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

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الملخص

تم عمل الدراسة بهدف معرفة و دراسة كمية الأشعة التي يتعرض لها أخصائي العظام علي اليدين و الغدد الصماء و الجسم في اثناء اجراء العمليات الجراحية لكسور الأطراف السفلية بمساعدة الاشعة (التلفزيون)، ايضاً كانت الفرضية في هذه الدراسة بأن اخصائي جراحة العظام لا يعتبر من فئة العاملين في الاشعة.

تم مراقبة الاشعة بإستخدام مجسات شعاعية "TLDs" تقوم بحفظ كمية الاشعة المتعرضة لها ومن ثم يتم قرائتها، في ثلاث مناطق من الأول وضع علي مستوى الرقبة لتسجيل كمية الاشعة للغدد الصماء والثاني كان يلبس في اليدين كخاتم في السبابة لتسجسل الأشعة علي اليدين اما الثالث فكان يوضع علي مستوي وسط الجسم لتسجيل كمية الاشعة المتعرض لها كل الجسم.كانت المجسات تغير بعد كل عملية جراحية و وقت العملية ووقت التعرض للاشعة كان يدون لكل عملية.

أجريت الدراسة علي 8 جراحيين و اجمالي العمليات الجراحية كان 96 عملية جراحية لكسور الأطراف السفلية منقسمة علي النحو التالي: 32 عملية جراحية للحوض و 32 عملية جراحية لكسور الفخذ و32 عملية جراحية لكسور الساق.كانت المجسات "TLDs" ترسل شهرياً للقراة.

كمية الأشعة التي تعرضت لها اليدين كانت بمعدل 0.22 مليسيفرت و 0.20 للغدد الصماء و 0.010 مليسيفرت في كل عملية جراحية اما كمية الاشعة التي تعرض لها الجسم في الشهر فكانت 0.11 مليسيفرت.

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من نتائج البحث اتضح ان جراح العظام ممكن ان يجري 681 عملية جراحية لكسور الأطراف السفلية دون ان يصل الي الكمية المحددة عالمياً لليدين "150 مليسيفرت".

إجمالاً أخصائي العظام الذي يجري عمليات جراحية لكسور الأطراف السفلية يتعرض الي جرعة معروفة من الاشعة تؤثر علي الغدد الصماء و خلايا الجسم و بما أن كمية الأشعة التي يتعرض لها تتجاوز ال 10% من كمية الأشعة التي يمكن ان يتعرض لها العاملين في الأشعة "20 مليسيفرت في السنة" لذلك يجب ان يصنف جراحيي العظام علي انهم من فئة ال عاملين في الأشعة و يجب مراقبتهم اشعاعياً بصفة دورية ، و ذلك لعدم معرفتنا بضرر هذه الجرعة الصغيرة علي جسم الإنسان.

ABSTRACT

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. Radiation was monitored with the use of a Panasonic thermoluminescent dosimeters (TLDs) placed at the level of the neckline to measure the radiation dose to the thyroid , a gas-sterilized TLDs worn on the index finger of each hand under the surgical gloves and 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 wornn during all the operative procedures that the orthopaedic registrar performed per month. The rings and TLDs were changed with every operation. The hand dominance of the orthopaedic registrar, the duration of the operative procedure, the type of operation, and the total time that fluoroscopy had been used were noted. The study was conducted during 96 internal fixation procedures of the lower limbs (32 neck of femur, 32 femur and 32 tibia). At the end of each month the TLDs were sent to the South African Bureau of Standards (SABS) for dose measurement. 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 International Commission on Radiological Protection (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. 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.

