection. The lateral recorded higher as a result of lateral needed by surgeons during screw placement and location of spinal levels.

4.5 Technique factors used in Surgical Procedures

4.5.1 Mean kV and mAs used per Procedure

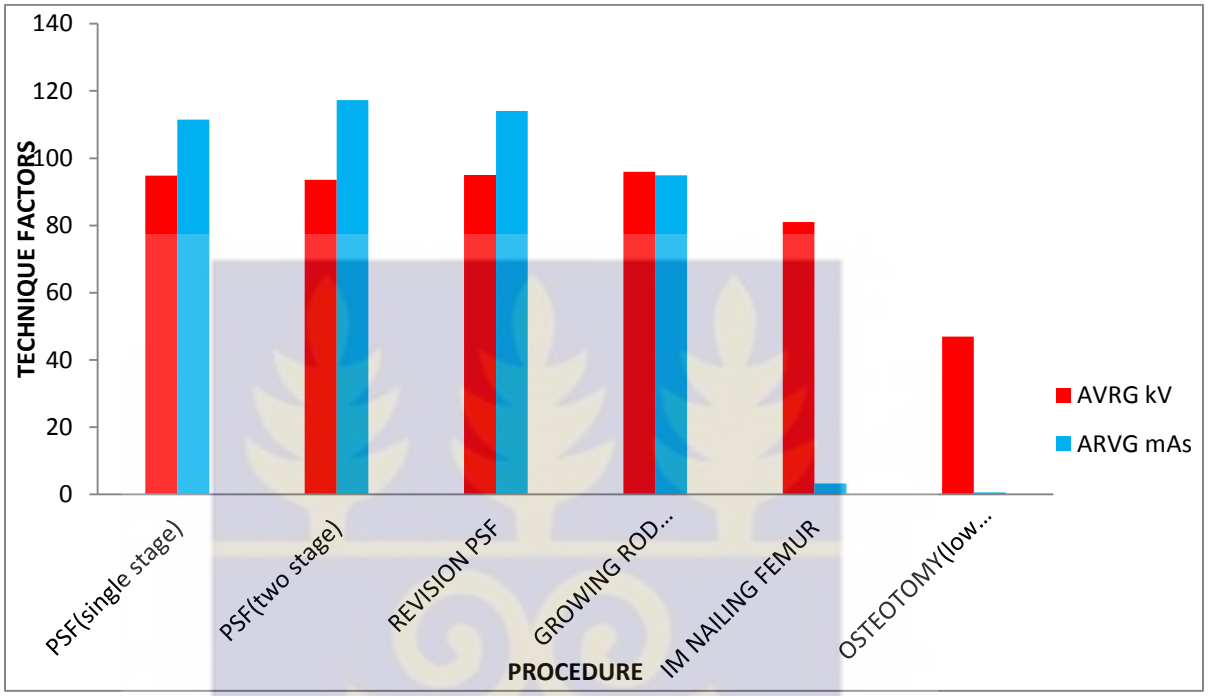

Figure 4.12: Average kV and mAs used per patient for a procedure

From Figure 4.12, Growing Rod recorded the highest kV of 96 followed by PSF (single stage) and revision PSF with kV of 95. PSF (two stage) recorded a kV of 93. IM Nailing (femur) and Osteotomy of the lower extremity recorded a rather lower kV of 81 and 49 respectively. This might be due to the smaller thickness of the body part undergoing the procedure. PSF (two stage) however recorded the highest mAs of 117.25 with Osteotomy recording almost a negligible mAs of 0.65. This observation could also be as results of the reason stated above.

