A QUANTITATIVE ANALYSIS OF IONISING RADIATION EXPOSURE TO THE HANDS, THYROID AND WHOLE BODY OF ORTHOPAEDIC REGISTRARS AT KING EDWARD VIII HOSPITAL DURING FLUOROSCOPIC INTERNAL FIXATION OF THE LOWER LIMBS.

BY

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A dissertation submitted to the Faculty of Health in full compliance with the requirements for the Master's Degree in Technology: Radiography at Durban Institute of Technology.

I, Khaled M. Abu Shab, do hereby declare that this dissertation represents my own work both in concept and execution.

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ABSTRACT

INTRODUCTION

The portable C-arm image intensifier has been of great value to orthopaedic registrars for many years. One of its common uses in trauma surgery is during controlled reduction of long bone fractures and accurate placement of internal or external fixation devices. Ionising radiation has therefore become a serious occupational hazard for the orthopaedic registrar.

A prospective study was conducted in order to quantify the amount of ionising radiation exposure to the hands, thyroid and whole body of orthopaedic registrars during fluoroscopic internal fixation of the lower limbs, and to determine whether these registrars need to be routinely monitored for radiation exposure. The study also quantified the average operative and screening times for internal fixation of the lower limbs.

The study provided information regarding the maximum number of internal fixations of the lower limbs that can be performed by the orthopaedic registrar before the maximum dose level to the hands is exceeded.

METHODS AND MATERIALS

During a three-month period from March to June 2004, a study was undertaken to evaluate the radiation exposure to the hands, thyroid, and whole body of orthopaedic registrars at King Edward VIII Hospital.

Eight full-time employees or working orthopaedic registrars, with a minimum of one-year orthopaedic experience were monitored. The study was conducted during 96 internal fixation procedures of the lower limbs (32 neck of femur, 32 femur and 32 tibia).

Each orthopaedic registrar wore a lead apron over the anterior aspect of the trunk. The orthopaedic registrar always faced the machine when imaging, so that the lead apron was between the orthopaedic registrar and the source of radiation. Additionally, the orthopaedic registrar stood approximately 30 centimetres away from the x-ray tube when the C-arm was in a vertical position and in contact with the x-ray tube when the C-arm was in a horizontal position.

Radiation exposure to the orthopaedic registrar was monitored in three ways using thermoluminescent dosimeters (TLDs).

(1) A gas-sterilized TLD ring with one chip was worn on the index finger of each hand of the orthopaedic registrar under the first surgical gloves. The TLD rings were changed after each operative procedure.

(2) Another TLD was placed at the level of the neckline to measure the radiation dose to the thyroid. The dosimeter was changed after each operative procedure. The registrars wore no thyroid shields.

(3) A further TLD was placed under the lead apron at the level of the waist to measure the radiation dose to the whole body. This TLD was worn during all the operative procedures that the orthopaedic registrar performed per month. At the end of each month the TLDs were sent to the South African Bureau of Standards (SABS) for dose measurement.

The operation and screening times were noted for each operative procedure. The times were recorded in minutes. The number of minutes that the fluoroscope was used was read directly from the C-arm unit, and represented the sum of real time fluoroscopy.

The start and end time of the operation procedure was noted for each procedure.

RESULTS

During the thirty-two internal fixations of the neck of femur, the mean radiation dose was 0.17mSv to the hands and 0.16mSv to thyroid and 0.008mSv to the whole body. The average screening and operation times were 2.31 minutes and 63 minutes respectively. During the thirty-two internal fixations of the femur, the mean radiation dose imparted to the hands was 0.27mSv and to the thyroid was 0.25mSv and 0.010mSv to the whole body. The average fluoroscopic time was 4.05 minutes with the average operation time being 82 minutes. The mean radiation dose to the hands was 0.21mSv; 0.19mSv to the thyroid and to the whole body was 0.010mSv during thirty-two internal fixations of the tibia. The average fluoroscopy time was 3.48 minutes and the average operation time was 87 minutes.

The overall mean radiation doses were 0.22mSv to the hands, 0.20mSv to the thyroid and 0.010 mSv to the whole body, with average operation and screening times of 77 minutes and 3.26 minutes respectively during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia). During a 3-month period, the average mean radiation dose to the whole body per month was 0.11 mSv.

It is extrapolated from the data that each registrar would be able to perform 681 surgical procedures of the lower limbs requiring fluoroscopy per year before meeting the established radiation exposure to hands limit (150mSv) for non radiation workers based on the ICRP radiation standards. However if the registrars were registered as radiation workers the limit to hands would be 500mSv per year, and consequently 2272 surgical procedures can be performed per year.

CONCLUSION

It can be concluded that the orthopaedic registrar who performs an internal fixation of the lower limbs absorbs a quantifiable dose of radiation to the hands and thyroid. Although these doses are within the ICRP recommended levels for radiation workers; there should be no complacency because of the uncertainty of the effects of low dose radiation. There is no safe dose of radiation and As Low As Reasonably Achievable (ALARA) principle should be observed for both the patient and registrars. The orthopaedic registrars should be monitored for radiation exposure regularly; therefore they should be registered as radiation workers

DEDICATION

This dissertation is dedicated to my lovely wife and my kids Loeay and Yara who had to endure my being away from home for a long time.

To my parents who always pray for me, thank you very much for mental support.

To my best friends R'afat, Tareque, Naeem and Belal

Above all thanks to ALLAH, almighty

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LIST OF ABBREVIATIONS

ALARA	-	As low As Reasonably Achievable
DNA	-	Deoxyribonucleic Acid
H_o	-	null hypothesis
ICRP	-	International Commission of radiological protection
MPD	-	maximum permissible dose
mrad	-	millirad
mrem	-	millirem
mSv	-	millisievert
NCRP	-	National Council of Radiation Protection and Measurments
ρ-Value	-	level of significance
R	-	roentgen
rad	-	radiation-absorbed-dose
rem	-	rad-equivalent-man
SABS		South African Bureau of Standards
Std.	-	standard
SI	-	International System of Unit
Sv	-	sievert
TLD	-	thermoluminescent dosimeter

DEFINING THE TERMS

Absorbed dose

The amount of energy per unit mass absorbed by irradiated object. This absorbed energy is responsible for whatever biologic damage occurs as a result of tissues being exposed to x-radiation. The gray (Gy) is the SI unit of this radiation quantity (Statkiewicz, Visconti & Ritenour 1998:237).

Absorption

Transference of energy from an x-ray beam to the atoms or molecules of the matter through which it pass (Statkiewicz, Visconti & Ritenour 1998:237).

ALARA concept

Precept holding the occupational exposure of the radiographer and other occupationally exposed persons should be kept "As low As Reasonably Achievable" (Statkiewicz, Visconti & Ritenour 1998:237). ALARA is the basic force of the procedures, policies and practices in radiation laboratories, to minimize the radiation exposure to staff and public to the greatest extent practical (Bushberg, et al. 2003)

Dose response

The dose response is defined as the functional dependence of the intensity of the measured TL signal upon the absorbed dose (McKeever, Moscovitch & Townsend 1995:31).

Gray (Gr.)

Gray is SI unit of absorbed dose, it's defined as an energy absorption of joule (J) per kilogram in the radiation object (Statkiewicz, Visconti & Ritenour 1998:45).

Image intensification

Use of an image intensifier to increase the brightness of the real time image produced on a fluoroscopy (Statkiewicz, Visconti & Ritenour 1998:247).

Image intensifier

A device that can increases the brightness of an image. An image is produced on a fluorescent screen by x-ray at the input end. The image at the output is view by a television camera (Statkiewicz, Visconti & Ritenour 1998:247).

International Commission on Radiological protection [ICRP]

Evaluates information on biologic effects of radiation and provides radiation protection guidance through general recommendations regarding occupational and public dose limits (Statkiewicz, Visconti & Ritenour 1998:247).

International system of unit [SI]

System of units that allows an interchange of units among all branches of science throughout the world (Statkiewicz, Visconti & Ritenour 1998:237).

Kerma

The dosimetric quantity is defined as the Kinetic Energy Released per unit Mass of the Absorbing medium, and expressed as dE_{tr}/ dm where dE_{tr} is the sum of kinetic energies of all the charged particles set in motion originating from material of mass dm (Dyson, 1993:250).

Law of Bergonie and Tribondeau

Ionising radiation is more effective against cells that are actively mitotic, undifferentiated and have a long dividing future; named after the two investigators who determined this effect; considered a byword in radiobiology (Statkiewicz, Visconti & Ritenour 1998:248).

Linear Non Threshold Model

It's the relationship between radiation dose and biological response, such as the chance of biological damage is directly proportional to the magnitude of the ionising radiation exposure (Statkiewicz, Visconti & Ritenour 1998:113-148).

Maximum permissible dose [MPD]

A term used to indicate the maximum dose equivalent of ionising radiation that an occupationally exposed person could absorb in a specific time period without sustaining appreciable bodily injury (Statkiewicz, Visconti & Ritenour 1998:249).

National Council of Radiation Protection and Measurments [NCRP]

Reviews regulations, formulated by the ICRP and decides how to include them in U.S. radiation protection criteria (Statkiewicz, Visconti & Ritenour 1998:250).

Occupational exposure

Radiation exposure received by radiation workers in the course of exercising their professional responsibilities (Statkiewicz, Visconti & Ritenour 1998:251).

Orthopaedic surgery

The orthopaedic surgery is a specialty where fluoroscopy procedures are frequently performed out side the radiology department, on mobile equipment (Crawly and Rogers, 2000).

rad [radiation-absorbed-dose]

The unit that indicates the amount of radiant energy transferred to an irradiated object by any type of ionising radiation. One milliard [mrad] is equal to one-thousandth of a rad [1/1000rad] (Statkiewicz, Visconti & Ritenour 1998:254).

Radiation protection

Tools and techniques employed by radiation workers to protect patients and personnel from exposure to ionising radiation (Statkiewicz, Visconti & Ritenour 1998:254).

Radiation worker

The personnel's who receive 3/10 of the annual occupational dose limits (20 msv/year) are defined as Radiation workers (ICRP, 1990).

Radiocarcinogenic

Cancerous neoplasm induced by exposure to ionising radiation (Statkiewicz, Visconti & Ritenour 1998:254)

Radiobiology

Study of effects of ionising radiation on a living things (Statkiewicz, Visconti & Ritenour 1998:256).

Rem [rad-equivalent-man]

The traditional radiation quantity unit for dose equivalent, rem was defined as the dose equivalent of any type of ionising radiation that produces the same biologic effect as one rad of x-radiation. One Millirem [mrem] is equal to one-thousandth of a rem [1/1000rem](Statkiewicz, Visconti & Ritenour 1998:255).

Roentgen [R]

Internationally accepted unit for measurement of exposure to x-ray and gamma radiation (Statkiewicz, Visconti & Ritenour 1998:256).

Sensitivity

The sensitivity of a particular TLD material is defined as the TL signal strength per unit absorbed dose (McKeever, Moscovitch & Townsend 1995:34).

Sievert [Sv]

The SI radiation quantity unit for dose equivalent**.** One sievert is equals 1 joule of energy absorbed per kilogram of tissue. This unit is used for radiation protection purposes. One Millisievert [mSv] is equal to one-thousandth of a sievert [1/1000Sv] (Statkiewicz, Visconti & Ritenour 1998:256).

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE PROBLEM

The use of ionising radiation has been an integral and essential part of the practice of orthopaedic surgery for almost a century. The portable C-arm image intensifier has been of great value to orthopaedic surgeons for many years. One of its' common uses in trauma surgery is during controlled reduction of long bone fractures and accurate placement of internal or external fixation devices. During these procedures, numerous changes and re-adjustments of the C-arm position are necessary to obtain the desired views (Al-Shawi and Fern, 2003). The introduction of new procedures, such as internal fixation of the lower limbs, has resulted in the increased use of fluoroscopic screening in the orthopaedic theatre. Ionising radiation has therefore become a serious occupational hazard for the orthopaedic surgeon and other theatre staff who are often ill-informed on the subject and poorly trained to minimize the associated radiation dose received (Hynes, et al. 1992).

The earliest risks of ionising radiation to the radiologist and cardiologist have been well documented (Faulkner and Moor, 1982; Jeans and Faulkner, 1985); however, only few studies have investigated the exposure risks to the orthopaedic surgeon in the operation theatre (Al-Shawi and Fern, 2003; Artigans, Conso, & Hazebrouq, 2003; Muller, et al. 1998 and O'Rourke, et al. 1996). Detail on the former studies results can be seen in Chapter 2 sections 2.10 and 2.11. The indication for surgical treatment of long bone fractures with intramedullary nailing has expanded in the last few years. The surgeon is therefore confronted with increasing exposure to radiation because reposition and distal interlocking are performed under fluoroscopic guidance (Muller, et al. 1998). The digital fluoroscopy has several drivers one of them being the automatic storage of the image and the ability to send them anywhere. Digital fluoroscopy can reduce the radiation dose through improvements in image quality and machine features. Better images and the ability to manipulate contrast and brightness reduce the number of images that must be obtained. Digital fluoroscopic also decreases screening time and enhance patient throughput. Filters are dose reduction features being incorporated by manufactures of digital system, to prevent delivery of low dose radiation. Adjustment of the x-ray tube output by software, which monitors the intensity of the radiation that strikes the detector also reduces the radiation output (Bronson, 2002).

Mehlman and DiPasquale (1997) and Theocharopoulos, et al. (2003) have done studies to evaluate the radiation dose to the orthopaedic theatre staff during fluoroscopic procedures in United States and Greece. They have demonstrated that the occupational radiation exposure and associated radiogenic risks to the orthopaedic surgeon and assisting staff are of increased interest and importance, due to the unknown long-term effect of low dose radiation.

O'Rourke, et al. 1996 stated that the hands of the orthopaedic surgeon are most likely to be directly exposed to ionising radiation during fluoroscopic screening in the orthopaedic theatre. The image intensifier should be positioned as close to the patient as possible to reduce backscatter and allow lower doses to be used (Jones and Stoddart, 1998). Studies performed by Al-Shawi and Fern (2003); Artigans, Conso, & Hazebrouq (2003); Muller et al. (1998) and O'Rourke, et al. (1996) reported that the doses received by the hands are usually high. The surgeons' hands receive the highest dose as they are often exposed directly to the x-ray beam (Al-Shawi and Fern, 2003 and Muller, et al. 1998).

Levin, Schoen, & Browner (1997) stated that the orthopaedic surgeon spends a significant amount of time working in close proximity to x-rays, therefore protection in the form of a lead apron is useful for reducing trunk exposure, but such protection is impractical for the protection of the hands due to the weight of the lead gloves and the registrar need a free hand in order to perform the operation.

Dewey and Incoll (1998) stated that the perceived increase in the incidence of thyroid carcinoma in orthopaedic surgeons prompted an assessment of the use and value of thyroid shields in the operating theatre. They performed a study to evaluate the radiation dose to the orthopaedic surgeon's thyroid over a 3-month period while they are operating. Dewey and Incoll (1998) stated that as it's accepted that there is no defined minimum exposure for provocation of thyroid carcinoma among the orthopaedic surgeons during fluoroscopic operation. They concluded that the orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from this radiation exposure.

1.2 OBJECTIVES OF THE STUDY

The aims of this study were to quantify the radiation dose to the orthopaedic registrars' hands, thyroid and whole body, and to quantify the average operation and screening times during fluoroscopic internal fixation of the lower limbs, during 3-month period (7/3 to 10/6/2004). Furthermore to determine the maximum number of internal fixations of the lower limbs that can be performed by an orthopaedic registrar per year before exceeding the International Commission of Radiological Protection (ICRP) recommended level of radiation to the hands. Further research question were: -

- What is the relationship between the radiation dose to the right and left hand?
- What is the relationship between screening time and radiation dose to both hands?
- What is the relationship between screening time and radiation dose to the thyroid?
- What is the relationship between screening time and radiation dose to the whole body?
- What is the relationship between operation and screening times?

1.3 MOTIVATION FOR THE STUDY

There is no known information available on the level of exposure to radiation during the normal working pattern of orthopaedic registrars in KwaZulu-Natal (Govender, 2004). Global information about the amount of radiation dose to the orthopaedic surgeon during internal fixation differs from one place to another. The differences may be related to the technique and skills of the surgeon who is performing the operation procedure and the type of C-arm used (Muller, et al. 1998). At present, no study in South Africa has mentioned the operation time during lower limbs internal fixation, and the relationship between the operation time and screening time.

The number of trauma patients in KwaZulu-Natal is higher when compared to the other provinces in South Africa (South African Road Accident Foundation, 2002), which means the number of orthopaedic procedures requiring fluoroscopy is higher, therefore the radiation exposure to the orthopaedic registrar may be also higher.

According to Professor Govender (2004), Head of the Orthopaedic Department at Nelson Rolihlahla Mandela School of Medicine, orthopaedic registrars in KwaZulu-Natal do not currently wear thyroid shields. A study was performed by Dewey and Incoll (1998) in Australia to evaluate thyroid shields for the reduction of radiation exposure to orthopaedic surgeons. The study was performed after a preliminary survey by the members of the Australian Orthopaedic Association, which suggested an increased incidence of thyroid carcinoma among the orthopaedic surgeons. They concluded that the orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from fluoroscopic radiation exposure. An experimental study conducted by Muller, et al. (1998) used a leg phantom to evaluate the radiation dose to the thyroid. Using lead thyroid protection no radiation exposure was registered up to 50 kV, whereas without thyroid protection, radiation exposure was registered. They determined the maximum radiation exposure with the lateral fluoroscopy plane of the lower leg phantom to be

0.03mSv with a lead thyroid shield and 0.08mSv without a lead thyroid shield. Muller, et al. (1998) found that the radiation dose to the thyroid without a lead shield is 70 times higher than the radiation dose to thyroid with a thyroid shield.

All orthopaedic registrars in KwaZulu-Natal are not wearing personal dosimeters during operational procedures requiring fluoroscopy (Govender, 2004). Monitoring of radiation exposure, to any person occupationally exposed to 3/10 of dose limit (20mSv/year) of ionising radiation is recommended by the International Commission on Radiological Protection (ICRP, 1990).

Studies performed by Levin, Schoen & Browner (1997)(USA); Lo, Goh and Khong, (1996)(Singapore); Madan and Blakeway (2002) (England) and Muller, et al. (1998)(Germany) have been performed over short time periods and have been confined to single procedures only, with a small sample size. The current study was performed during all internal fixations of the lower limbs, including neck of femur, femur and tibia, over a 3-month period, with a large number of procedures (96) as advised by a qualified statistician so that the calculation of the estimated radiation dose would be more accurate. The results of the previous studies will be discussed in Chapter 2 section 2.11 and Chapter 5 section 5.3.1

Chapter two focuses on an overview of the literature related to radiation dose to the orthopaedic registrar and on radiation dosimetry and protection, and the effects of radiation on human cells. Chapter three provides a detailed account of the materials and methods that were used for the study. Chapter four presents the results as well as an analysis of the results that were obtained from the study. In Chapter five, a detailed discussion of the results is provided. Chapter six includes the conclusions and recommendations of the dissertation.

CHAPTER TWO

REVIEW OF THE RELATED LITERATURE

2.1 INTRODUCTION

In this chapter, a review of the literature related to radiation dose to the orthopaedic registrar is provided. The review encompasses important aspects including internal fixation and anatomy of lower limbs. It deals with the purpose of radiation dosimetry and uses of protection uses. It describes different types of radiation measurements and units as well as the thermoluminescent dosimeter (TLD) construction and mechanisms of function. Additionally, it includes radiobiology and the effects of radiation on the human body. The construction and uses of fluoroscopy and the C-arm are reviewed.

2.2 INTERNAL FIXATION

Internal fixation is one method of maintaining the reduction of a fracture. Internal fixation is usually affected by means of metal plates, rods or screws. Additionally internal fixation is used when other methods (external fixation) of maintaining reduction are impracticable or unreliable. The disadvantage of internal fixation is the fact that it converts a closed fracture into an open one (Brashear and Raney, 1978:265-268).

Although metallic implants have been used previously, it was not until early in the twentieth century that reasonably good results were obtained. A scrupulous “no-touch” technique developed by Sir Arbithnot Lane lessened the danger of bacterial contamination during the insertion of metal plates

(Brashear and Raney, 1978:265). Interlocking intramedullary fixation is probably the most effective way of treating fractures of the lower limbs but the operation depends on fluoroscopic control (Madan and Blakeway, 2002).

The most common types of internal fixation are wires, plates, rods, pins, nails, and screws used inside the body to support the bone directly (Gunn, 1992:68-74).

Wires are often used as sutures or threads to "sew" the bones back together. The wires can be used in conjunction with other forms of internal fixation to hold the bones together. Furthermore, they can be used alone in the treatment of small bones fractures, such as those found in the hand or foot (Brashear and Raney, 1978:264). Plates are like internal splints that hold the fractured ends of bone together. The plates extend along the bone and are screwed in place. If two bones that run parallel to each other both break, such as in the lower leg, plating one bone may provide enough support for the other bone as well (Gunn, 1992:68-74). Due to the complexity of some long bone fractures the best way to align the bone is by inserting a rod or nail through the hollow centre of the bone. (Gunn, 1992:68-74). Bone screws are used for internal fixation more often than any other type of implant. Although the bone screw is a simple device, there are several designs based on how the screw will be used. They can be used alone to hold a fracture, or in conjunction with plates, rods, or nails (Gunn, 1992:68-74).

Many treatment combinations have been proposed for the neck of femur, fractures. One of these treatments is internal fixation, which found to be the most effective method in orthopaedic surgery (Laurin, Riely and Roy-Camille, 1992:443 and Hoppenfeld and Deboer, 2003). The neck of femur is upper part of the femur, which joined with the pelvis. The knowledge of the lower limbs anatomy is important for the current study in order to differentiate the density and thickness of each part.

The femur is the largest and thickest bone of the body comparing with other limbs and one of the principal loading-bearing bones in the lower extremity (Laurin, Riely and Roy-Camille, 1992:318). The upper end of the femur consists of the rounded head, the neck, and two processes: the greater and lesser trochanters (Butler, Mitchell & Ellis, 2001: 12). A femoral neck fracture is relatively vertical, frequently minimally displaced and it could be unrecognised. A coexisting fracture of the femoral neck is overlooked because either it is undisplaced or the x-ray film does not include the hip. A femoral neck fracture can be difficult to detect because of external rotation of the hip or because a bar of attraction splint obscures the femoral neck (Canale, 2003:2858-9).

Fractures of the femur are among the common fractures encountered in orthopaedic (Canale, 2003:2825). Fractures can cause prolonged morbidity and extensive disability unless treatment is appropriate (Laurin, Riely and Roy-Camille, 1992:318). Internal fixation of fractures of the femoral shaft is the most popular techniques used. Whoever infection or non-union occurring after open unlocked intramedullary nailing can be a serious complication. With improvement in technique and the availability of the image intensifiers, close nailing has almost replaced the open technique. Although closed methods reduce the risk of infection (Canale, 2003:2829). A variety of various devices are used in order to treat the femur fractures (nails-

Kuntscher, AO, Schneider, Sampson and Russell-Taylor). In the current study the Russell-Taylor technique was used.

The tibia has a shaft and expanded upper and lower ends. It articulates with the femur at the knee joint (Basmajian, 1982:64-65). At the ankle, its bears some four-fifths of the forces transmitted from the foot. The upper end of the tibia overhangs the tibia shaft posteriorly. It carries medial and lateral condyles for articulation with the femur. The lower end has anterior, medial, posterior, lateral and distal surfaces (Butler, Mitchell & Ellis, 2001:12 and Rogers, 1992:279).

The shaft of the tibia is the most commonly fractured long bone. One third of the tibia surface is subcutaneous throughout most of it is length, therefore open fractures are more common in the tibia than in any other major bone. (Canale, 2003:2754 and Laurin, Riely and Roy-Camille, 1992:550).

Internal fixation is the most commonly used treatment technique in tibial fractures. Intramedullary nailing preserves the soft tissue sleeve around the fracture site and allows early motion of the adjacent joints. Furthermore intramedullary nailing provides control of length, alignment and rotation in unstable fractures, due to the ability to lock the nails proximally and distally (Canale, 2003:7757).

The introduction of new procedures, such as internal fixation of the lower limbs, has resulted in the increased use of fluoroscopic screening in the orthopaedic practice. Therefore ionising radiation has confirmed a serious occupational hazard for the orthopaedic surgeon (Hynes, et al. 1992).

2.3 Radiation dosimetry

The purpose of radiation dosimetry is to establish the energy deposited per unit mass from a field of ionising radiation (Dyson, 1993:88). The use of ionising radiation to produce an image for diagnostic purposes should be of concern, due to the unknown long-term effects of low radiation dose (Bushong, 1993:521-539). If it is assumed that safety is risk related and that the risk is dose related, it is necessary to have a standard system of measurement for the radiation dose, which the patients and radiation workers receive during radiation exposure (Roberts, 1992). Dosimetry plays a pivotal role in establishing the potential for reducing the dose to patients and radiation workers and identifying the most effective ways of reducing dose (Wall, 1996).

2.3.1 Absorbed dose

Radiation exposure causes ionisation and excitation of some atoms in the medium through which it travels. Energy is thus deposited in the medium (Bushong, 1991:17-33). The ionisation of the air can be used for the detection and measurement of ionising radiation such as x-rays and gamma (γ) rays (Gifford, 1984:179). Ball and Moore (1994:207) stated that the effect of radiation on tissue is approximately proportional to the amount of energy absorbed by the tissue. It is therefore useful to measure the energy transferred from the radiation source to the body tissue. This indicates the radiation effect to the person irradiated (Ball and Moore, 1994: 213-220).

The deposition of energy transferred from ionising radiation to the material through which it is travelling is known as the radiation-absorbed dose or absorbed dose (Bushong, 1993:17-33). The absorbed dose is defined as the energy absorbed per unit mass of medium. The SI unit of absorbed dose is the gray (Gy), which represents one joule of energy absorbed per unit mass of tissue.

1Gy= 1 J/kg…………..2.1

2.4 RADIATION UNITS

The following are units used to express an amount of radiation (Dowd and Tilson, 1999:43).

- Roentgen (R)
- Gray (Gy)
- Sievert (Sv)

The Roentgen is a measure of the ionisation of air produced by x-ray and gamma radiation below 3 MeV. In addition, it is defined as a unit of radiation-exposure that will liberate a charge of 2.58 X 10^{-9} coulombs per kilogram of air (Dowd and Tilson, 1999:43-44).

The gray (Gy) is the SI unit for absorbed dose. It's defined as energy absorption of joule (J) per kilogram in the radiation object. The old unit of absorbed dose was the rad. If the absorbed dose is stated in rads, the equivalent number of gray may be determined by dividing 1 rad by 100 (Statkiewicz, Visconti & Ritenour, 1998:45).

1 Gy = 100 rad……………..2.2

If a person receives exposure from various types of ionising radiation, the dose equivalent for measuring biological effects may be determined and expressed in the SI unit, the Sievert (Sv). This unit is used only for radiation protection purposes (Statkiewicz, Visconti & Ritenour, 1998:45).

In radiation protection, it is not the dose equivalent at a point, but the average value of the equivalent dose over a tissue or organ for a particular type of radiation R to a tissue T, H_T that is often of interest. H_T is defined by the expression, $H_T = W_R D_T$. W_R is a weighting factor selected for the type of the radiation incident on the body or in the case of sources within the body, emitted by the source and D_T is the mean absorbed dose in the tissue or organ (Rana, 1990:44). When the radiation is composed of types and energies with different values of W_R, the equivalent dose must be calculated for each component and summed to determine the total equivalent dose (H_T), (Rana, 1990:45), using the formula,

$$H_T = \sum_R W_R D_{T.R} \quad \text{………………2.3}$$

Where $D_{T.R}$ is the average absorbed dose from radiation R in tissue T, and is defined as follows:

$$D_{T.R} = \frac{\epsilon_T}{m_T} \quad \text{……………………2.4}$$

Where ϵ_T is the total energy imparted in a tissue or organ and m_T is the mass of that tissue or organ.

The effective dose H_E is defined as the sum of the weighted equivalent doses in all the tissues and organs of the body. The factor by which the equivalent dose in tissue or organ T is weighted is called the tissue-weighting factor,

W_T. The values of W_T are chosen by the ICRP so that a uniform equivalent dose over the whole body gives an effective dose numerically equal to the uniform equivalent dose. This weighted equivalent dose was previously called the effective dose equivalent, but now the ICRP uses a new name as effective dose, H_E. The unit of effective dose is Jkg^{-1}, with a special name sievert (ICRP, 1990).

The effective dose equivalent, H_E, is defined by

$$H_E = \sum_T W_T . H_T \quad \text{..............2.5}$$

Where W_T is the tissue-weighting factor. H_T is the equivalent dose in tissue or organ.

2.5 DOSE MEASUREMENT

There are different types of methods for measuring radiation dose, which include primary methods, such as ionisation chambers, calorimeters, and secondary methods, which include films, solid-state detectors, and biological dosimeters. One type of solid-state system is the thermoluminescent dosimeter (TLD) (Rahn, Gerstenberg & Vavvina, 2002). The discussion on some of radiation measurements methods will be followed.

2.5.1 Ionisation chamber

Air in its normal state is a good electrical insulator because it contains molecules that are not charged. When air is exposed to radiation, some of the photons of radiation, release electrons from the atoms in the air. This ionisation process results in the ability of the air to conduct electricity. A greater exposure results in a larger number of ionisations and thus, the amount of charge that can be measured increases accordingly (Ball and Moore, 1994:237). The intensity of an x- or γ- ray beam can be obtained by the measurement of the quantity of charge on the ions produced in unit mass of air, called exposure (Ball and Moore, 1994:239).

The exposure measurement can be related to a value of absorbed dose in air since the average energy required to liberate an ion pair in air is almost constant for all electron energies. This means that if air is exposed to χ roentgens the air Kerma, D_{air}, is given by:

D_{air} (mGy) = χ x 8.69 (Suleiman, et al.1997) …….2.6

The absorbed dose (gray) = exposure (coulombs per kg) x conversion factor. This conversion factor varies according to the irradiated material (Statkiewicz, Visconti & Ritenour 1998:45).

In the National Council on Radiation Protection and Measurements (NCRP) report No. 102, it is stated that in diagnostic radiology, because the energy of the photons generating electrons is transferred to air very near the point of radiation interaction, air Kerma (Kinetic Energy Released per unit Mass) can be have a similar value to the absorbed dose in air (Cember, 1996:369-371).

