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Research Title

RADIATION EXPOSURE TO SURGEON DURING SELECTED ORTHOPAEDIC PROCEDURES UNDER FLUOROSCOPIC GUIDANCE TECHNIQUE

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DEFINITION OF TERMS

absorbed dose: the amount of energy transferred from ionizing radiation to an irradiated object per unit mass. This absorbed energy is responsible for whatever biological damage occurs as a result of tissue being exposed to x-radiation.

absorbed dose equivalent: the product obtained by multiplying the absorbed dose times the quality factor. This quantity considers the biological effects of various types of radiation to humans.

anneal: part of the reading process of the thermoluminescent dosimeter where high temprature is applied to ensure all electrons have been removed from the electrons traps.

awl: an instrument used to gain entry site at the piriform fossa of a femur.

carcinogenic: any substance which causes cancer.

C-arm fluoroscope: a portable device for producing real-time image of a patient. The opposite ends of the 'c'-shaped support arm hold the X-ray tube and the image intensifier.

controlled area: an area where the annual dose received by a worker is likely to exceed three-tenths of the annual dose limit.

deterministic effects: biological responses whose severity varies with radiation dose. A dose threshold usually exists

dose: Amount of energy absorbed by an irradiated object per unit mass.

dose equivalent: radiation quantity used for radiation protection purposes that expressed dose on a common scale for all radiations.

dosimeter: Instrument for detecting and measuring exposure to ionizing radiation.

dynamic hip screw(DHS): implant which is mainly used to treat stable trochantric fracture. It allows secondary impaction of the fracture along the axis of the gliding femoral neck screw.

effective dose: sum over specified tissues of the products of the equivalent dose in a tissue and the weighting factor for that tissue.

exposure time: the time an x-ray tube is energize and a useful beam produced.

fracture table: table which can break into portion where the surgeon can easily gain excess to the operative field.

fluoroscopy: X-ray imaging in real time.

-intermittent fluoroscopy: periodic activation of the fluoroscopic tube.

-image intensifier: electronic vacuum tube that increases the brightness of a fluoroscopic image.

Gray (Gy): SI unit of absorbed dose. It is equal to 1 J of energy absorbed from any type of ionizing radiation in 1 kg of any irradiated object.

interlocking nail (ILN) of femur: a surgical procedure where a rod-like implant (nail) is inserted through the medullary cavity of the femur. The rotations of the implant is prevented by placing screws over the proximal and distal part of the implant.

irradiated: substance which is exposed to ionizing radiation.

Internal System of Unit (SI): Standard system of units base on the meter, kilogram and second adopted by all countries and used in all branches of science.

Miliampere (mA): measure of x-ray tube current.

MINT: Malaysian Institute for Nuclear Technology.

occupational exposure: radiation exposure received by radiation workers.

Rad (radiation absorbed dose): special unit for absorbed dose. 1 rad = 0.01 Gy

real time: display for which the image is continuously renewed, often to view anatomical motion, fluoroscopy and ultrasound.

Rem: Special unit for dose equivalent and effective dose. It is replaced by the sievert (Sv) in the SI system. 1 rem = 0.01 Sv

piriform fossa: a depressed area over the very proximal part of femur around the trochantric area.

Scattered radiation: X-ray that change direction after an interaction with matter.

Sievert (Sv): Special name for the SI unit of dose equivalent and effective dose.

stochastic effect: probability or frequency of a biological response to radiation as a function of radiation dose. Disease incidence increases proportionately with dose and there is no dose threshold.

thermoluminescent dosimeter (TLD): Personnel monitoring device that contain sensing material.

threshold dose: a dose below which a person has a negligible chance of sustaining a specific biological response.

wilcoxan test: a statistical test to compare two parameters if there is any significance differences.

ABSTRAK (Bahasa Malaysia)

Bilangan kaedah pembedahan otopedik yang menggunakan bantuan paparan imej fluoroscopi (image intensification fluoroscopy) telah meningkat dengan banyaknya sejak beberapa tahun yang lepas. Terdapat kesangsian tentang kemungkinan adanya kesan buruk radiasi. Dalam kajian ini, pantulan rawak radiasi ke mata, tangan dan leher doktor bedah telah diukur semasa pembedahan memasukkan implant ke tulang peha (interlocking nail and dynamic hip screw) yang memerlukan bantuan mesin fluoroscopi. Dosimeter thermoluminescent telah digunakan untuk mengukur kuantiti dose radiasi yang diterima oleh doktor semasa pembedahan tersebut.

Purata masa pendedahan radiasi atau masa di mana fluoroscopi digunakan semasa kaedah pembedahan tulang peha 'interlocking nail' dan 'dynamic hip screw' adalah 3.89 minit dan 3.03 minit. Kajian menunjukkan doctor bedah telah menerima sejumlah kesan pantulan rawak radiasi semasa pembedahan tersebut. Tangan menerima kesan pantulan rawak radiasi yang tertinggi diukuti oleh mata dan leher. Kesan pantulan rawak radiasi ini adalah rendah. Analisis data dari kajian ini menunjukkan kemungkinan adalah amat rendah untuk seseorang doctor bedah menerima lebih dari had maksimum dose radiasi tahunan yang dibenarkan sebagaimana yang telah ditetapkan oleh badan antarabangsa.

ABSTRACT

The number of orthopaedic surgical procedures using image intensification fluoroscopic assistance had increased markedly over the past few years. There are growing concerns over possible associated radiation health hazards. In this study, scattered radiation to the eye, hand and neck of the primary surgeon were measured during interlocking nail of femur and dynamic hip screw fixation under fluoroscopic guidance. Thermoluminescent dosimeter was used to quantify the dose received by the surgeon.

Mean radiation exposure time or duration that fluoroscopy was used during the procedure for interlocking nail of femur and dynamic hip screw fixation were 3.89 minutes and 3.03 minutes respectively. Study showed that the primary surgeon received certain amount of scattered radiation dose during those procedures. The hand received the highest scattered dose followed by the eye and neck. The scattered dose was small. By extrapolating these results, it is unlikely for an individual surgeon to receive more than the recommended annual dose limit as set by the international organization.

1.0 INTRODUCTION

Orthopaedic surgeons are constantly working in closed proximity to x-rays. Fluoroscopy and radiography are increasingly being used for diagnosis and as an important aid during the operative fixation of the fractures. Over the past few years, the number and variety of the procedures utilizing fluoroscopic assistance have increased markedly. The used of fluoroscopy has now become an integral and essential part of the practice of orthopaedic surgery. As this machine produced ionizing radiation, we need to be aware of the potential hazard due to the repeated exposure to the radiation.(Fuchs at al. 1998; Friend, 2002)

The development of close interlocking intramedullary nailing and dynamic hip screw have allowed the orthopaedic surgeon to treat a larger variety of diaphyseal and proximal femoral fracture safely and effectively. A variety of implants had been designed. The insertion of all these implants relied on fluoroscopic control.

The hand of the surgeon is close to operating field and may be directly exposed to ionizing radiation.(Arnstein at al. 1994) Even though protective lead gloves may be used when screening an unstable fracture during a manipulation, many surgeons find them cumbersome and often prefer not to wear them.

Exposure to radiation can be associated with a range of harmful effects such as sterility, damage to the lens of the eye, the risk of developing neoplasm and skin necrosis (Lee et al., 2003). Ionizing radiation has therefore become a serious occupational hazard for the surgeons and other theatre staff who are often ill informed on the subject and poorly trained to minimize the associated risks.(Hynes at al. 1992)

The purpose of this study was to directly measure the scattered radiation dose to the hand, thyroid and eye of a primary surgeon during interlocking intramedullary nail of femur and dynamic hip screw fixation of proximal femur fracture.

2.0 THE IMPORTANCE OF THE STUDY

Orthopaedic surgeons are frequently exposed to scattered radiation during various procedures performed under the image intensifier. Unfortunately information on how much the scattered radiation dose received by the surgeon is not known in our local setting. The surgeon seldom wears the thyroid shield to protect the thyroid gland and rarely uses lead goggles to protect the eyes.

The surgeons, residents and operation theatre staffs do not have personnel monitoring devise to measure the radiation dose unlike their colleague in radiology department. Under the Radiation Protection (Basic Safety Standard) Regulations 1988, it stated that the doses received from external exposures shall be measured by the use of one or more approved personnel monitoring devices carried continuously on every person working in the 'controlled area'. Controlled area is an area where the annual dose received by a worker is likely to exceed three-tenths of the annual dose limit.

This study therefore is important to quantify the scattered radiation doses received by the surgeon during the procedure under fluoroscopic guidance technique and to predict whether the recommended annual dose limit is likely to be exceeded.

3.0 LITERATURE REVIEW

3.1 *History*

The carcinogenic potential of ionizing radiation was recognized soon after Roentgen's discovery of X-rays in December 1895. By 1902, the first radiation-induced cancer was reported arising in an ulcerated area of the skin. Within a few years, a large number of such skin cancers had been observed, and the first report of leukemia occurring in five radiation workers appeared in 1911.

3.2 Definition of radiation

Radiation is a general term used to describe the process of emitting radiant energy in a form of waves or particles. Simply, radiation can be define as energy in transit. When the word 'radiation' is used alone it usually refers to ionizing radiation.

Ionizing radiation produces positively and negatively charged particles as it passes through matter. Source of ionizing radiation can be manmade, for example; x-ray, nuclear power and nuclear waste or it can be natural background such as cosmic rays from the sun or radioactive material from the earth crust. It can also be in a form of particles (particulate radiation) or pure energy having neither mass or charge such as electromagnetic radiation (Dowd,1994).