INTRODUCTION:

The use of ionizing 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 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 orthopaedic theater. Ionizing radiation has therefore become a serious occupational hazard for orthopaedic surgeon and other theater staff who are often ill-informed on the subject and poorly trained to minimize the associated health risks (Hynes, *et al,* 1992).The earliest risks of ionizing radiation to the radiologist and cardiologist have been well documented (Faulkner and Moores, 1982; Jeans and Faulkner, 1985). Whereas only a few studies have investigated the exposure to orthopedic surgeon in operation theater. (Al-Shawi & Fern, 2003; Artigans, Conso, & Hazebrouq, 2003; Muller *et al*, 2002 and O’Rourke*, et al*, 1996). The indication for surgical treatment of long bone fractures with intramedullary nailing has expanded in the last few years. The surgeon is thereby confronted with increased exposure to radiation because reposition and distal interlocking are performed under fluoroscopic guidance (Muller *et al*, 2002). According to the Melman and DiPasquale (1997) and Theocharopoulos, *et al*, (2003) studies that have been done to evaluate the radiation dose to the orthopaedic theater staff during fluoroscopic procedures, 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. Only a few studies mention the doses received by the hands, which are usually high (Al-Shawi and Fern, 2003; Artigans, Conso, & Hazebrouq, 2003; Muller *et al*, 2002 and O’Rourke, *et al*, 1996). 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*, 2002. O’Rourke*, et al*, (1996) stated that the hands of the orthopaedic surgeon are most likely to be directly exposed to ionizing radiation during fluoroscopic screening in the orthopaedic theater. Therefore, 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 Stoddard, 1998). Levin, Schoen, and Browner (1997) stated that the orthopedic surgeon spends a significant amount of time working in close proximity to x-rays. Protection in the form of lead aprons is useful for reducing trunk exposure, but such protection is impractical for the protection of hands. Dewy and Incoll (1998) stated in their study for the evaluation of 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 theater. Dewy and Incoll (1998) concluded that the orthopaedic surgeons may be more likely to develop thyroid carcinoma if not protected from this radiation exposure. The purpose of this study was To quantify the ionising radiation exposure to the hands, thyroid and whole body of the orthopaedic registrar during internal fixations of the lower limbs.

MATERIALS AND METHODS:

All exposures were performed on an undercouch mobile C-arm fluoroscopy unit (Ziehm Exposcop / CB7-D) with last image hold ability (Figure 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.

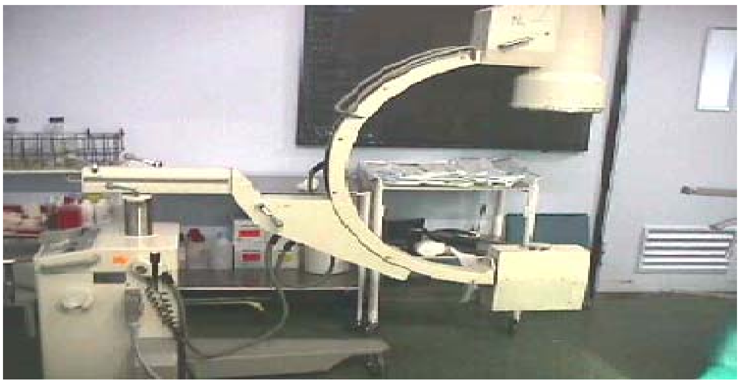


Figure1. Demonstrating A Mobile C-Arm Fluoroscopic Unit- Ziehm Exposcop / Cb7-D

The TLDs used for this study were Panasonic 802-A (Figure 2). The TLDs were stored in a room at a temperature of 20-25°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 2. Tld Used In The Study (Sabs, 1997)

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. 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. Radiation was monitored with the use of a Panasonic thermoluminescent dosimeters (TLDs) placed at the level of the neckline to measure the radiation dose to the thyroid , a gas-sterilized TLDs worn on the index finger of each hand under the surgical gloves and 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 wornn during all the operative procedures that the orthopaedic registrar performed per month. The rings and TLDs were changed with every operation. The hand dominance of the orthopaedic registrar, the duration of the operative procedure, the type of operation, and the total time that fluoroscopy had been used were noted. 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. 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.