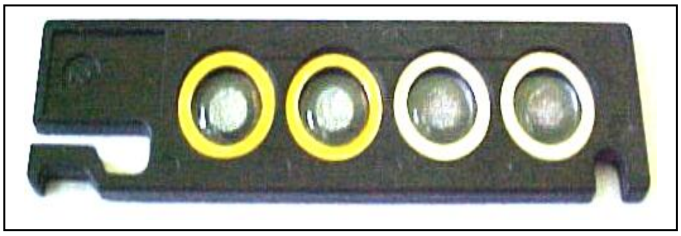
2.5.2 Thermoluminescent dosimeter (TLD)

A thermoluminescent dosimeter (TLD) is the radiation sensitive device most frequently used to measure skin dose directly (Statkiewicz, Visconti &

Ritenour, 1998:223). There are some crystals that are able to store radiation energy absorbed when they are exposed to ionising radiation. Upon heating of these crystals, light is emitted (Ball and Moore, 1994:231). This is explained in more detail in 2.6.2.1.

Thermoluminescent dosimeters (TLDs) are usually used in the form of finely powdered lithium fluoride in a solid matrix of Teflon. These are available as small rods or discs (Ball and Moore, 1994:238). The discs are small and commonly in the region of 3mm square and less than 1mm thick (Bushong, 1993:660) (Figure 2.1). As the TLDs are sensitive to ultraviolet light, they are usually sealed in black polythene case before use (Wade, 1994). These rods and discs are reusable as the heating process returns the electrons back to their original levels (Bushong, 1993:660).

FIGURE 2.1: TLD DISCS (SABS, 1997)



Examples of TLDs used in diagnostic radiology are those made of lithium fluoride, lithium borate, and calcium sulphate. Lithium borate has a flatter energy response and better tissue equivalence. In contrast calcium sulphate has very high sensitivity and a very small dose can be detected (Bushong, 1993:660). This is described in detail in Chapter 3 section 3.9.2.

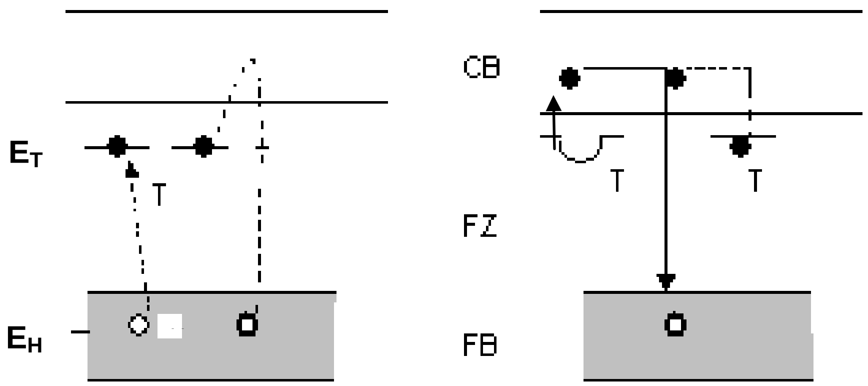
Lithium borate has close tissue equivalence. The lithium borate dosimeters are superior to lithium fluoride in term of tissue equivalence. The borates are stable chemical compounds and respond to low dose (McKeever, Moscovitch & Townsend 1995:182). Yamashita first described the method of preparation of calcium sulphate in 1971, but later Azorin in 1986 produced an equally high sensitive material. The sensitivity of calcium sulphate has been improved by a factor of 50%. Many researchers emphasise that the grain size and impurities of the calcium sulphate crystal influence the relative intensity of the broad glow peaks as well as overall sensitivity (McKeever, Moscovitch & Townsend 1995:162-163).

TLDs are ideal for general dosimetry surveys and for personnel monitoring. TLDs are most commonly used to measure entrance surface doses. Entrance surface dose can be defined as the absorbed dose to air at the centre of the beam, including backscattered radiation (Hart, Jones and Wall, 1994). The dose to other parts of the body is then calculated from these skin doses (entrance dose)(McKinlay, 1981 and Horowitz, 1984:76).

2.5.2.1 Thermoluminescent (TL) mechanism

When the TL material is irradiated the energy is absorbed from the radiation beam. Some of the electrons of the crystals are raised to higher energy levels. Most of the electrons are immediately returned to the ground state, but some remain trapped in the high energy levels. Upon subsequent heating of the material, these trapped electrons are elevated to still higher electrons levels from which they can return to the ground state with the emission of light (Johns and Cunningham, 1983:648-653) (Figure 2.2). The light emitted is measured with a sensitive photocell. The amount of the light emitted has been found to be directly proportional to the radiation exposure (Dowd and Tilson, 1999:55).

FIGURE 2.2: STEPS IN THE EMMISION OF THERMOLUMINESCENCE (Rana, 1990:79)



E_T	Electron Trap	FZ	Forbidden Zone
E_H	Electron Heated	FB	Field Band
CB	Conduction Band		

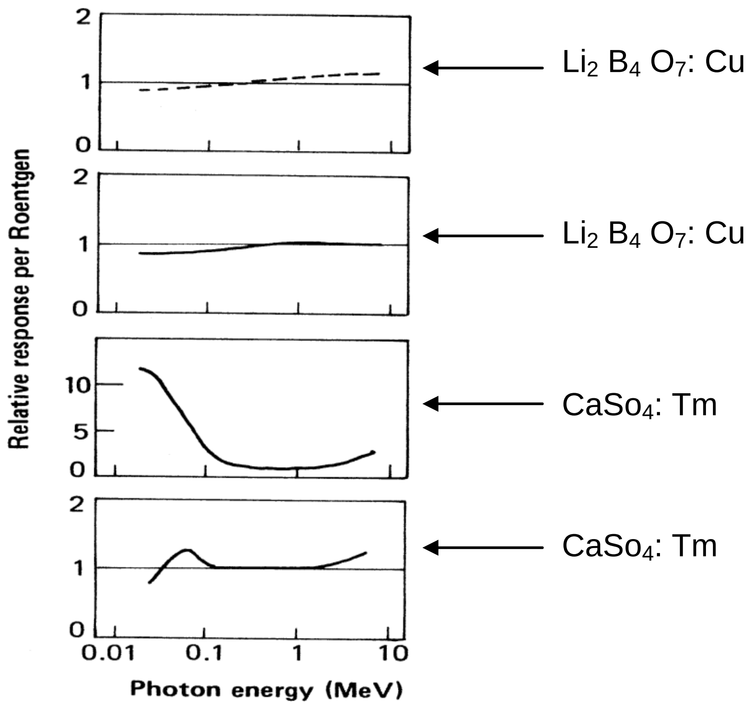
2.5.2.2 Thermoluminescent (TL) material properties

This section will describe the energy response, fading, thermal treatments and glow curve of the TL materials; - lithium borate (Li_2 B_4 O_7: Cu) and calcium sulphate ($CaSo_4$: Tm) that are used in the current study.

2.5.2.2.1 Energy response

The energy response is the variation of detected TL output, for a fixed dose, as a function of the energy of the absorbed radiation (McKeever, Moscovitch & Townsend 1995:36).

FIGURE 2.3: ENERGY RESPONSE OF TLD ELEMENTS (SABS, 1997)



The effective atomic number of $Li_2 B_4 O_7$: Cu is 7.3. This results in response independent of photon energy, within 10%, in the energy range from 40 KeV to 7 MeV (Takenaga, Yamamoto & Yamashita, 1980). The photon energy dependence of $CaSo_4$: Tm is characterized by a significant over-response for photon energies in the range of 25 – 200 keV. Figure 2.3 represents the energy responses for the TLD elements used in the current study ($Li_2 B_4 O_7$: CU and $CaSo_4$: Tm).

2.5.2.2.2 Fading

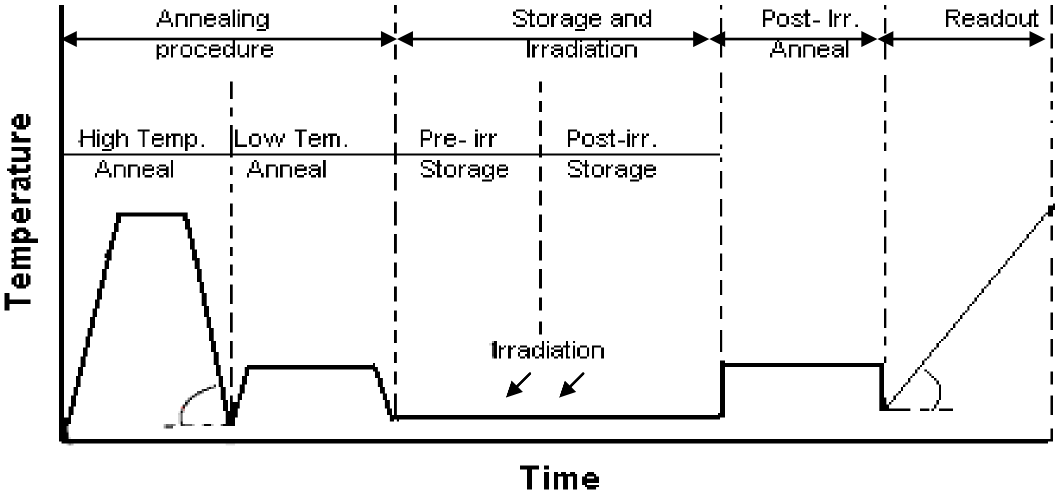
McKeever, Moscovitch & Townsend (1995:39) stated that after irradiation of the TLD, the output signal decreases with time. This phenomenon is known as fading.

The fading of $Li_2 B_4 O_7$: Cu, after 60 days is 9%, 20% and 32% at a storage temperature of 25 °C, 35 °C and 50 °C respectively. The hygroscopic nature of $Li_2B_4O_7$: Cu makes it sensitive to humidity, which means that the fading characteristics may be affected by the presence of water vapour. Lithium borate material should be stored in a low humidity environment (McKeever, Moscovitch and Townsend 1995:197). The fading of $CaSo_4$: Tm is 5% for a storage period of 6 months at room temperature or for storage of 20 days at 50 °C. A post irradiation annealing at 120 °C for 10 min is used in both cases (Takenaga, Yamamoto and Yamashita, 1980).

2.5.2.2.3 Thermal treatments

Thermal annealing is a procedure used to prepare the TLD for the next use. Thermal annealing consists of several stages (Figure 2.4): - pre-irradiation annealing, post irradiation annealing and readout. The purpose of pre-irradiation annealing is to remove the lower temperature satellite peaks and to re-establish the thermodynamic defect equilibrium, which existed in the material before irradiation and readout. The purpose of post-irradiation annealing is generally to remove unwanted, lower temperature satellite peaks, which may overlap with the main dosimetry signal (McKeever, Moscovitch & Townsend 1995:38-39).

FIGURE 2.4: THERMAL TREATMENTS PROGRAM FOR TLD MATERIAL (McKeever, Moscovitch & Townsend 1995:39)



2.5.2.2.4 TL glow curve

When the crystals are heated, the temperature will increase, and intense light emission, called peaks, will be produced whenever the characteristic temperature of the trap is reached. The peaks at low temperature are due to shallow traps, which require only a small amount of energy to release their trapped electrons; those at high temperature are due to deep traps. The curve of the light yield plotted as a function of the temperature of the thermoluminescent material is called the glow curve (Rana, 1990:79).

2.5.2.3 Advantages of TLDs

The TLDs do not suffer from loss of information following exposure to excessive radiation. They can be worn for intervals up to 3 months at a time (Bushong, 1993:660). In addition, one advantage of TLDs is that, unlike film, they absorb radiation in approximately the same way that human tissue does (Dowd and Tilson, 1999:55-57). TLDs can be very small and flexible in shape and chemically stable. TLD crystals can be reused, making the device somewhat cost-effective (Statkiewicz, Visconti & Ritenour 1998:226).

2.5.2.4 Disadvantages of TLDs

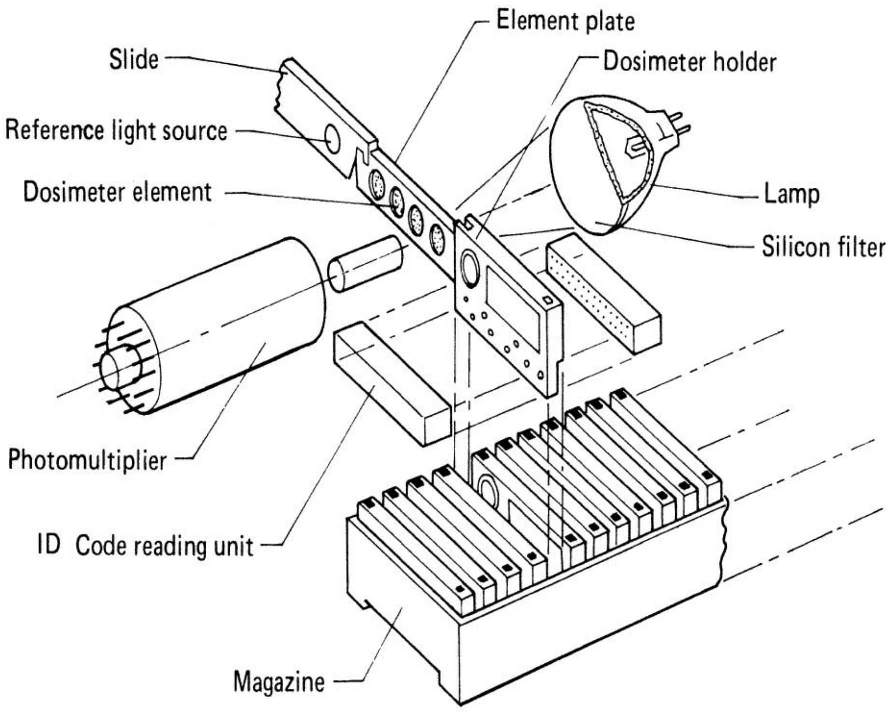
The TLD can be read once. TLD readouts must be carefully obtained, or results can be lost. Calibrated dosimeters must be prepared and read with each group of TLDs as they are processed. Furthermore, only the exposure received in the body area in which it is worn is recorded. The readout process destroys the stored information in the TLD. The TLD may be reused, but once the crystal is heated the record of any previous exposure is gone. Finally the accuracy of the TLDs is limited to ± 20% (Statkiewicz, Visconti & Ritenour, 1998:226). Accuracy can be defined on two levels; the first level is the detection threshold. This is the lowest true positive that can be measured. The second level is the best measurement capabilities (BMC). The international accepted worst measurement capability is to be within ± 50% of the true value. This best/worst measurement capability is also dependant on the magnitude of the dose. The higher the dose, the better the best/worst measurement capability is (SABS, 1997).

2.5.2.5 Automatic reader

The automatic reader used for the current research was model UD-710 with a magazine changer model UD-730. The reader was equipped with a microcomputer, which controlled self-checking functions, and all automatic functions, such as annealing of the TLDs for repeat use, reading the Identity (ID) code, and sensitivity adjustment for correction by the built-in reference light source (SABS, 1997) (Figure 2.5).

The dosimeter was guided to the reading position by an element positioning mechanism and then read. The dosimeter was lifted out of the magazine to the position where the dosimeter codes were detected by light transmission through punched holes. The inserted plate was then unlocked and pulled out of the holder by a slide with a coupling device. The 4-dosimeter elements were thus guided to the reading position one after another (SABS, 1997).

FIGURE2.5: AUTOMATIC READER MODEL UD -710 (SABS, 1997)



A small tungsten lamp, driven by pulse voltages, flashed three times to read one element, and accordingly, pre-heating, thermoluminescent (TL) reading and annealing for the next uses were performed. After the 4 elements of the dosimeter had been read, the dosimeter was returned to the magazine and was prepared for further use. The result was converted to roentgen units according to the sensitivity of the phosphor materials and the output was sent to an external device such as a computer or printer. The processing time was 20 sec/dosimeter. The accuracy of the TLD reading was 75% (SABS, 1997).

2.6 PERSONNEL DOSIMETRY

Personal Monitoring Technologies of Rochester New York developed the TLDs' personal monitoring program (Dowd and Tilson, 1999:57). The personnel dosimeter provides some indication of the working habits and working conditions of diagnostic imaging personnel. It indicates occupational exposure by detecting and measuring the quantity of ionising radiation to which the dosimeter has been exposed over a period of time (Statkiewicz, Visconti & Ritenour 1998:216).

The main objective of personnel dosimetry is to monitor the personnel dose during routine occupational exposure. Users of personnel dosimetry include radiotherapists, radiographers and naval personnel on nuclear power vessels. Such monitoring aims to ensure that the limit set for the exposure of such personnel remain within safety limits. These limits are based on recommendations of the International Commission on Radiological Protection (ICRP). The aim of personnel monitoring is to ensure that the individual's total exposure is being limited to the effective values as recommended by the ICRP (McKeever, Moscovitch & Townsend 1995:29).

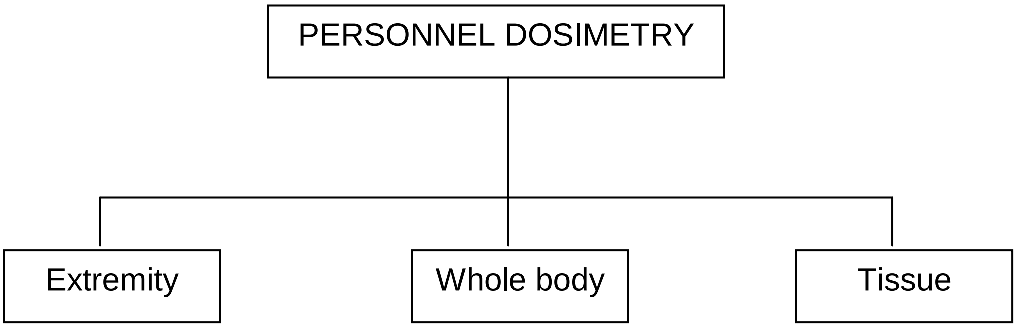
According to McKeever, Moscovitch & Townsend (1995:29) personnel dosimetry is divided into three categories (Figure 2.6).

(a) Extremity dosimetry: The determination of the maximum dose equivalent to the hands or feet.

(b) Whole body dosimetry: The dose equivalent absorbed at a depth of 1 cm in human tissue below the surface of the body.

(c) Tissue dosimetry: The dose equivalent absorbed at a depth of 0.5 to 1mm in human tissue.

FIGURE 2.6: AREAS OF TLDs MATERIAL USES (McKeever, Moscovitch & Townsend 1995:29)



Regarding to International Commission on Radiological Protection (ICRP, 1990).Monitoring of radiation exposure, to any person occupationally exposed to 3/10 of dose limit (20mSv/year) of ionising radiation is recommended by the

2.6.1 Personnel dosimeter

An example of a personnel dosimeter consists of 4 elements (SABS, 1997). Each element is mounted tightly on a plastic plate (12 x 48 x 1.8mm), which can be held with coded holes for the personnel number (Figure 2.7).

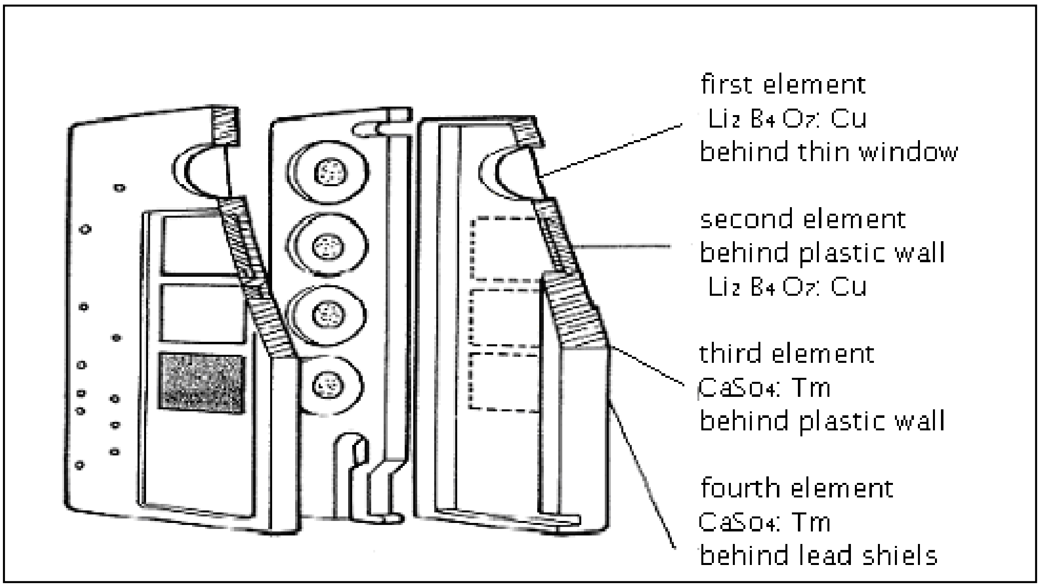
(i) The first element, $Li_2 B_4 O_7$: Cu is designed to evaluate skin dose-equivalent values. The phosphor layer is 15 mg/cm^2, and there are several plastic layers around it. The total thickness of the plastic layers of the front side is 14mg/cm^2, and of the backside is 25 mg/cm^2. This element can be used to estimate dose equivalent at a depth from 0.5 - 0.1 cm.

(ii) The second element, $Li_2 B_4 O_7$: Cu is the same size and has a plastic shield of 160 mg/cm² thick for reading of deep dose equivalent values. This element can be used to estimate dose equivalent at a depth of 1.6 cm.

(iii) The third element is $CaSo_4$: Tm is designed for low dose radiation with an energy compensation shield of plastic of 160 mg/cm². This element can be used for daily or arbitrary checks of doses.

(iv) The fourth element is $CaSo_4$: Tm is designed for high dose radiation the element is situated behind 0.7mm lead shield (SABS, 1997).

FIGURE 2.7: TLD BADGE CONSTRUCTIONS; MODEL UD – 802A (SABS, 1997)



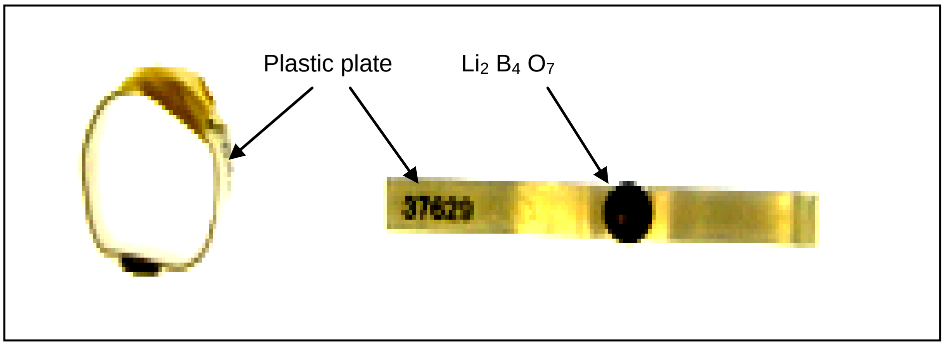
2.6.2 Extremity dosimeters

These are TLDs worn on the hand that could potentially receive the greatest radiation exposure. This would normally be the dominant hand that is the right hand of a right-handed individual (Dowd and Tilson, 1999:57). During surgery TLD finger ring dosimeters have to be small, convenient to wear and suitable for cold or gas sterilization. A new approach as reported by Duftschmid, et al (1996) is described below.

The approach is based on a circular TLD chip mounted with kapton foil on a small aluminium disc, containing a miniaturized circular bar code and a six-digit number. The ring is inserted into a disposable plastic finger ring and protected by a circular cover plate (Duftschmid, et al. 1996) (Figure 2.8). A semi-automated device opens the ring for reading, and four bar-coded discs are inserted into a modified standard TLD card for automatic processing by a special reader device. The reader contains a video bar code identification system based on a miniaturized CCD camera and image processing by special PC software (SABS, 1997).

An extremity dosimeter contains 1 element of lithium borate ($Li_2 B_4 O_7$: Cu). The element is mounted tightly on a plastic plate (12 x 48 x 1.8mm). This element is designed to evaluate skin dose-equivalent values. The phosphor layer is 15 mg /cm² thick (SABS, 1997).

FIGURE 2.8: EXTREMITY DOSIMETER (SABS, 1997)



2.7 FLUOROSCOPY

Fluoroscopic imaging is a moving or dynamic imaging. Fluoroscopy is used in a variety of settings to show motion. The basic fluoroscopic equipment consists of an x-ray tube designed to emit continuous radiation exposure and an image intensification unit from which the image is transmitted to a television monitor for viewing (Dowd and Tilson, 1999:212). Bushong (1993:648) and Sutherland and Finlayson, 1998) stated that in diagnostic radiology the radiologic technologists and orthopaedic surgeon occupational radiation exposure comes from fluoroscopy.

2.7.1 C-ARM

In addition to fluoroscopy in the radiology department, mobile fluoroscopy (C-arm) is often performed in the operating room for procedures such as nailing of long bone fracture and fixation of hip fractures (Dowd and Tilson, 1999:212).

The C-arm fluoroscopic units are extremely popular for surgical procedures. When coupled to a videodisc unit, both static and dynamic imaging can be instantly available. The units operate exactly as do stationary fluoroscopic units (Carlton and Adler, 2001: 546). The C-arm is the image modality routinely used for intraoperative imaging in orthopaedic surgery. The C-arm fluoroscopy is positioned and handled by a radiographer on vocal commands, which means that the surgeon depends on external help to manipulate the visual feedback and the workflow is not optimised (Suhm, et al. 2003).

The image intensifier is now commonly used in orthopaedic surgery for intraoperative assessment of fracture reduction and implant placement, especially with the increasing trend towards use of closed nailing devices (Lo, Goh & Khong, 1996). The purpose of a radiological examination in orthopaedic surgery is to use fluoroscopic screening to monitor or evaluate the progress of manipulative or corrective surgery of bones and joints (Crawley and Rogers, 2000). According to Kretic, et al. (1998) intraoperative fluoroscopic imaging is used routinely to provide the surgeons with optical feedback during the percutaneous insertion of surgical instruments, implants and for intraoperative control of length, axial, and rotation alignment during osteosynthesis. Furthermore Suhm, et al. (2003) stated in their study of adapting the fluoroscope to image-guided surgery that the surgeon should be able to manipulate the visual feedback from the C-arm, in order to achieve an optimised workflow.

2.7.1.1 RADIATION RISK FROM THE C-ARM

Scatter radiation poses the biggest hazard to personnel in the room during exposure. The patient is the primary scattering object and the larger the patient, the more scatter produced. During general radiography and image-intensified fluoroscopy, scatter radiation occurs from within the patient. Generally, the intensity of scatter radiation one meter from the patient is approximately 0.1% of the intensity of the useful or primary beam set at the patient position (Bushong, 1993: 632-633).

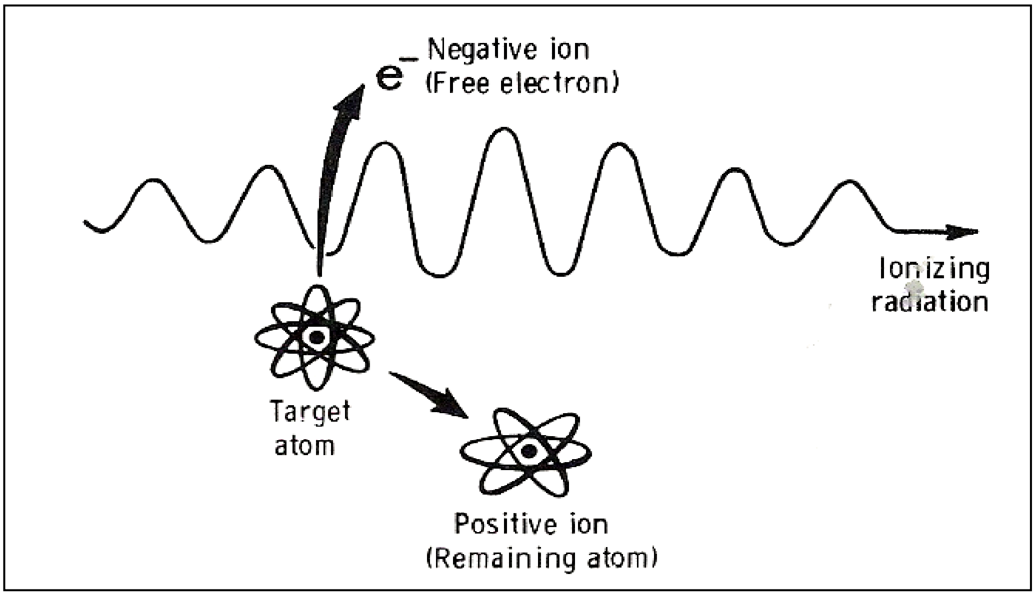
There is an increased use of the fluoroscopic guidance techniques in certain orthopaedic surgical procedures, which allow the accurate positioning of orthopaedic implants to bone, with the intraoperative images showing progress much more easily than plain radiographs (Sutherland and Finlayson, 1998). Surgeons and other operating-room personnel who are involved in these procedures are voicing growing concern over possible associated radiation health hazards (Fuchs, et al. 1998; Tremains, Georgiadis & Dennis, 2000 and Theocharopoulos, et al. 2003). Image intensifier machines, which are able to store and show the images taken, have the effect of greatly reducing the radiation dose to which the patient, surgeon, and operation theatre staff are exposed (Sutherland and Finlayson, 1998).

Technological improvement in the image quality has been such that, under certain circumstances, post- operative check radiographs are unnecessary (Haddad, Williams & Prendergast, 1995). Although the doses involved are generally low, image intensification is not a benign aid, and radiation exposure may become significant over a surgeon's career (Sutherland and Finlayson, 1998). As all medical radiation exposure should be kept to a minimum under the so-called As Low As Reasonably Achievable (ALARA) principal, fluoroscopic units should have modern fluoroscopes (Suhm, et al. 2003). The knowledge of radiation hazards and protection in orthopaedic practice are important in order to reduce the radiation exposure.

2.8 RADIATION PROTECTION

X-rays were discovered in 1895, by Conrad Roentgen, a professor of physics at the University of Warzburg Germany (Dowestt, Kenny & Johnston, 1998:12). The radiation emission produced by x-ray tubes and radioactive substances are known as ionising radiation because of their ability to disrupt atoms and molecules. Statkiewics, Visconti & Ritenour (1998:4) stated that if radiation produces positively and negatively charged particles (ions) as it passes through the matter, it is called ionising radiation. The ability is not shared by several other types of radiation such as microwaves, visible light, and ultrasound (Wall, 1996). Ionising radiation is any kind of radiation capable of removing an orbital electron from an atom with which it interacts (Bushong, 1993:5) (Figure 2.9).