3.3 Radiation Unit

Four units are used to express an amount of radiation (Table 3.1). They are two types of units; traditional and SI (Systeme International). In some country, it is still customary to use the traditional units but most country used SI units.

Table 1: Radiation Units

Quantity	Traditional Unit	SI Unit
Exposure (measured in air)	Roentgen (R)	coulombus per kilogram (C/kg)
Absorbed dose	rad	gray (Gy)
Dose equivalent (occupational)	rem	sievert (Sv)

3.4 Absorbed Dose

As ionizing radiation pass through an object, some of the energy of that radiation will be transferred to the object. Some of the radiation that is transferred to the object is absorbed (i.e., stays within the object). The quantity, 'absorbed dose', is define as the amount of energy per unit mass absorbed by the irradiated object. This absorbed energy is responsible for whatever biological damage occurs as a result of tissues being exposed to radiation (Statkiewicz et al, 1993).

The rad (traditional unit) and gray; (Gy; SI unit) are used to express the absorbed dose. The fraction of radiation absorbed depends on the energy or penetrating ability of the radiation and the composition of the absorbing material. This is called the *f-factor.*

The rad can be used for any type of ionizing radiation. Patient dose is often expressed in rad or grays. One gray is equivalent to 100 rad. It represents a specific quantity of energy absorbed. The draw back in the two units lies in the fact that the biological effect of 1 rad or 1 Gy varies with the type of radiation. (Dowd, 1994).

3.5 Occupational exposure (Absorbed dose equivalent)

Absorbed dose equivalent provides a method with which to calculate the effective absorbed dose for all types of ionizing radiation, including proton and neutrons as well as x-rays. It has been found that equal absorbed doses of different types of radiation produce different amounts of biological damage in body tissue. The absorbed dose equivalent take this into consideration by using modifying or quality factor

Absorbed Dose Equivalent = Absorbed dose X Quality factor

Traditionally, the rem has been used as the unit of the absorbed dose equivalent and may be define as absorbed dose equivalent of any type of ionizing radiation that produces the "same biological effect" as one rad of x-ray. One rem of neutrons will thus represent a different absorbed dose than does one rem of alpha particles. An absorbed dose in rad may be converted to a dose equivalent by use of a quality factor for the type of radiation being considered .

Rem mean *r*adiation *e*quivalent *m*an and is a traditional unit. The SI unit is sievert (Sv). In diagnostic radiology the three basic units are considered interchangeable. 1 R = 1 rad = 1 rem = 0.01 Sv since the factor are both approximately 1 for x-ray of these energies. The sievert (Sv) is equivalent to 100 rem. It is the SI unit that produces the same biologic effect as 1 Gy of high energy. x-ray. 1 Sv is equivalent to 1000 milisievert (mSv) (Dowd, 1994).

3.6 Image Intensification Fluoroscopy

Intraoperative image intensification fluoroscopy is commonly used in surgical procedure. It is the main source of ionizing radiation to the orthopaedic surgeon (Hynes at al. 1992). Image intensification fluoroscopy has three significant benefits:

1. Increased image brightness.

2. Saving of time for the radiologist.

3. Patient dose reduction.

The x-ray image intensification system converts the x-ray image pattern into a corresponding amplified visible light pattern. Overall brightness of the fluoroscopic image increases to 7000 times the brightness of the image on a conventional fluoroscopic system operating under the same conditions. This image brightness increase permits the radiologist increased perception of the fluoroscopic image.

Because an image intensification system permits viewing of the fluoroscopic image at ordinary brightness level (regular white light), the radiologist uses photopic or cone vision when viewing the image through this system. Because cone vision can be used, the radiologist does not need to go through the process of darkness adaptation; this saves time. Cone vision also considerably improves visual acuity, permitting the radiologist to better discriminate between small fluoroscopic images.

Because an image intensification system significantly increases brightness, image intensification fluoroscopy requires less milliamperage than does conventional fluoroscopy (about 1.5 to 2 mA is required for image intensification systems, whereas 3 to 5 mA is required for conventional fluoroscopy). The consequent decrease in exposure rate results in a reduction in dose for the patient.

3.6.1 Intermittent fluoroscopy

The practice of intermittent fluoroscopy (periodical activation of the fluoroscopic tube by the radiologist rather than lengthy, continuous activation) significantly decreases patient's dose, especially in long procedures, and helps to extend the life of the tube. Many systems include a "last-image-hold" feature that allows the radiologist to see the most recent image without exposing the patient to another pulse of radiation. This kind of fluoroscopy is commonly used in orthopaedic practice.

3.6.2 Limitation of the size of the fluoroscopic field

The radiologist must limit the size of the fluoroscopic field to include only the area of clinical interest by properly collimating the x-ray beam by adjusting the lead shutters placed between the fluoroscopic tube and the patient. When fluoroscopic field size is limited, patient dose decreases substantially.

Both primary beam length and width need to be confined within the image receptor boundary. Irrespective of the distance from the x-ray source to the image receptor, the useful beam should not extend outside the image receptor.

3.6.3 Filtration

The function of a filter in fluoroscopy as in radiographic procedures is to reduce the patient's skin dose. Adequate layers of aluminum-equivalent material placed in the path of the useful beam remove the more harmful lower energy photons from the beam by absorbing them. A minimum of 2.5 mm total aluminum-equivalent filtration must be permanently installed in the path of the useful beam of the fluoroscopic unit. With image intensification systems, a total aluminum-equivalent filtration of 3.0 mm may be preferred. Patient dose decreases by one fourth during fluoroscopic procedures when aluminum filtration increases from 1 mm aluminum to 3 mm aluminum.

3.6.4 Source-to-tabletop distance

The source-to-tabletop distance must be not less than 15 inches (38 cm) for fixed fluoroscopes and not less than 12 inches (30 cm) for mobile fluoroscopes. This ensures, as previously discussed (see p. 181), that the entrance surface of the patient does not receive excessive exposure. This reduces the exposure of the patient as well as that of the radiographer.

3.6.5 Cumulative timing device

A cumulative timer must be provided and used with each fluoroscopic unit. This device times the x-ray exposure and sounds an audible alarm after the fluoroscope has been activated for 5 minutes. It makes the radiologist aware of the length of time for which the patient receives exposure during each procedure and enables the staff radiographer to determine patient exposure for each fluoroscopic examination. When the fluoroscope is activated for shorter periods of time, the patient and the radiologist and radiographer receive less exposure.

3.6.6 C-arm fluoroscopy

C-arm fluoroscopes are frequently used in the operating room for orthopedic procedures (e.g., pinning of a fractured hip). This piece of equipment can be manipulated in almost any position and can be in an energized state for long periods of time to accommodate the surgeon during the procedure. Personnel routinely operating a C-arm fluoroscope or those who are in the immediate area of the unit should wear a protective apron. This garment should be 0.5 mm lead equivalent to ensure adequate protection. Appropriate monitoring of personnel normally involved in C-arm fluoroscopic procedures should be a routine procedure (Statkiewicz et al.,1993).

3.7 Detection Instruments

Radiation is not detectable by ordinary means that is, we cannot see, hear or feel it. The detection of radiation requires instruments specifically designed to detect ionizing radiation. This is done indirectly by measuring the effect radiation has on medium such as air (ionization) or film (density).

Dosimetry is the determination by scientific methods of the amount, rate and distribution of radiation emitted from a source of ionizing radiation. A dosimeter is a device used to detect and measure exposure to radiation. In radiation therapy, a dosimetrist is an individual who plans an optimal radiation treatment dosage pattern. There are two general classes of instruments used to detect ionizing radiation. They are field survey instruments and personal monitors.

There are three basic types of personnel monitors: film badges, thermoluminescent dosimeters and pocket ionization chambers. The desirable characteristics of personnel monitoring devices are (1) portability; (2) ability to withstand stress; (3) sensitivity; (4) reliability and (5) low cost. Each of these criteria must be evaluated when deciding which personnel monitoring system is to be used. In general monitoring is performed in any situation in which an individual is expected to receive 10% of the Effective Dose Equivalent (formally called MPD or maximum permissible dose) (Dowd, 1994).

3.7.1 Thermoluminescent Dosimeters (TLD)

TLD can provide accurate and precise measurement for both patient and personnel dosimetry in the medical imaging environment. (*Health Phys* 1990 Dec;59 (6):827-36) TLD materials are supplied in powder form and solid discs, rods and chips. This light-free device most often contains a crystalline form (powder or small chips) of lithium fluoride, which functions as the sensing material of the TLD.

Ionizing radiation causes the lithium fluoride crystals in the TLD to undergo changes in some of their physical properties. When irradiated, some of the electrons in the crystalline lattice structure absorb energy and are "excited" to higher energy levels or bands. The presence of impurities in the crystal causes these electrons to become trapped within these bands. When the lithium fluoride crystals are passed through a special heating process, these trapped electrons receive enough energy to rise above their present locations into a region called the conduction band. From here, the electrons can return to their original or normal state with the emission of energy in the form of visible light. The intensity of the light is proportional to the amount of radiation that interacted with the crystals. A device called a TLD analyzer (Fig. 9-9) measures the amount of ionizing radiation to which a TLD badge has been exposed by first heating the crystals to free the trapped, highly energized electrons and then recording the amount of light emitted by the crystals (which is proportional to the TLD badge exposure).