RESULTS:

Radiation Exposure to the Hands:

Over a period of 3 months, a ring dosimeter measurements were carried out on 8 orthopaedic registrars on both hands. In total there were 96 internal fixation of the lower limbs (32 neck of femur, 32 femur and 32 tibia). Table 1 shows the means and standard deviation for radiation dose to the hands of all 8 orthopaedic registrars during internal fixation of the lower limbs (N =32 for right and left hand and 64 for both hands). The average screening time per operation for 96 procedures was 3.26 minute and mean operation time was 77 minute (Table2). The pair t – test was conducted in order to asses weather there was any significant relationship between the amount of radiation dose to the right and left hand. Since the ρ-value = 0.025 (Table 3), 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.

Pearson's correlation coefficient and Scatterplot used to demonstrate the relationships between the screening time and radiation dose to the hands . 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) indicate that there is a linear relationship (Figure 3).

Table 1. mean and standard deviation for radiation DOSE TO the Hands of all 8 orthopaedic registrars During 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	0.85	0.18	0.16
	Left Hand	0.01	0.53	0.16	0.11
	Both Hands	0.01	0.85	0.17	0.13
Femur	Right Hand	0.05	0.59	0.30	0.13
	Left Hand	0.01	0.74	0.24	0.19
	Both Hands	0.1	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	0.1	0.75	0.21	0.16

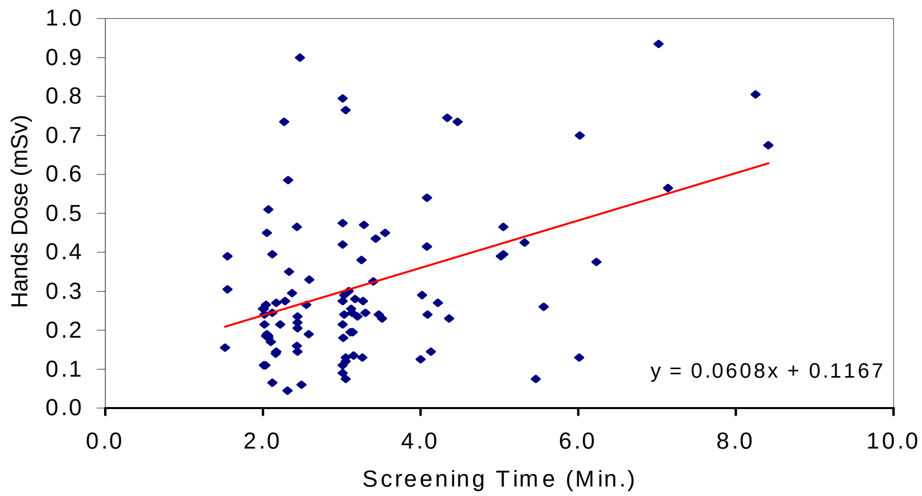
Table 2. The mean and standard deviation for operative and screening times during internal fixation of the lower limbs (8 registrars, 4 procedures each)

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

Table 3. 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



Pearson γ = .428, n = 96, ρ=. 000
Figure 3. Scatterplot of screening time and radiation dose to the hands during 96 internal fixations of the lower limbs