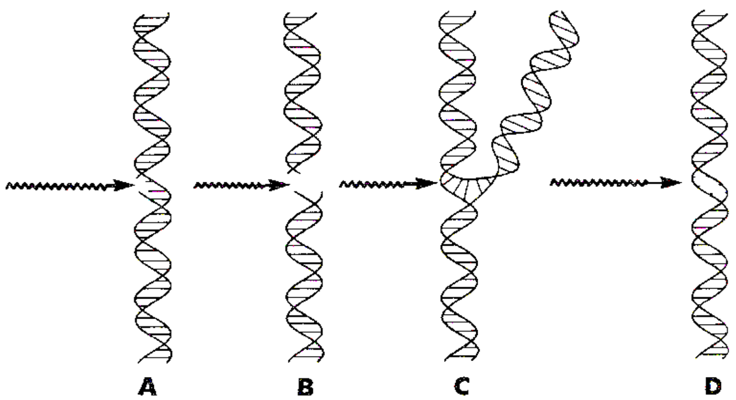
FIGURE 2.9: DIAGRAM DEMONSTRATING THE IONISATION PROCESS (AN ELECTRON IS REMOVED FROM A TARGET ATOM) (Bushong, 1993:5)



The basic philosophical principle of radiation protection concerning the use of ionising radiation emphasizes the need to maintain exposure to ionising radiation at a level of “ALARA” (Carlton and Adler, 2001:158 and Noordeen, et al. 1993). The ionising radiation disrupts human deoxyribonucleic acid (DNA) causing damage to the cell nucleus, genes and chromosomes (Wall, 1996).

DNA molecules are the main constituents of chromosomes, which are instrumental for transfer of genetic information to the daughter cells. The lesion in chromosomes, or chromosomal aberrations, gives a good indication of the lesions in a population of cells and can help in predicting the effects of irradiation (Tubiana, Dutreix & Wambersie, 1990:34) (Figure 2.10). The ability to ionise is the basis of the unique damage to cells and tissues, which x-rays and radioactive materials can create (Wall, 1996).

FIGURE 2.10: TYPES OF DAMAGE THAT OCCUR IN DNA: A, ONE SIDE RAIL SEVERED. B, BOTH SIDE RAIL SEVERED. C CROSS-LINKING. D, RUNG BREAK (Bushong, 1993:546)



The hazards of ionising radiation become rapidly evident after the discovery, initially in the form of damage to the skin (erythema) and blood fractions, and later as cancer induction and genetic mutation (Dyson, 1993:217 and Wall, 1996).

2.8.1 International Commission on Radiological Protection (ICRP)

According to Statkiewicz, Visconti & Ritenour (1998:55) the International Commission on Radiological Protection (ICRP) is considered to be the international authority regarding the safe use of sources of ionising radiation.

Since its inception in 1928, the ICRP has been the leading international organization responsible for providing clear and consistent radiation protection guidance through its recommendations on occupational and public dose limits.

2.8.2 Maximum Permissible Dose (MPD)

The limit placed on all exposures resulting from internal and external sources of radiation is the maximum permissible dose (MPD) limit (Dowd and Tilson, 1999:182). Furthermore, Bushong (1993:602) stated that the MPD is the maximum dose of radiation that in the light of present knowledge would be expected to produce no significant effects. At radiation doses below the MPD, no genetic response should occur (Statkiewicz, Visconti & Ritenour, 1998:57). The risk of a genetic response at the MPD level is not zero (Bushong, 1993:602).

In the clinical situation, it is not possible to measure the quantity of energy absorbed in tissue due to the exposure of the body to radiation directly. An estimation of the value of absorbed dose is determined indirectly by using one of the effects (interaction with a matter) of radiation, which can be more easily measured (Ball and Moore, 1994:224). The dose limits for application for radiation worker and the public are summarised in table 2.1. Radiation workers are defined as the personnel's who receive about 1%of the annual total effective dose equivalent (20mSv/year) in order to keep with ALARA concept (Statkiewicz, Visconti & Ritenour 1998:216).

TABLE 2 .1: RECOMMENDED DOSE LIMITS (ICRP, 1990).

Application	Dose Limit	
	Radiation workers	Public
Effective dose	20 mSv per year	1 mSv in a year
Annual effective dose in the skin	500 mSv	50 mSv in a year
Extremities	500 mSv per year	150mSv in a year

The use of ionising radiation during fluoroscopic procedures in orthopaedic practice can cause biological damage and changes to the human DNA.

2.9 RADIOBIOLOGY

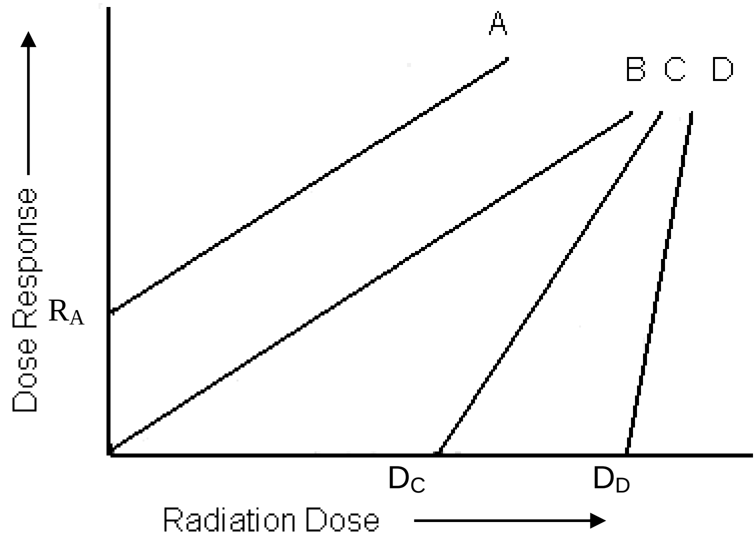
Radiobiology is the branch of biology concerned with the effects of ionising radiation on a living system (Statkiewicz, Visconti & Ritenour, 1998:4). Radiobiological studies have been conducted to establish the effects of low-dose irradiation. It is not possible to do this directly and the studies have extrapolated the dose-response relationship from the high-dose, known region into the low-dose, unknown regions of the curves. This results in a linear, non-threshold dose-response relationship (Hall, 1994:424). The discussion on a linear, non-threshold dose-response relationship follows in this chapter.

The effects of x-rays on humans are the result of interactions at atomic levels (Bushong, 1993:542-544). Herscovici and Sanders (2000) stated that the biological effects of radiation have been shown to inhibit mitosis by producing irreparable deoxyribonucleic acid double strand breaks or creating structural changes by damaging the nucleus, thereby producing potential genetic transmutations.

Radiation dose response relationships have two applications in radiology. First, relationships are used to design therapeutic treatment routines for patient suffering from malignant disease. Second, radiobiologic studies have been designed to provide information on the effects of low dose irradiation. These relationships obtained are the basis for radiation control activities, and are of particular significance to diagnostic radiobiology (Bushong, 1993:538).

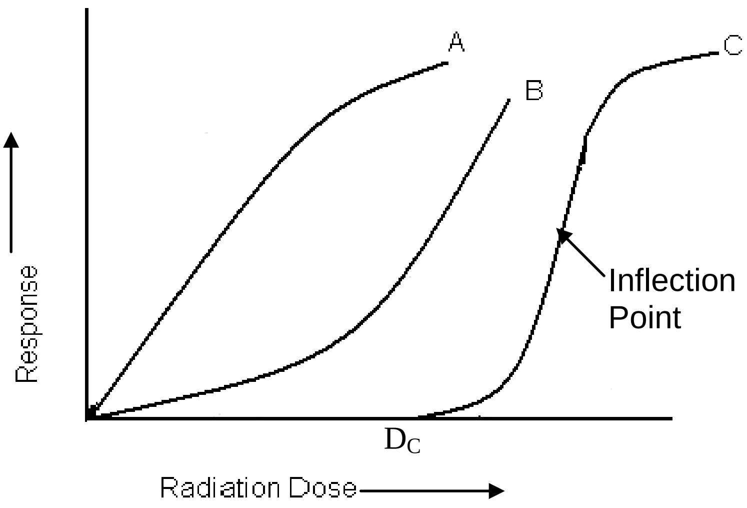
Every dose response relationship has two characteristics. It is either linear or non-linear, and it is threshold or non-threshold. The linear dose response relationship is so called because the response is directly proportional to the dose (Figure 2.11). When the radiation is doubled, the response to radiation is likewise doubled (ICRP, 1990). All other dose response relationships are defined as non-linear (Figure 2.12). The threshold is defined as the point at which a response to an increasing stimulation first occurs. If ionising radiation functions as the stimulus and the biologic effects it produces are the response and if a linear, non-threshold relationship exists between radiation dose and biologic response, some biologic effects will be caused in living organism by the smallest dose of ionising radiation. Consequently no radiation exposure level is absolutely safe (Statkiewicz, Visconti & Ritenour, 1998:113-115).

FIGURE 2.11: LINEAR DOSE RESPONSE RELATIONSHIPS (Bushong, 1993:538)



Dose response relationships A and B intersect the dose axis at zero or below. These relationships are therefore of the linear, non-threshold type. In a nonthreshold dose response relationship, any dose is expected to produce a response. At zero doses, the relationship A exhibits a measurable response, R_A. The level of R_A is called natural response level and indicates that even without a radiation exposure the response occurs. Dose response relationships C and D are identified as linear, threshold because they intercept the dose axis at value greater than zero. The threshold doses for C and D are D_C and D_D respectively. At dose levels below these values, no response would be expected (Bushong, 1993:538).

FIGURE 2.12: NON-LINEAR DOSE RESPONSE RELATIONSHIPS (Bushong, 1993:539)



Curve A and B demonstrate a non-linear dose relationship. In curve A, a large response will result from very little radiation dose. In curve B, a small response occurs at low dose; therefore a large response results from high dose. Curve C is a non-linear, threshold relationship and employed in radiation therapy to demonstrate the high dose response. The tail of the curve indicates that limited recovery occurs at low radiation doses. At a dose below D_C no response will be measured. At the highest radiation doses the curve gradually levels off and then veers downward, because the affected living tissue dies before the observed effect appears. As the dose increases above D_C, it becomes increasingly effective, until it reaches the dose corresponding to the inflection point of the curve (Bushong, 1993:539).

Although human cells are thought to be resistance to malignant change and no studies have shown toxic effects resulting from long-term exposure to low dose radiation, when an atom is ionised, its chemical binding properties change (Statkiewicz, Visconti & Ritenour, 1998). If the atom is a constituent of a large molecule, the ionisation may result in breakage of the molecule. The abnormal molecule may in time function improperly or cease to function, which can result in serious impairment or death of the cell (Bushong, 1993:542-545). In 1906, two French scientists theorized an observation that the radio-sensitivity of cells was a function of the metabolic rate of the tissue being irradiated. This is known as the law of Bergonie and Tribondeau and has been confirmed many times (Travis, 1989:66).

2.9.1 Short- lived effects (non-stochastic)

Non-stochastic effects are biologic somatic effects of ionising radiation that exhibit a threshold dose below which the effect does not normally occur and above which the severity of the biological damage escalates because a large number of cells are injured at higher doses. Non-stochastic effects occur only after large doses of radiation. Such radiation doses are much greater than those typically encountered by an individual in diagnostic radiology. These non-stochastic effects may be early such as: erythema, a decrease in white blood cell count, epilation, and haematopoietic and gastrointestinal syndrome (Shrivastava, and Ramakantan, 1998). There may also be late effects such as depigmentation, scarring, and late ulceration.

2.9.2 Delayed effects (stochastic)

The term stochastic literally means “random in nature”. This is also called the statistical response, which means that the probabilities of occurrence of effects increase in proportion to the radiation dose of the entire population (Dowd and Tilson, 1999:111). Stochastic effects are non-threshold, randomly occurring biologic somatic changes in which the chance of occurrence of the effect, rather than severity of effect is proportional to the dose of ionising radiation. Examples of these are cancer and genetic alterations (Statkiewicz, Visconti & Ritenour, 1998:60).

The health effects that are expected from low levels of exposure will not be observable in the short term. The delay will often be many years and in addition they will usually not be distinguishable from similar effects arising from other causes (NCRP, 1989). Herscovici and Sanders (2000) stated that although the human cells are thought to be resistant to malignant changing and no studies have shown toxic effects resulting from long term exposure to low dose radiation, risk is still assumed. Since 1991, the risk estimates for low dose radiation have been re-evaluated and increased six-fold. This has led to a reduction in dose limits to radiation workers from a 50 mSv/year to a 20-mSv/year whole body dose (Hynes, et al. 1992).

2.10 RADIATION DOSE TO THE HANDS

Dowd and Tilson (1999:130-148) stated that the skin is a highly vascular, very large organ that consists of an outer layer (epidermis), connective tissue, (dermis) and a subcutaneous layer of fat and connective tissue. Skin is sensitive because it represents a continually renewing system of cells. Damage to the germ cells of the skin by radiation is common. Skin cancer induced by radiation follows a threshold dose-response relationship. Several radiation reactions were reported on the hands of early radiologists and technicians soon after Roentgen discovery. The first case of skin cancer reported in 1902 on the hand of a technician. Due to the fact that their machines were crude, radiologists repeatedly placed their hands in the beam to check the efficiency, resulting in high exposure to the hands, with a large number of individuals developing skin carcinoma year's later (Travis, 1989:171). A number early of radiation workers (radiologists, dentists and technologists) were exposed to large amounts of ionising radiation. This resulted in some severe radiation injuries, and many radiologists and dentists developed cancerous skin lesions on their hands as a result of occupational exposure (Statkiewicz, Visconti & Ritenour, 1998:123).

Studies by Al-Shawi and Fern (2003); Artigans, Conso & Hazebrouq (2003); Goldstone, Wright & Cohen (1993); Levin, et al. (1997); Madan and Blakeway (2002) and Rampersaud, et al. (2000), have investigated the radiation exposure to the orthopaedic surgeon in the operation theatre. These studies will be briefly described below.

Rampersaud, et al. (2000) stated that compared with the eyes, head, neck, or body, the greatest risk of radiation exposure is typically to the surgeons hands, which are often unprotected and in closest proximity to the area of ionising radiation. According to Madan and Blakeway (2002), the hands of the surgeon are most likely to be directly exposed to ionising radiation during intraoperative fluoroscopic screening.

The study performed by Goldstone, Wright & Cohen (1993) in the United Kingdom at Addenbrooke's Hospital aimed to evaluate the radiation dose to the orthopaedic surgeon within 44 procedures. They concluded that the total radiation dose received to the hands per surgeon ranged from 0.048 – 2.3 mSv. Similarly Muller, et al. (1998) evaluated the radiation dose to the hands during 41 procedures of intramedullary nailing of femoral and tibial fractures, and found that the average dose of radiation to the dominant hand of the primary surgeon is 1.27mSv and 1.19mSv to the first assistant. Levin, Schoen and Browner, (1997) also used thermoluminescent rings to study the radiation dose to the orthopaedic surgeon during 30 close interlocking intramedullary nailing procedures. They reported an average of 0.23 mSv to the orthopaedic surgeon hands of exposure during insertion of the intramedullary nail and proximal locking screw.

2.11 RADIATION DOSE TO THE THYROID

Thyroid cancer is of concern after radiation exposure. It accounts for approximately 6% to 12% of the mortality attributed to radiation-induced cancers (Bushberg, et al. 2002:849). Thyroid cancer has been identified as the most pronounced health effect of radiation accidents (Balter, 1996). The dose response data for thyroid cancer fits a linear, non-threshold dose response relationship (Dowd and Tilson, 1999). According to Balter, (1996) the increased numbers of thyroid cancers are related to:

(A) Chronic iodine deficiency during the years preceding the Chernobyl disaster in the children living in regions contaminated with radiation and,

(B) Genetic predisposition to developing thyroid malignancy after radiation exposure in some subgroups of exposed population

Two studies (Shore, et al. 1985 and Ron, 1990) have shown small excesses of thyroid cancer beginning about 5 years after low dose irradiation, which then became more pronounced by 10-15 years after irradiation. Statkiewicz, Visconti & Ritenour (1998: 127) concurred with Shore, et al. (1985) and Ron, (1990) by stating that the approximate time for the appearance of such radiation- induced thyroid malignancies is usually between 10 years and 20 years after low dose exposure.

In 1996, a preliminary survey of the membership of the Australian Orthopaedic Association (AOA) suggested an increased incidence of thyroid carcinoma in orthopaedic surgeons, due to the used of fluoroscopic image (Dewey, 1997). This perception is the subject of on going investigation.

Dewey and Incoll (1998) stated in their study for evaluation of the thyroid shields that the perceived increase in the incidence of thyroid carcinoma in orthopaedic surgeons prompted an assessment of the use and value of thyroid shields in the operating theatre. They used TLDs to monitor the orthopaedic registrars' thyroid, in addition, thyroid function, thyroid-stimulating hormone (TSH), free T4., free T3., antimicrosomal antibody, and antithyrolobulin antibody tests were performed to exclude any abnormality related to radiation exposure. The radiation exposure measured on the TLD monitor ranged from of 0.01 to 0.4 mSv. They found that the thyroid function results were within normal limits, however the higher TSH levels occurred in trainees with the longest service. Dewey and Incoll (1998) concluded that the orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from this radiation exposure.

Experimental studies by Muller, et al. (1998); Schneider, Wittke & Rob, (1993) and Theocharopoulos, et al. (2003) were performed to evaluate the radiation dose to the orthopaedic surgeons' thyroid, based on the use of leg phantoms. This study is difficult to compare with the current study. The difficulties of comparing will be discus in chapter 5. Schneider, Wittke & Rob (1993) investigated the dose the examiner received over a period of one year, during coronary angiographies, both with and without thyroid protection, and found that without thyroid protection the examiner received a dose 30 times higher than with thyroid protection. Muller, et al. (1998) found that the radiation dose to the thyroid without a lead shield is 70 times higher than with a thyroid shield. A study performed by Theocharopoulos, et al. (2003) to evaluate the radiation exposure in orthopaedic surgery, concluded that the use of thyroid protection leads to a further 2.5- fold decrease of radiation dose than without thyroid protection.

Madan and Blakeway (2002) performed a study to estimate the radiation hazard to the patient's gonads and orthopaedic surgeon's hands during intramedullary nailing of the femur, but did not calculate the radiation dose to the thyroid of the orthopaedic surgeon. Therefore a study, which investigates the radiation dose to the thyroid of the orthopaedic surgeons, is necessary. No studies have been done in South Africa in order to investigate the radiation dose to the orthopaedic registrars thyroid.

2.12 SCREENING TIME

The orthopaedic surgeon spends a significant amount of time working in close proximity to x-rays. Screening time gives a useful idea of the amount of time that the image intensifier machine is operating, but not of the radiation dose to the surgeons. Sutherland and Finlayson (1998) performed a study to evaluate the relationships between screening time and radiation dose to the orthopaedic surgeons during fluoroscopic procedures. They concluded that the reduction of the time that the machine is operating should reduce the potential exposure to harmful radiation. Jones and Stodart (1998) stated that prolonged exposure time per patient might be required during operational procedure, resulting in increased exposure of orthopaedic surgery theatre staff.

The addition of a stored image facility to a basic fluoroscopy machine reduces screening time by a factor of four, while a more modern digital image facility results in a further eightfold reduction. Therefore, the radiation dose to the orthopaedic theatre staff and patient will be decreased (Wallace, et al.1987).

The aims of this study were to quantify the radiation dose to the orthopaedic registrars' hands, thyroid and whole body, and to quantify the average operation and screening times during fluoroscopic internal fixation of the lower limbs, during three-month period (7th March to 10th June 2004). Furthermore to determine the maximum number of internal fixations of the lower limbs that can be performed by an orthopaedic registrar per year before exceeding the ICRP recommended level of radiation to the hands. Further research question were: -

- What is the relationship between the radiation dose to the right and left hand?
- What is the relationship between screening time and radiation dose to both hands?
- What is the relationship between screening time and radiation dose to the thyroid?
- What is the relationship between screening time and radiation dose to the whole body?
- What is the relationship between operation and screening times?

CHAPTER THREE

MATERIALS AND METHODS

3.1 INTRODUCTION

In this chapter, a detailed account of the research methodology that was employed in this study is provided, highlighting the data used, the method of participant selection, and in addition, the C-arm and TLDs used. Furthermore, this chapter includes a description of the methods used in collecting data and the statistical procedures that were utilized to analyse the results.

3.2 STUDY DESIGN

The study was a quantitative, convenience and judgemental sampling study using a Ziehm Exposcop / CB7-D fluoroscopic unit and thermoluminescent dosimeters (TLDs) designed to measure radiation dose to the hands, thyroid and whole body of the orthopaedic registrar.

3.3 PERMISSION LETTERS TO PERFORM THE STUDY

Letters were sent to the:

- Secretary General of Health Services in KwaZulu-Natal**.**
- Chief Medical Superintendent at King Edward VIII Hospital
- Head of the Orthopaedic Department at, the Nelson Rolihlahla Mandela School of Medicine, and
- Head of the Radiography Department at King Edward VIII Hospital.

These letters requested their permission to perform the study at King Edward VIII Hospital(Appendix A).

3.4 PARTICIPANT INFORMATION LETTER AND INFORMED CONSENT FORM

A participant information letter that described the study in detail (Appendix B) was given to orthopaedic registrars at King Edward VIII Hospital, inviting them to join the study. The letters were sent to 8 orthopaedic registrars, which is the maximum number of registrars who complied with the inclusion criteria at King Edward VIII Hospital. If the orthopaedic registrars agreed to participate in the research study, they were then asked to complete and sign an informed consent form (Appendix C), which explained the terms and conditions of the study. Eight orthopaedic registrars agreed to participate in the study.

The total number of orthopaedic registrars, registered at the medical school at KwaZulu-Natal is 28. In the current study, 8 orthopaedic registrars were monitored. This represents 29% of the total number (28) of the registrars in KwaZulu-Natal and 100% of the total number of the registrars at King Edward VIII Hospital. Presently orthopaedic registrars at King Edward VIII Hospital perform approximately 30 to 35% of all internal fixations of the lower limbs in KwaZulu-Natal (Katia, B. 2004)

3.5 INCLUSION CRITERIA

The inclusion criteria for selection of orthopaedic registrars were as follows:

- More than one-year orthopaedic experience is required.

- Full-time at King Edward VIII Hospital, and
- They need to be registered with Health Profession Council of South Africa (HPCSA).

3.6 ETHICAL CONSIDERATIONS

When the orthopaedic registrars were informed about the study, the researcher also informed each registrar that their personal particulars would be excluded from data analysis and data presentation (codes have been used for each research participant). The orthopaedic registrars were informed that their participation in the study was voluntary and that they could withdraw at any time during the research. No cost was involved to the orthopaedic registrars as the South African Bureau of Standards (SABS) sponsored the TLDs. The proposal for this research was approved by the Faculty of Health sciences Research Committee.

3.7 THE NUMBER OF OPERATION PROCEDURES PER ORTHOPAEDIC REGISTRAR

Each orthopaedic registrar performed 12 operation procedures. A total number of 96 operation procedures of internal fixation of the lower limbs over a three-month period from 7th March to 10th June 2004 (32 neck of femur, 32 femoral and 32 tibial operation procedures) were performed by 8 orthopaedic registrars. The number of operation procedures was selected on the advice of a statistician. The statistician stated that 25 participants or procedures were sufficient for medical studies as the number is adequate for performing parametric statistics (Robert, 2004).

Each of the 8 orthopaedic registrars performed 4 operation procedures for each part of the lower limb (4 neck of femur, 4 femur and 4 tibia), 12 per registrar in total over a three-month period.

Based on the information in 3.4 above registrars were chosen using a combination of convenience and judgmental sampling. Convenience in the sense that most of the internal fixations of the lower limb are performed at King Edward VIII Hospital and the registrars were willing to participate in the study, and judgmental sampling as the researcher only chose registrars with more than one-year experience.

For the purposes of this study it was assumed that the sample chosen was representative of the population at King Edward VIII Hospital, and in KwaZulu-Natal. Refer to chapter five, section 5.3.4 for more discussion on the total number of the registrars.

3.8 RECORD OF RADIATION DOSE MEASUREMENTS

The radiation dose for each orthopaedic registrar’s hands (right and left) was measured for each operational procedure (2 x 12 = 24 measurements over the 3 month period) of neck of femur, femur and tibia. In this research the dominant hand of all 8 orthopaedic registrars was the right hand. The radiation dose to the thyroid of each orthopaedic registrar was measured for each operation procedure (1 x12 = 12 measurements over the 3 month period). The radiation dose to the whole body of the orthopaedic registrar was measured in two ways. Firstly the radiation dose was calculated from the thyroid badges. Secondly the TLD was placed under the lead apron to measure the radiation dose monthly for all fluoroscopic operation procedures performed over the 3-month period**.** The TLDs were handed to the orthopaedic registrars before the performance of the operation procedure every day (see section 3.12.2).

3.9 EQUIPMENT

3.9.1 C-arm

All exposures were performed on an undercouch mobile C-arm fluoroscopy unit (Ziehm Exposcop / CB7-D) with last image hold ability (Figure 3.1). The total filtration of the x-ray tube is 3mm aluminium, the focus to image intensification distance is 94cm, and the input field is 23cm in diameter. Exposure parameters were determined by means of an automatic brightness control. The unit was equipped with 5-minutes rest timers to remind the operator that a certain recommended time limit had elapsed for beam on time. The kilovoltage peak (kVp) level ranges from 36kVp to 110kVp and may be adjusted automatically by the unit or manually by the radiographer. The (milliampere) mA level was set automatically according to the thickness of the imaged part and may range up to 3.2 mA. In the current study the kVp and mA were set automatically. The focal spot size for fluoroscopy was 0.6 mm.

FIGURE 3.1: DEMONSTRATING A MOBILE C-ARM FLUOROSCOPIC UNIT- Ziehm Exposcop / CB7-D (source- permission obtained from S block operation theatre at King Edward VIII Hospital)

3.9.2 TLDs

The discussion in Chapter 2 section 2.5.2 (review of the related literature) introduced the thermoluminescent dosimeter (TLD) as a sensitive device most frequently used to measure radiation dose directly. The TLDs used for this study were Panasonic 802-A (Figure 3.2 and Table 3.1). The TLDs were stored in a room at a temperature of 20-25^{o}C. At the end of each month, the TLDs were sent to the SABS for reading. Ideally the wearing period as specified by the SABS is 28 days. The extremity dosimeters were gas sterilized before used.

FIGURE 3.2: TLD USED IN THE STUDY (SABS, 1997)

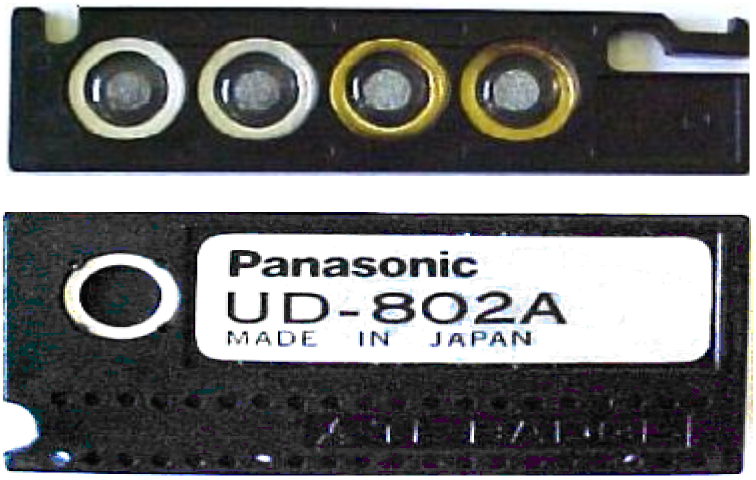


TABLE: 3.1: CONSTRUCTION AND CHARACTERISTIC OF THE TLD (SABS, 1997)

		Element 1	**Element 2**	**Element 3**	**Element 4**
UD-802A	Phosphor	$Li_2 B_4 O_7$ (Cu)	$Li_2 B_4 O_7$ (Cu)	$CaSo_4$ (Tm)	$CaSo_4$ (Tm)
	Density	2,3 grams/cm^3		2.61	
	Atomic Number	7,3		15,3	
	Front Filtration	Plastic – 14 mg/cm²	Plastic –160 mg/cm²	Plastic – 160 mg/cm²	Lead – 0.7 mm
	Rear Filtration	Plastic – 25 mg/cm²	Plastic – 160 mg/cm²	Plastic – 160 mg/cm²	Lead – 0.7 mm

3.10 PATIENT AND ORTHOPAEDIC REGISTRAR POSITIONING

3.10.1 Patient position

3.10.1.1 Position for the neck of femur

The patient was placed in a supine position on a standard traction table. Both feet were mounted in padded foot holders. The patient was aligned in the horizontal position. The affected hip was adducted. The unaffected limb was abducted and extended at the hip and flexed at the knee to facilitate adequate imaging from the lateral aspect. The torso was angled away from the fracture and the ipsilateral arm to the affected hip was strapped to a bar over the chest of the patient.

3.10.1.2 Position for the femur

The patient was placed in a supine position on a standard traction table. Both feet were mounted in padded foot holders. The patient was aligned in the horizontal position. The affected femur was adducted and the unaffected limb was abducted and extended at the hip. The ipsilateral arm to the affected femur was strapped to a bar over the chest of the patient.

3.10.1.3 Position for the tibia

The patient was placed in a supine position on the standard table. The unaffected hip was flexed at approximately 70 to 90 degrees and the knee was flexed at an angle to allow a horizontal orientation of the tibia, with the foot resting on the table. Then the table was adjusted to the appropriate height of the orthopaedic registrar to perform the operation procedure.

3.10.2 Position of the orthopaedic registrar

The C-arm was opposite the registrar on the uninjured side of the patient during all the procedures. The orthopaedic registrar stood laterally to the patient on the side of the injured limb. With the C-arm in a vertical position, the orthopaedic registrar was approximately 30cm away from the C-arm, whereas when the C-arm was in a horizontal position, the registrar was in contact with the x-ray tube.

3.11 OPERATION TECHNIQUE

All the procedures were conducted with the patient in the supine position on a traction table. The C-arm was positioned between the patient's lower limbs so that the radiation beam could remain perpendicular to the limb for both the posterior-anterior and lateral projections.

After the patient was secured on the traction table, fluoroscopic imaging was used to verify that a closed reduction had been successful. Thereafter, both the anteroposterior and lateral projections were used to verify that the starting hole was centred over the medullary canal. Placement of the guide wire was also performed under fluoroscopic control in order to prevent eccentric reaming and to serve as a measure to determine the length of the nail.

