The training and knowledge of radiation exposure among Wits University Orthopaedic Registrars and their implementation of radiation protective measures

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Imraan Suliman

Supervisor: Prof S.K. Magobotha (FCS Orth (SA))

Co-supervisor: Dr. M. Jingo (PhD, Wits)

Co-supervisor: Dr. D. Bhana (FC Rad D)

DECLARATION

I, Imraan Suliman, declare that this research project is my own work, which is being submitted for the degree of Master of Medicine in the branch of Diagnostic Radiology at the University of Witwatersrand, Johannesburg.

It has not been submitted before for any examination or degree at this or any other University.

…………………………
(Signature of candidate)

23 day of September 2021 in Johannesburg

Dedication

This research study is dedicated to my wife and family for their everlasting love and support.

ACKNOWLEDGEMENT

I would like to extend my deepest thanks to my supervisor Prof S. Magobotha, for his invaluable insight and guidance.

I'm extremely grateful to Professor Ramokgopa, the HOD in Orthopaedic surgery at the University of the Witwatersrand, for allowing me the opportunity to conduct my study in the Orthopaedic department.

I cannot begin to express my gratitude to my co- supervisors, Dr Jingo and Dr Bhana for their constructive criticism, ingenious suggestions and unwavering support.

Finally, I am indebted to my wife for her continued encouragement and patience throughout my post-graduate endeavours.

Abstract

Introduction: The use of fluoroscopy in the management of orthopaedic injuries has increased significantly in recent decades, particularly in the trauma setting. However, this has exposed the surgeon, hospital staff and patient to higher levels of radiation. This study aimed to evaluate the knowledge of WITS orthopaedic registrars on ionising radiation and assess their use of radiation protection.

Methods: A survey addressing the knowledge of radiation and methods of protection was conducted amongst 50 registrars enrolled at the WITS training centre.

Results: There was a 76% response rate and the data obtained was statistically evaluated. Although 87% know what ionising radiation is, only 34% believe they are adequately familiar with the effects of radiation and methods of protection. Focused education was particularly low with 26% of registrars having received formal lectures. Fifty percent of registrars were unfamiliar with the guidelines of radiation optimisation, and more concerning, even fewer implemented the basic methods of protection. There was no accurate record of individualised annual radiation exposure with only 3 registrars being equipped with dosimeters. Furthermore, registrars were found to be indifferent to the harmful effects of radiation with 76% of trainees regularly obtaining unjustified post-operative x-rays.

Conclusion: Knowledge about ionising radiation and utilisation of protective measures were insufficient amongst Wits Orthopaedic trainees. These findings are consistent with other training institutions in South Africa and around the world. Authors recommend a structured program on radiation and radiation protection be introduced as part of the training program to reduce the detrimental effects of radiation on the surgeon, theatre staff and patient.