4.5.1 Mean Fluoroscopic Beam on Time per Procedure

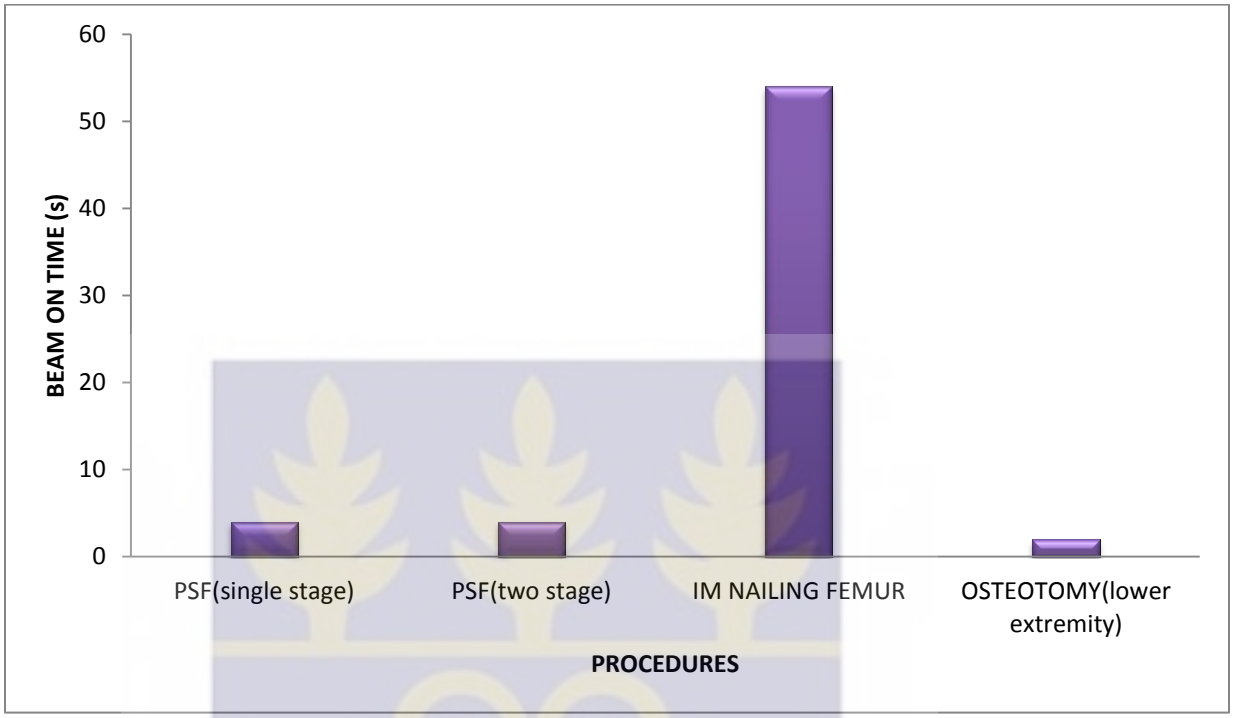

Figure 4.13: Mean Fluoroscopic beam on time per procedure

As shown in Figure 4.13, IM Nailing of the femur recorded the highest beam on time. This might resulted from the procedure been solely fluoroscopic and the need for imaging intensifier in all stages of the procedure. PSF(single stage) and PSF (two stage) recorded equal and lower time possibly due to its combination with plain x-rays and fluoroscopic usage been surgeon dependent. Osteotomy of lower extremity recorded the lowest possibly due to the procedural stages not been solely dependent on the use of image intensifier.