3.7.1.1 Reading Process

Read out of dose is achieved using specialized instrumentation. The TLD material is heated either by direct contact with a heated tray or by hot gas. The heating cycle is divided into a series of stages.

Pre read: A low temperature is applied to the TLD to fade any low temperature traps.

Read: A higher temperature is applied to the TLD material to liberate the electrons caught in the electrical traps and release light for collection and measurement.

Anneal: A high temperature is applied to ensure that all electrons have been removed from the electrons traps. This process sets the sensitivity of the TLD and therefore it is important that batches of TLDs are annealed together. Separate annealing ovens are often used for this purpose.

The TLD is finally allowed to cool. The exact temperature and length of each part of the cycle is determined by the TLD phosphor used. Light emitted by the TLD material is measured using a photomultiplier, which converts the light into a current signal which is then amplified and displayed. It should be noted that the read out count is dependant on the temperature and duration of the annealing cycle and the section of the glow curve sampled during read out. It is essential, therefore, that both of these are predetermined and fixed for any particular batch of TLDs used.

3.7.1.2 Advantages

Among the advantages are that the TLD is re-usable. Automated read out is also available. It is capable of measuring over a wide range of doses. Small physical size make it possible to place almost anywhere.

The thermoluminescent dosimeter has several advantages over the film badge. The lithium fluoride crystals interact with ionizing radiation as human tissue does; hence this monitor determines dose more accurately. Exposure 5 mR can be measured with precision. Humidity, pressure, and normal temperature changes do not affect the TLD. Unlike the film in the film badge, which can fog if worn for more than 1 month, the TLD may be worn for as long as 3 months. After the TLD reading has been obtained, the crystals can be reused. This makes the device somewhat cost-effective, even though the initial cost is high (approximately twice the cost of a film badge service).

3.7.1.3 Limitations

The TLD has few limitations. Immediate read out is not possible. The precision can be affected by poor handling and storage. Fading can occur , i.e. the unintentional release of trapped electrons in a thermolumnescent material prior to read out. Fading may be caused by exposure to heat (thermal fading), or light, particularly ultraviolet (optical fading.) For this reason TLD materials should be stored away from strong light or heat sources.

Light emission is related to the total mass of phosphor present and therefore any loss of mass or scratches on the surface of the TLD will affect the light emission characteristics. Contamination of the TLD material with grease or adhesives used to secure the device to a patient will affect precision. For this reason it is important not to handle TLDs directly and to use vacuum rather than mechanical tweezers.

3.7 Biological Effect of Ionizing Radiation

Ionizing radiation produces damage in living systems by ionizing the atoms composing the molecular structures of these systems. An ionized atom will not bond properly into the molecules necessary for the normal functioning of an organism.

The universal nature of radiation as a carcinogen relates to a specific characteristic of ionizing radiation that differentiates it from chemical toxic agents or other physical carcinogens, which are usually tissue specific in their action. This is its ability to penetrate cells and to deposit energy within them in a random fashion, unaffected by the usual cellular barriers presented to chemical agents. All cells in the body are thus susceptible to damage by ionizing radiation; the amount of damage will be related to the physical parameters that determine the radiation dose received by the particular cells or tissue (John B Little, 2000).

Radiation to the eye can induce cataract. Evidences come from the lab experiment on mice and observation group of people who accidently received substantial doses of radiation to the eyes. Thyroid carcinoma can occur as a late effect of radiation especially in children. There are also reports that ionizing radiation result in skin necrosis (Jin et al,2003).

Human response to radiation exposure are classified as either early effects which are termed *deterministic effects* and late effect also known as *stochastic effects.* (Bushong; 1998)

3.8.1 Stochastic effects

The term stochastic literally means "random in nature." This is also called the statistical response, which means that the probability of occurrence of effects increases in proportion to radiation dose of the entire population. It is assumed that stochastic effects do not exhibit a threshold. They are associated with the linear and the non-linear quadratic dose-response curves.

An analogy that may be helpful to remember this concept is investing money. If this money (radiation dose) is invested in the lottery, there is only a small chance that any return will be seen. There is no threshold in that someone or some amount of people will receive a payoff (have a radiation effect). As the amount of money invested increases, the individuals investing that money have a greater (though still remote) chance of winning, and the overall cash pot (number of effects) increases.

Thus, a stochastic effect, especially at diagnostic levels where doses are low, puts the odds heavily in one's favor that no effect will occur. An unlucky few (who cannot be predicted because it is random chance) will experience an effect. Radiation risks from diagnostic imaging, with the exception of in utero exposure of a viable fetus, are considered to be stochastic. Heredity effects and carcinogenesis are considered to be stochastic.

3.8.2 Deterministic Effect

Non-stochastic effects increase in severity with dose and a threshold is assumed. In 1991 the ICRP recommended using the term deterministic rather than non-stochastic. They are also sometimes called certainty effects because at high doses such as in radiotherapy, it is assumed that certain effects will occur, such as skin erythema or cataracts. They are associated with the sigmoid dose-response curve.

Our investment analogy holds here also. Here, the money would be invested in a savings account, and we are certain of some kind of return, unless the amount Invested is too low (threshold). Most banks, for example, would not accept a deposit of 50 cents to open an interest-bearing account. Thus, below a certain amount, no effect would occur.

Cataract induction, nonmalignant damage to skin, hematologic deficiences, and impairment to fertility are considered nonstochastic effects. The dose must be high enough to begin the effect, at which point the probability of an effect occurring is fairly high. (Statkiewicz et al.,1993).

3.9 Protective Devices

Protective lead aprons and gloves should be used whenever the person involved *cannot* remain behind a protective lead barrier during an exposure. If the peak energy of the x-ray beam is 100 kVp, a protective lead (Pb) apron must be equivalent to a 0.25 mi-n thickness of lead. A lead apron of 0.5 or 1 mm lead equivalent would afford greater protection. All three of these thickness are available for protective apparel. However, the 0.5 mm lead equivalent is the *most* widely used thickness in diagnostic radiology. During fluoroscopic examinations, the radiographer should always wear a protective apron. Protective lead gloves of a minimum of 0.25 min lead equivalent should be worn whenever the hands must be protected from the beam.

Because there is usually no protective barrier (i.e., control booth or moveable shield) present, lead aprons must be worn by radiographers during fluoroscopic and mobile radiographic procedures. For the latter the 6 foot long exposure cord, when fully extended, affords a significantly reduced exposure level because of the inverse square law.

A neck and thyroid shield of 0.5 mm lead equivalent can protect the thyroid area of occupationally exposed people during general fluoroscopy and x-ray special procedures.

Scatter radiation to the lens of the eyes of diagnostic radiology personnel can be substantially reduced by wearing protective eyeglasses with optically clear lenses that contain a minimum lead equivalent protection of 0.35 mm. Side shields on the protective glasses are also available for procedures that require turning of the head.

3.10 Recommended Radiation Dose Limit

In early twentieth century radiation dose limits were call tolerance doses. Then from 1940 to1990 radiation dose limits were known as maximum permissible dose. Currently occupational radiation dose limits are referred to simply as recommended dose limits. It is express as **effective dose** (E). Recommended dose limit for radiation workers are set at a risk level comparable to that for workers in other industrial. For the general public they are set at a risk level comparable to those experienced by the public under other similar circumstances.

Recommended dose limit are based on both stochastic and deterministic effects. A stochastic radiation response is one in which the probability of occurrence increases with increasing effective dose. This response is an all-or-nothing response. A deterministic radiation response increases in severity with increasing effective dose. It does not occur below the dose threshold. Recommended dose limit are all below the threshold value for deterministic radiation response. Much higher radiation doses are required for deterministic response then for stochastic responses.

The recommended annual dose limit for the lens of the eye is 150 mSv (15,000 mrem). For the extremities as well as thyroid the recommended dose are 500 mSv (50,000 mrem) (National Council on Radiation Protection and Measurements Report 91, 1987). Regardless of recommended dose limits radiation protection practices should be geared to implement ALARA i.e maintain dose as low as reasonably achievable. (Bushong., *1998)*

3.11 Principal of ALARA and Organizations That Derive Standard

As a long term potential risks of radiation have become known, radiation protection standards has focused on minimizing the potential long and short term effects. Today radiation protection programs are base on a simple philosophy that is to maintain exposures of patient, general public and personnel as low as reasonably achievable (ALARA). ALARA assumes that the relationship between dose and risk is strictly linear and without threshold. Although this may be an overly conservative model, it is desirable to overestimate rather than underestimate the risk.

Many organizations contribute to radiation protection standards. Some report on scientific research into radiation and its effects, some make recommendations for standards. The major players in this arena are Internasional Commission on Radiological Protection (ICRP), National Council on Radiological Protection (NCRP), Conference of Radiation Control Program Directors (CRCPD) and the National Research Council Committee on the Biological Effects of Ionizing Radiation (BEIR).

3.12 Interlocking Nail of Femur

Interlocking nails are used when the location or comminution of the fracture site will lead to either shortening or malrotation. Fractures proximal or distal to the diaphysis of the femur are treated with interlocking nails since the nail does not achieve a snug fit in the intramedullary canal on both sides of the fracture line. Insertion of this implant require fluoroscopic image to be taken during the procedure.

Interlocking fixation is described as being either static or dynamic. Static nailing refers to interlocking bolts placed at both the proximal and distal ends of the nail. Dynamic interlocking place bolts at only one end of the nail, proximal or distal, depending on the fracture pattern. Static interlocking provides axial stability, in contrast to dynamic interlocking, which relies on coaptation of the fracture site to prevent shortening.