The fluoroscopic image was then used to verify eccentric reaming at the initial use of the reamer, and to investigate any abnormal resistance to reaming. As the nail was passed across the fracture, fluoroscopy was employed to ensure that intraoperative comminution had not occurred and to check the distal alignment. Fluoroscopic imaging was also used to verify the depth of insertion of the nail proximally, to prevent a too proximal insertion of the proximal screw.

At the time of the insertion of the distal interlocking screw, the C-arm was positioned so that the image intensifier was adjacent to the medial aspect of the lower limbs. The C-arm was then adjusted so that it was perpendicular to the affected lower limb, and then rotated. Fluoroscopic imaging was used to verify the screw holes. When the profiles of the distal screw holes were visualized as perfect circles, the drill-bit was passed through the lateral cortex (of the bone) holes in the nail and the medial part of the cortex in sequence. The appropriate location of the drill-bit was verified on the lateral fluoroscopic projection. Thereafter the correct length of the interlocking screws was verified on the anteroposterior projection.

3.12 MEASUREMENT OF RESEARCH PARAMETER

3.12.1 The **first objective** was to quantify the ionising radiation exposure to the hands of the orthopaedic registrar.

A gas-sterilized thermoluminescent dosimeter (TLD) ring with one chip (one element of $CaSo_4$) was worn on the index finger of each hand of the orthopaedic registrar under the surgical gloves to monitor the radiation dose to the hands. The rings were changed and replaced with new rings for every operation procedure. The TLDs rings and badges were sent to the SABS for dose measurement.

All the data, including the surgeon's code, kilovoltage, milliampere, operation time, screening time, operation procedure type, dominant hand, and TLD series number were recorded on a data sheet during the operation procedure (Appendix Di).

The mean and standard deviation for radiation dose to the hands were analysed for a total of 96 internal fixations of the lower limbs (32 operation procedures for each part of the neck of femur, femur and tibia) as well as per registrar (4 operation procedures for each part of the neck of femur, femur and tibia) (Appendix E).

The paired t-test was conducted in order to assess whether there was any significant relationship between the amount of radiation dose to the right and left hands.

3.12.2 The **second objective** was to quantify the ionising radiation exposure to the thyroid of each orthopaedic registrar.

The orthopaedic registrars were asked to place the TLD badge anteriorly over their thyroid gland at neckline level using metal clips. The TLD was changed and sent to SABS for reading and replaced with a new TLD for every operation procedure. The researcher was present in the operation theatre during all operation procedures to assist the orthopaedic registrar in placing the TLDs in the correct position. A data sheet was designed to record the data during the operation procedure (Appendix Dii).

The mean and standard deviation of the radiation dose to the thyroid were analysed for a total of 96 internal fixations of the lower limbs (32 operation procedures for each part of the neck of femur, femur and tibia) as well as per registrar (4 operation procedures for each part of the neck of femur, femur and tibia) (Appendix F).

3.12.3 The **third objective** was to quantify the ionising radiation exposure to the orthopaedic registrar's whole body.

As the orthopaedic registrars were not wearing their own personal dosimeters, the whole body dose was monitored in two ways:

(i) The whole body dose was calculated from the thyroid badges as reported by Sweetlove, et al. (1998), and this reflected the amount of radiation dose to the orthopaedic registrars per operation procedure. The calculation of the whole body dose was as follows:

Thyroid reading x weight factor (0.05) = whole body dose (As recommended by the National Council on Radiation Protection and Measurements (NCPR 122). Where the weight factor is defined as the factor by which the equivalent dose in tissue or organ is weighted (ICRP, 1990)

(ii) Each orthopaedic registrar was given one TLD to be worn under the lead apron for whole body monitoring, and was requested to wear the TLD for all the operation procedures during the month. To ensure that the orthopaedic registrars were wearing the TLDs, the researcher was present daily to deliver and collect the TLDs. The TLDs were changed every month for processing. A data sheet was designed to record the registrar code, dosimeter series number, type of operation procedure, and the total number of operations per month (Appendix Diii).

The mean and standard deviation for radiation dose to the whole body was analysed for a total of 96 internal fixations of the lower limbs (32 operation procedures for each part of the neck of femur, femur and tibia) as well as per registrar (4 operation procedures for each part of the neck of femur, femur and tibia). The mean and standard deviation for radiation dose to the whole body also analysed for each registrars per month over a period of 3 months (Appendix G).

3.12.4 The **fourth objective** was to quantify the average operation and screening times per procedure.

The operation and screening times were noted for each operation procedure. The time was recorded in minutes. The number of minutes that the fluoroscope was used was read directly from the machine, and represented the sum of real time fluoroscopy. The timer was always set at zero at the start of each procedure.

The researcher recorded the time at which the orthopaedic registrar started performing the operation procedure and the time that the orthopaedic registrar completed the operation procedure, during all the procedures. The data were recorded on the data sheet for each operation procedures (Appendix Di)

The average operation procedure and screening times were analysed per operation procedure and per registrar (Appendix H).

The average values for operation time and screening time were correlated using Pearson's correlation coefficient and demonstrated by the use of a scatterplot to assess if there was any linear relationship.

Pearson's correlation coefficient and scatterplot curve were also used to correlate and demonstrate the relationship between screening time and radiation dose to hands, thyroid and whole body during internal fixation of the lower limbs (neck of femur, femur and tibia) to assess if there were any linear relationships.

3.12.5 The **fifth objective** was to determine the maximum number of internal fixations of the lower limbs that could be performed by an orthopaedic registrar per year before the radiation limit to the hands was exceeded.

The mean and standard deviation were analysed for radiation dose to the hands during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia).

The maximum number of internal fixation of the lower limbs per year was determined by dividing the maximum permissible dose to the extremities (150mSv for non-radiation workers and 500mSv for radiation workers, as recommended by the International Commission on Radiological Protection (ICRP, 1990) by the mean radiation dose to the hands of the orthopaedic registrars.

STATISTICAL PACKAGE

All the data entries and analytical procedures were accomplished using the Statistical Package for the Social Sciences (SPSS) package version 11.0, with the assistance of a qualified statistician. Normal distribution was used in order to analyse the results of the study. The statistician advised the used of the normal distribution because the sample size was small and in most medical studies the use of normal distribution is the most accurate method in analysing data.

CHAPTER FOUR

RESULTS

4.1 INTRODUCTION

This chapter encompasses the results obtained from the statistical analyses of the primary data collected for the duration of the study. It includes the descriptive statistics and inferential analyses of radiation dose to the hands, thyroid and whole body and the average screening and operational times during internal fixation of the lower limbs for each operational procedure. Additionally, the maximum number of internal fixations per year, which can be performed by a registrar, was calculated and recorded. The data were presented in the form of tables, figures and statements.

The aims of this study were to quantify the radiation dose to the orthopaedic registrars' hands, thyroid and whole body, and to quantify the average operation and screening times during fluoroscopic internal fixation of the lower limbs. Further research question for the current study were: -

- What is the relationship between the radiation dose to the right and left hand?
- What is the relationship between screening time and radiation dose to the hands?
- What is the relationship between screening time and radiation dose to the thyroid?
- What is the relationship between screening time and radiation dose to the whole body?
- What is the relationship between operation time and screening time?

4.2 DESCRIPTIVE STATISTICS

Eight orthopaedic registrars participated in the study. Each registrar performed 4 operation procedures each of the neck of femur, femur and tibia. The descriptive statistics for radiation dose to the hands, thyroid, whole body and operation and screening times during internal fixations of the lower limbs are presented in appendices E to H. Tables, bar graphs and histograms with normal curves are used to present the frequency distributions. The measures of variability used are range and standard deviation. The mean is used as the measure of the central tendency. Normal distribution was used in order to analyse the results of the current study. The reason for using the normal distribution is that the sample size was small and in most of medical studies the use of normal distribution is the most accurate method in analysing data (Robert, 2004).

4.2.1 DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE LOWER LIMBS

The descriptive statistics for radiation dose to the hands of 8 orthopaedic registrars during internal fixation of the lower limbs (neck of femur, femur and tibia) were obtained and the results are outlined in Figures 4.1 to 4.6.

FIGURE 4.1: FREQUENCY DISTRIBUTION OF RADIATION DOSE TO THE RIGHT HAND DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS

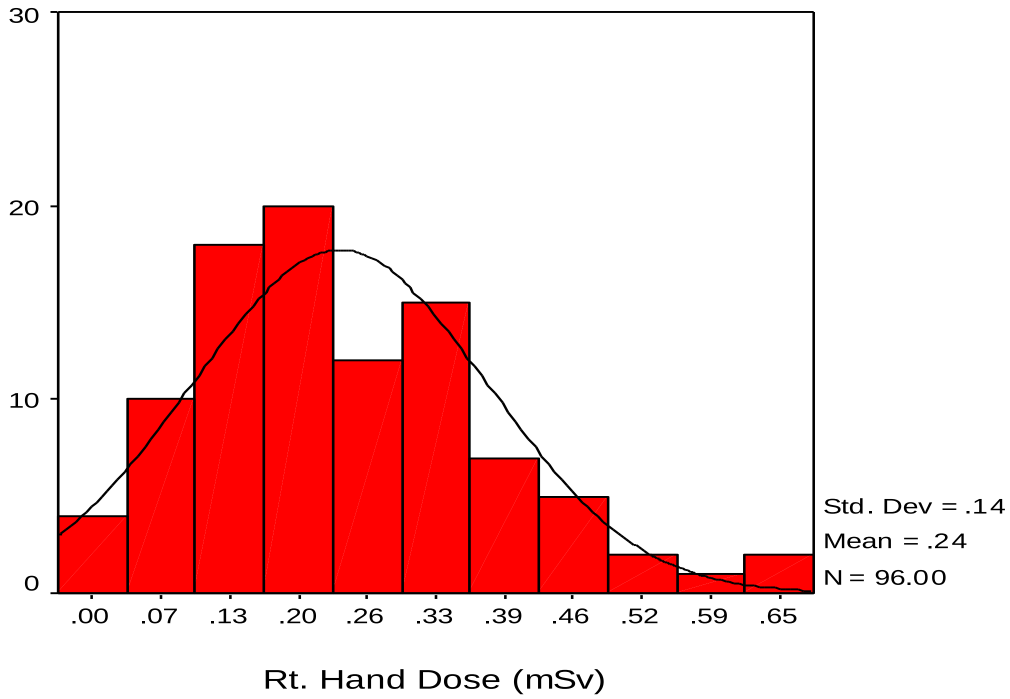


Figure 4.1 depicts the frequency distribution of radiation dose to the right hand during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia). The mean was 0.24mSv and standard deviation was 0.14, the interval used was 0.065. The histogram appears normal. (Refer to Appendix E).

FIGURE 4.2: FREQUENCY DISTRIBUTION OF RADIATION DOSE TO THE LEFT HAND DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS

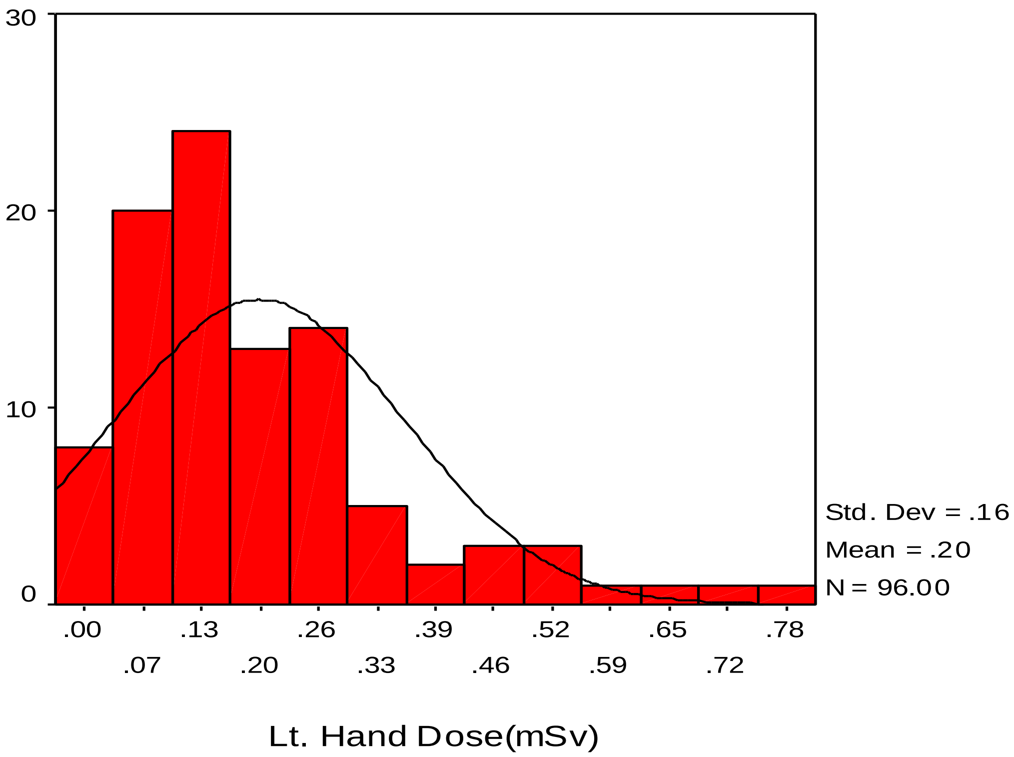


Figure 4.2 depicts the frequency distribution of radiation dose to the left hand during 96 internal fixations of the lower limbs. The mean was 0.20mSv and standard deviation was 0.16, the interval used was 0.065. The histogram is slightly positively skewed. (Refer to Appendix E).

FIGURE 4.3: FREQUENCY DISTRIBUTION OF RADIATION DOSE TO BOTH HANDS DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS

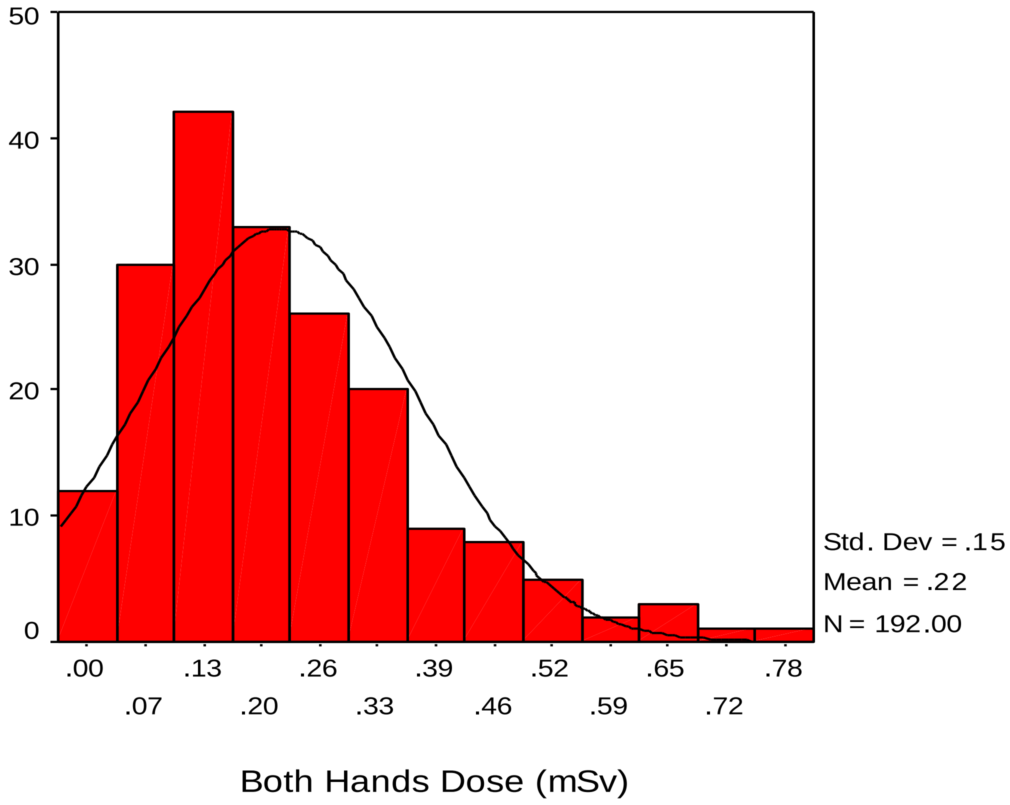


Figure 4.3 depicts the frequency distribution of radiation dose to the right hand during 96 internal fixations of the lower limbs. The mean was 0.22mSv and standard deviation was 0.15, the interval used was 0.065. The histogram for the 96 internal fixations of the lower limbs appears normal. (Refer to Appendix E)

Figures 4.4 to 4.6 and Table 4.1 present the radiation dose to the hands during internal fixation of the lower limbs (neck of femur, femur and tibia). Number 1 to 8 represents the same registrars in all the tables.

FIGURE 4.4: MEAN FOR RADIATION DOSE TO THE HANDS OF EACH ORTHOPAEDIC REGISTRAR DURING 4 INTERNAL FIXATIONS OF THE NECK OF FEMUR.

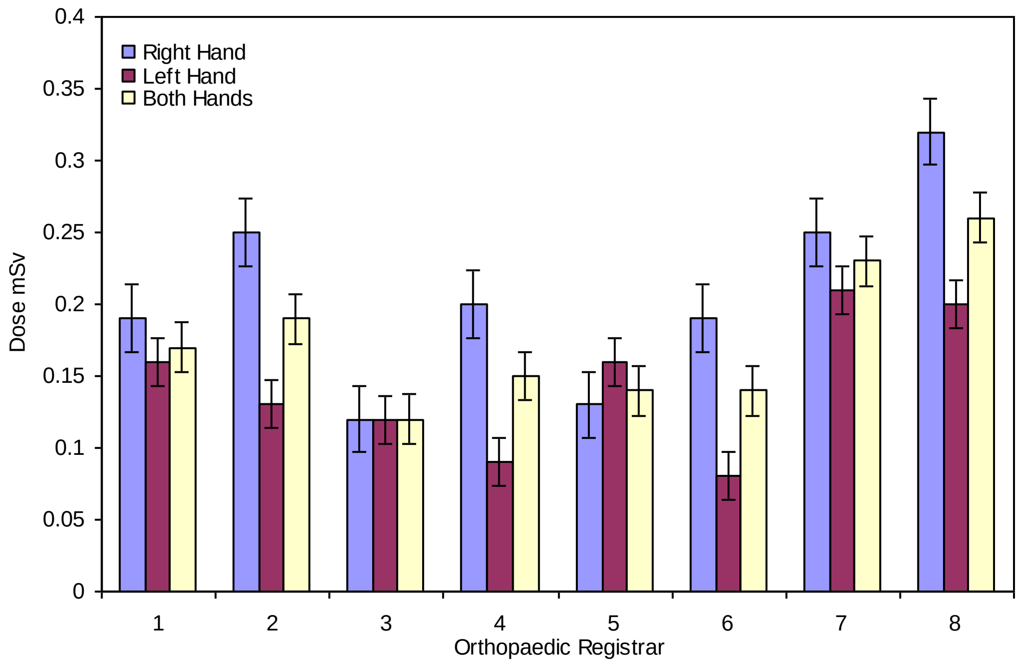


Figure 4.4 depicts the bar graph and standard error bars of radiation dose to the hands during 4 internal fixations of the neck of femur per registrar. (Detailed results can be seen in Appendix E). The results of the mean were rounded of to the nearest two decimal places. For example for orthopaedic registrar 3 the values were 0.1150 mSv to right hand, and 0.1225mSv to left hand and 0.1188 to both hands and these were rounded of to 0.12mSv.

FIGURE 4.5: MEAN FOR RADIATION DOSE TO THE HANDS OF EACH ORTHOPAEDIC REGISTRAR DURING 4 INTERNAL FIXATIONS OF THE FEMUR.

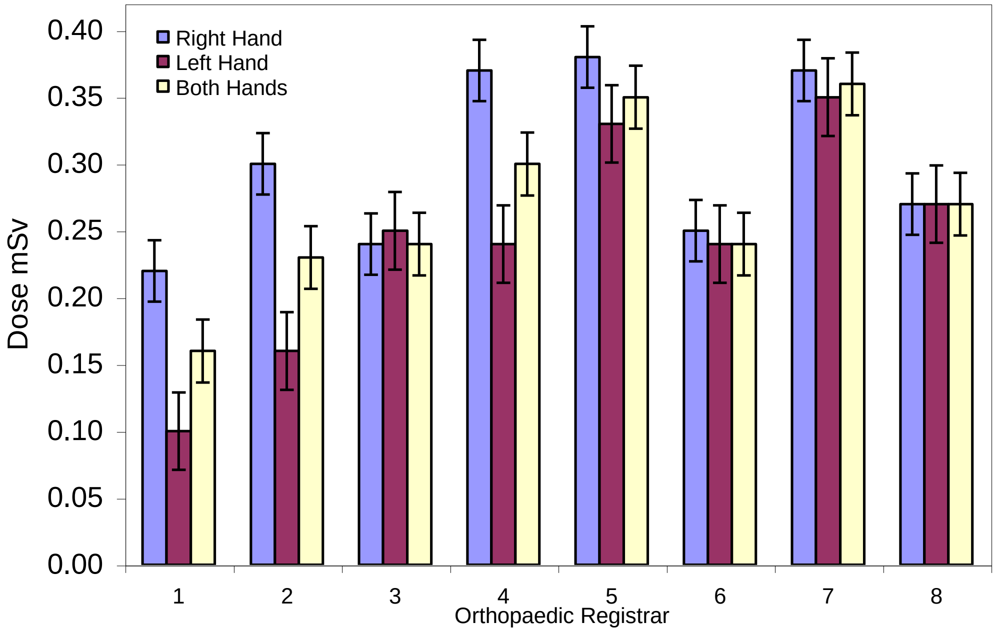


Figure 4.5 depicts the bar graph and standard error bars of radiation dose to the hands during 4 internal fixations of the femur per registrar. (Detailed results can be seen in Appendix E).

FIGURE 4.6: MEAN FOR RADIATION DOSE TO THE HANDS OF EACH ORTHOPAEDIC REGISTRAR DURING 4 INTERNAL FIXATIONS OF THE TIBIA.

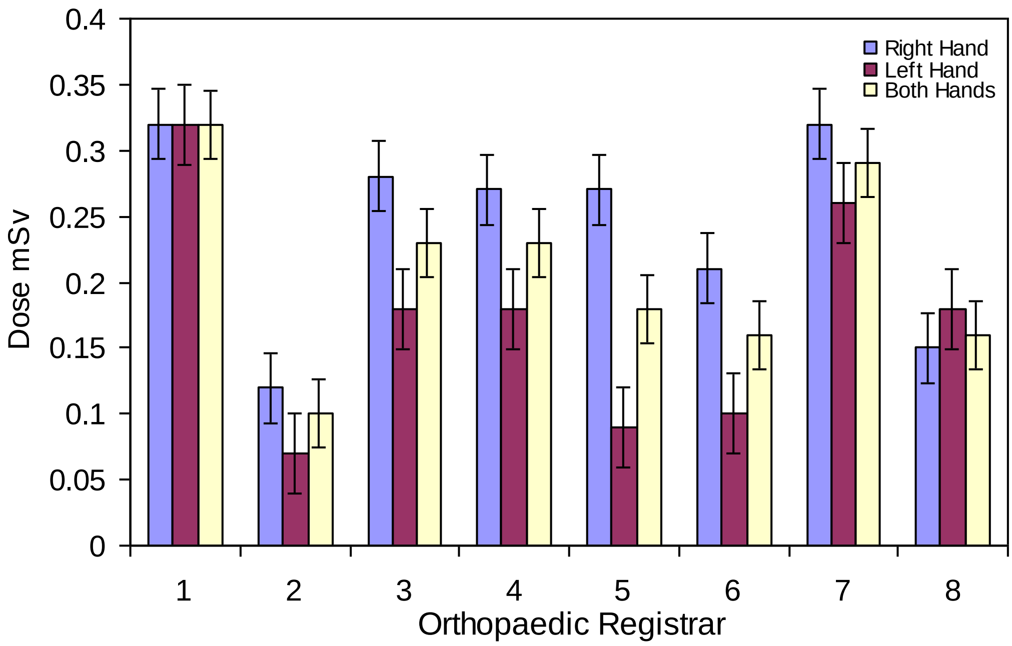


Figure 4.6 depicts the bar graph and standard error bars of radiation dose to the hands during 4 internal fixations of the tibia per registrar. (Detailed results can be seen in Appendix E).

TABLE 4.1: MEAN AND STANDARD DEVIATION FOR RADIATION DOSE TO THE HANDS OF ALL 8 ORTHOPAEDIC REGISTRARS DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS (N= 32 for right & left hand and 64 for both hands)

Lower limbs	Hands	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation
Neck of Femur	Right Hand	0.01	0.65	0.18	0.16
	Left Hand	0.01	0.53	0.16	0.11
	Both Hands	0.01	0.65	0.17	0.12
Femur	Right Hand	0.05	0.59	0.30	0.13
	Left Hand	0.01	0.74	0.24	0.19
	Both Hands	0.01	0.74	0.27	0.16
Tibia	Right Hand	0.06	0.62	0.23	0.14
	Left Hand	0.01	0.75	0.19	0.17
	Both Hands	0.01	0.75	0.21	0.16

4.2.2 **DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE THYROID DURING INTERNAL FIXATION OF THE LOWER LIMBS**

In this section, the descriptive statistics for radiation dose to the thyroid during internal fixation of the lower limbs (neck of femur, femur and tibia) are outlined in Figure 4.7 and Appendix F. It includes the mean for radiation dose to the thyroid of all 8 orthopaedic registrars during internal fixation of the lower limbs, as well as for each registrar (Figure 4.8 and Table 4.2).

The histogram (Figure 4.7) shows that the distribution of the sample is slightly positively skewed.

FIGURE 4.7: FREQUENCY DISTRIBUTION OF RADIATION DOSE TO THE THYROID DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS

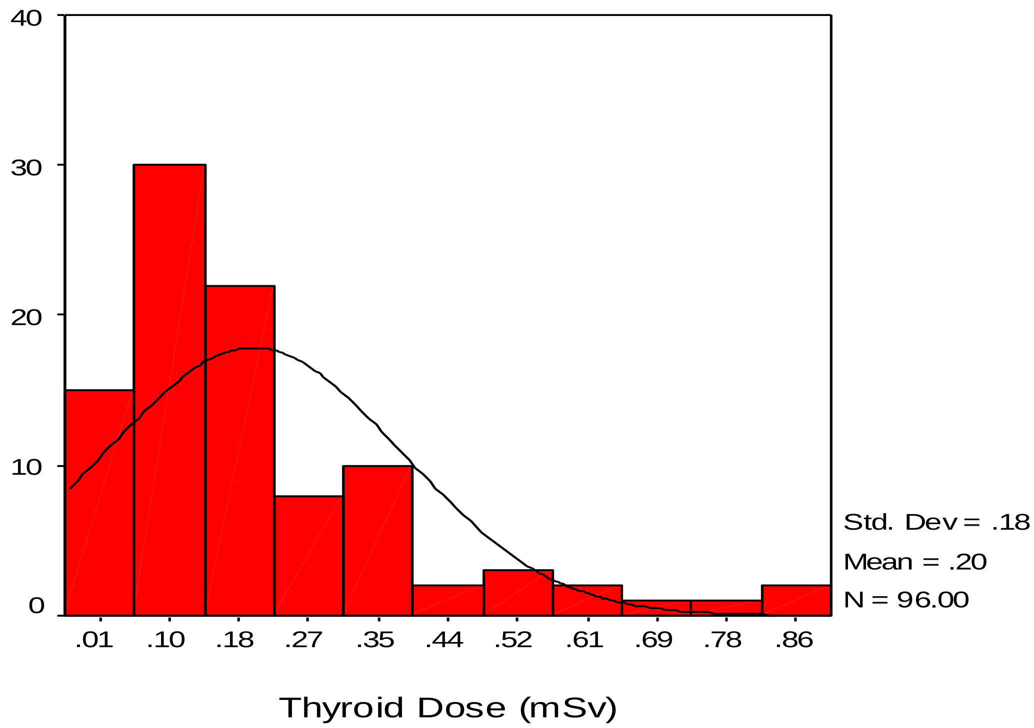


Figure 4.7 depicts the frequency distribution of radiation dose to the thyroid during 96 internal fixations of the lower limbs. The mean was 0.20mSv and

standard deviation was 0.18, the interval used was 0.08. The histogram appears normal. (Refer to Appendix F)

FIGURE 4.8: MEAN FOR RADIATION DOSE TO THE THYROID OF EACH ORTHOPAEDIC REGISTRAR DURING INTERNAL FIXATION OF THE LOWER LIMBS (4 neck of femur, 4 femur and 4 tibia) [see Appendix F]

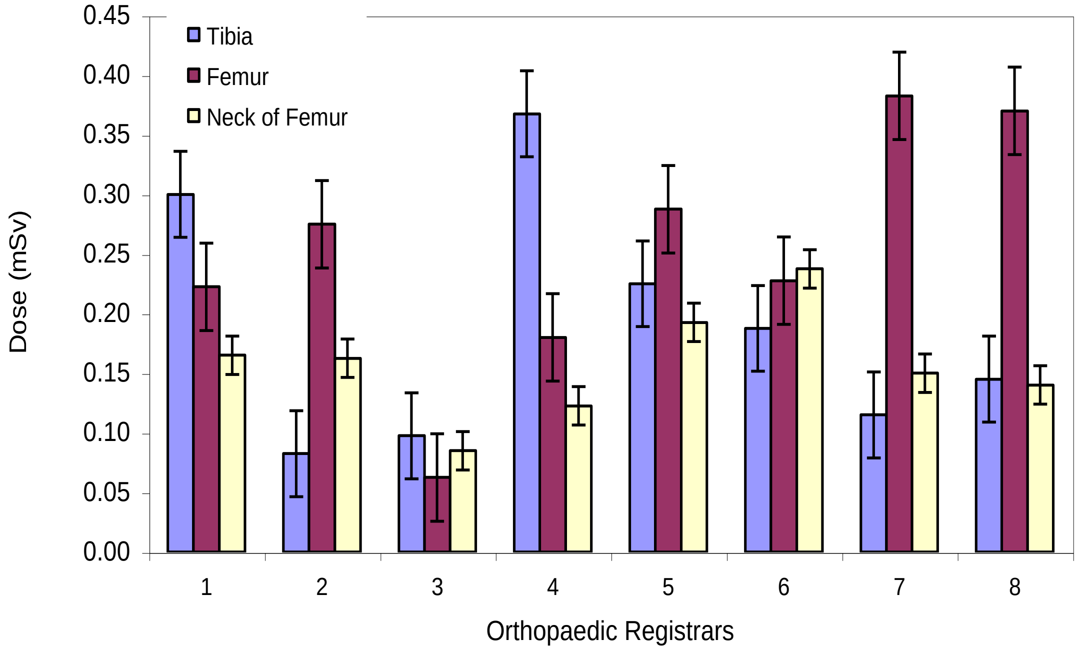


Figure 4.8 depicts the bar graph and standard error bars of radiation dose to the thyroid during 4 internal fixations of the lower limbs per registrar. (Detailed results can be seen in Appendix F).