4.6 Mean Effective Doses and Measured Entrance Surface Dose

4.6.1 Estimated Mean Effective Dose and Measured Entrance Surface Dose

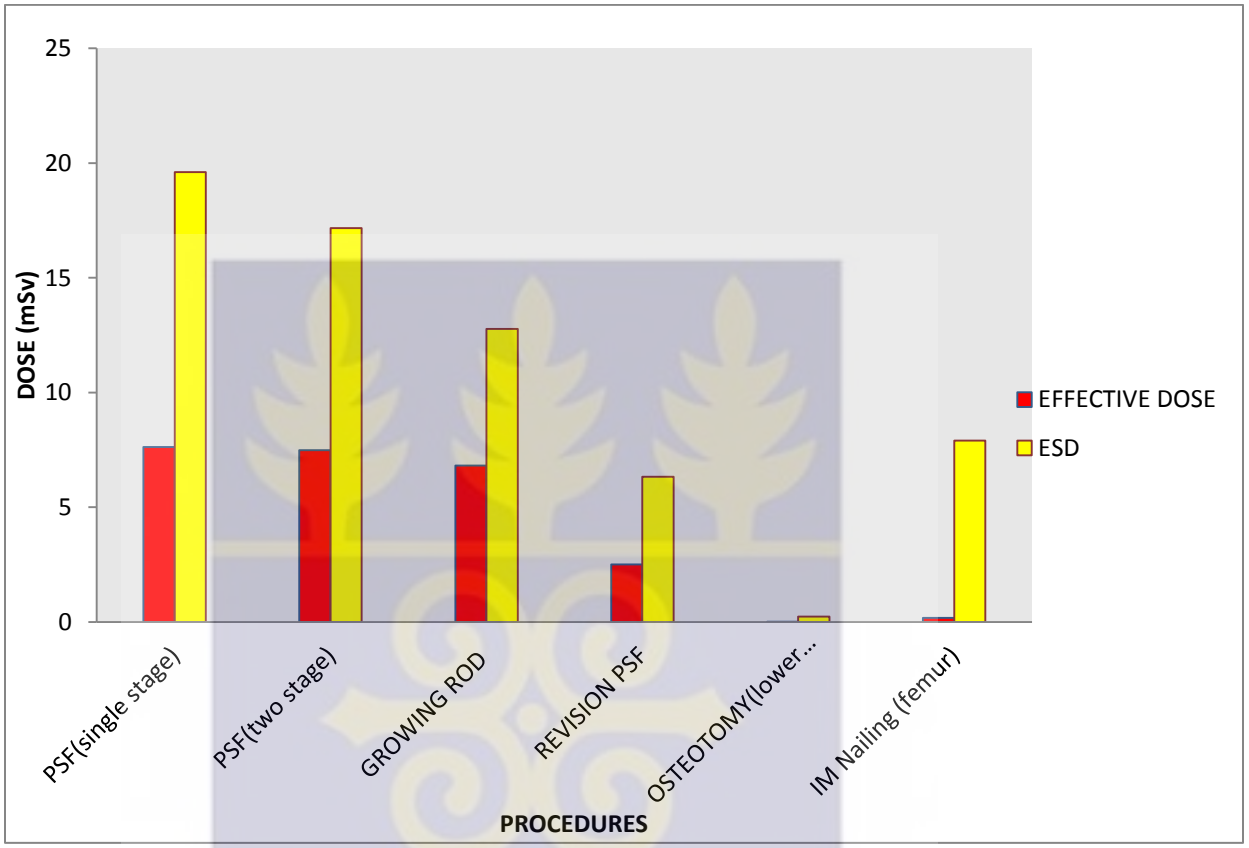

Figure 4.14: Estimated Mean Effective Dose and ESD per procedure

From Figure 4.14, the measured Mean ESD for PSF (single stage) was 19.61 ±1.1.9 mSv accounting for the highest radiation dose. It was followed by PSF (two stage) with17.17 ± 1.98 mSv, Growing Rod with 12.77 ± 2.73 mSv, IM Nailing (femur) with 7.91 ± 4.31 mSv, Revision PSF with 6.33 ± 0.07 mSv and lastly Osteotomy (lower extremity) with 0.23 ± 0.10 mSv. Similarly, the effective dose followed with PSF (single stage) recording 7.62 ± 0.84 mSv, PSF (two stage) with 7.48 ± 1.0 mSv, Growing Rod with 6.82 ± 0.99 mSv, Revision PSF with 2.50 ± 0.27 mSv, IM Nailing (femur) with 0.18 ± 0.09 mSv and Osteotomy (lower extremity) with 0.001 ± 0.06E3 mSv. Patients

undergoing spinal procedures receives higher dose compared to other procedures as a results of the thickness of the body part understudy. Also procedures guided with plain x ray recorded higher dose compared to fluoroscopic guided procedures. This trend of observation might be as a result of Automatic Exposure Control in fluoroscopic equipment as compared to manual selection for plain x ray which based on operator's discretion, the thickness of the body part and the area receiving the radiation. ESD was higher than Effective dose as Patient dose is often described by the patient's entrance surface dose, which is measured on the patient's skin at the centre of the x-ray beam.

4.6.2 Mean ESD and Effective Dose to Patient Group

Table 4.4: Mean ESD and Effective dose to Patient Group Undergoing PSF (Single Stage)

DOSE (mSv)	PAEDIATRIC	YOUNG ADULT
ESD	18.23 ± 2.15	24.32 ± 4.04
EFFECTIVE	7.83 ± 1.03	6.88 ± 1.22

From Table 4.4, PSF (single stage) which recorded the highest number of patients, recorded a higher mean ESD for young adult and a lower Effective dose as compared to Paediatrics with a lower ESD and a higher Effective dose. This was as a result of larger thickness and higher exposure needed to produce quality images for young adult patients as compared to paediatrics.

4.7 Risk Assessment

4.7.1 Risk of exposure induced cancer death (REID)

Table 4.5: Risk of exposure induced cancer death (REID) from all cancer type for the procedures.

Procedure	Mean age at exposure (years)	Sex	Risk of exposure-induced cancer death (%)
Posterior Spinal Fusion - Single Stage	15	Female	0.0755
		Male	0.0409
Posterior Spinal Fusion-Two Stage	19	Female	0.0647
		Male	0.0348
Growing Rod	8	Female	0.0954
		Male	0.0500
Revision PSF	14	Female	0.0238
		Male	0.0123
Osteotomy of lower Extremity	14	Female	0.0000205
		Male	0.0000194
Intramedullary Nailing of Femur	14	Female	0.00147
		Male	0.00121

Risk of radiation exposure induced cancer death from any cancer for all the procedures considered for the study has been shown in Table 4.5. The risk assessment was done for both male and female patients since the risk models according to BEIR for the sexes vary. For all the risk of exposure induced cancer death values, the female values are more than male's. This is mainly due the high risk factors associated with females dues to their vulnerability to radiation exposure and hence cancer deaths.

The mean age at exposure for all the procedures were considered as well since BEIR risk models takes into consideration the age at exposure of the patient. The lowest mean age

at exposure is 8 years for growing rod instrumentation procedure and the highest mean age at exposure is 19 years for Posterior Spinal Fusion-Two Stage procedure.

Generally, the procedure with the highest risk of exposure induced cancer death from Table 4.3 is growing rod. This is followed by posterior spinal fusion -single stage, posterior spinal fusion -two stage, revision- posterior spinal fusion, Intramedullary nailing of femur and Osteotomy of extremity accordingly. This is because generally, risk increases with increase in organ doses and lower mean age of exposure. The recorded highest risk of exposure induced cancer death for growing rod instrumentation procedure for female is 0.0954 %. This means female patients with the mean age of 8 years undergoing growing rod procedure at the facility has the probability of 9.54 patients out of 10,000 patients die from any cancer due to radiation exposure. The recorded lowest risk of exposure induced cancer death for Osteotomy of extremity procedure for male is 0.0000194 % i.e. male patients with the mean age of 14 years undergoing Osteotomy of extremity procedure at the facility have the probability of 1.94 patients out of 10,000,000 patients die from any cancer due to radiation exposure.

4.7.2 Expected length of reaming life and loss of life expectancy

Table 4.6: Expected length of reaming life and loss of life expectancy for the procedures in the study.

Procedure	Mean age at exposure (years)	Sex	Loss of life expectancy (days,*hours)	Expected length of remaining life (years)
Posterior Spinal Fusion (Single- Stage)	15	Female	7.4	64.8
		Male	3.5	59.4
Posterior Spinal Fusion (Two- Stage)	19	Female	6.6	60.9
		Male	2.9	55.6
Growing Rod	8	Female	9.1	71.7
		Male	4.5	66.3
Revision Posterior Spinal Fusion	14	Female	2.2	65.8
		Male	1.0	60.4
Osteotomy of lower Extremity	14	Female	0.1*	65.8
		Male	0.1*	60.4
Intramedullary Nailing of Femur	14	Female	4.2*	65.8
		Male	2.9*	60.4

Loss of life expectancy and the expected length of remaining life for patients undergoing the considered procedures are shown in Table 4.6. Generally, the loss of life expectancy due to radiation exposure for female is more than that of male. The same can be said for expected length of remaining life. This is because of the high risk factors used by BEIR for females than for males due to the vulnerability of women to radiation exposure than men.