Dynamic interlocking is most frequently used for fractures that extend outside the diaphysis of the femur into the proximal or distal metaphysis, but only when the fracture site has axial stability.

3.12.1 Surgical Technique

After the patient is positioned on the fracture table and before surgical draping, the surgeon confirms that a closed reduction can be achieved. In addition to verifying fracture reduction, the fluoroscopic C-arm is used to ensure that AP and lateral views of the femur can be obtained. Correct imaging of the proximal and distal ends of the femur is necessary for the insertion of interlocking bolts. Failure to obtain a closed reduction prior to starting surgery risks intra operative difficulties in obtaining a reduction and passing guide wires. When these steps are completed prior to starting surgery, it is much easier to adjust the fracture table. The C-arm verifies that the length, angulations, and fracture site translation have been corrected by manipulations of the fracture table.

The skin incision begins about 2 cm distal to the greater trochanter and extends proximally, in line with the gluteus maximus muscle fibers. The postero superior aspect of the spine can be used as a proximal landmark. An incision of 6 to 10 cm is usually sufficient. A sharp scalpel dissection is made through the skin and subcutaneous layers and carefully through the gluteus maximus fascia. The gluteus maximus fibers are gently divided in line with their direction to gain access to the posterior border of the gluteus medius. An retractor placed beneath the gluteus medius allows palpation of the underlying short external rotators and greater trochanter with the fingertip. The piriform tendon is palpated and followed to its insertion site. This identifies the piriform fossa, which is above the medullary canal of the femur and is the insertion site for the intramedullary nail. Correct identification of the piriform fossa is essential.

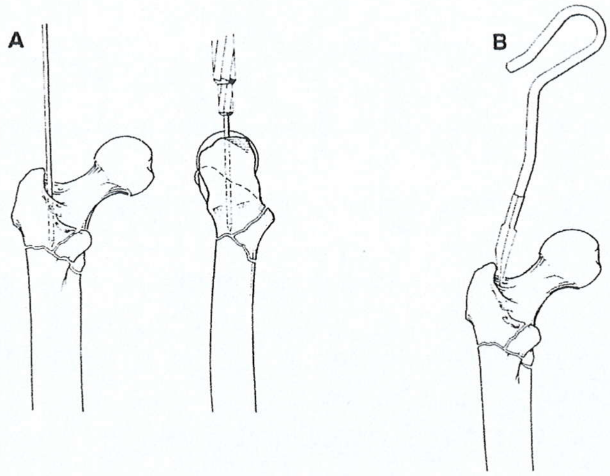

Figure 2: A: Identification and insertion of a guide pin in the piriform fossa. B: An awl is used to gain an entry site at the piriform fossa. (Adapted from Ramon B. Gustilo et al. (1993); *Fracture and Dislocation*; Vol 2, pg. 869. Mosby – Year Book, Inc.)

Next, a fingertip is used to place either a small T-handled reamer or a Kfintscher awl in the piriform fossa and aim the instrument in line with the femoral shaft (Fig 2). The position of the starting point can be checked with the fluoroscope. The T-handled reamer is inserted into the level of the lesser trochanter, and its position is verified in the AP and lateral planes by fluoroscopy. The T-handled reamer must be kept parallel to the axis of the femoral shaft as it is inserted.

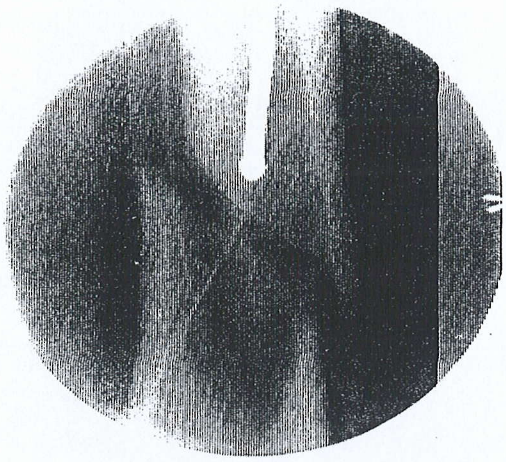

Figure 3: Fluoroscopic image of the ball-tipped guide wire just proximal to fracture site. (Adapted from Ramon B. Gustilo et al. (1993); *Fracture and Dislocation*; Vol 2, pg. 872. Mosby – Year Book, Inc.)

Next, the T-handled reamer is exchanged with a ball-tipped guide-wire. If the fracture site is reduced, it is easy to pass the guide-wire across the fracture site. The fracture site must be seen in both planes of fluoroscopy before attempts are made to place the ball tip across the fracture site (Fig 3). When the ball tip cannot be directly passed across the fracture site, several tricks are, helpful: (1) the tip of the guide wire is bent to direct the ball tip in a second plane, or (2) the proximal end of the femur is over reamed and a small straight nail inserted over the guide pin (usually a 10-mm straight nail works best). The nail is used to manipulate the proximal fragment, reduce the fracture site, and pass the guide-wire across the fracture (Fig 4). The guide-wire must not be passed across the fracture site until the fracture site is reduced on both the AP and lateral fluoroscopic images. The guide wire is then passed to the epiphyseal scar of the distal end of the femur.

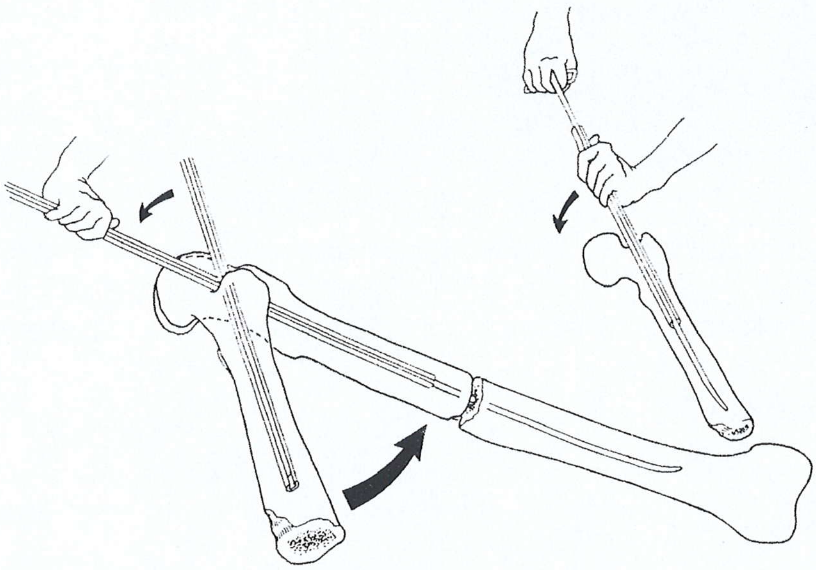

Figure 4: A small intramedullary nail is used to manipulate the proximal fragment, and the guide-wire is passed through the nail. (Adapted from Chapman MW; *Contemporary Orthop* 1982; 4.)

3.12.2 *Insertion of distal interlocking bolts*

Insertion of distal interlocking bolts is difficult. A variety of targeting devices (C-arm mounted. proximal nail mounted, and ultrasound directed) are available, but none have received wide clinical use. Most surgeons prefer different variations of the freehand technique. This method requires that the image intensifier be used to get a perfect lateral image of the distal interlocking holes within the nail (Figure 5)

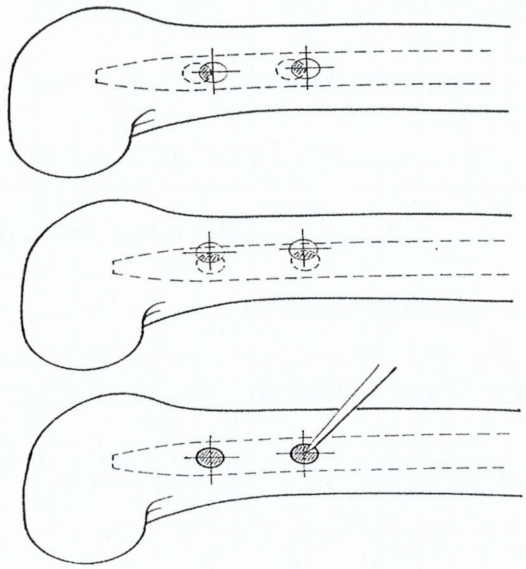

Figure 5: Diagram depict image obtained when projecting the holes for distal locking. The image intensifier fluoroscopy is manipulated until a perfect image is seen as in the bottom diagram. (Adapted from Ramon B. Gustilo et al. (1993); *Fracture and Dislocation*; Vol 2, pg. 873. Mosby – Year Book, Inc.)

For freehand insertion of the distal interlocking bolts, the C-arm is adjusted until the lateral image shows a perfectly round hole. This identifies an area over the lateral aspect of the femur where a small incision is made. This incision should be carried to bone, with slight retraction of the soft tissues so that they do not interfere with subsequent insertion of the interlocking bolts. Next, a Stemmann. pin, Kirschner wire, or drill bit is placed in the center of the hole, and the surgeon then moves this device parallel to the beam of the image intensifier. With perfect placement, the outer cortex is penetrated, the device crosses the nail, and the media] cortex can then be drilled. Unfortunately, minimal errors in position result in misdrilled tracts and malpositioned screws. The technique must be meticulously performed and can become tedious. Once the drill tract is measured, appropriate-length bolts are inserted. After the bolts are inserted, the C-arm should be rotated to ensure that the screw was successfully placed through the nail. The recent development of radiolucent drills is another modification of the freehand technique. With a radiolucent drill, it is possible to obtain direct images of the drill bit and center the bit as it is directed through the nail.