Table of contents

Declaration……………………………………………………………………………….....i

Dedication……………………………………………………………………………...ii

Acknowledgement…………………………………………………………………….iii

Abstract……………………………………………………………………………..iv

Nomenclature..vviii

1. **INTRODUCTION / BACKGROUND**……………………………………………......1

1.1. Fluoroscopy and Orthopaedic Surgery…………………………………………….1

1.2. Effects of Ionising Radiation on Living Tissue…………………………………….1

1.2.1. Damage at a cellular level……………………………………………………..1

1.2.2. Stochastic and Deterministic Effects…………………………………………….2

1.2.3. Direct and Scatter radiation…………………………………………………...3

1.3. Basic Principles in Radiation Protection……………………………………………...3

1.3.1. Optimisation…………………………………………………………………..3

1.3.1.1. The hands………………………………………………………………….4

1.3.1.2. Thyroid gland……………………………………………………………….4

1.3.1.3. Eyes…………………………………………………………………………4

1.3.1.4. Body…………………………………………………………………………...5

1.3.2. Limitation………………………………………………………………………..5

1.3.3. Justification…………………………………………………………………….....5

1.4. Training Programmes…………………………………………………………………...6

2. **LITERATURE REVIEW**……………………………………………………….....7

2.1 Registrar Training Programmes and literature…………………………………………...7

2.2. Direct and Scatter radiation……………………………………………………………..7

2.3. Basic Principles in Radiation Protection……………………………………………...8

2.3.1 Optimisation……………………………………………………………………...8

2.3.2. Minimising radiation……………………………………………………………8

2.3.3. Body exposure and personal protective equipment………………………………8

2.3.3.1. Hands...8

2.3.3.2. Thyroid Gland……………………………………………………………9

2.3.3.3. Eye……………………………………………………………………….9

2.3.3.4. Body...9

2.4 Limitation……………………………………………………………………………10

3. **STUDY AIM AND OBJECTIVES**……………………………………………….11

3.1. Aim……………………………………………………………………………….11

3.2. Objectives……………………………………………………………………...11

3.2.1 Primary Objectives…………………………………………………………...11

3.2.2 Secondary Objective………………………………………………………….11

3.3. METHODS…………………………………………………………………………11

3.3.1 Research question………………………………………………………..11

3.3.2. Research design…………………………………………………………….11

3.3.3. Material and Methods…………………………………………………………12

3.3.4. Sample selection……………………………………………………………13

3.3.5. Limitations……………………………………………………………………………13

4. **RESULTS**……………………………………………………………………………………14

5. **DISCUSSION**………………………………………………………………………….. 18

5.1. Educational material offered to WITS registrars…………………………………………...18

5.2. Direct and scatter radiation………………………………………………………………19

5.3. Basic Principles in Radiation Protection…………………………………………………19

5.3.1. Optimisation…………………………………………………………………………..19

5.3.1.1 Distance……………………………………………………………………...20

5.3.1.2. Personal protective equipment………………………………………………...20

5.3.2 Limitation………………………………………………………………………...21

5.3.3 Justification……………………………………………………………………22

CONCLUSION…………………………………………………………………………...23

REFERENCES…………………………………………………………………………....28

Nomenclature

ALARA	- As low as reasonably achievable
CMJAH	- Charlotte Maxeke Johannesburg Academic Hospital
CHBAH	- Chris Hani Baragwaneth Academic hospital
DNA	– Deoxyribonucleic Acid
ER	- Emergency Room
HJH	- Helen Joseph Hospital
ICRP	- International Commission of Radiation Protection
MRI	- Magnetic Resonance imaging
OR	- Operating Room
PPE	- Personal protective equipment
UK	– United Kingdom
UP	- University of Pretoria
USA	– United States of America
WITS	- University of the Witwatersrand

CHAPTER 1

1. INTRODUCTION / BACKGROUND

Since the introduction of radiography in the late 19th century, diagnostic imaging technology has seen major advances. Ionising modalities which include plain film and cross-sectional imaging, together with non-ionising techniques such as sonography and Magnetic Resonance Imaging (MRI) have become an integral part of modern day medicine [1, 2]. Diagnostic imaging has proven itself to be an invaluable resource in the setting of acute trauma and medical emergencies [3]. Radiation exposure from medical imaging now accounts for the greatest source of man-made radiation to the population in the United States of America (USA) [4, 5].

1.1. Fluoroscopy and Orthopaedic Surgery

Fluoroscopy in the management of orthopaedic injuries has significantly increased in recent decades [6]. Minimally invasive techniques which relies heavily on fluoroscopy, is fast becoming standard practice in orthopaedic surgery. It has radically changed the management of orthopaedic injuries in the operating theatre by making surgeons more capable and efficient, thereby reducing patient morbidity and mortality [1, 7]. In the emergency room, fractures and dislocations are reduced under fluoroscopy which negate the need for surgery and hospital admission [8, 9]. However, it poses an added risk, as the surgeon, patient and hospital staff are exposed to increasing levels of ionising radiation [10].

1.2. Effects of Ionising Radiation on Living Tissue

1.2.1. Damage at a cellular level

Radiation predominantly affects rapidly dividing cell components, namely the cell membrane and Deoxyribonucleic acid (DNA), through direct and indirect mechanisms. The structural integrity of the cell membrane and the covalent bonds of the cell's DNA are compromised when a fluoroscopy generated x-ray photon directly collides with the cell. The molecular bonds within the DNA are disrupted through an indirect process of water radiolysis and the generation of oxygen free radicles resulting in added damage. Both the direct and indirect effects of ionising radiation on the cell's DNA lead to point mutations, single stranded DNA breaks and more importantly, double stranded DNA breaks. Furthermore, neighbouring cells are affected through intercellular communication mechanisms. The cumulative insults result in a toxic environment that prompts the body to initiate an immediate process of damage control and repair [11-13]. This process of cellular repair is typically affected by low dose radiation and may result in incorrect pairing and mutations [12, 13].