The highest loss of life expectancy (LLE) due to radiation exposure is growing rod instrumentation procedure and this is followed by posterior spinal fusion -single stage, posterior spinal fusion -two stage, revision- posterior spinal fusion, Intramedullary nailing of femur and Osteotomy of extremity procedure accordingly. This is because

generally, organ doses due to the procedures increases in that order. The highest LLE due to exposure is 9.1 days for growing rod instrumentation procedure for female i.e. for patient with a mean age of 8 years, loses 9.1 days from their life expectancy had the patient not undergone the procedure. The lowest LLE due to radiation exposure is 0.1 hours for Osteotomy of extremity procedure for both sexes i.e. for patient with a mean age of 14 years, losses 0.1 hours from their life expectancy had the patient not undergone the procedure.

The highest expected length of remaining life (ELL) after radiation exposure is 71.7 years for female patients undergoing growing rod instrumentation procedure when age at exposure is 8 years. Revision- posterior spinal fusion, Intramedullary nailing of femur and Osteotomy of extremity procedures recorded the second highest ELL after radiation exposure of 65.8 years for female patients undergoing these procedures when age at exposure is 14 years. The third highest is 64.8 years for female patients undergoing posterior spinal fusion -single stage when age at exposure is 15 years. Lastly is 60.9 years for female patients undergoing posterior spinal fusion-two stage when age at exposure is 19 years. The ELL for the male patients is in the same order but lower values.

Table 4.7: Radiation induced cancer death for specific cancer type for Posterior Spinal Fusion-Single stage.

Cancer Type	Risk of exposure induced cancer death- Female (%)	Risk of exposure induced cancer death- Male (%)
Leukaemia	0.002560	0.003320
Breast cancer	0.019600	-
Colon cancer	0.001290	0.005510
Liver cancer	0.000564	0.000833
Lung cancer	0.028000	0.013100
Ovary cancer	0.001810	-
Stomach cancer	0.006110	0.004480
Bladder cancer	0.002710	0.002080
Other cancers	0.012900	0.011600

(-) value not available

Risk of exposure induced cancer death for posterior spinal fusion- single stage procedure for specific cancer types is shown in Table 4.7. It can be seen that the risk of exposure induced cancer death in males is higher than females for leukaemia, colon and liver specific cancer sites. This is because these cancers are more prevalent in males than females and hence high risk coefficient factors in the BEIR risk model. The risk exposure induced caner death in females is higher than males for lung, stomach, bladder and other cancer. This observation was as a result of similar reason given for the males.

Breast and ovary cancer risk of exposure induced death for males is not considered because they are not a worry. The highest risk of exposure induced cancer death when patients undergo posterior spinal fusion- single stage procedure is lung cancer in females with a value of 0.028 %. This means 2.8 patients out of 10,000 patients may die from lung cancer when they undergo posterior spinal fusion- single stage procedure in the hospital. The lowest risk of exposure induced cancer death is 0.000564 % for liver cancer

in female patients. This means 5.64 patients out of 1,000,000 patients may die from liver cancer when they undergo posterior spinal fusion- single stage procedure.

It must be noted that the overall risk of exposure induced death in females for posterior spinal fusion- single stage procedure is more probable than in males as discussed in Table 4.7.

Table 4.8: Radiation induced cancer death for specific cancer type for Posterior Spinal Fusion-two stage.

Cancer Type	Risk of exposure induced cancer death – Female (%)	Risk of exposure induced cancer death- Male (%)
Leukaemia	0.002350	0.002980
Breast cancer	0.016400	-
Colon cancer	0.003020	0.004670
Liver cancer	0.000726	0.001080
Lung cancer	0.022100	0.010400
Ovary cancer	0.001380	-
Stomach cancer	0.004630	0.000341
Bladder cancer	0.002680	0.002070
Other cancers	0.011400	0.010300

(-) value not available

Risk of exposure induced cancer death for posterior spinal fusion- two stage procedure for specific cancer sites is shown in Table 4.8. The risk of exposure induced cancer death in males is higher than females for leukaemia, colon and liver specific cancer sites because these cancers are more prevalent in males than females, and hence high risk coefficient factors in the BEIR risk model. The risk exposure induced cancer death in

females is higher than males for lung, stomach, bladder and other cancers with a similar reason given for males above.

The highest risk of exposure induced cancer death when patients undergo posterior spinal fusion- two stage procedure is lung cancer in females with a value of 0.0221 %. This means 2.21 patients out of 10,000 patients may die from lung cancer when they undergo posterior spinal fusion- two stage procedure in the facility. The lowest risk of exposure induced cancer death is 0.000726 % for liver cancer in female patients. This means 7.26 patients out of 1,000,000 patients may die from liver cancer when they undergo posterior spinal fusion- two stage procedure.

Table 4.9: Radiation induced cancer death for specific cancer type for Growing Rod.