TABLE 4.2: THE MEAN AND STANDARD DEVIATION FOR RADIATION DOSE TO ORTHOPAEDIC REGISTRARS THYROID DURING INTERNAL FIXATION OF THE LOWER LIMBS (8 orthopaedic registrars)

Screening Area	**N Valid**	**Minimum (mSv)**	**Maximum (mSv)**	**Mean (mSv)**	**Std. Deviation**
Neck of Femur	32	0.01	0.49	0.16	0.13
Femur	32	0.01	0.82	0.25	0.19
Tibia	32	0.01	0.85	0.19	0.21
Total	96	0.01	0.85	0.20	0.18

4.2.3 DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE WHOLE BODY.

The analysis of radiation dose to the whole body was obtained in two ways:

(i) The descriptive statistics for the radiation dose to the whole body was obtained per operation procedure during internal fixation of the lower limbs (neck of femur, femur and tibia). The results were outlined in Figures 4.9 - 4.10, Table 4.3 and Appendix G.

(ii) The mean and standard deviation for radiation dose to the whole body were obtained for the 3 months period during all operation procedures performed for all 8 registrars (Figure 4.11 and Table 4.4).

FIGURE 4.9: FREQUENCY DISTRIBUTION OF RADIATION DOSE TO THE WHOLE BODY DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS (32 neck of femur, 32 femur and 32 tibia)

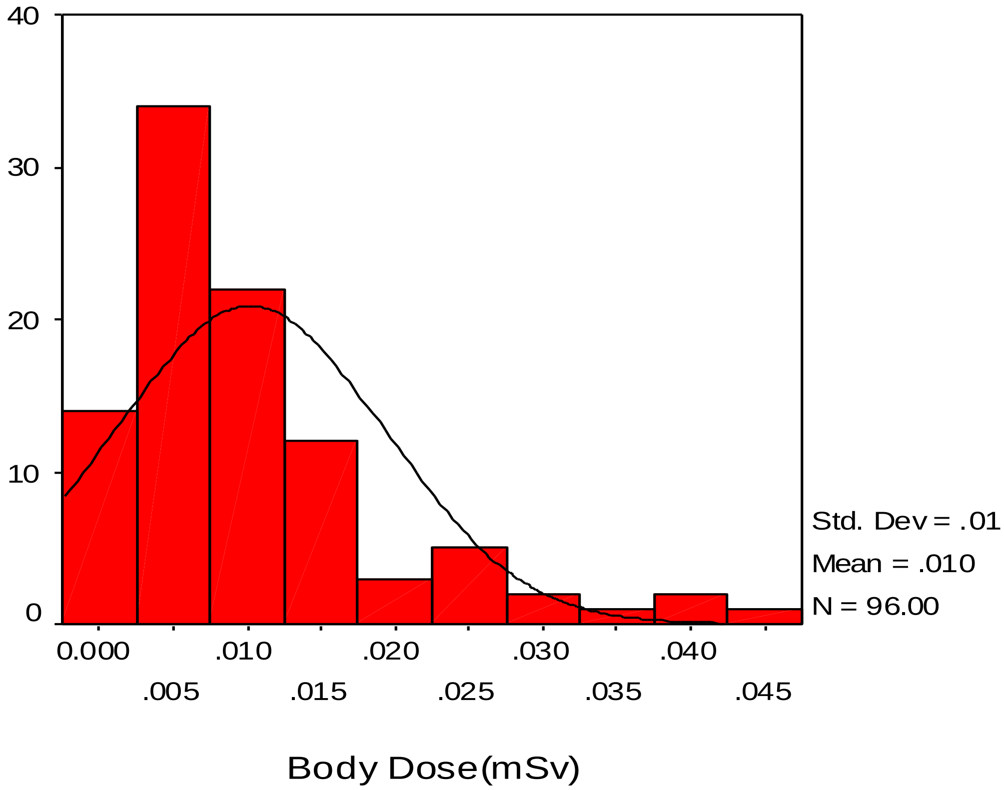


Figure 4.9 depicts the frequency distribution of radiation dose to the whole body during 96 internal fixations of the lower limbs. The mean was 0.010mSv and standard deviation was 0.01, the interval used was 0.05. The histogram appears normal. (Refer to Appendix G)

FIGURE 4.10: MEAN FOR RADIATION DOSE TO THE WHOLE BODY DURING INTERNAL FIXATION OF THE LOWER LIMBS FOR EACH REGISTRAR (total of 12 operation procedures each) [see Appendix G]

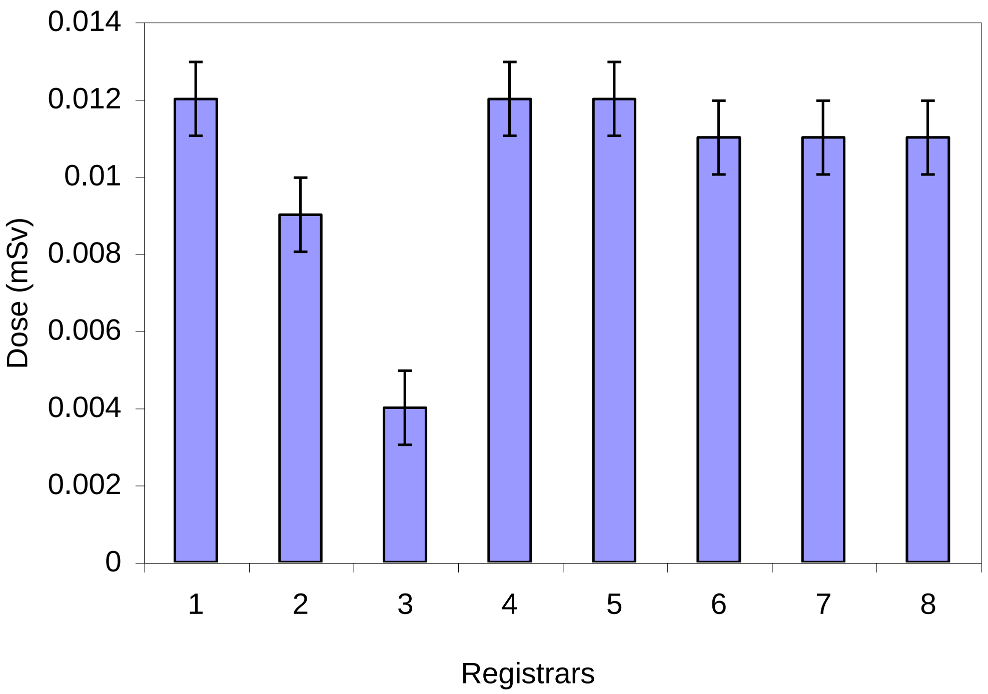


Figure 4.10 depicts the bar graph of standard error bars of radiation dose to the thyroid during 12 internal fixations of the lower limbs per registrar. (Detailed results can be seen in Appendix G).

TABLE 4.3: THE MEAN AND STANDARD DEVIATION FOR RADIATION DOSE TO THE ORTHOPAEDIC REGISTRARS WHOLE BODY DURING INTERNAL FIXATION OF THE LOWER LIMBS PER PROCEDURE (8 orthopaedic registrars).

	N	**Minimum (mSv)**	**Maximum (mSv)**	**Mean (mSv)**	**Std. Deviation**
Neck of femur	32	0.001	.025	0.008	0.006
Femur	32	0.001	.041	0.013	0.010
Tibia	32	0.001	.043	0.010	0.011
Total	96	0.001	.043	0.010	0.009

FIGURE 4.11: MEAN FOR RADIATION DOSE TO THE WHOLE BODY FOR EACH REGISTRAR PER MONTH OVER A 3-MONTH PERIOD

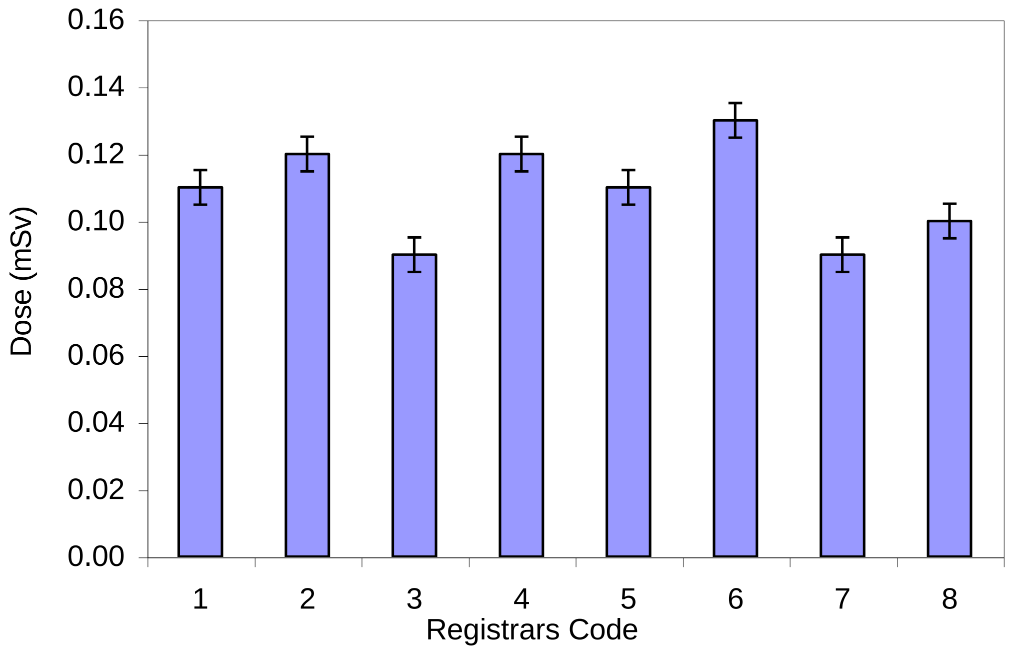


Figure 4.11 depicts the bar graph of standard error bars of radiation dose to the whole body during internal fixations of the lower limbs per month for each registrar. (Detailed results can be seen in Appendix G).

TABLE 4.4: THE MEAN AND STANDARD DEVIATION FOR RADIATION DOSE TO ALL 8 REGISTRAR'S WHOLE BODY PER MONTH (total 3 months)

Period	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation
1st Month	8	0.07	0.13	0.10	0.02
2nd Month	8	0.08	0.14	0.11	0.02
3rd Month	8	0.06	0.19	0.12	0.04
Total	24	0.06	0.19	0.11	0.03

4.2.4 DESCRIPTIVE STATISTICS FOR OPERATION AND SCREENING TIMES DURING INTERNAL FIXATION OF THE LOWER LIMBS

The descriptive statistics for the operation and screening times during 96 internal fixations of the lower limbs (neck of femur, femur and tibia) were obtained and the results are outlined in Figures 4.12 – 4.13, Table 4.5 and Appendix H.

Two histograms (Figures 4.12 and 4.13) describe the operation and screening time's values during internal fixation of the lower limbs. The histograms show that the distribution of the sample is positively skewed.

FIGURE 4.12: FREQUENCY DISTRIBUTION OF OPERATION TIME DURING 96 INTERNAL FIXATION OF THE LOWER LIMBS (32 neck of femur, 32 femur and 32 tibia)

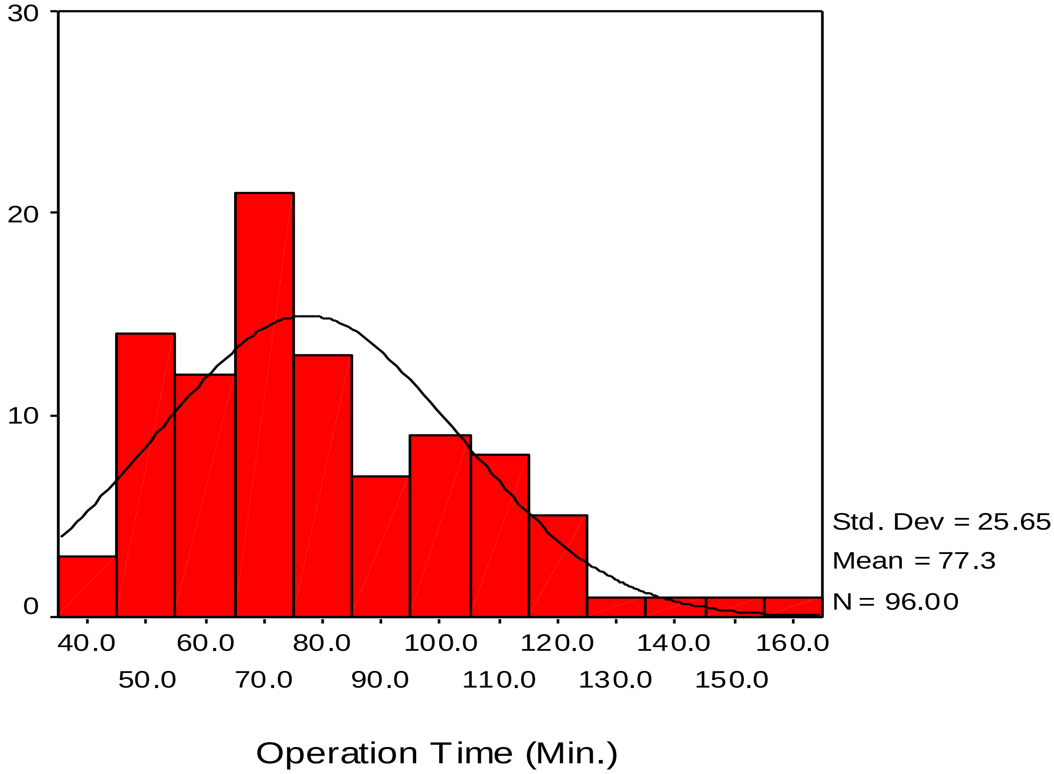


Figure 4.12 depicts the frequency distribution of operation time during 96 internal fixations of the lower limbs. The mean was 77.3 minutes and standard deviation was 25.65, the interval used was 10. The histogram slightly positively skewed. (Refer to Appendix G).

FIGURE 4.13: FREQUENCY DISTRIBUTION OF SCREENING TIME DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS (32 NECK OF FEMUR, 32 FEMUR AND 32 TIBIA)

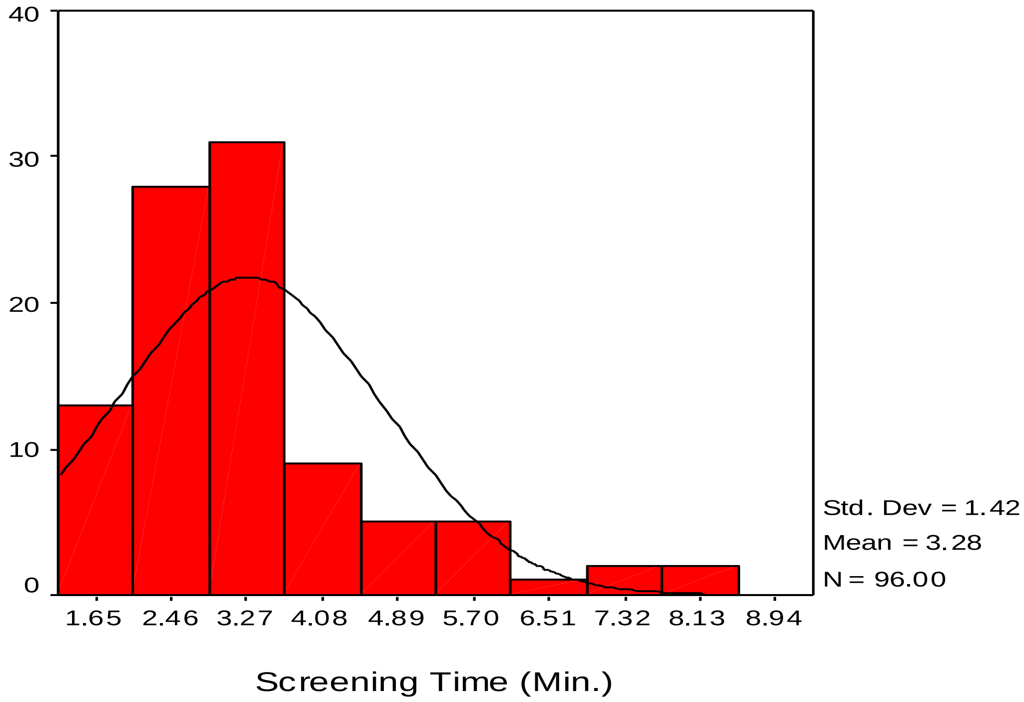


Figure 4.13 depicts the frequency distribution of screening time during 96 internal fixations of the lower limbs. The mean was 3.28 minutes and standard deviation was 1.42, the interval use was 0.81. The histogram slightly positively skewed (Refer to Appendix G).

TABLE 4.5: THE MEAN AND STANDARD DEVIATION FOR OPERATION AND SCREENING TIMES DURING INTERNAL FIXATION OF THE LOWER LIMBS (8 registrars, 4 procedures each)

Operative area	**N Valid**	**Type**	**Minimum (Min.)**	**Maximum (Min.)**	**Mean (Min.)**	**Std. Deviation**
Neck of femur	32	Operation	40	122	63	19
		Screening	1.52	3.17	2.31	0.47
Femur	32	Operation	45	155	82	27
		Screening	2	8.41	4.05	1.75
Tibia	32	Operation	40	140	87	25
		Screening	2.03	6.23	3.48	1.14
Total	96	Operation	40	155	77	26
		Screening	1.52	8.41	3.26	1.40

4.2.5 CALCULATION OF THE MAXIMUM NUMBER OF INTERNAL FIXATION OF THE LOWER LIMBS PER YEAR

The number of operation procedures which could be performed by the orthopaedic registrar per year before the hand dose limit is exceeded was determined by dividing the maximum permissible dose 150mSv to the extremities for non-radiation workers or 500mSv for radiation workers (ICRP, 1990) by the mean radiation dose to the hands during internal fixation of the lower limbs.

TABLE 4.6: MEAN AND STANDARD DEVIATION FOR RADIATION DOSE TO THE HANDS DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS

N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Operation procedure / year**	
					150mSv	500mSv
192	.01	.75	0.22	0.15	681	2272

- The maximum number of internal fixations of the lower limbs that can be done by the orthopaedic registrar per year when he/she is defined as a non-radiation worker is:

  150/0.22mSv = 681 operation procedures per year.

- The maximum number of internal fixations of the lower limbs that could be done by the orthopaedic registrar per year when he/she is defined as radiation worker is:

  500/0.22 mSv = 2272 operation procedures per year.

4.3 INFERENTIAL STATISTICS

4.3.1 PROCEDURE 1.0

Research Question

What is the relationship between the radiation dose to the right and left hand during internal fixations of the lower limbs?

Test used

Paired sample t-test

The Pie chart was used to depict the result (Figure 4.14)

$$\text{T Test Statistic} = \frac{\sqrt{(n-1)}\Sigma d}{\sqrt{n\Sigma d^2 - (\Sigma d)^2}}$$

Where d = the difference between the 2 columns.

And n = the number of pairs.

The reason for the selection of the paired t-test is the central limit theorem, which refers to sample sizes larger than 30, and the sampling distribution of means follows a normal distribution.

Sample

N = 96

THE HYPOTHESIS:

The null hypothesis (H_O) stated that: $\mu_1 = \mu_2$,

where μ_1 = left hand dose and μ_2 = right hand dose

DECISION RULE

If the ρ-value is $< \alpha$, reject H_o, where α = 0.05 (significance level)

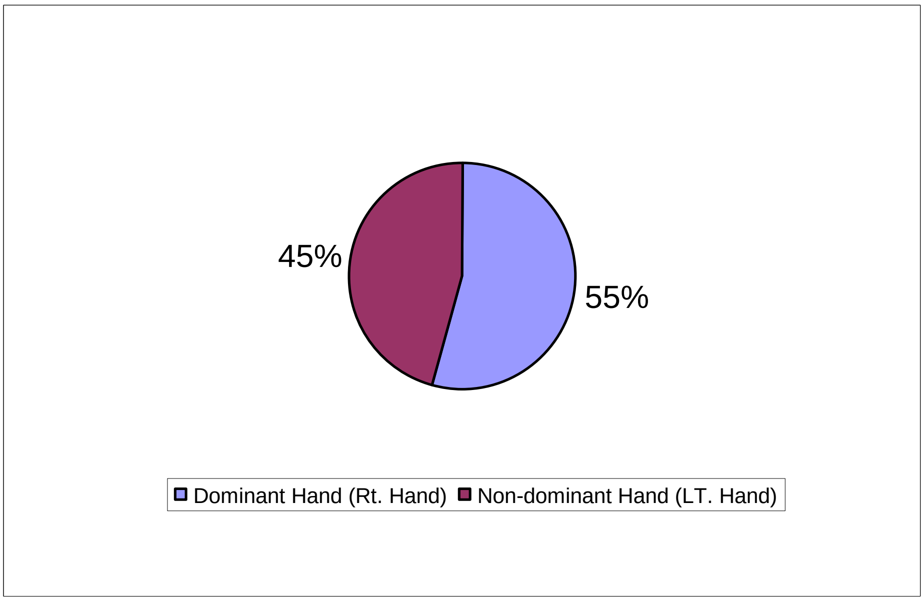
Computation

TABLE 4.7: PAIRED T-TEST FOR RADIATION DOSE TO THE RIGHT AND LEFT HANDS DURING INTERNAL FIXATION OF THE LOWER LIMBS

	Mean	**N**	**Std. Deviation**	**Std. Error mean**
Lt. Hand	0.20	96	0.16	.016
Rt. Hand	0.24	96	0.15	.015

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error mean	Lower	Upper	T	df	Sig.
Lt. Hand-Rt. Hand	.0411	.17706	.01807	.0770	.0053	2277	95	.025

FIGURE 4.14: PIE CHART DEPICTING RADIATION DOSE TO THE DOMINANT AND NON-DOMINANT HAND OF ALL 8 ORTHOPAEDIC REGISTRARS DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS (32 neck of femur, 32 femur and 32 tibia).



N= 96

Decision

Since the ρ-value = 0.025 (Table 4.7), which is less than α (0.05), the null hypothesis (H_O) was rejected and it was concluded that sufficient evidence exists to suggest that the sample mean radiation exposure to the right hands is significantly different to the sample mean radiation exposure to the left hands at a 5% significance level. This is depicted by the Pie chart (Figure 4.14).

4.3.2 Procedure 2.0

Research question

What is the relationship between the screening time and radiation dose to the hands during internal fixation of the lower limbs?

Test Used

Pearson's correlation coefficient

Scatterplot used to demonstrate the relationships between the screening time and radiation dose to the hands (Figure 4.15).

For the above test, the population correlation coefficient is identified by ρ and the sample correlation coefficient is identified by γ.

Sample

N= 96

THE HYPOTHESIS:

The hypothesis test takes the following structure:

H_o: $\rho = 0$

H_1: $\rho \neq 0$

The null hypothesis (H_o) states that there is no linear relationship

DECISION RULE

If the ρ-value is < α reject $H_{o,}$

where α = 0.05 (significance level)

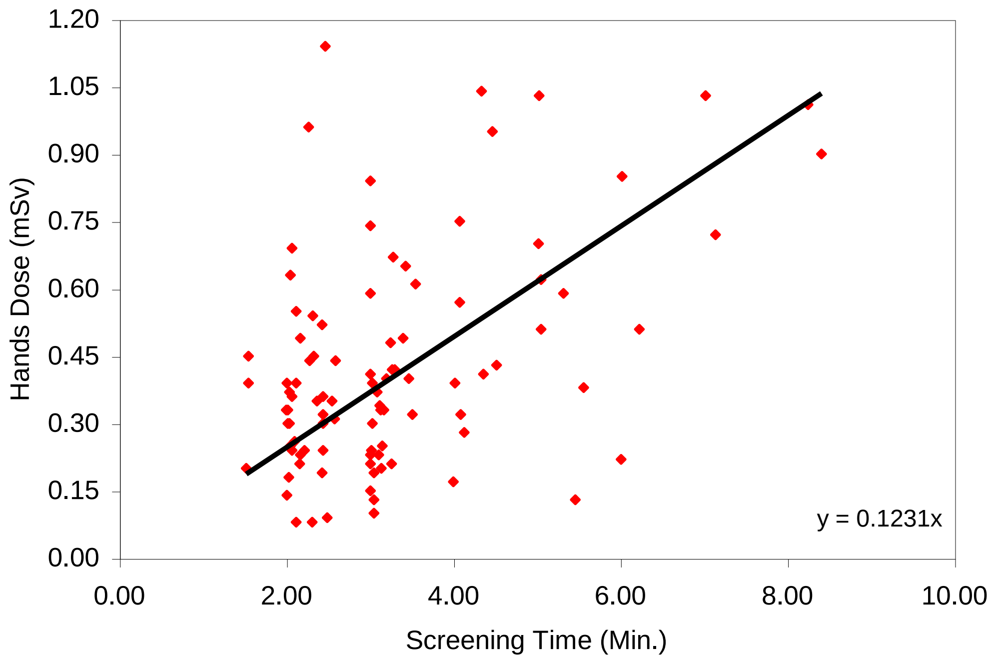
Computation

TABLE 4.8: CORRELATIONS BETWEEN SCREENING TIME AND RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE LOWER LIMBS

N	Pearson Correlation	Sig. (2-tailed) ρ Value
96	.428	.000

A scatterplot of screening time and radiation dose to the hands during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia) indicates that there is a linear relationship (Figure 4.15).

FIGURE 4.15: SCATTERPLOT OF SCREENING TIME AND RADIATION DOSE TO THE HANDS DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS



Pearson γ = .428, n = 96, ρ=. 000

It is clear that the resultant linear regression model is y = 0.1231x. This particular model allows one to predict the expected radiation dose to the hands (dependent variable in this case) based on a given screening time (independent variable in this case). For example if screening time was 4 minutes, the expected radiation dose to the hands would be y = 0.1231(4) = 0.49 mSv.

<u>Decision</u>

The sample Pearson's correlation coefficient value (γ) equals 0.428 and the corresponding ρ value equals 0.000 (Table 4.8), which is less than α (0.05), therefore the null hypothesis (H_o) was rejected at a 5% significance level. This implies that there is sufficient evidence to suggest that a significantly positive linear relationship exists between screening time and radiation dose to the hands during 96 internal fixations of the lower limbs. This is demonstrated by the results of scatterplot (Figure 4.15).

4.3.3 PROCEDURE 3.0

<u>Research question</u>

What is the relationship between the screening time and radiation dose to the thyroid during internal fixation of the lower limbs?

<u>Test Used</u>

Pearson's correlation coefficient

Scatterplot used to demonstrate the relationship between the screening time and radiation dose to the thyroid (Figure 4.16).

For the above test, the population correlation coefficient is identified by ρ and the sample correlation coefficient is identified by γ.

Sample

N= 96

THE HYPOTHESIS:

The hypothesis test takes the following structure:

H_o: $\rho = 0$

$H_{1:}$ $\rho \neq 0$

The null hypothesis (H_o) states that there is no linear relationship

DECISION RULES

If the ρ-value is $< \alpha$ reject $H_{o,}$

where $\alpha = 0.05$ (significance level)

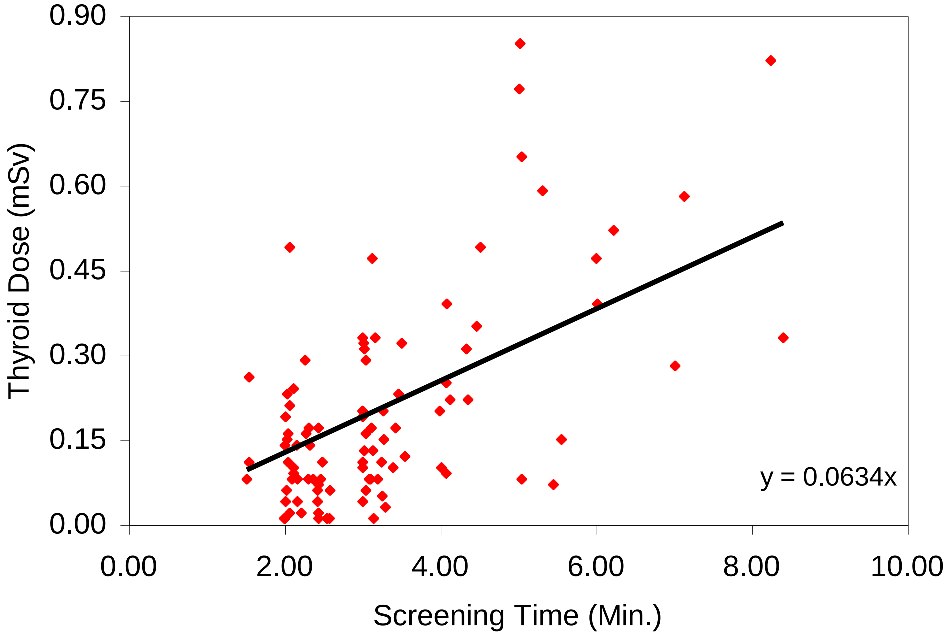
Computation

TABLE 4.9: CORRELATIONS BETWEEN SCREENING TIME AND RADIATION DOSE TO THE THYROID DURING INTERNAL FIXATION OF THE LOWER LIMBS

N	Pearson Correlation	Sig. (2-tailed) ρ Value
96	.571	.000

A scatterplot of screening time and radiation dose to the thyroid during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia) indicates that there is a linear relationship (Figure 4.16).

FIGURE 4.16: SCATTERPLOT OF SCREENING TIME AND RADIATION DOSE TO THE THYROID DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS



Pearson γ = .571, n = 96, ρ=. 000

It is clear that the resultant linear regression model is y = 0.0634x. This particular model allows one to predict the expected radiation dose to the thyroid (dependent variable in this case) based on a given screening time (independent variable in this case). For example if screening time was 4 minutes, the expected radiation dose to the thyroid would be y = 0.0634(4) = 0.25 mSv.

Decision

The sample Pearson's correlation coefficient value (γ) equals 0.571 and the corresponding ρ value equals 0.000 (Table 4.9), which is less than α (0.05), therefore the null hypothesis (H_o) was rejected at a 5% significance level. This implies that there is sufficient evidence to suggest that a significantly positive linear relationship exists between screening time and radiation dose to the thyroid during internal fixation of the lower limbs. This is demonstrated by the results of scatterplot (Figure 4.16).