It must be remembered that to place the distal bolts, a true lateral image of the holes in the interlocking nail must be obtained. Improper rotation of the nail and faulty positioning of the C-arm relative to the leg usually make bolt insertion a frustrating experience (Gustilo et al., 1993).

3.13 Dynamic Hip Screw

The dynamic hip screw can be used in fracture neck, trochantric and subtrochantric of the femur. In the fracture neck or trochantric of the femur, it allows secondary impaction of the fracture along the axis of the gliding femoral neck screw, which must be placed in the center of the femoral head. A position in the superior quadrant may lead to failure by pull out, particularly in osteoporotic bone. To avoid malposition of DHS, correct placement of guide wire is essential and has to be checked carefully in two planes using fluoroscopy (Ruedi et al.,2000). Fluoroscopy therefore is essential in this procedure as the implant has to be precisely fixed to the bone.

4.0 OBJECTIVES OF THE STUDY

General objective of the study is to quantify the scattered radiation to which the primary surgeon is exposed during interlocking nail of femur and dynamic hip screw.

The specific objectives:

1) To find the mean duration of radiation exposure or duration of image intensification fluoroscopy being used during the following surgical procedures:

I Interlocking nail of femur.

II Dynamic Hip Screw of proximal femur fracture.

2) To study the amount of scattered radiation dose to eye, hand and neck of the primary surgeon during those procedures.

3) To study if there is possibility that the scattered radiation dose to the surgeon's hand, neck and eye will exceed the recommended annual dose limit to those area for occupational exposure set by the National Council on Radiological Protection (NCRP).

5.0 METHODOLOGY

In this study the scattered radiation dose to hands, neck and eyes of the primary surgeon during interlocking nail and dynamic hip screw fixation of femur under fluoroscopic guidance were quantified. The duration of fluoroscopy being used (duration of radiation exposure) in each of these procedures was measured directly from the fluoroscopic machine.

The scattered dose to the primary surgeon was quantified using a thermoluminescent dosimeter chip (TLD). These monitoring devices were prepared in Malaysian Institute For Nuclear Technology where they were calibrated and the reading was set to zero before they could be used in this study.

5.1 Selection Criteria

Patients that were admitted to Hospital USM from January 2003 until August 2003 who required interlocking nail of the femur or dynamic hip screw for fracture proximal femur were analyzed.

Inclusion criteria are as follow:

1. All orthopaedic surgeons who performed the procedures from January 2003 until August 2003.
2. Interlocking nail of femur or dynamic hip screw of proximal femur. Only interlocking nail of femur and dynamic hip screw fixation were included because they required prolonged usage of fluoroscopy.

3. The procedures were for primary fixation of fracture of the femur.

Exclusion criteria:

1. Prophylactic fixation. This was a relatively short procedure and did not involve fracture reduction.

2. Interlocking nail other than the femur eg humerus and tibia. They were excluded because the procedure was uncommon and it required lesser fluoroscopic time.

3. Procedure that involved nail exchange. This was excluded as it was not a primary procedure.

4. Nailing which do not require distal interlocking. This required less fluoroscopic time.

5.2 Radiation dose measurement

5.2.1 Scattered dose to the eye

Two TLDs were placed to the upper part of surgical mask just below the eyes. One TLD below the each eye as shown in figure 6 and 7 below.

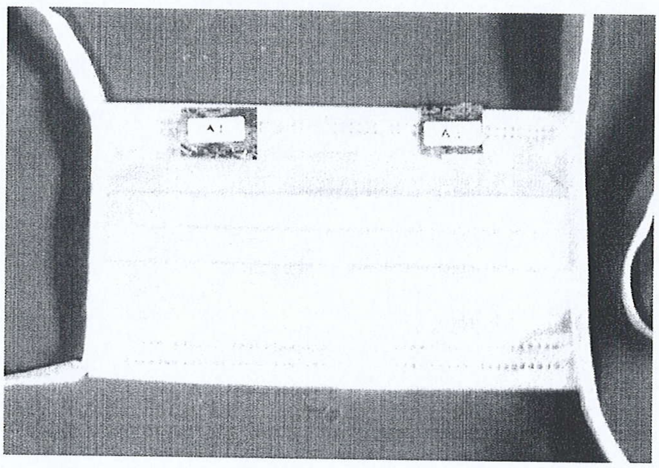

Figure 6: TLD chips wrapped with aluminum foil were placed over the upper part of the facial mask, adjacent to the right and left eye.

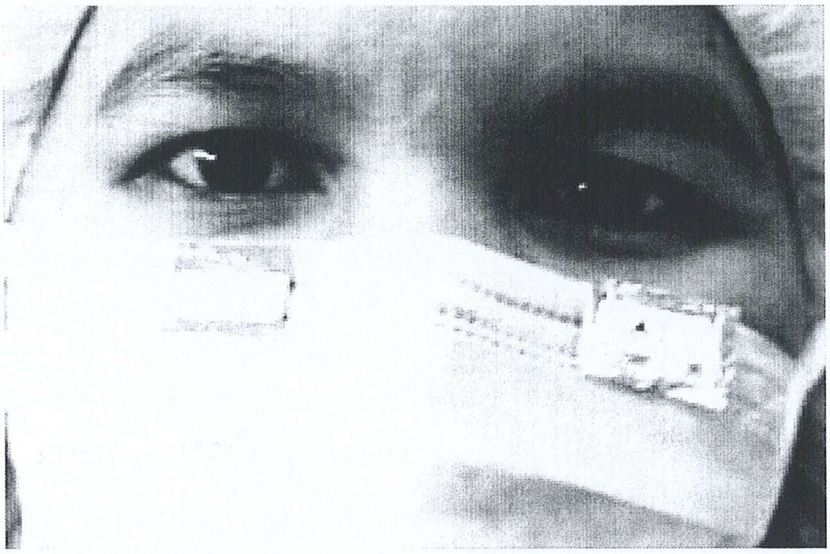

Figure 7: A surgeon wearing the facial mask with TLD chips.

5.2.2 Scattered dose to neck

Radiation dose to the neck was measured by placing the TLD chip (wrapped with aluminium foil) to the thyroid shield (0.5mm Pb equivalent). Two TLD chips were placed over the thyroid shield and another two TLD chips beneath the thyroid shield (figure 8).

Figure 8: Two TLD chips wrapped with aluminum foil are placed over the thyroid shield front.

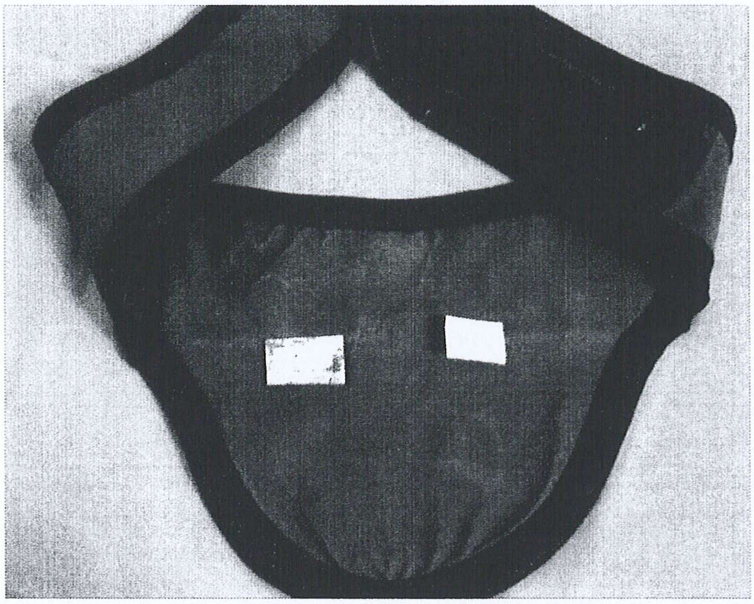

Figure 9: Two TLD chips wrapped with aluminum foil were placed on the inner side of thyroid shield.

5.2.3 Scattered dose to hand

TLD rings were used to measure radiation dose to the hands. Each ring contained one TLD chip. The TLD ring would be sterilized by standard sterilization gas (ethylene oxide). The surgeon who did the procedure wore the TLD rings. The rings were place over the middle and index finger of both right and left hands. Each ring contains one TLD chip. Figure 10 and 11 showed how the rings were placed to the fingers.

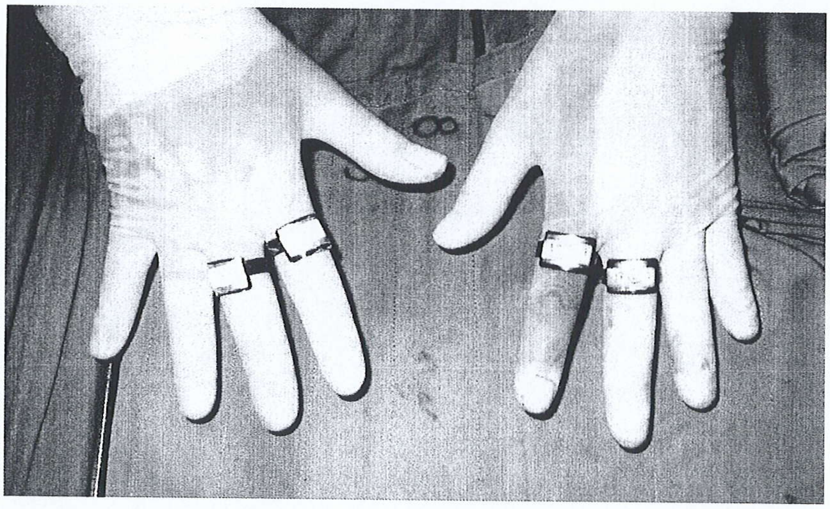

Figure 10: Sterile TLD rings worn by the surgeon after wearing the first glove.