Cancer Type	Risk of exposure induced cancer death – Female (%)	Risk of exposure induced cancer death- Male (%)
Leukemia	0.002460	0.003380
Breast cancer	0.024300	-
Colon cancer	0.004350	0.006700
Liver cancer	0.001100	0.001630
Lung cancer	0.034800	0.016300
Ovary cancer	0.001790	-
Stomach cancer	0.007200	0.005270
Bladder cancer	0.003160	0.002430
Other cancers	0.016200	0.014300

(-) value not available

Risk of exposure induced cancer death for growing rod instrumentation procedure for specific cancer sites is shown in Table 4.9. The risk of exposure induced cancer death in

males is higher than females for leukaemia, colon and liver specific cancer sites because these cancers are more prevalent in males than females, and hence high risk coefficient factors in the BEIR risk model. The risk exposure induced caner death in females is higher than males for lung, stomach, bladder and other cancers with a similar. The highest risk of exposure induced cancer death when patients undergo growing rod procedure is lung cancer in females with a value of 0.0348 %. This means 3.48 patients out of 10,000 patients may die from lung cancer when they undergo growing rod procedure in the facility. The lowest risk of exposure induced cancer death is 0.0011 % for liver cancer in female patients. This means 11.0 patients out of 1,000,000 patients may die from liver cancer when they undergo growing rod procedure.

Table 4.10: Radiation induced cancer death for specific cancer type for Revision - Posterior Spinal Fusion.

Cancer Type	Risk of exposure induced cancer death – Female (%)	Risk of exposure induced cancer death- Male (%)
Leukaemia	0.000706	0.000921
Breast cancer	0.007990	-
Colon cancer	0.001360	0.002090
Liver cancer	0.000282	0.000416
Lung cancer	0.006390	0.002990
Ovary cancer	0.000036	-
Stomach cancer	0.002200	0.001610
Bladder cancer	0.000917	0.000705
Other cancers	0.003970	0.003560

(-) value not available

Risk of exposure induced cancer death for revision- posterior spinal fusion procedure for specific cancer sites is shown in Table 4.10. The risk of exposure induced cancer death in males is higher than females for leukaemia, colon and liver specific cancer sites because these cancers are more prevalent in males than females, and hence high risk coefficient factors in the BEIR risk model. The risk exposure induced caner death in females is higher than males for lung, stomach, bladder and other cancers specific with a similar reason given for the males above. The highest risk of exposure induced cancer death when patients undergo revision- posterior spinal fusion procedure is breast cancer in females with a value of 0.00799 %. This means 7.99 patients out of 100,000 patients may die from breast cancer when they undergo revision- posterior spinal fusion procedure in the facility. The lowest risk of exposure induced cancer death is 0.000036 % for ovary cancer in patients. This means 3.6 patients out of 10,000,000 patients may die from ovary cancer when they undergo revision-posterior spinal fusion procedure.

Table 4.11: Radiation induced cancer death for specific cancer type for Osteotomy of Extremity.

Cancer Type	Risk of exposure induced cancer death – Female (%)	Risk of exposure induced cancer death- Male (%)
Leukaemia	2.550 E-6	3.330 E-6
Breast cancer	-	-
Colon cancer	-	-
Liver cancer	-	-
Lung cancer	-	-
Ovary cancer	-	-
Stomach cancer	-	-
Bladder cancer	-	-
Other cancers	1.800 E-5	1.610 E-5

(-) value not available

Risk of exposure induced cancer death for osteotomy of extremity procedure for specific cancer sites is shown in Table 4.11. The risk of exposure induced cancer death in males is higher than females for leukaemia specific cancer site because this cancer is more prevalent in males than females, and hence high risk coefficient factors in the BEIR risk model. The risk exposure induced caner death in females is higher than males for other cancers with similar reason given above for the males.

The highest risk of exposure induced cancer death when patients undergo osteotomy of extremity procedure is 'other cancer' in females with a value of 0.000018 %. This mean 1.8 patients out of 10,000,000 patients may die from 'other cancers' when they undergo osteotomy of extremity procedure in the facility. The lowest risk of exposure induced cancer death is 0.00000255 % for leukaemia in female patients. This means 2.55 patients out of 100,000,000 patients may die from leukaemia when they undergo osteotomy of extremity procedure. The risk of exposure induced cancer death for breast, colon, liver, lung, ovary, stomach and bladder were not available because these organs were not exposed to radiation during the procedure.

Table 4.12: Radiation induced cancer death for specific cancer type for Intramedullary Nailing of Femur.

Cancer Type	Risk of exposure induced cancer death – Female (%)	Risk of exposure induced cancer death- Male (%)
Leukaemia	1.210 E-4	1.580 E-4
Breast cancer	2.940 E-6	-
Colon cancer	7.220 E-5	1.120 E-4
Liver cancer	4.360 E-7	6.430 E-7
Lung cancer	7.470 E-7	3.490 E-7
Ovary cancer	1.760 E-4	-
Stomach cancer	5.220 E-6	3.830 E-6
Bladder cancer	3.340 E-4	2.570 E-4
Other cancers	7.610 E-4	6.820 E-4

(-) value not available

Risk of exposure induced cancer death for intramedullary nailing of femur procedure for specific cancer sites is shown in Table 4.12. The risk of exposure induced cancer death in males is higher than females for leukaemia, colon and liver specific cancer sites because these cancers are more prevalent in males than females, and hence high risk coefficient factors in the risk model. The risk exposure induced caner death in females is higher than males for lung, stomach, bladder and other cancers with similar reason given for males above. The highest risk of exposure induced cancer death when patients undergo intramedullary nailing of femur procedure is 'other cancers' in females with a value of 0.000761 %. This mean 7.61 patients out of 1,000,000 patients may die from 'other cancers' when they undergo intramedullary nailing of femur procedure in the facility. The lowest risk of exposure induced cancer death is 0.000000349 % for lung cancer in patients. This means 3.49 patients out of 1,000,000,000 patients may die from lung cancer when they undergo intramedullary nailing of femur procedure.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the data collected on the patient and equipment, paediatric and young adult patients in the selected orthopaedic facility who undergo surgical procedures presents mainly deformities as their medical condition. The major was spine deformities including scoliosis, kyphosis and kyphoscoliosis. Surgical Procedures were largely guided by plain x-rays.