4.3.4 PROCEDURE 4.0

Research question

What is the relationship between the screening time and radiation dose to the whole body during internal fixation of the lower limbs?

Test Used

Pearson's correlation coefficient

Scatterplot used to demonstrate the relationship between the screening time and radiation dose to the thyroid (Figure 4.17)

For the above test, the population correlation coefficient is identified by ρ and the sample correlation coefficient is identified by γ.

Sample

N= 96

THE HYPOTHESIS:

The hypothesis test takes the following structure:

H_o: $\rho = 0$

H_1: $\rho \neq 0$

The null hypothesis (H_o) states that there is no linear relationship

DECISION RULES

If the ρ-value is $< \alpha$ reject H_o,

where $\alpha = 0.05$ (significance level)

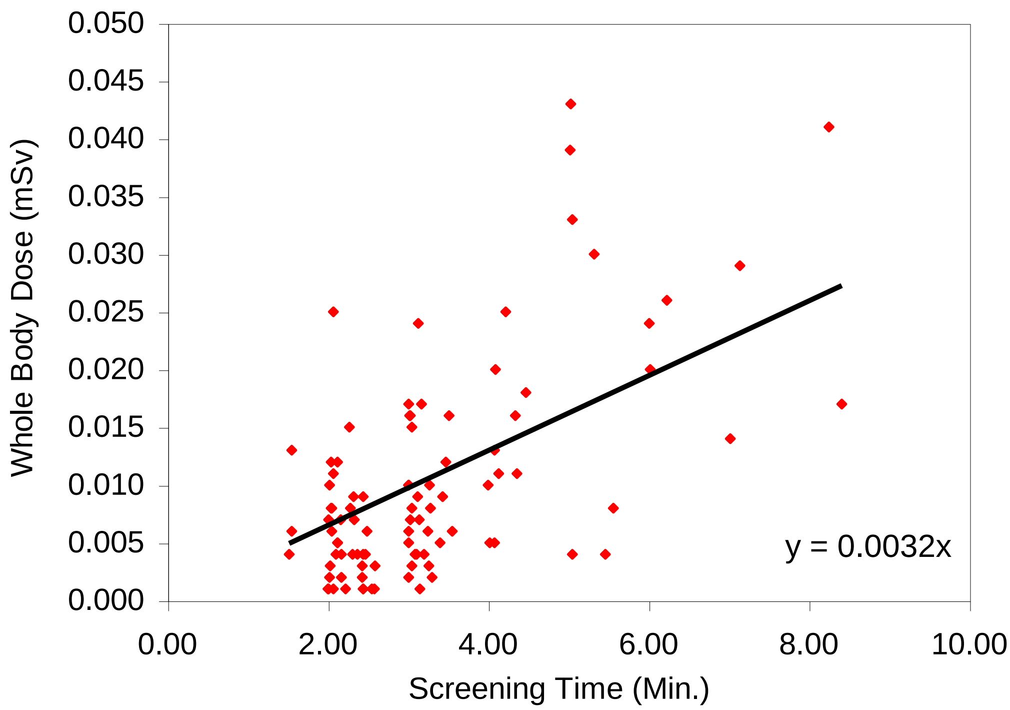
Computation

TABLE 4.10: CORRELATIONS BETWEEN SCREENING TIME AND RADIATION DOSE TO THE WHOLE BODY DURING INTERNAL FIXATION OF THE LOWER LIMBS

N	Pearson Correlation	Sig. (2-tailed) ρ Value
96	.617	.000

A scatterplot of screening time and radiation dose to the whole body during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia) indicates that there is a linear relationship (Figure 4.17).

FIGURE 4.17: SCATTERPLOT OF SCREENING TIME AND RADIATION DOSE TO THE WHOLE BODY DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS



Pearson γ = .617, n = 96, ρ=. 000

It is clear that the resultant linear regression model is y = 0.0032x. This particular model allows one to predict the expected radiation dose to the thyroid (dependent variable in this case) based on a given screening time (independent variable in this case). For example if screening time was 4 minutes, the expected radiation dose to the thyroid would be y = 0.0032(4) = 0.013 mSv.

Decision

The sample Pearson's correlation coefficient value (γ) equals 0.617 and the corresponding ρ value equals 0.000 (Table 4.10), which is less than α (0.05), therefore the null hypothesis (H_o) was rejected at a 5% significance level. This implies that there is sufficient evidence to suggest that a significantly positive linear relationship exists between screening time and radiation dose to the whole body during internal fixation of the lower limbs. This is confirmed by the results of scatterplot (Figure 4.17).

4.3.5 Procedure 5.0

Research question

What is the relationship between the operation and screening times during internal fixation of the lower limbs?

Test Used

Pearson's correlation coefficient

Scatterplot used to demonstrate the relationships between the operative and screening times (Figure 4.18)

For the above test, the population correlation coefficient is identified by ρ and the sample correlation coefficient is identified by γ.

Sample

N= 96

THE HYPOTHESIS:

The hypothesis test takes the following structure:

H_o: $\rho = 0$

H_1: $\rho \neq 0$

The null hypothesis (H_o) states that there is no linear relationship

DECISION RULES

If the ρ-value is $< \alpha$ reject H_o,

where $\alpha = 0.05$ (significance level)

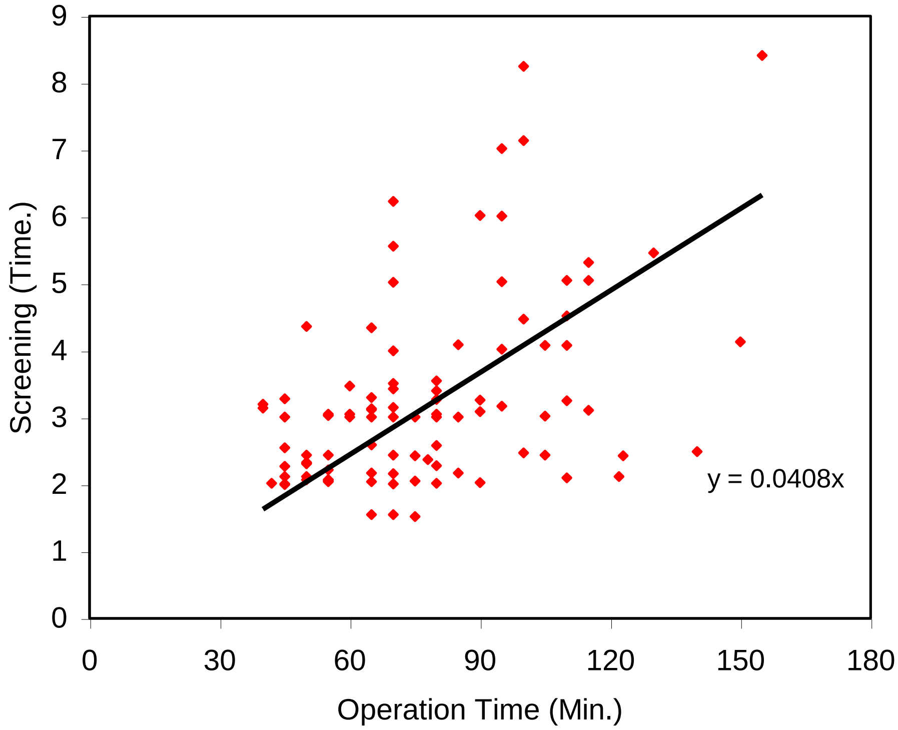
Computation

TABLE 4.11: CORRELATIONS BETWEEN OPERATION AND SCREENING TIMES DURING INTERNAL FIXATION OF THE LOWER LIMBS

N	Pearson Correlation	Sig. (2-tailed) ρ Value
96	.455	.000

A scatterplot of operation and screening times during 96 internal fixations of the lower limbs (32 neck of femur, 32 femur and 32 tibia) indicates that there is a linear relationship (Figure 4.18).

FIGURE 4.18: SCATTERPLOT OF OPERATION AND SCREENING TIMES DURING 96 INTERNAL FIXATIONS OF THE LOWER LIMBS



Pearson γ = .455, n = 96, ρ=. 000

It is clear that the resultant linear regression model is y = 0.0408x. This particular model allows one to predict the expected screening time (dependent variable in this case) based on a given operation time (independent variable in this case). For example, if the operation time was 100 minutes, the expected screening time would be y = 0.0408(100) = 4 minutes.

Decision

The sample Pearson's correlation coefficient value (γ) equals 0.455 and the corresponding ρ value equals 0.000 (Table 4.11), which is less than α (0.05), therefore the null hypothesis (H_o) was rejected at a 5% significance level. This implies that there is sufficient evidence to suggest that a significantly positive linear relationship exists between operation and screening times during internal fixation of the lower limbs. This is confirmed by the results of scatterplot (Figure 4.18).

CHAPTER FIVE

DISCUSSION

5.1 INTRODUCTION

In the current chapter, the results that were obtained from the data presented in the form of tables, figures and statements in chapter 4 will be discussed.

5.2 REDEFINITION OF THE AIMS OF THE STUDY

The aim of this study was, firstly to quantify the radiation dose to the orthopaedic registrars' hands, thyroid and whole body. Secondly to quantify the average operational and screening times during fluoroscopic internal fixation of the lower limbs. Finally, to determine the maximum number of internal fixations of the lower limbs that may be performed by an orthopaedic registrar according to ICRP standards before the hand dose limit is exceeded.

5.3 CLASSIFICATION OF THE DISCUSSION

The discussion will be classified according to five major sections.

- Radiation dose to the hands
- Radiation dose to the thyroid
- Radiation dose to the whole body
- Operation and screening times
- Maximum number of internal fixations of the lower limbs per year, which may be performed by the orthopaedic registrar, before the dose limits to the hands are exceeded for radiation workers and non-radiation workers according to ICRP regulations (ICRP, 1990).

Radiation dose to the hands and thyroid (5.3.1 and 5.3.2) include discussions on the mean and standard deviation for exposure dose during internal fixation of the lower limbs (neck of femur, femur and tibia) (Tables 4.1-4.2, Figures 4.1-4.8 and Appendices E-F). It further includes the analyses of radiation dose to the right and left hand, which were presented in Table 4.7 and Figure 4.14. The relationships between the screening time and the radiation dose to the hands and thyroid were discussed, which was presented in Table's 4.8- 4.9, Figures 4.15- 4.16.

Radiation dose to the whole body (5.3.3) includes discussions on the mean radiation dose to the whole body, which was presented in Tables 4.3-4.4, Figures 4.9-4.11 and Appendix G. Furthermore the relationship between the radiation dose to the whole body and screening time was discussed which was presented in Table 4.10, Figure 4.17.

Operation and screening times (5.3.4) includes a discussion on the operation and screening times during internal fixation of the lower limbs, which was presented in Table 4.5 Figures 4.12-4.13 and appendix H. The discussion also includes discussion on the relationships between the operation and screening times (Table 4.11 and Figure 4.18).

The number of internal fixations of the lower limbs that an orthopaedic registrar may perform before exceeding the maximum permissible dose to the hands for radiation and non-radiation workers (5.3.5) includes discussion on calculation of the maximum number of internal fixations of the lower limbs that may be performed by the orthopaedic registrar per year.

5.3.1 Radiation dose to the hands

For most fluoroscopically assisted internal fixations of the lower limbs, radiation exposure to the registrar's hands tends to be the highest compared to other parts of the body (Al-Shawi and Fern, 2003). Most occupational radiation exposures to the registrars during lower limbs internal fixations occur from backscatter. This effect predominately occurs at the surface of the tissue where the primary beam enters the patient. The direction of the scatter is non-coherent, thus creating an entire area of potentially significant radiation exposure other than the point source of the fluoroscope. This effect creates significant levels of radiation over a large area of the lower limbs' surface (Rampersaud, et al. 2000). This is a source of radiation to the orthopaedic registrar, who may rest his/her hands on the patient's limbs during fluoroscopic imaging. Furthermore, the bilateral nature of certain fluoroscopically assisted internal fixation procedures requires that the registrar stand on the same side of the primary x-ray beam source (Rampersaud, et al. 2000).

In the current study (2004), the TLDs were placed on the index finger of each hand, and therefore reflected the amount of radiation dose to the fingers as well as to the hand. There are several factors, which affect the amount of radiation dose to the hands. These factors include the fluoroscopic devices, experience, and qualifications of different surgeons and operative techniques. A discussion of these factors will follow below.

By using thermoluminescent rings, Sanders, et al. (1993) determined the mean radiation dose to the surgeon's fingers to be 0.28 mSv during 21 intramedullary nailing procedures (tibial nailing and femur nailing). In the same way Levin, Schoen & Browner, (1997) also used thermoluminescent rings to measure the radiation dose to the orthopaedic surgeon, recording an average dose of 0.23 mSv to the hands during the insertion of the intramedullary nail. The study conducted by Lo, Goh and Khong, (1996) to evaluate the radiation dosage from use of the image intensifier in orthopaedic surgery reported the radiation dose to the hands to be 0.42mSv. Muller, et al. (1998) used the lower leg phantom, with the dosimeter positioned on the primary beam to calculate the radiation dose to the hands during 4.6 minutes. Muller, et al. (1998) found the average dose of radiation to the dominant hand of the primary surgeon to be 1.23mSv. The study that was performed by Madan and Blakeway (2002) to evaluate the radiation exposure to surgeon and patient in intramedullary nailing of the lower limbs, reported a mean radiation dose to the surgeons' hands to be 0.32 mSv during tibial and femoral nailing. In average the mean radiation dose to the hands from the precious studies (Levin, Schon & Browner, 1997; Lo, Goh and Khong, 1996; Madan & Blakeway, 2002; Muller, et al. 1998 and Sanders, et al. 1993) mention above was 0.49msv. Table 5.1 summarizes the radiation dose to the hands for the above studies as well as for the current study (2004).

TABLE 5.1: RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE LOWER LIMBS.

Study	Hands Dose (mSv)
Sanders, et al. (1993)	0.28
Lo, Goh and Khong, (1996)	0.42
Levin, et al. (1997)	0.23
Madan and Blakeway (2002)	0.32
Muller, et al. (1998)*	1.23
Current study (2004)	0.22

* Muller, et al. (1998) calculated the radiation dose from the primary beam

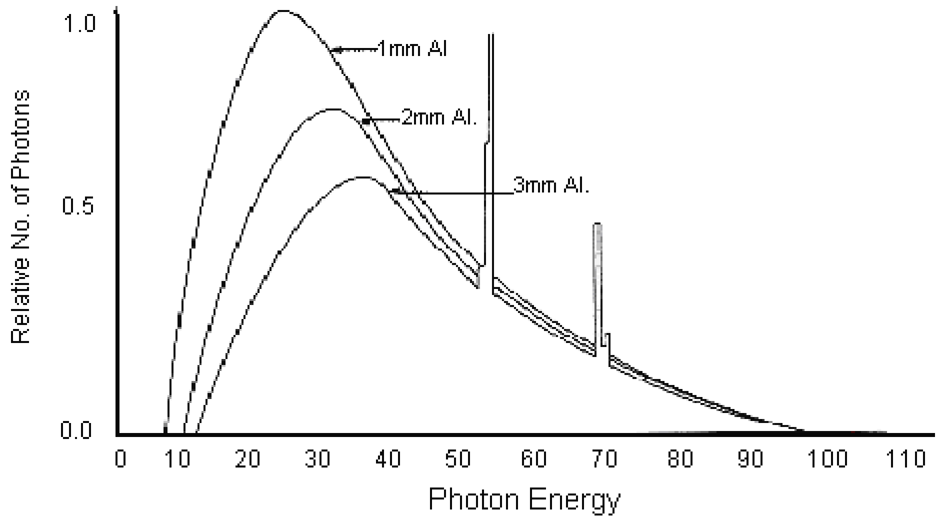
In comparing the result of radiation dose to the hands for the current study (2004) with the average radiation dose from other literature (Levin, Schon & Browner, 1997; Lo, Goh and Khong, 1996; Madan & Blakeway, 2002; Muller, et al. 1998 and Sanders, et al. 1993), the former are lower by 0.27 mSv (Table 5.1). The high number of trauma patients at King Edward VIII Hospital reflects the experience of the registrars, consequently the lower dose compares to the previous studies. The results are difficult to compare due to varying:-

1- Fluoroscopic devices,
2- Experience, and qualifications of different surgeons and
3- Operative techniques.

C-arm fluoroscopy has Aluminium (Al) filters positioned in the useful beam. The primary purpose of these filters is to reduce the number of low energy x-rays that reach the patient. An increased filtration (thicker Al) in the mobile C-arm unit, results in decreased overall patient and registrar's exposure to radiation (Bushong, 1993:630). In the current study (2004), the fluoroscopic filtration used was 3mm Al. This filter (3mm Al) was more than that of the filter (2.5mm Al) used in the study by Muller, et al. (1998).

Filtration in the x-ray machine has an effect on the relative shape of the spectrum. Low energy x-rays are more effectively absorbed by filtration than high energy x-rays, and therefore the emission spectrum is reduced more on the left than on the right (Figure 5.1). The overall result is an increase in the effective energy of the x-ray beam (higher penetration), with an accompanying reduction in beam intensity (Bushong, 1993:168).

FIGURE 5.1: X-RAY EMISSION SPECTRA FOR 100 KVp, WITH TOTAL FILTRATION VALUES OF 1,2 AND 3 mm ALUMINIUM (Hendee and Ritenour, 1992)



The direction of the primary radiation beam with relation to the patient determines the location of maximum backscatter radiation and also significantly influences the registrars' exposure to radiation. Giachino and Cheng (1990) recommended in their experimental study using a leg phantom that, for the lateral image, the image converter should be set so that the x-ray beam runs from the medial to the lateral aspect of the patient limbs, in order to reduce the direct radiation exposure of the surgeon as much as possible. Muller, et al. 1998, concurred with the recommendation of Giachino and Cheng (1990) that to reduce the amount of radiation exposure to the surgeons hands, the lateral fluoroscopy plane should be set from the medial to the lateral aspect of the patient limbs (the x-ray tube distal from the surgeon).

When an internal fixation is performed with the patient in the supine position, the physical characteristics of the C-arm prevent it from being positioned in the manner described by Giachino and Cheng (1990) and Muller, et al.

(1998). In the current study (2004), the C-arm was positioned so that the beam was directed from lateral to medial aspect of the patient limbs. This position was directly opposite to that recommended by, Giachino and Cheng (1990) and Muller, et al. (1998), and should result in the registrar receiving increased exposure to scatter radiation.

The instruments used during internal fixation of the lower limbs differ from place to place. Examples of these instruments are Russell-Taylor, Marchetti Vlacenzi nail, Brooker-Wills intramedullary nail Klemm-Schellman intramedullary nail and Grosse-Kempf nail. The registrars have to frequently hold the instrument during fluoroscopic imaging, thereby placing the hands at the high risk of exposure. In the current study (2004), the orthopaedic procedures were performed using the Russell-Taylor set.

The length of the instrument used, and the technique involved in instrumented internal fixation procedure typically brings the registrar's hands to within a safe distance from the direct beam and the area of maximal backscatter during fluoroscopic image acquisition. The use of the Russell-Taylor set could be the reason for low dose to the orthopaedic registrars' hands compared with the literature studies (Levin, Schoen & Browner, 1997; Madan and Blakeway 2002; Muller, et al. 1998 and Sanders, et al. 1993), in which Marchetti Vlacenzi nail was used in Levin, Schoen & Browner (1997) study. Brooker-Wills intramedullary nail was used in Muller, et al. (1998) and Sanders, et al. (1993) studies. Madan and Blakeway (2002) performed the study using Grosse-Kempf nail to perform the operative procedures.

Maintaining a safe distance from the radiation source reduces radiation exposure to negligible levels. If the instrument must be held to maintain its' location, the registrar should make certain that the instrument is held at its hind end, to maximize distance from the patient's limbs' surface, as well as from the primary radiograph beam source (Levin, Schoen & Browner, 1997).

The most important factors that can affect radiation exposure to the hands are screening time and location of the hands. Screening time is under the control of the registrar; therefore it is affected by the experience of the registrars. Goldstone, Wright & Cohen (1993) investigated radiation exposure related to the qualification of the surgeon, during 13 osteosyntheses (using dynamic hip screws), found that, the younger and less experienced surgeons received the highest radiation dose. In the current study (2004), the registrars' experience was between 2 to 5 years. Variability from registrar to registrar with respect to the procedural technique and the practice of radiation safety also influences individual dose rate. Despite these variables, the results in the current study (2004) have demonstrated that the overall radiation dose rate to the registrars' hands is well below the ICRP recommended annual dose limits (500mSv) for radiation workers.

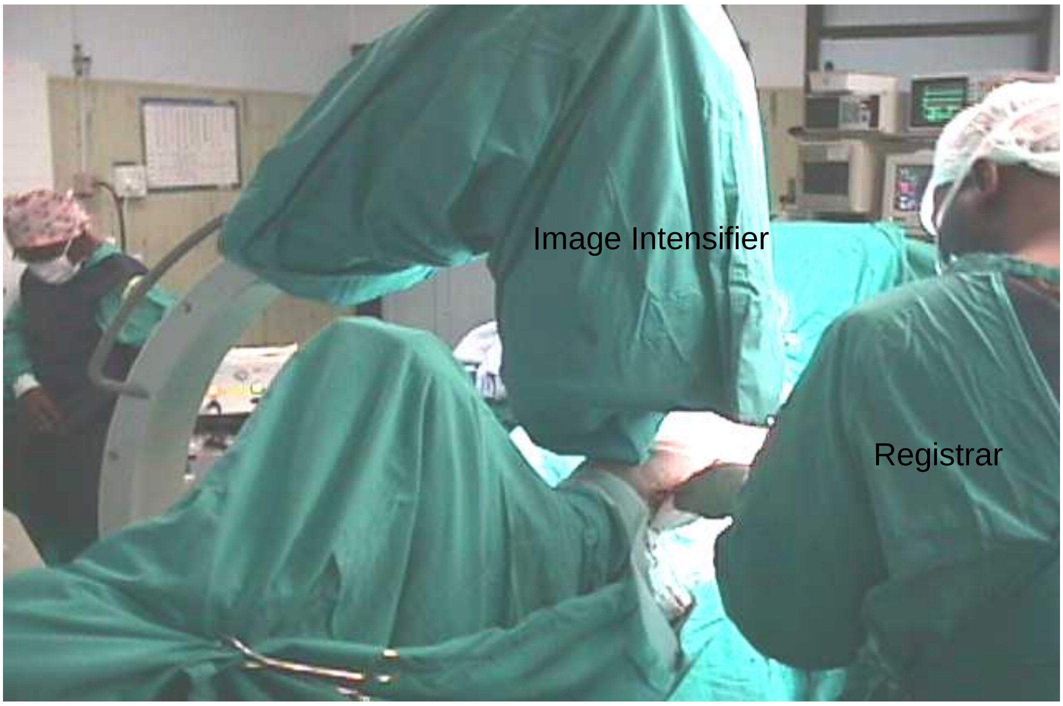
In the current study (2004), the reduction of the screening time demonstrates a decrease in radiation dose to the registrar's hands and thyroid. The relationship between the screening time and radiation dose to the hands and thyroid will be discussed later in section 5.3.4.

Location of the orthopaedic registrar's hands during fluoroscopic procedure is another factor, which affects the amount of the radiation dose to the hands. Obviously, one should avoid positioning the hands directly in the beam. However, this is not always possible due to difficult repositioning manoeuvres.

Attention to the factors mentioned above (screening time and location of the hands) during fluoroscopically assisted procedures should result in a significant decrease in radiation exposure to the registrars, surgical team and the patient. Each registrar must assess his current practice with respect to the above factors.

The major factors affecting dose rate to the orthopaedic registrar during internal fixation of the lower limbs are the proximity of the orthopaedic registrar to the x-ray source and anatomic location of the lower limb (thickness of the imaged body part). Mehlman and DiPasquale (1997) recommended that operating personnel remain a minimum of 46 to 70 cm from the x-ray beam. People working more than 90 cm from the beam have been considered to be at low risk for radiation exposure (Mehlman and DiPasquale 1997). The surgeon may often be within this radius and can be subjected to a large amount of scatter radiation. In the current study (2004), the orthopaedic registrar stood 30cm away from the x-ray source during anterior-posterior projection and in contact with the x-ray tube during lateral projection. Therefore, this location of the registrar (Figures 5.2 and 5.4) increases the amount of occupational radiation dose. The current study (2004) did not investigate the radiation dose to the orthopaedic registrars regarding to distance from the x-ray tube. Further studies could be performed to investigate the amount of the radiation dose to the orthopaedic registrar within difference distances.

FIGURE 5.2: ORTHOPAEDIC REGISTRAR LOCATION DURING INTERNAL FIXATION OF LOWER LIMBS (POSTERIO – ANTERIOR PROJECTION)



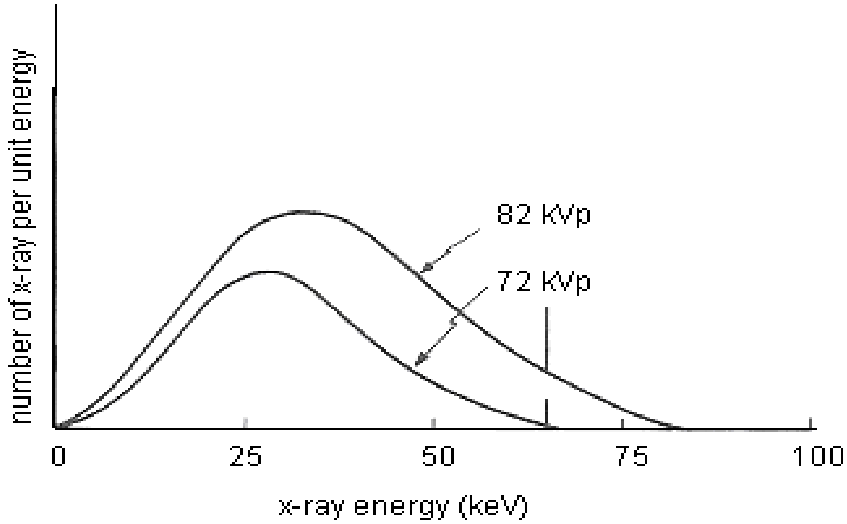
* The photograph was taken at King Edward VIII Hospital.

More scatter radiation results from thick parts of the body than from thinner parts of the body (Bushong, 1993:174). In the current study (2004), the registrar's hands received the maximum dose during internal fixation of the femur compared with the internal fixation of the tibia and neck of femur. This increase is attributed to several factors.

Firstly, compared with other anatomic areas (tibia) of lesser tissue thickness, fluoroscopic imaging of the femur requires significantly high energy to obtain adequate penetration (kVp) and image quality (mA). Consequently, an associated increase in the energy of the backscatter radiation (Compton scatter) at the primary beam-patient entry site also occurs. As the x-ray energy (kVp) increases, the relative number of x-rays that undergo Compton interaction also increases. A change in kVp affects both the amplitude and the position of the x-ray emission spectrum (Figure 5.3). As kVp is raised, the area under the curve approximately increases with the square of the factor by which kVp was increased (Bushong, 1993:157).

Secondly, due to the complexity of the operation procedure, a long screening time is required; and consequently, an increase in the amount of radiation dose to the registrar. The relationship between the screening time and the operative time will be discussed later in section 5.3.4.

FIGURE 5.3: EFFECT OF kVp ON EMISSION SPECTRUM (Bushong, 1993:157)



The current study (2004) uncovered that there is a statistically significant relationship between the radiation dose to the right and left hands as stated in 4.3.1 and presented in Table 4.7 and Figure 4.14. The results of the current study demonstrate a procedure-specific dose of 0.24mSv to the right hand of the orthopaedic registrars. This finding represents a small, but significant increase in the radiation dose to the right hand as compared to the left hand (0.20mSv). In the current study (2004) the right hand received the highest dose. All eight registrars who participated in this study were right handed. This result supports the views of Madan and Blakeway (2002) and Muller, et al. (1998) (See table 5.1 for comparison of the radiation dose to the hands) that the dominant hand receives the maximum exposure. In analysing this information, it can be stated that during localisation of the proximal starting hole, the passage of the guide-wire, and initial reaming and insertion of the intramedullary nail, the dominant hand often came close to the x-ray beam and radiation scatter. For this reason, it becomes clear that the registrar should be extremely careful with location of the hands during insertion of the proximal interlocking screws, as well as during the insertion of the distal interlocking screws.

5.3.2 Radiation dose to the thyroid

In the current study (2004) the radiation dose to orthopaedic registrars thyroid was 0.16mSv during internal fixation of the neck of femur. During internal fixation of the femur and tibia the amount of radiation dose to the thyroid were 0.25mSv and 0.19 mSv respectively. Overall the radiation dose was 0.20mSv to the thyroid during internal fixation of the lower limbs.

In the study conducted by Lo, Goh, and Kong (1996) to measure the radiation dose to the surgeon, the thyroid dose was reported to be 0.51mSv with a thyroid shield and 0.75mSv without a thyroid shield. Dewey and Incoll (1998) reported in their study regarding evaluation of thyroid shields, in 19 surgeons that the radiation dose to thyroid ranged from 0.01 to 0.4mSv.

TABLE 5.2: RADIATION DOSE TO THE THYROID DURING INTERNAL FIXATION OF THE LOWER LIMBS.