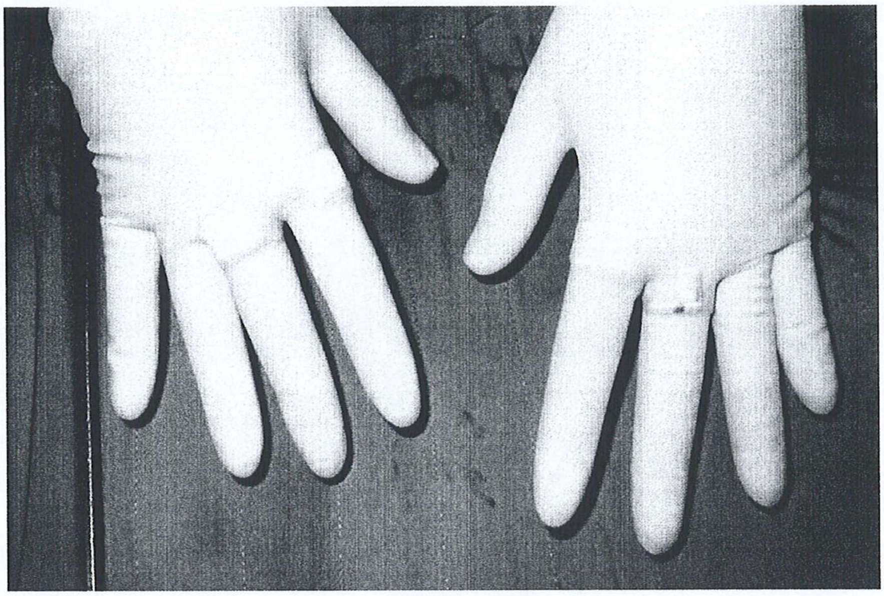

Figure 11: The TLD rings were covered by the second glove.

5.3 Technique

A control TLD chip was kept well away from the operation theatre during the procedure to avoid any scattered radiation produced by the image intensification fluoroscopy. It will only measure the background radiation dose from the environment. At the end of the procedure, these TLD chips and the control TLD chip were sent to Malaysian Institute for Nuclear Technology for analyzing process.

After the analyzing process has completed, the TLD chip reading will be reset to zero and is ready to be used again.

All the procedures were done with the patient in supine position on fracture table with traction. The C-arm of the image intensifier fluoroscopy was position between patient's lower limbs in such a way that radiation beam can remained perpendicular to the limb for both anteroposterior and lateral views. All the procedures were performed using Siemens Siremobil Compact image intensifier fluoroscopy or Stenoscop image intensifier fluoroscopy.

The surgeon experiences with these procedures varied. There was no criteria set for the selection of surgeon. Operation technique varied according to attending surgeon preference. For interlocking nail, distal interlocking screws were inserted in all cases. There was no rule to restrict surgeon movement or the surgeon's distance to the source of radiation throughout the procedure.

6.0 RESULT

During the study period from January 2003 until August 2003, there were thirteen patients who underwent interlocking nail of femur. Ten were included in the study. Seven surgeons that include orthopaedic surgeons and the residents performed this procedure. For dynamic hip screw, only three out of five number of procedure performed were included in the study as they meet the criteria. Two orthopedic residents and a surgeon performed this procedure.

6.1 Interlocking nail of femur

Table 2 showed the lengths of time the image intensification fluoroscopy being used or radiation exposure time during the procedure of interlocking nail and the average amount of scattered radiation dose to the eyes, hand and thyroid. Scattered radiation dose to eyes, hand and neck were measured and the average reading was taken.

Table 2: Radiation exposure time during interlocking nail of femur and the scattered doses to eye, hand and thyroid.

Procedure	Radiation exposure time (minutes)	Average scattered radiation dose (mSv)			
		Eye	Hand	Over thyroid shield	Beneath thyroid shield
1	2.86	0.12	0.21	0.15	0.06
2	6.15	0.18	0.36	0.06	0.04
3	1.30	0.06	0.11	0.07	0.06
4	2.10	0.03	0.19	0.02	0.01
5	6.15	0.12	0.38	0.05	0.02
6	4.20	0.14	0.38	0.13	0.03
7	3.22	0.05	0.28	0.10	0.00
8	5.33	0.08	0.23	0.06	0.02
9	5.43	0.08	0.44	0.07	0.03
10	2.38	0.02	0.14	0.03	0.02

6.1.1 Radiation exposure time

The radiation exposure time is the duration where fluoroscopy is used during the procedure. During interlocking nail of femur the average radiation exposure time per procedure was 3.89 minutes and the median was 3.71 minutes. The maximum radiation exposure time was 6.15 minutes and minimum was 1.3 minutes.

6.1.2 Scattered radiation dose to eye

The average scattered radiation dose to the eyes was 0.09 mSv per procedure or 0.02 mSv per minute. The median was 0.08 mSv. The minimum and maximum doses were 0.02 mSv and 0.18 mSv respectively. Figure 12 showed a scattered plot graft, scattered radiation to the eyes versus duration of radiation exposure.

6.1.3 Scattered radiation dose to hand

The average scattered radiation dose to the hand was 0.27 mSv per procedure or 0.07 per minute. Median was 0.26 mSv and the maximum and minimum scattered radiation dose to the hand were 0.44 mSv and 0.11 mSv. Figure 13 showed a scattered plot graph, scattered radiation to the hand versus duration of radiation exposure.

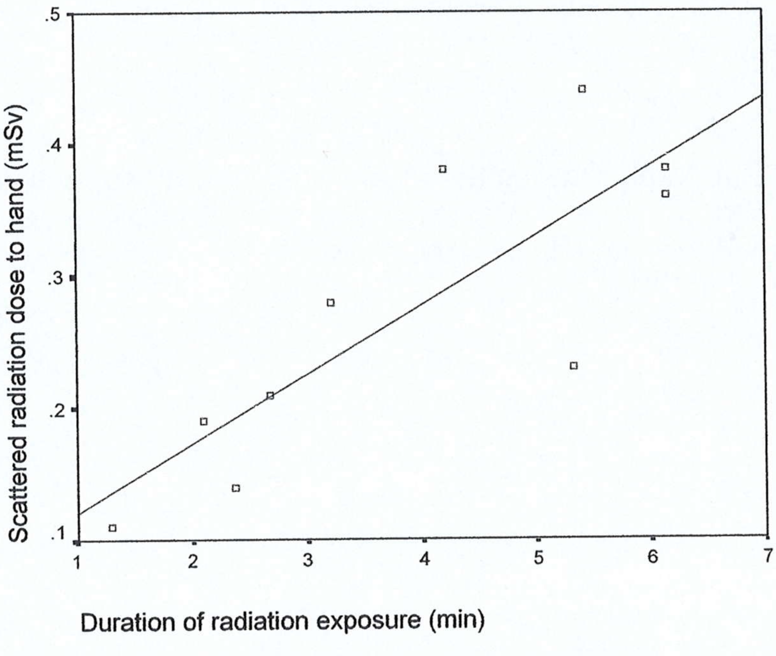

Figure 13: Scatter plot graph showing the relationship of scatter dose to the hand and the radiation exposure time during ILN.

6.1.4 Scattered radiation dose to neck

Mean scattered radiation dose to the area over the thyroid shield was 0.074 mSv per procedure or 0.019 mSv per minute of radiation exposure. The median was 0.065 mSv per procedure. With regard to the area beneath the thyroid shield, mean scattered dose was 0.0285 mSv per procedure or 0.001 per minute of radiation exposure. The median was 0.025mSv per procedure. The maximum and minimum scattered radiation doses to the area over the thyroid shield were 0.15 mSv and 0.02 mSv and those beneath the thyroid shield were 0.06 mSv and 0.00 mSv respectively. Using statistical analysis, Wilcoxon Test, there was significance different between the scattered radiation dose over and beneath the thyroid shield ($p=0.05$). Figure 14 shows a scattered plot graph, scattered radiation dose over the thyroid shield versus duration of radiation exposure.

6.2 *Dynamic hip screw*

Table 3 showed radiation exposure time or the lengths of time the image intensifier was used during the three procedures of dynamic hip screw and the scattered radiation dose to the eyes, hand and neck.

Table 3: Radiation exposure time during each of the dynamic hip screw procedure and the average scattered dose to eye, hand and neck.

Procedure	Radiation exposure time (minutes)	Average scattered radiation (mSv)			
		Eye	Hand	Over thyroid shield	Beneath thyroid shield
1	2.04	0.12	0.26	0.17	0.01
2	1.10	0.07	0.11	0.12	0.02
3	5.95	0.3	1.29	0.33	0.13

6.2.1 Radiation exposure time

The mean radiation exposure time during dynamic hip screw was 3.03 minutes per procedure and the median was 2.04 minutes. Maximum exposure time was 5.95 minutes and minimum exposure was 1.10 minutes.

6.2.2 Scattered radiation dose to eye

Mean scattered radiation dose to the eyes was 0.16 mSv per procedure or 0.05 mSv per minute of radiation exposure. The median was 0.12 mSv. Maximum and minimum exposure was 0.30 mSv and 0.07 mSv respectively. Figure 6.2a showed the scattered plot graph of radiation exposure time versus scattered radiation dose to the eye during dynamic hip screw fixation.