It can be concluded from observation and analysis that, PSF (single stage) recorded the highest effective dose of 7.62 ± 0.84mSv, followed by Posterior Spinal Fusion (two stage), Growing Rod, Revision Posterior Spinal Fusion, and Intramedullary Nailing of the femur and Osteotomy of the lower extremity due to influence in the ESD, techniques factors, number of radiographs and the size and position of patient and body parts. Also from the effective dose and ESD obtained from the surgical procedures, plain radiographic procedures recorded a higher radiation dose as compared to fluoroscopic guided procedures. Also from the study, as the Beam on Time increases radiation dose to the patient also increases. In conclusion for the measured doses, effective dose received by patients are in range of 0.1 – 10mSv (UNSCEAR, 2000) and from the study, effective dose from the procedures fell within this range.

In addition, for the procedures that involved the spine, the Ribs recorded the highest radiation dose. The stomach recorded the highest soft tissue organ dose followed by the breast and thyroid for the sensitive organs. Patients for Revision Posterior Spinal Fusion

received lower dose as compared to the other spine procedures. Taking the full spine into consideration, the upper spine receives the highest dose. Also, for the gonads, the testicles received a higher radiation dose than the ovaries.

For Intramedullary Nailing of the femur, the pelvis recorded the highest radiation dose followed by the prostate and testicles. Osteotomy of the lower extremity recorded the lowest radiation dose with the lower leg recording the highest radiation dose.

Based on Comparison between radiation dose received by paediatric or young adult from Posterior Spinal Fusion (single stage) it can be concluded that exposure to patients depends on the tissue density, mass and sensitivity. .

Also for all the risk of exposure induced cancer death values, the female values were more than male's with Growing Rod procedure having the highest radiation risk. In addition, for specific cancers, risk of lung cancer was prevalent followed by breast cancer and other cancers. Risk of leukemia however is in males than females. Finally small mean age and increased radiation increases risk to exposure induced cancer death.

5.2 Recommendations

Based on the conclusion of this study, the following recommendations have been set to further reduce radiation dose to paediatric and young adult patients due to medical exposure while maintaining efficacy and accuracy of their clinical objectives.

5.2.1 Medical Professionals

5.2.1.1 Surgeons

It is recommended that surgeons adapt the use of fluoroscopy if possible in most procedures since fluoroscopy if managed well produce low dose as compared to plain x-rays. However surgeons should exercise caution, and consistently follow radiation safety guidelines, when using fluoroscopy because there is a real risk of radiation exposure. If necessary, minimum radiographs or critical images should be taken to limit exposure to paediatric and young adult patients. It is also recommended that surgeons employ surgical techniques that will limit the beam on time to patients. Finally there should be effective communication between radiographers and surgeons to avoid unnecessary screening of patients especially for fluoroscopic guided procedures.

5.2.1.2 Radiographers

It is recommended that technique factors that are low but equally produce quality images be adapted since an optimized exposure gives a lower effective dose. Also radiographers should be present during patient preparation for surgery especially before draping of the patient to have a fair judgment of the patient thickness for selection of equipment parameters. Finally exposure charts should be prepared to serve as a source of reference guide to new operators.

5.2.1.3 Hospital Managers:

It is recommended that management employ the use of equipment with high radiation optimized features. Also, there should be follow up checks on patient especially for those with Growing Rod due to their increased risk to cancer. Finally radiation exposure records should be part of patient's medical records to aid in consistency in exposure selection especially for those that may come for revision and two stages Post Spinal Fusion.

5.2.2 Regulatory Authority

It is recommended that the Regulatory Authority (Radiation Protection board) to have a regular inspection on equipment and during its operation in operating theatres. Secondly development of protocols for surgical procedures by facilities should be required by the Radiation Protection Board (RPB) and enforce the requirement to implementation of recording and storage of patients radiation dose as part of patients medical records.

5.2.3 Research Community

It is recommended that the study is extended to other medical specialties outside the imaging department. Also there should be research extension of this study to aid in generating dose reference levels (DRL) especially for full spine and other orthopedic surgical procedures by bodies like ICRP and other relevant institution. Thirdly the study can be extended to other facilities in the country. Finally this study should be continued to generate specific optimization methodology using phantom.

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APPENDIX A

INFORMED CONSENT

Project title: Determination of Dose to paediatrics and young adult patients undergoing plain radiographic and Fluoroscopic guided surgical procedures

I …… have been invited to take part in this research. I have been told of the purpose and procedure of this study which is to estimate the doses of radiation that I would be exposed to during surgery and the data obtained would be used to make appropriate recommendations on how to optimize the doses. I will not be reimbursed monetarily for participating in this research study. My personal information such as age, weight and height would be taken.