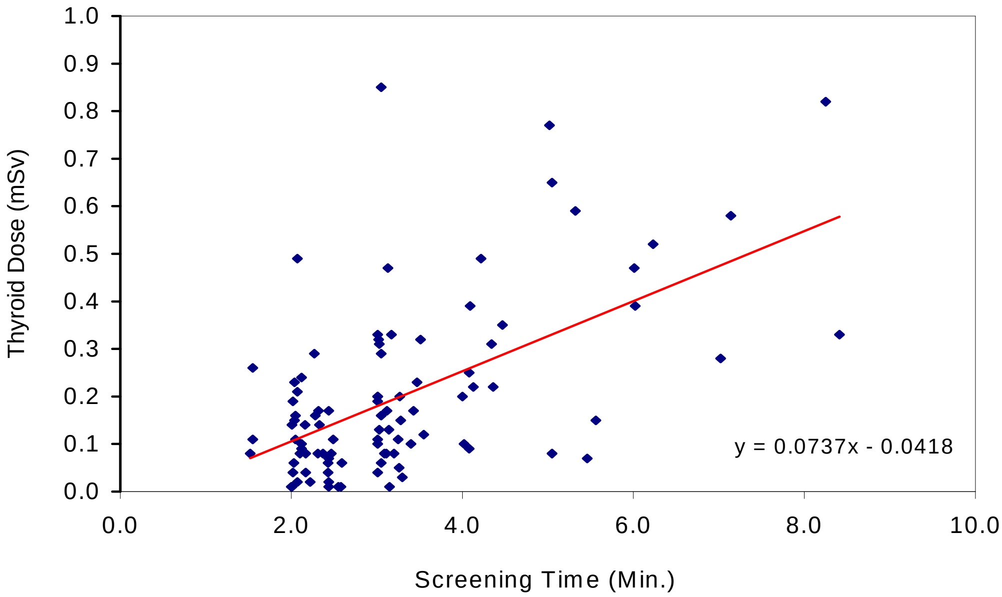
Radiation Exposure to the Thyroid:

The TLD badge was placed anteriorly over orthopaedic registrars thyroid gland at neckline level. 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 (table 4). A scatterplot of screening time and radiation dose to the thyroid during 96 internal fixation of the lower limbs suggested that a significant positive linear relationship was exists (Figure 4).

Table 4. 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



Pearson γ = .571, n = 96, ρ=. 000

Figure 4. Scatterplot of screening time and radiation dose to the thyroid during 96 internal fixations of the lower limbs

Radiation exposure to the whole body:

Radiation dose to the whole body was obtained in two ways; firstly the dose was calculated from the thyroid badges and this reflect the amount of radiation dose to the orthopaedic registrars per operation procedure. The mean radiation dose was 0.010 mSv per operation (Table 5). Secondly: each orthopaedic registrars was given one TLD to be worn under the lead apron.This TLD was wornn during all the operative procedures that the orthopaedic registrar performed per month. The mean radiation dose to the registrar whole body was 0.11 mSv per month over a period of three months (Table 6).

Table 5. The mean and standard deviation for radiation DOSE TO the orthopaedic registrars whole body during internal fixation of the lower limbs (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

Table 6. 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

Discussion:

Radiation Exposure to the Hands:

For most fluoroscopically assisted internal fixation 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. 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). 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, Schon & 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 image intensifier in orthopaedic surgery reported 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. Table 7 summarized the literature studies' values for radiation dose to the hands as well as for the current study (2004).

Table 7. Radiation dose to the hands during lower limbs internal fixation.

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 7). 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:

I- Fluoroscopic devices,

II- Experience, and qualifications of different surgeons and.

III- Operative techniques.

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 this study, 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 (Figure 5) increases the amount of occupational radiation dose. The study 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. Orthopaedic registrar location during internal fixation of lower limbs (posterio – anterior projection)

The study uncovered that there is a statistically significant relationship between the radiation dose to the right and left hands as presented in Table 3. The results of the 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). 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) 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.

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 8).

Table 8. 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	3.26

In comparing the results of the this study , 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 this 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. 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.

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). 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.

Radiation Exposure to the Thyroid:

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. Based on the current study results, the exposure rate to the thyroid during internal fixation of the lower limbs (0.20mSv per operation) was lower than previous studies (Dewey and Incoll, 1998 and Lo, Goh and Kong, 1996). It is assumed that the values of the this study are related to the fluoroscopy devices, experience and qualifications of different surgeons and varying operative techniques. 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). 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.

Radiation Exposure 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).

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.

In the current study 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).

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, 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.

CONCLUSION:

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.

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

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