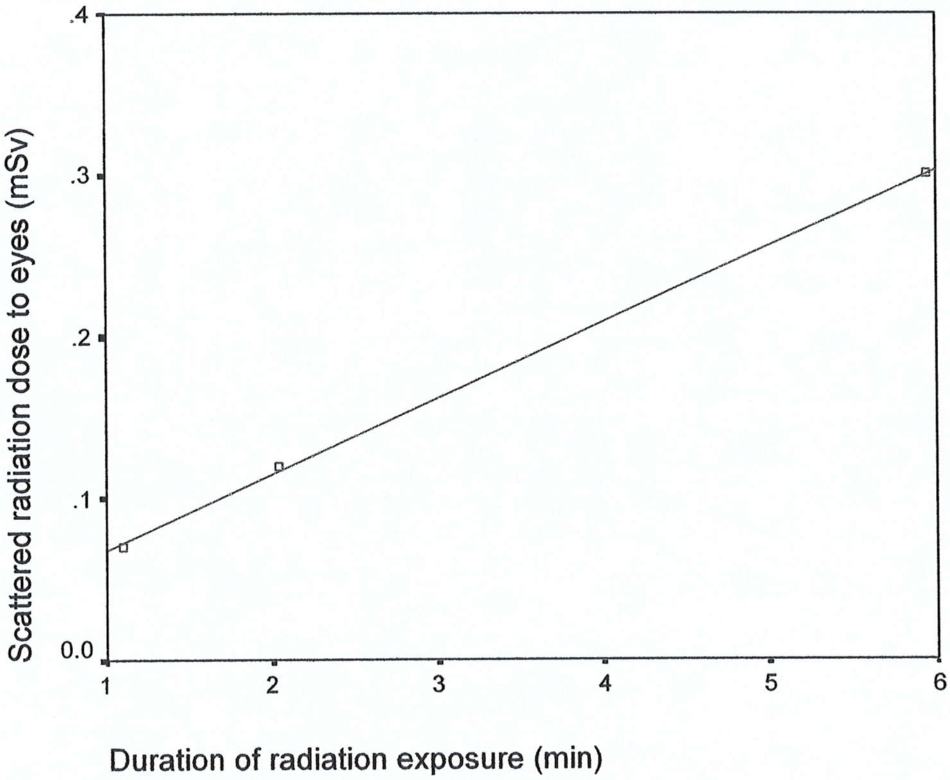

Figure 15: Scatter plot graph showing the relationship of scattered radiation dose to eye and the exposure time during DHS

6.2.3 Scattered radiation dose to hand

The mean scattered radiation dose to hand was 0.55 mSv per procedure or 0.18 mSv per minute of radiation exposure. The median was 0.26mSv. Maximum scattered radiation dose to the hand was 1.29 mSv and minimum was 0.11 mSv. Figure 16 showed scattered plot graph of scattered radiation dose to the hand versus duration of the radiation exposure.

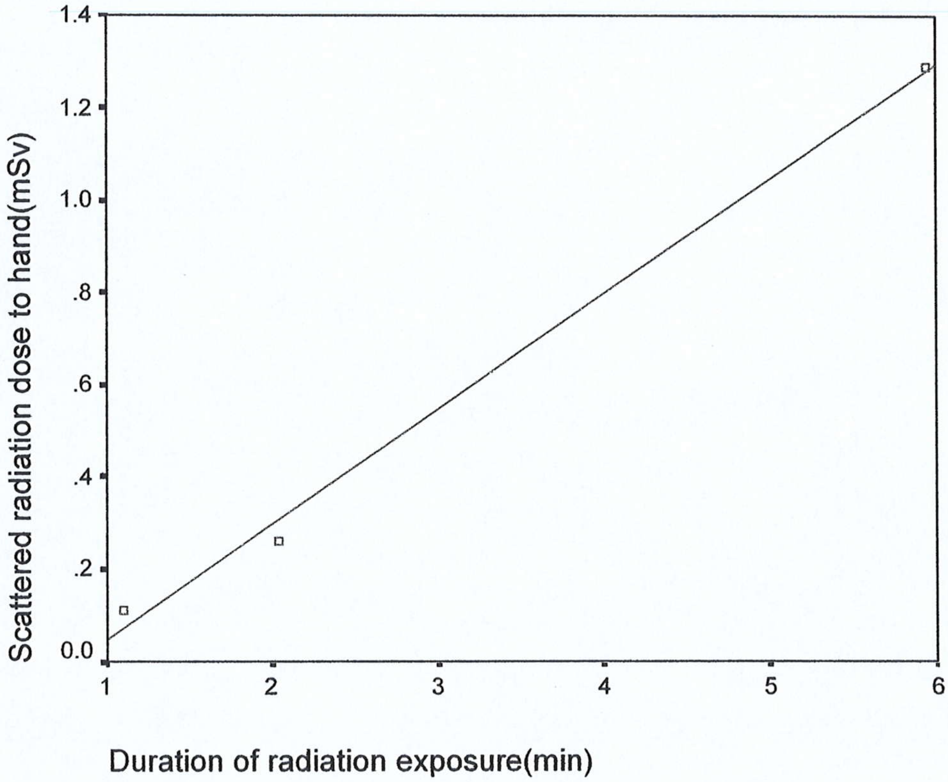

Figure 16: Scatter plot graph showing the relationship of scattered radiation dose to hand and the radiation exposure time during DHS

6.2.4 Scattered radiation dose to neck

The average scattered radiation dose to the area over the thyroid shield was 0.207 mSv per procedure or 0.023 mSv per minute of radiation exposure. The median was 0.17 mSv per procedure whereas beneath the shield the mean was 0.153 mSv per procedure or 0.016 mSv per minute with the median 0.16mSv per procedur. Figure 17 demonstrated scattered radiation dose to the area above the thyroid versus duration of exposure time.

7.0 DISCUSSION

The goal of this study is to quantify the scattered radiation dose received by the surgeon during interlocking nail (ILN) fracture femur and dynamic hip screw (DHS) fixation for proximal femur fracture. Scattered dose to the eye, neck and hand were measured in each of those procedures.

7.1 Radiation exposure time during ILN and DHS

The duration where fluoroscopy was being used in the procedure is the radiation exposure time. Results from ten procedures of interlocking nail varied greatly from maximum radiation exposure time of 6.15 minutes to minimum exposure time of 1.3 minutes with mean exposure of 3.89 minutes. The surgeon experiences and expertise varied greatly and may influence this outcome. This was supported by indirect evidence from previous study. Goldstone et al during his study on radiation exposure to orthopaedic surgeon noted that the most junior and least experience surgeon received the highest radiation dose (Goldstone et al.,1993). This study showed that the surgeon received more radiation dose when radiation exposure time was increased. In other words, least experience surgeon received highest radiation dose and had longer radiation exposure time.

In my observation in this study, the duration from time of injury until the surgery is carried out and the personality of fracture may influenced the reduction process and thus lead to increased usage of fluoroscopic time. However there was no establish evidence to support this.

7.2 Scattered radiation dose during ILN of femur

The data in this study indicated that the mean scattered radiation dose to hand was highest as compared to those to the eyes and neck. This finding was expected as the hand was close to the operating field and may be directly exposed to ionizing radiation. Noorden et al. in their study on radiation dose to hand, thyroid and eyes found that there was more radiation to the hand then the others (Noorden et al., 1993). Previous study had shown that the greatest level of scattered radiation was recorded during the femoral nailing procedures including distal locking (Sanders et al., 1993).

7.2.1 Scattered dose to eye

During interlocking nail of femur, mean scattered radiation dose to the eye was 0.09 mSv per procedure or 0.02 mSv per minute of radiation exposure. The annual dose limit to the lens of eye as recommended by National Council on Radiation Protection and Measurement Report 91, 1987, is 150 mSv. Therefore to reach this limit, a surgeon would have to perform 1666 procedures of interlocking nail in a year. With regard to duration of radiation exposure, the surgeon needs a total of 7500 minute of radiation exposure in a year to reach the limit.

7.2.2 Scattered dose to hand

The mean scattered radiation dose to hand during interlocking nail was 0.27 mSv per procedure or 0.07 mSv per minute of radiation exposure. Base on this finding, a surgeon need to performed 1852 interlocking nail procedures to exceed the recommended annual dose limit to the hand which was 500 mSv or a total of 119 hours of radiation exposure in a year.

7.2.3 Scattered dose to neck

Scattered radiation dose to the neck were measured over and beneath the thyroid shield. The dose beneath the shield is the actual dose to the neck whereas those over the shield were the amount received if the surgeon did not wear a thyroid shield. Mean scattered radiation dose beneath and over the shield was 0.03 mSv and 0.07 mSv respectively. As the recommended dose limit to the thyroid is 500 mSv, a total of 16,667 interlocking nail procedures in a year are required to exceed the limit if the surgeon wore the thyroid shield. Similarly, if the shield is not worn, it need 7 143 procedures in a year to exceed the limit. As proven statistically by Wilcoson test, thyroid shield in this study has significantly reduced the scattered dose to surgeon's neck. Studies in the past had also found the usefulness of thyroid shield in reducing the scattered dose (Dewy and Incole, 1998; Tse et al., 1999).

7.3 Scattered radiation dose during dynamic hip screw

There was not much to comment on scattered radiation dose during dynamic hip screw as there were only three procedures. However I observed that the level of scattered radiation dose to the eye, hand and neck increased as the radiation exposure time increased. Scattered radiation dose to the hand was the highest compared to those to the eye and neck.