I have been assured that the technique is non-invasive and no additional risk to existing exposure risk will be incurred. The study team will maintain anonymity by using codes rather than names.

I promise to comply with the research team and I consent accordingly.

Signature……..……

Thumbprint……

(PARTICIPANT)

Date:……..

Signature……..

(Researcher)

APPENDIX B

DATA SHEET

NAME OF INSTITUTION:…….

PATIENT ID:……

EQIPMENT TYPE:……..

PATIENT INFORMATION

WEIGHT:…… HEIGHT:…… SEX: ……..
AGE:……..

EXAMINATION PARAMETERS

PROCEDURE:……. DIAGNOSIS……

INITIAL TIME: ……. FINAL TIME: …… BEAM ON TIME:……..

TLD CHIP 1 READING:……..

TLD CHIP 2 READING:……

TLD CHIP 3:……

NUMBER OF IMAGES OBTAINED:……. DATE……..

FLUOROSCOPY MODE

KV	MAS	TIME	COMMENTS (RATIONALE)

AVERAGE KV:……. FID……

AVERAGE MA:…… AVERAGE MAS:…….

RADIOGRAPHY

kV	mAs	PROJECTION	BODY PART

X RAY SERIES	RATIONAL(comments)

AVERAGE kV: …….. AVERAGE mAs: ……

FFD……

IMAGE HEIGHT……..

IMAGE WIDTH……

APPENDIX C

Table C.1: Mean effective and entrance surface dose for x-ray guided procedures considered for the study.

Procedure	Entrance Surface Dose (mSv)	Effective Dose (mSv)
Posterior Spinal Fusion - Single Stage	19.61 ± 1.96	7.62 ± 0.84
Posterior Spinal Fusion - two Stage	17.17 ± 1.98	7.48 ± 1.0
Growing Rod Instrumentation	12.77 ± 2.73	6.82 ± 0.99
Revision - Posterior Spinal Fusion	6.33 ± 0.07	2.50 ± 0.27
Osteotomy of Extremity	0.23 ± 01	0.001 ± 0.6E4
Intramedullary Nailing of Femur	7.91 ± 4.31	0.18 ± 0.09

Values presented as mean± standard deviation

APPENDIX D

Table D.1: Mean organ doses to patients during Posterior Spinal Fusion- Two Stage

Organ	Dose (mGy)
Active bone marrow	4.78 ± 0.72
Adrenals	3.58 ±0.52
Brain	1.59 ± 0.84
Breasts	11.83 ± 1.30
Extrathoracic airways	7.94 ± 1.47
Gall bladder	5.17 ± 0.82
Heart	7.81 ± 0.98
Kidneys	4.80 ± 0.81
Liver	4.72 ± 1.01
Lungs	7.13 ± 0.92
Lymph nodes	6.87 ± 1.00
Muscle	5.65 ± 0.93
Oral mucosa	6.64 ± 1.43
Ovaries	4.38 ± 0.31
Pancreas	6.33 ± 1.02
Prostate	5.41 ± 1.049
Salivary glands	8.62 ± 1.17
Skeleton	11.40 ± 2.26
(Upper Spine)	17.88 ± 2.78
(Middle Spine)	7.75 ± 1.29
(Lower Spine)	7.22 ± 1.37
(Ribs)	24.15 ± 3.22
(Pelvis)	13.12 ± 2.07
Skin	6.75 ± 1.18
Small intestine	5.83 ± 0.86
Spleen	9.64 ± 2.05
Stomach	10.48 ± 1.14
Testicles	7.49 ±1.13
Thymus	7.93 ± 1.08
Thyroid	10.22 ± 1.21
Urinary bladder	6.79 ±1.10
Uterus	5.66 ± 0.95

Table D.2: Mean organ doses to patients during Posterior Spinal Fusion-Single stage

Organ	Dose (mGy)
Active bone marrow	5.00 ± 0.63
Adrenals	3.90 ± 0.57
Brain	2.18 ± 0.77
Breasts	11.49 ± 1.22
Extrathoracic airways	7.21 ± 0.88
Gall bladder	4.37 ± 0.57
Heart	8.07 ± 0.87
Kidneys	4.51 ± 0.52
Liver	3.19 ± 0.44
Lungs	7.79 ± 0.88
Lymph nodes	6.89 ± 0.79
Muscle	5.74 ± 0.67
Oral mucosa	6.47 ± 1.13
Ovaries	5.01 ± 0.60
Pancreas	7.54 ± 0.90
Prostate	4.65 ± 0.48
Salivary glands	7.50 ± 1.15
Skeleton	10.07 ± 1.44
(Upper Spine)	17.37 ± 2.29
(Middle Spine)	9.08 ± 1.16
(Lower Spine)	8.55 ± 1.28
(Ribs)	25.55 ± 2.81
(Pelvis)	15.12 ± 1.91
Skin	6.50 ± 0.81
Small intestine	6.02 ± 0.67
Spleen	13.09 ± 1.66
Stomach	12.08 ± 1.27
Testicles	6.15 ± 0.88
Thymus	7.02 ± 0.91
Thyroid	9.88 ± 1.31
Urinary bladder	6.00 ± 0.67
Uterus	4.98 ± 0.56