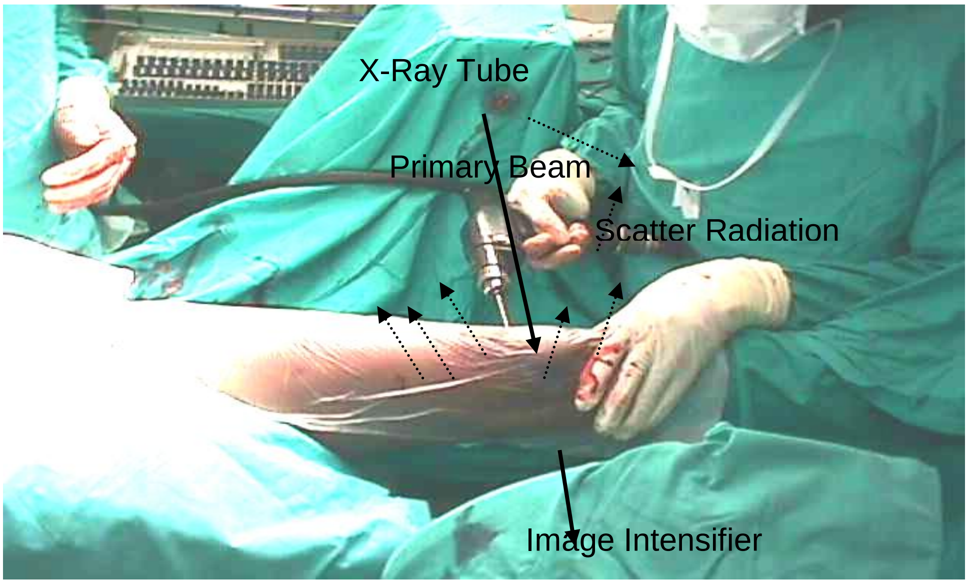
Study	Thyroid Dose (mSv)	
	With shield	Without shield
Lo, Goh and Khong, (1996)	0.51	0.75
Dewey and Incoll (1998)	0.01 to 0.4	-
Current study (2004)	-	0.20

Based on the current study (2004) results, the exposure rate to the thyroid during internal fixation of the lower limbs (0.20mSv per operation) was lower than previous studies (Table 5.2) (Dewey and Incoll, 1998 and Lo, Goh and Kong, 1996). It is assumed that the values of the current study are related to the fluoroscopy devices, experience and qualifications of different surgeons and varying operative techniques, as discussed in section 5.3.1. However, the results of the current study do not inform us about the long-term effects of ionising radiation. Thyroid cancer follows a linear, non-threshold dose-response relation. In a nonthreshold dose response relationship, any dose is expected to produce a response. In order to reduce the probability of thyroid carcinoma among the orthopaedic registrars, the thyroid should be protected during internal fixation procedure (Dewey and Incoll, 1998).

In the current study (2004), the average registrar's thyroid received the highest dose during femur internal fixation (0.25mSv) compared with the tibia and neck of femur internal fixation. This increase is attributed to the factors discussed above in section 5.3.1 (Thickness of the thigh during fixation of the femur, kVp, screening time and distance of the orthopaedic registrar from the x-ray source).

Theocharopoulos, et al. (2003) stated that the lateral projection of the C-arm resulted in increased effective dose rate values compared with anterior-posterior or posterior-anterior projections, due to the fact that higher exposure parameters are needed for side imaging which increases the exposure to the thyroid. Furthermore Theocharopoulos, et al. (2003) concluded that the surgeons receive three to eleven times higher dose from a lateral projection than from a posterior-anterior projection regarding the patient limbs. In the current study (2004), the orthopaedic registrars stood very close to the x-ray tube during the lateral projection (Figure 5.4). Therefore, this location of the registrar increases the amount of radiation dose to the thyroid. This increase of radiation dose is due to high kVp used to penetrate the thick limbs' tissue, and the large amount of scatter radiation. During the lateral position, the distance between the x-ray source and the object (limbs) was increased; therefore a large amount of scatter radiation was produced. The relationship between the distance and radiation intensity will be discussed in section 5.3.3.

FIGURE 5.4: LATERAL PROJECTION OF THE C-ARM



* The photograph was taken at King Edward VIII Hospital.

According to Muller et al. (1998), the average registered radiation dose without a thyroid shield was approximately 70 times higher than with thyroid lead protection. Schneider, Wittke & Rob (1993) concluded in their study that without thyroid protection the coronary angiography examiner received a dose 30 times higher than with thyroid protection. Theocharopoulos, et al. (2003) reported in their experimental study that the use of thyroid protection leads to a further 2.5 - fold decrease of radiation dose. Muller et al. (1998) and Theocharopoulos, et al. (2003) used different experimental techniques to evaluate the thyroid shield (screening time, distance from the source of the radiation and the thyroid shield thickness). A limitation of the current study was that it was not practical to separate the doses between the lateral and posterior-anterior projections.

Orthopaedic registrars in KwaZulu-Natal do not currently wear thyroid shields during fluoroscopic internal fixation (Govender, 2004). Therefore, there is an increased possibility of thyroid carcinoma if not protected, as it is accepted that there is no defined minimum exposure for provocation of thyroid carcinoma. Orthopaedic registrars may be more likely to develop thyroid carcinoma if not protected from this radiation exposure (Dewey and Incoll, 1998). A thyroid shield greatly reduces the radiation exposure to the gland as reported by Lo, Goh, and Kong (1996); Muller et al. (1998); Schneider, Wittke & Rob (1993) and Theocharopoulos, et al. (2003) and therefore must be assumed to reduce the risk of thyroid carcinoma. Further research is needed to define the long term effect on the orthopaedic registrars in South Africa.

5.3.3 Radiation dose to the whole body

The lifetime radiogenic risk of the orthopaedic registrars depends on the annual operation workload, the radiation protection measures used and the duration of occupational exposure (Rampersaud, et al. 2000). Statkiewicz, Visconti, and Ritenour (1998:216) stated that monitoring of radiation exposure to any person occupationally exposed on a regular basis to ionising radiation is recommended. During the fluoroscopic procedures when the lead apron alone is used, the occupational exposure-limiting factor is restricted by the 150mSv eye dose limit. When lead apron, goggles, and thyroid collar are used, the occupational exposure limit factor is restricted by 500mSv extremities dose limit. This interpretation is accepted because irradiation of any of these parts carries a presumed risk of late effects equal to the risk associated with whole body irradiation (ICRP, 1990).

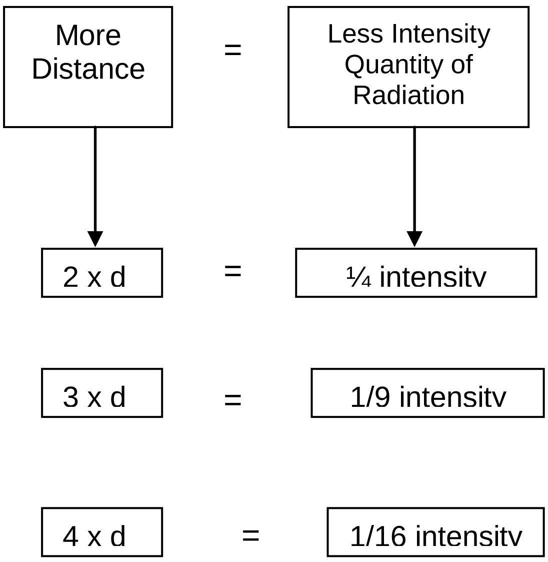
Distance is the most effective means of protection from ionising radiation. Radiation workers receive less radiation exposure by standing further away from a source of radiation (Alonso, et al. 2001). The inverse square law expresses the relationship between the distance and intensity of the x-ray beam. The law states that, as the distance between the radiation source and a measurement point increases the quantity of radiation measurement at the point decreases by the square of the distance from the source (Statkiewicz, Visconti & Ritenour, 1998:199) (Figure 5.5). The inverse square law is expressed as follow:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$ (Bushong, 1993:67)

Where I_1 is the intensity at distance d_1 from the source, and I_2 is the intensity at a distance d_2 from the source.

Giachino and Cheng (1990) measured the scatter radiation that the orthopaedic surgeon was exposed to, during pinning of the neck of femur and found that when the surgeon moved at least 46cm from the greater trochanter, the exposure to radiation was greatly reduced. Dosch, Dupuis & Beck (1993) measured the relationship between radiation dose recorded in the operating room and the distance during interlocking intramedullary nailing, reported that during seven minute's fluoroscopy, the dose of radiation was 0.17mSv when the distance was 40cm and 0.02mSv when the distance was 80cm.

FIGURE 5.5: RELATIONSHIP BETWEEN THE DISTANCE AND INTENSITY OF THE RADIATION (Statkiewicz, Visconti & Ritenour, 1998:199)



In the current study (2004) the orthopaedic registrar stood approximately 30cm away from the x-ray source during the posterior-anterior projection and in contact with the x-ray tube during lateral projection. As a rule of thumb, standing 1m from the patient, the fluoroscopist receives from scattered radiation approximately 1/1000 of the exposure incident upon the patient (Dowd and Tilson, 1999:211). There is a concern about the amount of radiation exposure to the registrars at this small distance. In the current study the orthopaedic registrars will receive 1.1% of incident exposure upon the patient when the distance is 30cm.

$$0.1\% \times \frac{1}{(0.3)^2} = 1.11\%$$

According to the European Council Directive (Euratom, 1997), the working area in which occupational exposure may approach 6 mSv per year is defined as the “controlled area”. Radiation workers in controlled areas should be designated as classified and subjected to individual monitoring and special medical surveillance. Furthermore, in the United States, all employees who are likely to receive 5mSv per year as occupational exposure should be provided with a dosimeter (NCRP, 1993). In South Africa the ICRP recommendations are set as a baseline for radiation protection, although employees who are likely to receive 6mSv per year as occupational exposure should be provided with a dosimeter (ICRP, 1990).

A number of studies (Artigans, Conso and Hazebrouq, 2003; Muller et al. 1998; O’Rourke et al. 1996; and Sanders, et al. 1993) have investigated the exposure of the orthopaedic surgeon’s whole body to radiation and have concluded that the dose received to the whole body was well within the recommended levels but have emphasised caution due to the uncertainty of long-term effects of low dose radiation. Personnel who regularly operate or are in the immediate vicinity of a C-arm fluoroscope should wear a radiation monitor in addition to protective apparel (Bushong, 1993:649).

Jones and Stodart, (1998) Muller, et al. (1998) and O'Rourke, et al. (1996) in their studies concluded that the orthopaedic surgeon should be registered as a radiation worker, in order to monitor the radiation dose regularly. Currently established guidelines recommended monitoring for personnel who are exposed to greater than 10% of the maximum annual whole body dose (NCRP, 1993). The permissible dose for whole body is 20 mSv per year for radiation workers and 1mSv per year for non-radiation workers (ICRP, 1990). In compliance with the ALARA concept, most of the radiological institutions issue dosimetry devices when personnel might receive about 1% of the annual total effective dose equivalent limit in any month (Statkiewicz, Visconti & Ritenour, 1998:216). No known studies about the amount of radiation dose to the orthopaedic registrars during fluoroscopic procedure have been performed in South Africa. The orthopaedic registrars that participated in the study are not registered as radiation workers (Govender, 2004).

In the current study (2004), the mean for radiation dose to the registrar's whole body was 0.11mSv per month over a period of 3 months and 0.010mSv per operative procedure. These results are similar to the results of Artigans, Conso & Hazebrouq, (2003); Muller, et al. (1998); O'Rourke, et al. (1996) and Sanders, et al. (1993). With a mean radiation dose of 0.11mSv per month, the orthopaedic registrar will receive 1.32mSv per year. This value exceeds the limit value of 1mSv per year for non-radiation workers. If it is assumed that the orthopaedic registrar performs 10 operation procedures of internal fixations of the lower limbs per month, then the registrar will receive 0.10mSv per month as effective dose (0.010mSv x 10). Consequently, the registrar will receive 1.2mSv per year, which also exceeds the limit factor to the non-radiation workers. However, the workload at King Edward VIII Hospital exceeds the 10 operation procedures for each registrar per month. The number of operative procedures per year will be discussed later in section 5.3.5. According to Theocharopoulos, et al. (2003) the working area in which the occupational exposure may approach 6mSv is defined as a control area. Radiation worker in controlled areas should be classified and subject to individual monitoring. In the current study the orthopaedic registrars exceed the annual limit factor for non-radiation workers and they are defined as radiation workers within the control area. Although there is not much information about the long- term effects of low dose radiation and the risk estimate for low dose radiation have been re-valuated and increase six fold (Jones and Stoddart, 1998 and Herscovici and Sanders, 2000). The orthopaedic registrars should be registered as radiation workers and be regularly monitored.

5.3.4 Operation and screening times

At present, no study in South Africa or internationally has mentioned the operation time for experienced registrars during lower limbs internal fixation. In this study, the average operation time during internal fixation of the lower limbs was reported to be 77minutes.

A maximum operational time was recorded during internal fixation of the tibia (87 minutes), due to the complexity of the operation procedure and the time consuming insertion of screws to the distal part of the tibia.

The orthopaedic registrars represented 29% for the total number of the registrars in KwaZulu-Natal and 100% for the total number of the registrars at King Edward VIII Hospital as mentioned in 3.4. Statistically, this indicated that the results of operation time could be set as an average operation time for internal fixation of the lower limbs at King Edward VIII Hospital as well as in KwaZulu-Natal among the orthopaedic registrars.

In the current study, there was a positive linear relationship between operation time and screening time during internal fixation of the lower limbs as stated in 4.3.5. As the operation time increased the screening time also increased. This long operation time is due to the complexity of the fracture. Orthopaedic registrars spend a significant amount of time working in close proximity to x-rays. Reduction of the time that the machine is operating should reduce the potential exposure to harmful radiation. Skjeldal and Backe (1987) have reported that exposure to 5 minutes fluoroscopy during distal interlocking will limit the number of operations to 25% per year if the hands are placed in the primary x-ray beam. The dose to personnel is reduced when the dose to the patient is reduced; so reducing the total fluoroscopy time will benefit both personnel and patients (Jones and Stodart, 1998).

In a study, performed by Sanders, et al. (1993) to evaluate the exposure to the orthopaedic surgeon to radiation, an average fluoroscopic time of 4.7 minutes during intramedullary nailing was recorded. According to Levin, Schoen & Browner (1997), the average screening time for tibial intramedullary nailing was 5.43 minutes and 5.12 minutes during femur intramedullary nailing, and 5.28 minutes during lower limbs intramedullary nailing. Muller, et al. (1998) reported that the use of image memory mode decreased the duration of fluoroscopy by an average of 60%. Muller, et al. (1998) also noted an average time of exposure during intramedullary nailing of femoral and tibial fractures of 4.06 minutes (Table 5.3).

TABLE 5.3: AVERAGE FOR SCREENING TIME DURING INTERNAL FIXATION OF THE LOWER LIMBS

Study	Screening Time (Min.)
Levin, et al. (1997)	5.28
Muller, et al. (1998)	4.06
Sanders, et al. (1993)	4.07
Current study (2004)	3.26

In comparing the results of the current study (2004), the average screening time was lower than the time reported in the literature (Levin, Schoen & Browner, 1997; Muller, et al. 1998 and Sanders, et al. 1993). This lower value of screening time could be related to the experiences of the orthopaedic registrars who participated in the study. More knowledge about the operation performed result in less screening time and lower radiation dose.

Image intensifier radiation is rapidly scattered and exposure can be limited by keeping as far away from the primary beam as physically possible. The use of pulsed imaging during fluoroscopy has been shown to reduce overall exposure by 20 to 75% (Boice and Mandel, 1995 and Herandez and Goodsitt, 1996). The C-arm used in the current study (2004) was the Ziehm Exposcop / CB7-D which has last image hold ability. The pulsed image intensifier and digital image facility should be employed in orthopaedic practice, to decrease the amount of radiation exposure to the orthopaedic registrars.

In the current study, Pearson's correlation was performed in order to assess if there were any relationships between the screening time and radiation dose to the hands, thyroid and whole body. As stated in 4.3.2-4.3.3 and 4.3.4 and presented in Table 4.8-4.10 and Figures 4.15-4.17, there were a significant positive correlation coefficient and linear relationships during internal fixation of the lower limbs. As the screening time increase the radiation dose to the hands, thyroid and whole body also increases. Reduction of the time that the machine is operating should reduce the potential exposure to harmful radiation.

Pearson's correlation was also performed in order to assess if there were any relationships between the operative and screening times. There was a positive correlation coefficient and linear relationships as stated in 4.3.5 and presented in Table 4.11 and Figure 4.18. As the operation time increased, the screening time also increased and this could be related to the complexity of the operation procedure.

The amount of radiation dose to the hands and thyroid was lower than previous literature studies (Levin, Schon & Browner, 1997; Lo, Goh and Khong, 1996; Madan & Blakeway, 2002; Muller, et al. 1998 and Sanders, et al. 1993) as stated in 5.3.1 and 5.3.2. It can be concluded that the lower radiation dose values to the hands and thyroid was related to the low screening time, and consequently, the experience of the orthopaedic registrars.

5.3.5 Maximum number of internal fixations of the lower limbs per/year

Exposure of the hands has been shown to be the limiting factor in orthopaedic practice (Sanders, et al. 1993; Smith, et al.1992 and Smith, Wakeman & Briggs, 1996), whereas in cardiological practice, the lens of the eye is the limit factor (Jeans and Faulkner, 1985). The annual dose limit to the hands is 150mSv for non-radiation workers and 500mSv for radiation workers (ICRP, 1990).

The study conducted by Lo, Goh and Khong, (1996) to evaluate the radiation dose from the use of the image intensifier in orthopaedic surgery in Alexandra Hospital in Singapore, concluded that the surgeon would exceed the limits factor to the hands (500mSv) as recommended by ICRP after 1190 procedures. Muller, et al. (1998) extrapolated that the radiation dose to the hands of the surgeon during 41 procedures of intramedullary nailing of femoral and tibial fracture in Germany was 1.23mSv, so that a surgeon can perform 407-intramedullary nailing before the maximum permissible dose to the extremities per year would be exceeded according to ICRP limit.

According to Madan and Blakeway (2002) in a study, which was performed in the United Kingdom, the orthopaedic surgeons will exceed the maximum limits to the hands (500mSv) after 2506 intramedullary nailing of the lower limbs.

According to Prof. Govender (2004) the orthopaedic registrars currently are non-radiation workers, and therefore the annual extremity dose limit is 150mSv (ICRP, 1990).

In the current study (2004), the mean for radiation dose to the hands was 0.22mSv during internal fixation of the lower limbs; so that 681 internal fixations of the lower limbs can be performed by a registrar before the limit factor (according to ICRP standards for non-radiation workers) to the hands is exceeded.

If the orthopaedic registrars are registered as radiation workers, the limiting factor to the extremities will be 500mSv per year. Therefore, the maximum number of operative procedures will be increased to threefold and there will be 2272 internal fixation of the lower limbs per year. However, this is not meaning that orthopaedic registrars can perform this number of operation without risk and should not make registrars complacent, because there is no information about the long-term effects of low dose radiation to the human being.

TABLE 5.4: MAXIMUM NUMBER OF INTERNAL FIXATION OF THE LOWER LIMBS PER YEAR REGARDS THE LIMIT DOSE TO THE HANDS.

Study	Hands Dose (mSv)	Maximum number of internal fixation/year
Lo, Goh and Khong, (1996)	0.42	1190
Muller, et al. (1998)	1.23	407
Madan and Blakeway (2002)	0.20	2506
Current study [non-radiation workers] (2004)	0.22	681
Current study [radiation workers] (2004)	0.22	2272

According to the studies performed by Lo, Goh and Khong, (1996); Madan and Blakeway, (2002) and Muller, et al. (1998), the maximum number of operation procedures was calculated considering that the orthopaedic registrars were radiation workers (Table 5.4). Therefore, the limit dose to the hands was 500mSv per year. Comparing the current study (2004) results with the literature results (Lo, Goh and Khong, 1996 and Muller, et al. 1998) the number of internal fixations of the lower limbs per year for the non-radiation workers was lower. However, the number of internal fixations was more than the results of previous studies when the calculation was determined regarding radiation workers.

The exposure of the hands has been shown to be the occupational exposure limit factor in orthopaedic practice as reported by Sanders, et al. (1993); Smith, et al. (1992) and Smith, Wakeman &Briggs (1996). In the current study (2004), the radiation exposure to the registrar's whole body per operation procedure was 0.010mSv. This value (0.010mSv) of radiation dose leads to the fact that the orthopaedic registrar will receive 6.81mSv per year as whole body dose, after 681 internal fixations of the lower limbs (0.010mSv x 681= 6.81mSv/year). This value (6.81mSv) has exceeded the effective dose level (1mSv) to non-radiation workers.

If the registrars are registered as radiation workers, the amount of whole body dose will be increased approximately threefold (0.01mSv x 2271 =22.7mSv/year). This value (22.7mSv/year) has also exceeded the effective dose to the radiation workers (20mSv). But in fact the orthopaedic registrars at King Edward VIII Hospital will not reach this number of procedures (2271) during their normal work. However these findings lead to the fact that the orthopaedic registrars will exceed the occupational limit dose to the public if they are considered non-radiation workers. Therefore the orthopaedic registrars should be registered as radiation workers and be regularly monitored.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

(i) Extrapolating from the results it was concluded that if the registrar receives 0.22mSv per procedure, on average, a registrar would be able to perform 681 fluoroscopic procedures per year, before reaching the yearly limit dose to the hands for non-radiation workers and 2272 procedures before exceeding the dose limit to the hands to radiation workers as recommended by the ICRP.

(ii) In comparison with results of the amount of radiation dose to the hands and thyroid and screening time from other literature (Artigans, Conso and Hazebrouq, 2003; Lo, Goh and Khong, 1996; Madan and Blakeway, 2002; Muller, et al. 1998; O'Rourke, et al. 1996 and Sanders, et al. 1993), the current study results are lower (Tables 5.1-5.2). However the results are difficult to compare because of varying fluoroscopy devices, qualifications and experience of different surgeons and operation technique as discussed previously in chapter five. The results of the current study could be used as a baseline for King Edward VIII Hospital and KwaZulu-Natal and for future research for other centres in South Africa.

(iii) Although the radiation exposure to the orthopaedic registrars hands, thyroid and whole body is within the ICRP recommended levels per year for radiation workers, there should be no complacency because of the uncertainty in the effects of low dose radiation. There is no safe dose of radiation and the ALARA principle should be observed for any person.

(iv) In conclusion, it can be determined that the registrar who performs an internal fixation absorbs a quantifiable dose of radiation to the hands and thyroid. Although the hand doses are well below the established guidelines of the ICRP for radiation workers, the long-term effects of this exposure are unknown.

6.2 Recommendations

There is evidence that carcinogenic and non-carcinogenic potential exists from low-doses (Statkiewicz, Visconti & Ritenour, 1998:60 and Sutherland and Finlayson, 1998). Based on the results of the current study (2004), it is recommended that the following precautions be taken.

(i) The orthopaedic registrars should be registered as radiation workers and be regularly monitored.

(ii) The orthopaedic department should check its staff exposure at regular intervals as part of its ongoing assessment of radiation safety, with help from a radiation protection officer.

(iii) The registrars who perform internal fixation should be familiar with the technique, so that the total time for fluoroscopy may be decreased.

(iv) Further teaching is needed to minimize the hazards from the use of ionising radiation during surgical procedures. Training in radiation safety must be provided for all orthopaedic registrars who are performing medical surgical procedures using radiation, in order to protect the patient from unnecessary radiation and also to minimize the dose to themselves and other staff. The C-arm should be positioned with the patient as far from the x-ray tube and as close to the image intensifier as possible. This will minimize scatter radiation, skin entry dose and optimise image quality. Orthopaedic registrars performing fluoroscopically assisted procedures in internal fixation of the lower limbs must be aware of the factors that increase the radiation dose to the hands (screening time, location of the hands), in order to decrease the radiation exposure.

(v) The protective lead apron must be checked on a regular basis to conform that there are no cracks in the lead. Additionally the hospital should make thyroid shields, and lead glasses available to orthopaedic registrars and monitor their usage.

(vi) The registrars must refrain from using live fluoroscopy instead, the image memory mode should be employed whenever possible. The stored image facility fluoroscopy machine reduces the screening time by a factor of four, while a more up- to- date digital image facility gives a further eightfold reduction (Muller, et al. 1998). Because all medical radiation exposure should be kept to a minimum, under the so-called 'ALARA' principle, orthopaedic units for which fluoroscopy is used should have modern fluoroscopes.

(vii) This research project could provide a basis for further studies and investigations into radiation dose to the orthopaedic registrars thyroid and the other staff at the operation theatres in South Africa. Further research needs to be conducted to establish the true exposure for other personnel such as the scrub nurse and the anaesthetist. Further research on the long-term effect of the ionising radiation on orthopaedic registers in South Africa is required.

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APPENDICES

APPENDIX A

Ai

Secretary General of Health
Professor R. W. Green-Thompson
Department of Health
Kwa-Zuly Natal
Durban
4000
Dear Professor Green Thompson

RE**: REQUEST TO PERFORM RESEARCH IN ORTHOPAEDIC DEPARTMENT**

I am currently a master's student at the Durban Institute of Technology. I am keen to conduct a research project towards an M. Tech in Radiography.

The proposed title of my dissertation is **a quantitative analysis of ionizing radiation exposure to the hands, thyroid, and whole body of the orthopaedic registrars during fluoroscopic internal fixation of the lower limbs**. The aim of this study is to quantify the ionizing radiation exposure to the hands, thyroid and whole body of the orthopaedic registrar during fluoroscopic internal fixation of the lower limbs, at King Edward VIII Hospital. The researcher will be in the operation theater during the operative procedures for recording all the data.

I hereby seek permission to undertake this research on orthopaedic registrars at King Edward VIII hospital.

My proposal has been reviewed by the Department of Radiography and approved by the Research Committee of the Faculty of Health Sciences at the Durban Institute of Technology. Appropriate ethical approval has been obtained. Experts in the field will supervise the project internally and externally.

The results of this study shall inform the orthopedic registrar about the amount of radiation exposure to the hands, thyroid, and whole body. Informed decisions can therefore be made with regards to protective measures to be taken (if any).

Your support and permission (in writing) to perform this study at King Edward VIII Hospital will be greatly appreciated, for a period of three months (16th November 2003 to 15th February 2004).

You're sincerely

……………………….
Mr. Khaled Abu Shab
Student: M Tech: Radiography
Cell: 0837350794
E-mail: khaledshap@hotmail.com

Supervisor Name: Loganee Moodley
tel.: 031 2042695
E-mail: loganeem@dit.ac.za

Aii

Chief Medical Superintendent
King Edward VIII Hospital
Durban
4000

Dear Sir/Madam

RE**: REQUEST TO PERFORM RESEARCH IN ORTHOPAEDIC DEPARTMENT**

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……………………….
Mr. Khaled Abu Shab

Student: M Tech: Radiography
Cell: 0837350794

Supervisor Name: Loganee Moodley

tel.: 031 2042695
E-mail: loganeem@dit.ac.za

Aiii

Professor Govender
Head of Department
Orthopaedic
NR Mandela School of Medicine
Durban

Dear Professor Govender

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I hereby seek permission to undertake this research on orthopaedic registrars at King Edward VIII hospital.

My proposal has been reviewed by the Department of Radiography and approved by the Research Committee of the Faculty of Health Sciences at the Durban Institute of Technology. Appropriate ethical approval has been obtained. Experts in the field will supervise the project internally and externally.

The results of this study shall inform the orthopedic registrar about the amount of radiation exposure to the hands, thyroid, and whole body. Informed decisions can therefore be made with regards to protective measures to be taken (if any).

Your support and permission (in writing) to perform this study at King Edward VIII Hospital will be greatly appreciated, for a period of three months (16th November 2003 to 15th February 2004).

You're sincerely

……………………….
Mr. Khaled Abu Shab

Student: M Tech: Radiography
Cell: 0837350794

Supervisor Name: Loganee Moodley

tel.: 031 2042695
E-mail: loganeem@dit.ac.za

Aiv

Ms. G. Ramlakhan
Head of Radiography Department
King Edward VIII Hospital
Durban
4000

Dear Ms. G. Ramlakhan

RE**: REQUEST TO PERFORM RESEARCH IN ORTHOPAEDIC DEPARTMENT**

I am currently a master's student at the Durban Institute of Technology. I am keen to conduct a research project towards an M. Tech in Radiography.

The proposed title of my dissertation is **a quantitative analysis of ionizing radiation exposure to the hands, thyroid and whole body of the orthopaedic registrars during fluoroscopic internal fixation of the lower limbs**. The aim of this study is to quantify the ionizing radiation exposure to the hands, thyroid and whole body of the orthopaedic registrar during fluoroscopic internal fixation of the lower limbs, at King Edward VIII Hospital. The researcher will be in the operation theater during the operative procedures for recording all the data.

I hereby seek permission to undertake this research on orthopaedic registrars at King Edward VIII hospital.

My proposal has been reviewed by the Department of Radiography and approved by the Research Committee of the Faculty of Health Sciences at the Durban Institute of Technology. Appropriate ethical approval has been obtained. Experts in the field will supervise the project internally and externally.

The results of this study shall inform the orthopedic registrar about the amount of radiation exposure to the hands, thyroid, and whole body. Informed decisions can therefore be made with regards to protective measures to be taken (if any).

Your support and permission (in writing) to perform this study at King Edward VIII Hospital will be greatly appreciated, for a period of three months (16th November 2003 to 15th February 2004).

You're sincerely

……………………….

Mr. Khaled Abu Shab
Student: M Tech: Radiography
Cell: 0837350794

Supervisor Name: Loganee Moodley
tel.: 031 2042695
E-mail: loganeem@dit.ac.za

Av

Avi

APPENDIX B

PARTICIPANT INFORMATION LETTER

Durban Institute of Technology; Radiography Department

Title:

A quantitative analysis of ionizing radiation exposure to the hands, thyroid and whole body of the orthopaedic registrars during fluoroscopic internal fixation of the lower limbs.

Dear participant:

I am performing a study on the evaluation of radiation exposure to the hands, thyroid and whole body of the orthopaedic surgeon during internal fixation of the lower limbs. The aim of the study is to measure the radiation dose to the hands, thyroid and whole body. This study shall inform you about the amount of radiation dose you received during the use of fluoroscopic screen.

Procedure

In order to measure the dose to your hands two finger ring dosimeter will be given to you and you are requested to wear them on your index figure of each hand under surgical gloves. These will be changed after each operative procedure. For measuring the radiation dose to thyroid you are requested to place the dosimeter (TLDs) anteriorly on the skin over your thyroid. This will be changed after each operative procedure. For measurement of the whole body dose you are requested to place the dosimeter under your lead apron during all the operative procedures you performed per month. This will be changed after each month. The researcher will be present during the operative procedure and will assist in exact placement of TLD.

Risk/ Discomfort

There is no risk or discomfort to your participation in this study

Benefits

The results of this study will inform you of the radiation dose to your hands and thyroid and whole body, and whether this dose was exceeded according to ICRP regulations.

Confidentiality

The orthopaedic surgeons personal particulars will be excluded from data analysis and data presentation (Codes will be used for each research participant). Please be aware that you are free to withdraw at any time during the research.

Cost to participant

There is no cost to the research participant. All measurements will be done free of charge, all personal dosimeters will be provided at no cost to yourself.

Person to contact with regards to questions related to the research

Mr. Khaled Abu Shab
Cell: 0837350794
E-mail: khaledshap@hotmail.com

Supervisor Name: Mrs. Loganee Moodley
tel.: 031 2042695
E-mail: loganeem@dit.ac.za

Co-supervisor name: Mrs. Nalene Naidoo
Tel: 031 2042695
E-mail: NaleneN@dit.ac.za

APPENDIX C

INFORMED CONSENT FORM

I,…………………………………………………………… hereby voluntarily consent to participate in the research entitled:

A quantitative analysis of ionizing radiation exposure to the hands, thyroid and whole body of the orthopaedic registrars during fluoroscopic internal fixation of the lower limbs.