7.4 Relationship of scattered dose and exposure time

The scattered plot graph in figure 5.1 and 5.2 showed there were increased in radiation dose to the hand and the eye as the radiation exposure time (duration of fluoroscopy being used) increased. This relationship was expected. In figure 5.3, the scattered plot graph of scattered radiation dose over the thyroid shield versus duration of radiation exposure showed a horizontal line. The result of ten interlocking nail of femur did not indicate an increased in radiation dose over the shield despite there was increased in exposure time.

In my observation the surgeon always moving and did not always directly facing the C-arm of fluoroscopic machine. When the surgeon faced directly the C-arm i.e. the source of radiation, the scattered radiation dose will travel straight to the radiation-monitoring device (TLD) over the thyroid shield without any blockage. As the surgeon turn away from the machine, the radiation-monitoring device (TLD) over the thyroid shield will also follow this change of direction. When the turning was more than ninety degrees from the machine, obviously the thyroid shield will block the radiation to the TLD over the shield because at this point the shield is 'position' between the C-arm and the TLD. As a result, graph in figure 5.1c is differenced from graph in figure 5.1a and 5.1b. However there was no scientific evidence to prove this and further study is needed.

7.5 Possibility to exceed recommended annual dose limit

The radiation exposures received by an individual surgeon will be related to the number of procedures that he or she performed. In order to exceed the recommended annual dose limit, a very large number of procedures needed to be carried out in a year as I have extrapolated from the result of my study.

Table 4: The minimum number of interlocking nail of femur procedure required to exceed recommended annual dose limit to the eye, hand and thyroid.

	Scattered dose per-procedure (mSv)	Recommended annual dose limit (mSv)	Number of procedure needed to exceed annual dose limit.
Eye	0.09	150 (eye)	1 666
Hand	0.27	500 (hand)	1 850
Over thyroid shield	0.07	500 (thyroid)	7 143
Beneath thyroid shield	0.03	500 (thyroid)	16 667

Table 4 showed the mean scattered dose per procedure to eye, hand and neck and the minimum number of procedure require to exceed the recommended annual dose limit. With respect to the scattered radiation dose to the eye, hand and neck in this study, the eye was the most likely to be affected. It required 1 666 procedures of interlocking nail in a year to exceed the annual dose limit. In other word, a surgeon needs to perform at least 4.5 procedures of ILN each day in a year! Although the surgeon would have performed other cases under image intensification fluoroscopic guidance, this large number of procedures were very unlikely to be reached by an individual surgeon in a year.

According to Radiation Protection (Basic Safety Standard) Regulation 1988, personal monitoring of radiation dose for all workers must be carried out if the working area is likely to exceed three tenth of the recommended dose limit in a year. To exceed this limit, an individual surgeon must do at least 500 cases of interlocking nail in a year or 1.3 procedures of ILN on every single day in a year. Thus, it is still a large number of procedures for a surgeon to perform in a year.

Goldstone et al. in his study on radiation exposure to the hand conclude that radiation exposure was low and continuous monitoring for the surgeon is not necessary. Levin et al in his study also found that radiation exposure is well below the recommended dose (Levin et al.,1987).

However despite the fact that the scattered radiation to the surgeon is within safe limit, no author suggest to reduce the protective measures. It is a basic principal of radiation protection that all medical radiation to both patients and medical personnel should be kept to a minimum under the ALARA principal (As Low As Reasonable Achievable). The long terms effect of radiation exposure are unknown. Although the deterministic effect can be avoided if the dose is kept below the tissue-specific threshold, but the stochastic effect for which there is no threshold dose, can result in subsequent development of neoplasm. This is why ALARA principle is important.

8.0 CONCLUSION

During interlocking nail of femur and dynamic hip screw fixation under image intensification fluoroscopy, the surgeon was exposed to scattered radiation. Scattered dose received by the surgeon increased as the radiation exposure time was increased. Mean radiation exposure time or duration where the fluoroscopy was being used during interlocking nail of femur was 3.89 minutes per procedure. For dynamic hip screw, the mean radiation exposure time was 3.03 minutes.

Scattered radiation dose to the surgeon's hand during interlocking nail of femur was 0.27 mSv per procedure. The dose to the eye was 0.09 mSv per procedure. With respect to the neck, scattered radiation dose underneath the thyroid shield was 0.0285 mSv per procedure and the dose over the shield was 0.074 mSv.

During dynamic hip screw fixation, scattered radiation dose to the surgeon's hand and eye were 0.55 mSv per procedure 0.16 mSv per procedure respectively. The dose to the neck underneath the thyroid shield was 0.153 mSv per procedure. Over the thyroid shield the dose was 0.207 mSv per procedure.

Although the surgeon was exposed to scattered radiation, the dose was very minimal. It is very unlikely for an individual surgeon to receive more than the

9.0 LIMITATION

Sample size for interlocking nail procedure was ten whereas for dynamic hip screw procedure, the sample size was only three. The results in this study can be affected by the small sample size. Statistical test cannot be carried out because of the small sample size except for Wilcoxon test that was used to determine the differences between the scattered dose over and underneath the thyroid shield during interlocking nail.

In this study, two image intensification fluoroscopy machines were used. One was Sieman Siramobile and the other was Stenoscope. It would be better if only one fluoroscopic machine is used for all the procedures in this study. However this was not possible as one machine broke down and the study was continued with another fluoroscopic machine.

10.0 RECOMMENDATION

It was found that the risk from radiation exposure to the theatre personnel was small if sensible precautions were taken, but increased significantly if ignored (Arnstein et al., 1994). From this study a number of precautions can be taken to minimize the scattered radiation dose intra-operatively.

I. In addition to lead apron, surgeon is encouraged to wear lead goggle during the procedure since the eye was more likely to be affected as compared to hand and thyroid in this study. The used of thyroid shield is also recommended as this will effectively reduced the amount of scattered dose to the neck.

II. The surgeon involved should be familiar with the operative technique. There should be no attempt to visualize fluoroscopically the steps that do not require visualization.

III. The hand of the operating surgeon should always be kept away from the radiation field whenever possible. It will be much better if the surgeon can steps backward when fluoroscopic image was visualized.

11.0 CASE ILLUSTRATION

TF was admitted to Hospital USM on 3rd of February 2003 following a motor-vehicle injury. He sustained a closed fracture of the distal third of left femur. He underwent surgery on 10th of February 2003 where interlocking nail of left femur was performed. The operation was done under the guidance of Siemens Siremobil Compact image intensification fluoroscopy. The primary surgeon was an orthopaedic registrar, assisted by two orthopaedic residents. During this procedure, scatter radiation dose to the eye, hand and neck of the primary surgeon were quantified using radiation monitoring device. Thermoluminescent dosimeter (TLD) chips were used to quantify the scatter radiation to the eye and neck whereas for the hand, TLD rings were used.

Prior to the usage, these TLDs were processed in the Secondary Standard Dosimetry Laboratory (SSDL) in Malaysian Institute for Nuclear Technology (MINT). Each of TLD chips was wrapped in aluminum foil or placed in the ring (TLD ring) before they could be used and sent to Hospital USM for this study. In hospital USM, the TLD rings would be sterilized by mean of ethylene okside. The surgeon during the procedure wore the rings to his index and middle fingers of both hands. Two TLD chips were placed to the upper part of the facial mask just below the right and left eyes. Four TLD chips were used to quantify the scattered dose to the neck. Two of them were placed over the front part of the thyroid shield while another two were placed underneath the thyroid shield.

Table 5:Reading from TLDs and mean scattered radiation dose to the respective area. These are the detail result of procedure no. 1 in table 2, page 56.

Control TLD	0.19 mSv
Scattered dose to- Right index finger - Right middle finger - Left index finger - Left middle finger **Mean scattered dose to hand**	0.40 – 0.19 = 0.21 mSv 0.40 – 0.19 = 0.21 mSv 0.40 – 0.19 = 0.21 mSv 0.40 – 0.19 = 0.21 mSv **0.21 mSv**
Scattered dose over the front part of thyroid shield (reading from two TLD chips). **Mean scattered dose to front part of the shield** Scattered dose underneath the thyroid shield (reading from two TLD chips). **Mean scattered dose underneath the shield.**	a) 0.33 – 0.19 = 0.14 mSv b) 0.34 – 0.19 = 0.15 mSv **0.145 mSv** a) 0.24 – 0.19 = 0.05 mSv b) 0.25 – 0.19 = 0.06 mSv **0.055 mSv**
Scattered dose to right eye Scattered dose to left eye **Mean scattered dose to the eye**	0.31 – 0.19 = 0.12 mSv 0.31 – 0.19 = 0.12 mSv **0.12 mSv**

This surgery took two hour and ten minutes. Radiation exposure time recorded directly by the image intensifer fluoroscopy was 2.86 minutes. The TLD chips and TLD rings were sent back to Secondary Standard Dosimetry Laboratory (SSDL) in Malaysian Institute for Nuclear Technology for the reading process before they can be used again in the next procedure. A TLD chip which was not used in this procedure was also sent to SSDL. This TLD chip would be a control TLD. It was kept well away from the place where the procedure was done to avoid the scattered radiation from the image intensifier fluoroscopy. Reading from this TLD comes from radiation from surrounding environment.

The scattered radiation doses received by the primary surgeon in this procedure were as below. To get the actual scattered radiation dose, the value from the control TLD chip would be deducted from the other TLDs as shown in table 5.

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