Table D.3: Mean organ doses to patients during Revision-Posterior Spinal Fusion

Organ	Dose (mGy)
Active bone marrow	1.36 ± 0.23
Adrenals	1.30 ± 0.00
Brain	0.09 ± 0.05
Breasts	4.46 ± 0.21
Extrathoracic airways	0.65 ± 0.48
Gall bladder	0.65 ± 0.48
Heart	2.11 ± 0.05
Kidneys	3.03 ± 0.09
Liver	1.54 ± 0.02
Lungs	1.71 ± 0.13
Lymph nodes	2.51 ± 0.17
Muscle	1.94 ± 0.17
Oral mucosa	1.61 ± 0.26
Ovaries	0.09 ± 0.01
Pancreas	1.70 ± 0.23
Prostate	2.14 ± 0.03
Salivary glands	0.24 ± 0.09
Skeleton	3.28 ± 0.50
(Upper Spine)	2.10 ± 1.09
(Middle Spine)	2.77 ± 0.05
(Lower Spine)	3.01 ± 0.02
(Ribs)	8.52 ± 0.67
(Pelvis)	3.85 ± 0.56
Skin	1.80 ± 0.41
Small intestine	2.21 ± 0.11
Spleen	3.41 ± 0.03
Stomach	4.21 ± 0.03
Testicles	1.93 ± 1.17
Thymus	3.06 ± 0.24
Thyroid	2.41 ± 1.11
Urinary bladder	1.96 ± 0.52
Uterus	1.77 ± 0.25

Table D.4: Mean organ doses to patients during Growing Rod

Organ	Dose (mGy)
Active bone marrow	4.52 ± 0.84
Adrenals	3.90 ± 0.89
Brain	2.92 ± 0.87
Breasts	10.04 ± 1.28
Extrathoracic airways	6.91 ± 1.75
Gall bladder	4.85 ± 0.64
Heart	7.86 ± 1.14
Kidneys	4.95 ± 0.88
Liver	3.17 ± 0.37
Lungs	7.45 ± 1.22
Lymph nodes	6.84 ± 1.31
Muscle	5.49 ± 0.99
Oral mucosa	6.50 ± 1.42
Ovaries	3.93 ± 0.62
Pancreas	8.10 ± 1.49
Prostate	5.35 ± 1.01
Salivary glands	7.85 ± 1.74
Skeleton	10.96 ± 2.03
(Upper Spine)	16.59 ± 3.57
(Middle Spine)	10.37 ± 1.88
(Lower Spine)	9.53 ± 1.88
(Ribs)	23.81 ± 3.84
(Pelvis)	14.96 ± 2.69
Skin	5.84 ± 1.05
Small intestine	5.82 ± 0.94
Spleen	12.72 ± 2.36
Stomach	11.29 ± 1.86
Testicles	4.44 ± 0.80
Thymus	6.00 ± 0.77
Thyroid	8.17 ± 1.35
Urinary bladder	5.57 ± 0.91
Uterus	4.60 ± 0.79

Table D.5: Mean organ doses to patients during Intramedullary Nailing of Femur

Organ	Dose (mGy)
Active bone marrow	0.23 ± 0.11
Adrenals	0.003 ± 0.002
Breasts	1.64E-3 ± 1.09E-3
Gall bladder	0.009 ± 0.003
Heart	0.001 ± 0.00
Kidneys	0.005 ± 0.002
Liver	0.002 ± 0.00
Lungs	0.20E-3 ± 1.9799E-05
Lymph nodes	0.05 ± 0.02
Muscle	0.37 ± 0.15
Ovaries	0.47 ± 3.34E-05
Pancreas	0.003 ± 0.001
Prostate	0.72 ± 5.13E-06
Skeleton	0.45 ± 0.12
(Ribs)	0.001 ± 0.36E-3
(Pelvis)	1.80 ± 0.96
Skin	0.41 ± 0.17
Small intestine	0.11 ± 0.06
Spleen	0.003 ± 0.001
Stomach	0.009 ± 0.005
Testicles	0.62 ± 0.22
Urinary bladder	0.71 ± 0.35
Uterus	0.35 ± 0.20

Table D.6: Mean organ doses to patients during Osteotomy (Extremity)

Organ	Dose (mGy)
Active bone marrow	0.004 ± 0.003
Adrenals	0.00 ± 0.00
Breasts	0.00 ± 0.00
Heart	0.00 ± 0.00
Kidneys	0.00 ± 0.00
Liver	0.00 ± 0.00
Lungs	0.000 ± 0.00
Lymph nodes	0.41E-3 ± 0.19E-3
Muscle	0.007 ± 0.003
Oral mucosa	0.00 ± 0.00
Ovaries	0.00 ± 0.00
Pancreas	0.00 ± 0.00
Prostate	0.00 ± 0.00
Salivary glands	0.00 ± 0.00
Skeleton	0.02 ± 0.14
(Upper leg bones)	0.10E-3 ± 7.17E-05
(Middle leg bones)	1.99E-3 ± 1.04
(Lower leg bones)	0.17 ± 0.08
(Pelvis)	0.00 ± 0.00
Skin	0.01 ± 0.00
Small intestine	0.00 ± 0.00
Spleen	0.00 ± 0.00
Stomach	0.00 ± 0.00
Testicles	0.00 ± 0.00
Thymus	0.00 ± 0.00
Thyroid	0.00 ± 0.00
Urinary bladder	0.00 ± 0.00
Uterus	0.00 ± 0.00