Conducted by:

Name of researcher: **Khaled Abu Shab**
Name of supervisor: Mrs. **Loganee Moodley**
Name of co-supervisor: Mrs. **Nalene Naidoo**

Please circle the appropriate answer

1 Have you read and understood the research information sheet? Yes / No
2 Have you had an opportunity to discuss the study? Yes /No
3 Have you had an opportunity to ask questions regarding this study? Yes /No
4 Who have you spoken to?………………………………………….
5 Have you received satisfactory answers to your questions? Yes /No
6 Have you received enough information about the study? Yes /No
7 Do you understand that you are free to withdraw from this study;
   a) at any time and
   b) without having reason for withdrawing? Yes / No
8 Do you agree to voluntarily participate in this study? Yes / No

If you have answered No to any of the above questions, please obtain the appropriate information before signing.

………………………………………………………………………………………………
………………………………………………………………………………………………

Persons to contact

Mr. Khaled Abu Shab
Cell: 0837350794
E-mail: khaledshap@hotmail.com

Supervisor Name: Mrs. Loganee Moodley
tel.: 031 2042695
E-mail: loganeem@dit.ac.za

Co-Supervisor Name: Mrs. Nalene Naidoo
Tel: 031 2042695
E-mail: NaleneN@dit.ac.za

Please print in block letters

Participant Name:……………………**signature** ……………Date…………………….

Witness Name ………………………**Signature**…………….Date………………………

APPENDIX D

Di

DATA SHEET FOR RADIATION DOSE TO THE HANDS

Orthopaedic registrar code: …………………

Operation type: Tibia ☐ Femur ☐ Neck of Femur ☐

Hand dominance of surgeon: Rt. Lt.

TLDs series No. Rt. hand……

TLDs series No. Lt. hand……

Date: ……/…/…………

Procedure	**1st Scout**	**2nd Scout**	**3rd Scout**	**4th Scout**	**5th Scout**	**6th Scout**	**7th Scout**	**8th Scout**	**9th Scout**	**10th Scout**	
KV											**Average KV**
MA											**Average mA**
Screening time											**Total time/min.**
Operative time		From……………………… To…………………………..									**Total time/min.**
TLD reading Rt. Hand		…………………..mSv/per operative									
TLD reading Lt. Hand		……………………mSv/per operative									

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DURBAN INSTITUTE of TECHNOLOGY

DATA SHEET FOR RADIATION DOSE TO THE THYROID

Orthopaedic registrar code: ………………… TLDs series No. …………

Operation type: Tibia ☐ Femur ☐ Neck of Femur ☐ Date: ……/…/…………

Procedure	**1st Scout**	**2nd Scout**	**3rd Scout**	**4th Scout**	**5th Scout**	**6th Scout**	**7th Scout**	**8th Scout**	**9th Scout**	**10th Scout**	
KV											**Average KV**
MA											**Average mA**
Screening time											**Total time/min**
Operative time	From……………………… To…………………………..										**Total time/min**
TLD	…………………..mSv/per operative										

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DURBAN INSTITUTE of TECHNOLOGY

DATA SHEET FOR RADIATION DOSE TO THE WHOLE BODY

Date:…………\………..\…………

Orthopaedic registrar code	TLD series No.	Reading in mSv	Total No. of operation per month	Tibial	Femur	Neck of femur	Other

Appendix E

Ei

RADIATION DOSE READING FOR THE RIGHT HAND DURING INTERNAL FIXATION OF THE NECK OF FEMUR

Orthopaedic registrar code	TLDs Reading (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.12	0.36	0.18	0.09
K1971	0.27	0.35	0.17	0.21
M1974	0.03	0.22	0.19	0.02
SM1975	0.2	0.29	0.07	0.24
R1973	0.17	0.03	0.12	0.2
RK1972	0.05	0.01	0.1	0.17
XM1976	0.18	0.17	0.11	0.36
T1978	0.06	0.23	0.65	0.12

RADIATION DOSE READING FOR THE LEFT HAND DURING INTERNAL FIXATION OF THE NECK OF FEMUR

Orthopaedic registrar code	TLDs Reading (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.03	0.33	0.15	0.11
K1971	0.12	0.01	0.22	0.16
M1974	0.05	0.22	0.11	0.11
SM1975	0.19	0.1	0.01	0.07
R1973	0.06	0.2	0.12	0.25
RK1972	0.19	0.19	0.23	0.16
XM1976	0.08	0.13	0.43	0.27
T1978	0.08	0.07	0.31	0.33

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO HANDS DURING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Registrar code	Hand	N	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Jk1970	Right	4	0.09	0.36	0.19	0.12	0.06
	Left	4	0.03	0.33	0.16	0.13	0.06
	Both	8	0.03	0.36	0.17	0.12	0.04
K1971	Right	4	0.17	0.35	0.25	0.08	0.04
	Left	4	0.01	0.22	0.13	0.09	0.04
	Both	8	0.01	0.35	0.19	0.10	0.04
M1974	Right	4	0.02	0.22	0.12	0.10	0.05
	Left	4	0.05	0.22	0.12	0.07	0.04
	Both	8	0.02	0.22	0.12	0.08	0.03
SM1975	Right	4	0.07	0.29	0.20	0.09	0.05
	Left	4	0.01	0.19	0.09	0.08	0.04
	Both	8	0.01	0.29	0.15	0.10	0.03
R1973	Right	4	0.03	0.2	0.13	0.07	0.04
	Left	4	0.06	0.25	0.16	0.08	0.04
	Both	8	0.03	0.25	0.14	0.08	0.03
RK1972	Right	4	0.01	0.17	0.19	0.07	0.03
	Left	4	0.16	0.23	0.08	0.03	0.01
	Both	8	0.01	0.23	0.14	0.08	0.03
XM1976	Right	4	0.11	0.36	0.21	0.11	0.05
	Left	4	0.08	0.43	0.23	0.16	0.08
	Both	8	0.08	0.43	0.22	0.13	0.07
T1978	Right	4	0.06	0.65	0.27	0.27	0.13
	Left	4	0.07	0.33	0.20	0.14	0.07
	Both	8	0.06	0.65	0.23	0.20	0.07

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE NECK OF FEMUR

	N	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Rt. hand dose	32	0.01	0.65	0.18	0.13	0.02
Lt hand dose	32	0.01	0.53	0.16	0.10	0.02
Both hand dose	64	0.01	0.65	0.17	0.12	0.01

Eii

RADIATION DOSE READING FOR THE RIGHT HAND DURING INTERNAL FIXATION OF THE FEMUR

Orthopaedic registrar code	TLDs Reading (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.05	0.31	0.14	0.36
K1971	0.35	0.27	0.27	0.31
M1974	0.53	0.15	0.11	0.17
SM1975	0.24	0.23	0.59	0.42
R1973	0.33	0.44	0.39	0.34
RK1972	0.19	0.4	0.3	0.09
XM1976	0.45	0.29	0.31	0.43
T1978	0.33	0.17	0.41	0.16

RADIATION DOSE READING FOR THE LEFT HAND DURING INTERNAL FIXATION OF THE FEMUR

Orthopaedic registrar code	TLDs Reading (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.05	0.24	0.07	0.05
K1971	0.07	0.01	0.14	0.41
M1974	0.21	0.18	0.41	0.18
SM1975	0.14	0.02	0.45	0.33
R1973	0.26	0.05	0.74	0.25
RK1972	0.05	0.27	0.55	0.08
XM1976	0.45	0.13	0.31	0.52
T1978	0.16	0.17	0.6	0.16

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO HANDS DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Registrar code	Hand	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Jk1970	Right	4	0.05	0.36	0.22	0.14	0.07
	Left	4	0.05	0.24	0.10	0.09	0.05
	Both hands	8	0.05	0.36	0.16	0.13	0.05
K1971	Right	4	0.27	0.35	0.30	0.04	0.02
	Left	4	0.01	0.41	0.16	0.18	0.09
	Both hands	8	0.01	0.41	0.23	0.14	0.05
M1974	Right	4	0.11	0.53	0.24	0.19	0.10
	Left	4	0.18	0.41	0.25	0.11	0.06
	Both hands	8	0.11	0.53	0.24	0.15	0.10
SM1975	Right	4	0.23	0.59	0.37	0.17	0.09
	Left	4	0.02	0.45	0.24	0.19	0.10
	Both hands	8	0.02	0.95	0.30	0.18	0.06
R1973	Right	4	0.33	0.44	0.38	0.05	0.03
	Left	4	0.05	0.64	0.30	0.25	0.12
	Both hands	8	0.05	0.64	0.34	0.16	0.05
RK1972	Right	4	0.09	0.4	0.25	0.13	0.07
	Left	4	0.05	0.55	0.24	0.23	0.11
	Both hands	8	0.05	0.55	0.24	0.17	0.06
XM1976	Right	4	0.29	0.45	0.37	0.08	0.04
	Left	4	0.13	0.52	0.35	0.17	0.09
	Both hands	8	0.13	0.52	0.36	0.13	0.04
T1978	Right	4	0.16	0.41	0.27	0.12	0.06
	Left	4	0.16	0.60	0.27	0.22	0.10
	Both hands	8	0.16	0.60	0.27	0.16	0.06

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE FEMUR

	N	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Rt. Hand dose	32	0.05	0.59	0.30	0.13	0.02
Lt. hand dose	32	0.01	0.64	0.24	0.18	0.03
Both hands dose	64	0.01	0.64	0.27	0.16	0.02

Eiii

RADIATION DOSE READING FOR RIGHT HAND DURING INTERNAL FIXATION OF THE TIBIA

Orthopaedic registrar code	TLDs Reading (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.48	0.2	0.32	0.27
K1971	0.12	0.06	0.12	0.16
M1974	0.2	0.11	0.33	0.09
SM1975	0.11	0.32	0.12	0.53
R1973	0.14	0.62	0.25	0.06
RK1972	0.33	0.12	0.18	0.2
XM1976	0.23	0.31	0.32	0.43
T1978	0.07	0.18	0.14	0.2

RADIATION DOSE READING FOR LEFT HAND DURING INTERNAL FIXATION OF THE TIBIA

Orthopaedic registrar code	TLDs Reading (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.66	0.28	0.11	0.24
K1971	0.07	0.03	0.13	0.05
M1974	0.01	0.24	0.11	0.75
SM1975	0.02	0.08	0.12	0.5
R1973	0.04	0.08	0.11	0.13
RK1972	0.07	0.18	0.04	0.12
XM1976	0.28	0.26	0.29	0.22
T1978	0.16	0.14	0.23	0.19

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE TIBIA (PER REGISTRAR)

Registrar code	Hand	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Jk1970	Right	4	0.2	0.48	0.32	0.12	0.06
	Left	4	0.11	0.66	0.32	0.24	0.11
	Both hands	8	0.11	0.66	0.32	0.73	0.06
K1971	Right	4	0.06	0.16	0.12	0.04	0.02
	Left	4	0.03	0.13	0.07	0.04	0.01
	Both hands	8	0.03	0.16	0.10	0.05	0.02
M1974	Right	4	0.09	0.33	0.18	0.11	0.05
	Left	4	0.01	0.75	0.18	0.33	0.16
	Both hands	8	0.01	0.75	0.23	0.23	0.08
SM1975	Right	4	0.11	0.53	0.27	0.20	0.10
	Left	4	0.02	0.5	0.18	0.22	0.11
	Both hands	8	0.02	0.53	0.23	0.20	0.07
R1973	Right	4	0.06	0.62	0.27	0.25	0.12
	Left	4	0.04	0.13	0.09	0.04	0.02
	Both hands	8	0.04	0.62	0.18	0.19	0.07
RK1972	Right	4	0.12	0.33	0.21	0.09	0.04
	Left	4	0.04	0.18	0.10	0.06	0.03
	Both hands	8	0.04	0.33	0.16	0.09	0.03
XM1976	Right	4	0.23	0.43	0.32	0.08	0.04
	Left	4	0.22	0.29	0.26	0.03	0.02
	Both hands	8	0.22	0.43	0.29	0.07	0.02
T1978	Right	4	0.07	0.20	0.15	0.06	0.03
	Left	4	0.14	0.23	0.18	0.04	0.02
	Both hands	8	0.07	0.23	0.16	0.05	0.02

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE HANDS DURING INTERNAL FIXATION OF THE TIBIA

	N	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Rt. Hand dose	32	0.06	0.62	0.23	0.14	0.02
Lt. hand dose	32	0.01	0.75	0.19	0.17	0.03
Both hands dose	64	0.01	0.75	0.21	0.16	0.02

APPENDIX F

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RADIATION DOSE READING FOR THE THYROID DURING INTERNAL FIXATION OF THE NECK OF FEMUR

Orthopaedic registrar code	TLDs reading in mSv			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.33	0.21	0.04	0.08
K1971	0.14	0.02	0.26	0.23
M1974	0.10	0.06	0.02	0.16
SM1975	0.31	0.09	0.08	0.01
R1973	0.04	0.10	0.49	0.14
RK1972	0.02	0.13	0.33	0.47
XM1976	0.08	0.19	0.17	0.16
T1978	0.01	0.15	0.29	0.11

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE THYROID DURING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Registrar code	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Jk1970	4	0.04	0.33	0.17	0.13	0.07
K1971	4	0.02	0.26	0.16	0.11	0.05
M1974	4	0.02	0.16	0.09	0.06	0.03
SM1975	4	0.01	0.31	0.12	0.13	0.06
R1973	4	0.04	0.49	0.19	0.20	0.10
RK1972	4	0.02	0.47	0.24	0.20	0.10
XM1976	4	0.08	0.19	0.15	0.05	0.04
T1978	4	0.01	0.29	0.14	0.12	0.06
Total	32	0.01	0.49	0.16	0.13	0.02

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RADIATION DOSE READING FOR THYROID DURING INTERNAL FIXATION OF THE FEMUR

Orthopaedic registrar code	TLDs reading in mSv			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.29	0.24	0.14	0.22
K1971	0.03	0.22	0.2	0.58
M1974	0.19	0.01	0.04	0.01
SM1975	0.15	0.01	0.31	0.25
R1973	0.59	0.08	0.28	0.2
RK1972	0.17	0.15	0.39	0.2
XM1976	0.33	0.20	0.65	0.35
T1978	0.10	0.17	0.82	0.39

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE THYROID DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Registrar code	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviations	Std. Error
Jk1970	4	0.14	0.29	0.22	0.06	0.03
K1971	4	0.03	0.58	0.28	0.23	0.11
M1974	4	0.01	0.19	0.06	0.09	0.04
SM1975	4	0.01	0.31	0.18	0.13	0.06
R1973	4	0.08	0.59	0.29	0.22	0.10
RK1972	4	0.15	0.39	0.23	0.11	0.06
XM1976	4	0.20	0.65	0.38	0.19	0.10
T1978	4	0.10	0.82	0.37	0.32	0.16
Total	32	0.01	0.82	0.25	0.19	0.04

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RADIATION DOSE READING FOR THYROID DURING INTERNAL FIXATION OF THE TIBIA

Orthopaedic registrar code	TLDs reading in mSv			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.08	0.11	0.49	0.52
K1971	0.06	0.11	0.11	0.05
M1974	0.04	0.08	0.16	0.11
SM1975	0.07	0.23	0.32	0.85
R1973	0.06	0.77	0.01	0.06
RK1972	0.08	0.13	0.47	0.07
XM1976	0.08	0.09	0.12	0.17
T1978	0.08	0.32	0.08	0.1

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE THYROID DURING INTERNAL FIXATION OF THE TIBIA (PER REGISTRAR)

Registrar code	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviations	Std. Error
Jk1970	4	0.08	0.52	0.30	0.24	0.11
K1971	4	0.05	0.11	0.08	0.03	0.02
M1974	4	0.04	0.16	0.10	0.05	0.03
SM1975	4	0.07	0.85	0.37	0.34	0.16
R1973	4	0.01	0.77	0.23	0.36	0.18
RK1972	4	0.07	0.47	0.19	0.19	0.10
XM1976	4	0.08	0.17	0.12	0.04	0.02
T1978	4	0.08	0.32	0.15	0.12	0.06
Total	32	0.01	0.85	0.19	0.21	0.04

APPENDIX G

Calculation of the whole body dose from thyroid badges:
Thyroid reading x weight factor (0.05) (Sweetlove, et al. 1996)
(As recommended by the NCPR 122)

Neck of femur

Registrars	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose
Jk1970	0.33	0.017	0.21	0.011	0.04	0.002	0.08	0.004
K1971	0.14	0.007	0.02	0.001	0.26	0.013	0.23	0.012
M1974	0.1	0.005	0.06	0.003	0.02	0.001	0.16	0.008
SM1975	0.31	0.016	0.09	0.005	0.08	0.004	0.01	0.001
R1973	0.04	0.002	0.1	0.005	0.49	0.025	0.14	0.007
RK1972	0.02	0.001	0.13	0.007	0.33	0.017	0.47	0.024
XM1976	0.08	0.004	0.19	0.010	0.17	0.009	0.16	0.008
T1978	0.01	0.001	0.15	0.008	0.29	0.015	0.11	0.006

Femur

Registrars	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose
Jk1970	0.29	0.015	0.24	0.012	0.14	0.007	0.22	0.011
K1971	0.03	0.002	0.22	0.011	0.2	0.010	0.58	0.029
M1974	0.19	0.010	0.01	0.001	0.04	0.002	0.01	0.001
SM1975	0.15	0.008	0.01	0.001	0.31	0.016	0.25	0.013
R1973	0.59	0.030	0.08	0.004	0.28	0.014	0.2	0.010
RK1972	0.17	0.009	0.15	0.008	0.39	0.020	0.2	0.010
XM1976	0.33	0.017	0.2	0.010	0.65	0.033	0.35	0.018
T1978	0.1	0.005	0.17	0.009	0.82	0.041	0.39	0.020

Tibia

Registrars	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose	Thyroid dose	Whole body dose
Jk1970	0.08	0.004	0.11	0.006	0.49	0.025	0.52	0.026
K1971	0.06	0.003	0.11	0.006	0.11	0.006	0.05	0.003
M1974	0.04	0.002	0.08	0.004	0.16	0.008	0.11	0.006
SM1975	0.07	0.004	0.23	0.012	0.32	0.016	0.85	0.043
R1973	0.06	0.003	0.77	0.039	0.01	0.001	0.06	0.003
RK1972	0.08	0.004	0.13	0.007	0.47	0.024	0.07	0.004
XM1976	0.08	0.004	0.09	0.005	0.12	0.006	0.17	0.009
T1978	0.08	0.004	0.32	0.016	0.08	0.004	0.1	0.005

RADIATION DOSE READING FOR THE WHOLE BODY DURING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Registrars	Effective dose (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.017	0.011	0.002	0.004
K1971	0.007	0.001	0.013	0.012
M1974	0.005	0.003	0.001	0.008
SM1975	0.016	0.005	0.004	0.001
R1973	0.002	0.005	0.025	0.007
RK1972	0.001	0.007	0.017	0.024
XM1976	0.004	0.010	0.009	0.008
T1978	0.001	0.008	0.015	0.006

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE WHOLE BODY DURING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Registrars code	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviations	Std. Error
Jk1970	4	.002	.017	0.008	0.007	0.003
K1971	4	.001	.013	0.008	0.005	0.003
M1974	4	.001	.008	0.004	0.003	0.001
SM1975	4	.001	.016	0.007	0.007	0.003
R1973	4	.002	.025	0.010	0.01	0.005
RK1972	4	.001	.024	0.01	0.01	0.005
XM1976	4	.004	.010	0.008	0.003	0.001
T1978	4	.001	.015	0.007	0.006	0.003
Total	32	.001	.025	0.008	0.006	0.001

RADIATION DOSE READING FOR THE WHOLE BODY DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Registrars	Effective dose (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.015	0.012	0.007	0.011
K1971	0.002	0.011	0.010	0.029
M1974	0.010	0.001	0.002	0.001
SM1975	0.008	0.001	0.016	0.013
R1973	0.030	0.004	0.014	0.010
RK1972	0.009	0.008	0.020	0.010
XM1976	0.017	0.010	0.033	0.018
T1978	0.005	0.009	0.041	0.020

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE WHOLE BODY DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Registrars code	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviations	Std. Error
Jk1970	4	.007	.015	0.010	0.003	0.002
K1971	4	.002	.029	0.010	0.010	0.006
M1974	4	.001	.010	0.004	0.004	0.002
SM1975	4	.001	.016	0.009	0.007	0.003
R1973	4	.004	.030	0.010	0.010	0.006
RK1972	4	.008	.020	0.010	0.006	0.003
XM1976	4	.010	.033	0.011	0.010	0.005
T1978	4	.005	.041	0.011	0.010	0.008
Total	32	.001	.041	0.010	0.009	0.002

RADIATION DOSE READING FOR THE WHOLE BODY DURING INTERNAL FIXATION OF THE TIBIA (PER REGISTRAR)

Registrars	Effective dose (mSv)			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	0.004	0.006	0.025	0.026
K1971	0.003	0.006	0.006	0.003
M1974	0.002	0.004	0.008	0.006
SM1975	0.004	0.012	0.016	0.043
R1973	0.003	0.039	0.001	0.003
RK1972	0.004	0.007	0.024	0.004
XM1976	0.004	0.005	0.006	0.009
T1978	0.004	0.016	0.004	0.005

DURING INTERNAL FIXATION OF THE TIBIA (PER REGISTRAR)

Registrars code	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviations	Std. Error
Jk1970	4	.004	.026	0.015	0.010	0.006
K1971	4	.003	.006	0.005	0.011	0.0008
M1974	4	.002	.008	0.005	0.003	0.001
SM1975	4	.004	.043	0.011	0.002	0.008
R1973	4	.001	.039	0.011	0.002	.009
RK1972	4	.004	.024	0.009	0.010	0.005
XM1976	4	.004	.009	0.006	0.002	0.001
T1978	4	.004	.016	0.007	0.006	0.003
Total	32	.001	.043	0.010	0.010	0.002

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE WHOLE BODY DURING INTERNAL FIXATION OF THE LOWER LIMBS PER PROCEDURE (FOR EACH REGISTRAR)

Registrars code	N	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Jk1970	12	.002	.026	0.012	0.008	0.002
K1971	12	.001	.029	0.009	0.008	0.002
M1974	12	.001	.010	0.004	0.003	0.0009
SM1975	12	.001	.043	0.012	0.011	0.003
R1973	12	.001	.039	0.012	0.013	0.004
RK1972	12	.001	.024	0.011	0.008	0.002
XM1976	12	.004	.033	0.011	0.008	0.002
T1978	12	.001	.041	0.011	0.011	0.003
Total	96	0.001	0.043	0.010	0.009	0.0009

RADIATION DOSE READING FOR THE WHOLE BODY PER REGISTRAR

Orthopaedic registrar code	TLDs reading in mSv		
	1st month	2nd month	3rd month
Jk1970	0.12	0.1	0.1
K1971	0.11	0.1	0.15
M1974	0.07	0.14	.06
SM1975	0.08	0.08	0.19
R1973	0.11	0.1	0.13
RK1972	0.13	0.12	0.13
XM1976	0.09	0.13	0.06
T1978	0.09	0.09	012

DESCRIPTIVE STATISTICS FOR RADIATION DOSE TO THE WHOLE BODY PER MONTH (PER REGISTRAR)

Registrars codes	N Valid	Minimum (mSv)	Maximum (mSv)	Mean (mSv)	Std. Deviation	Std. Error
Jk1970	3	.10	.12	0.11	0.01	0.007
K1971	3	.10	.15	0.12	0.26	0.02
M1974	3	.06	.14	0.09	0.44	0.03
SM1975	3	.08	.19	0.12	0.06	0.04
R1973	3	.10	.13	0.11	0.02	0.009
RK1972	3	.12	.13	0.13	0.01	0.003
XM1976	3	.06	.13	0.09	0.04	0.02
T1978	3	.09	.12	0.10	0.02	0.01
Total	24	0.06	0.19	0.02	0.003	0.006

APPENDIX H

Hi

READING OF OPERATION PROCEDURE TIME DUTING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Orthopaedic registrar code	Time in Minutes			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	75	55	42	75
K1971	70	50	65	55
M1974	122	65	55	60
SM1975	55	45	50	80
R1973	65	65	55	50
RK1972	55	40	95	65
XM1976	110	80	50	55
T1978	45	65	45	70

READING OF SCREENING TIME DURING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Orthopaedic registrar code	Time in Minutes			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	3.01	2.07	2.02	1.52
K1971	2.01	2.07	1.55	2.04
M1974	2.12	2.59	2.44	3.05
SM1975	3.03	2.12	2.31	2.58
R1973	2.17	3.01	2.07	2.33
RK1972	2.22	3.14	3.17	3.13
XM1976	2.10	2.02	2.32	2.05
T1978	2.01	2.04	2.27	1.55

DESCRIPTIVE STATISTICS FOR OPERATION AND SCREENING TIMES DURING INTERNAL FIXATION OF THE NECK OF FEMUR (PER REGISTRAR)

Registrar code	N Valid	Time	Minimum (Min.)	Maximum (Min.)	Means (Min.)	Std. Deviation	Std. Error
Jk1970	4	Operation	42	75	62	16	8
		Screening	1.52	3.01	2.2	0.6	0.31
K1971	4	Operation	50	70	60	9	5
		Screening	1.55	2.07	1.9	0.2	0.12
M1974	4	Operation	55	122	76	31	15
		Screening	2.12	3.05	2.6	0.4	0.19
SM1975	4	Operation	45	80	58	15	8
		Screening	2.12	3.03	2.5	0.4	0.20
R1973	4	Operation	50	65	59	8	4
		Screening	2.07	3.01	2.4	0.4	0.21
RK1972	4	Operation	40	95	64	23	12
		Screening	2.22	3.17	2.9	0.5	0.23
XM1976	4	Operation	50	110	74	28	14
		Screening	2.02	2.32	2.1	0.1	0.07
T1978	4	Operation	45	70	56	13	7
		Screening	1.55	2.27	2.0	0.3	0.15
Total	32	Operation	40	122	63	19	3
		Screening	1.52	3.17	2.31	0.4	0.08

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READING OF OPERATION PROCEDURE TIME DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Orthopaedic registrar code	Time in Minutes			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	80	50	70	50
K1971	65	150	80	100
M1974	85	45	75	45
SM1975	70	70	65	110
R1973	115	85	95	70
RK1972	50	45	90	70
XM1976	155	80	115	100
T1978	80	65	100	85

READING OF SCREENING TIME DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Orthopaedic registrar code	Time in Minutes			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	3.05	2.12	2.16	4.36
K1971	3.30	4.13	3.01	7.14
M1974	3.01	2.00	2.43	2.55
SM1975	5.56	3.15	4.34	4.08
R1973	5.32	2.17	7.02	3.01
RK1972	2.44	3.28	6.02	4.00
XM1976	8.41	3.27	5.05	4.47
T1978	3.40	3.12	8.25	4.09

DESCRIPTIVE STATISTICS FOR OPERATION AND SCREENING TIMES DURING INTERNAL FIXATION OF THE FEMUR (PER REGISTRAR)

Registrars code	N Valid	Time	Minimum (Min.)	Maximum (Min.)	means (Min.)	Std. Deviation	Std. Error
Jk1970	4	Operation	50	80	63	15	7
		Screening	2.12	4.36	2.9	1.1	0.5
K1971	4	Operation	65	150	99	37	19
		Screening	3.01	7.14	4.4	1.9	0.9
M1974	4	Operation	45	85	63	21	10
		Screening	2.00	3.01	2.5	0.4	0.2
SM1975	4	Operation	65	110	79	21	10
		Screening	3.15	5.56	4.3	1.0	0.5
R1973	4	Operation	70	115	91	19	9
		Screening	2.17	7.02	4.4	2.2	1.1
RK1972	4	Operation	45	90	64	21	10
		Screening	2.44	6.02	3.9	1.5	0.8
XM1976	4	Operation	80	155	113	32	16
		Screening	3.27	8.41	3.3	2.2	1.1
T1978	4	Operation	65	100	83	14	7
		Screening	3.12	8.25	4.7	2.4	1.2
Total	32	Operation	45	155	82	27	4
		Screening	2.00	8.41	4.05	1.8	0.3

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READING OF OPERATION PROCEDURE TIME DURING INTERNAL FIXATION OF THE TIBIA (PER REGISTRAR)

Orthopaedic registrar code	Time in Minutes			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	100	110	110	70
K1971	55	140	75	90
M1974	45	78	80	60
SM1975	130	60	105	95
R1973	90	70	70	123
RK1972	40	55	95	105
XM1976	110	105	80	70
T1978	115	70	90	95

READING OF SCREENING TIME DURING INTERNAL FIXATION OF THE TIBIA (PER REGISTRAR)

Orthopaedic registrar code	Time in Minutes			
	1st procedure	2nd Procedure	3rd Procedure	4th Procedure
Jk1970	2.47	3.25	4.52	6.23
K1971	3.05	2.49	2.05	3.26
M1974	3.01	2.37	2.28	3.01
SM1975	5.46	3.47	3.02	3.05
R1973	2.03	5.02	2.44	2.43
RK1972	3.20	3.03	6.01	2.44
XM1976	5.05	4.08	3.55	3.43
T1978	3.11	3.51	3,09	4.02

DESCRIPTIVE STATISTICS FOR OPERATION AND SCREENING TIMES DURING INTERNAL FIXATION OF THE TIBIA PER (REGISTRAR)

Registrars code	N Valid	Time	Minimum (Min.)	Maximum (Min.)	Mean (Min.)	Std deviation	Std. Error
Jk1970	4	Operation	70	110	98	19	9
		Screening	2.47	6.23	4.0	1.6	0.8
K1971	4	Operation	55	140	90	36	18
		Screening	2.05	3.26	2.7	0.5	0.3
M1974	4	Operation	45	80	66	17	8
		Screening	2.28	3.01	2.7	0.4	0.2
SM1975	4	Operation	60	130	98	29	15
		Screening	3.02	5.45	3.8	1.2	0.6
R1973	4	Operation	70	123	88	25	13
		Screening	2.03	5.02	3.0	1.4	0.7
RK1972	4	Operation	40	105	74	31.2	16
		Screening	2.44	6.01	3.7	1.6	0.8
XM1976	4	Operation	70	110	91	19	10
		Screening	3.43	5.05	4.0	0.7	0.4
T1978	4	Operation	70	115	93	18	9
		Screening	3.09	4.02	3.4	0.4	0.2
Total	32	Operation	40	140	87	25	4
		Screening	2.03	6.23	3.47	1.1	0.2