1.2.2. Stochastic and Deterministic Effects

The harmful effects of radiation are classified into deterministic and stochastic effects. Deterministic effects occur on cells of a particular organ or tissue when radiation exposure exceeds tissue specific levels. The severity, thereafter, is proportional to the amount of radiation the cells receive. Typical deterministic effects include cataracts, malignancies, infertility, hair loss and skin reactions. Stochastic effects, unlike deterministic effects, are not dependent on a specific radiation dose and effects on a cell are random, however the probability of incurring a harmful event increases with increasing exposure. If these events involve the DNA of cells capable of reproduction, there is a risk of an oncogenic mutation and the development of cancer. Insults on the genetic material in a germ cell (within the gonads) will increase the probability of inheritable conditions [1].

The development of cataracts, malignancies and hereditary disorders have been associated with long-term exposure to low dose radiation, which is the type of radiation orthopaedic surgeons are exposed to [14-18]. It is therefore paramount that orthopaedic surgeons know the risks and effects of inadequate protection from ionising radiation.

1.2.3. Direct and Scatter radiation

Orthopaedic surgeons are exposed to both primary (direct) and secondary (scatter) radiation. Direct exposure to the hand can be as much as 100 times greater compared to the scatter radiation [19, 20]. Scatter radiation is negligible at a distance of 2 m from the radiation source and multiple studies have advised surgeons to distance themselves from the x-ray source in order to efficiently reduce their exposure from direct and scatter radiation [21, 22].

1.3. Basic Principles in Radiation Protection

In 2007, the International Commission of Radiation Protection (ICRP) developed three principles that would help reduce exposure to ionising radiation, namely optimisation, limitations and justification [23].

1.3.1. Optimisation

This principle is the most pertinent in terms of orthopaedic surgery and is based on achieving an adequate image with the least amount of radiation exposure (ALARA) to the surgeon, surrounding health care professionals and the patient [23]. Minimising radiation, increasing the distance from the radiation source and personal protective equipment are specific measures enshrined in the ALARA policy, and are necessary to ensure implementation of good practice and optimisation [1, 24]

Minimising radiation exposure is achieved through careful positioning of the patient and the C-arm, pulsed screening, collimation, limiting magnification and the use of image memory facilities. Radiation exposure obeys the inverse square law, and therefore small increments in distance significantly impacts radiation exposure [21, 25, 26]. Personal protective equipment includes the use of lead gowns, glasses, thyroid shields and protective gloves [22]. Multiple studies have demonstrated correct utilisation of personal protective equipment significantly reduces radiation exposure to the surgeon [27, 28].

The maximal annual limit equivalent dose established by the ICRP is 500 mSV to the hands and body, 150 mSv to the thyroid and 20 mSv to the eye [23, 29]. Radiation doses to different parts of the body vary depending on the use of personal protective equipment, surgical technique and the implementation of the ALARA principles.

Multiple studies have confirmed radiation doses to the hands, thyroid gland and eyes do not exceed yearly limits in orthopaedic surgery [19, 30-32]. Although these results are reassuring, the uncertainty regarding the effects of long-term low dose radiation is a concern and appropriate measures must be taken to limit exposure.

1.3.1.1. The hands

The hands of an orthopaedic surgeon receive both direct and scatter radiation. Therefore, due to their close proximity to the primary beam in theatre, they are the dose-limiting organs in orthopaedic surgery [33, 34]. A study on open and minimally invasive procedures in orthopaedic surgery showed the hands of an orthopaedic surgeon are exposed to 44.5 mSv annually which is within the normal limit of 500 mSv [35]. Radiation protective gloves can reduce radiation exposure to the hand by 26.5%, however they offer no protection from direct radiation and should be used in conjunction with proper technique while adhering to the principles of ALARA [21, 36].

1.3.1.2. Thyroid gland

The thyroid gland of an orthopaedic surgeon has been shown to receive up to 33 mSv annually [23, 29]. Multiple studies have stressed the importance of a thyroid shield, demonstrating a significant reduction in radiation exposure, in some instances by as much as 70% [37, 38].

1.3.1.3. Eyes

The eye is one of the more radio-sensitive organs in the body and recent studies demonstrated a higher prevalence of cataracts amongst medical staff who were exposed to long term low dose radiation [15]. This has prompted the IRCP to significantly reduce the limit of occupational exposure from 150 mSv to 20 mSv annually [29]. Open surgical orthopaedic procedures can expose the eye to as much as 17.4 mSv annually and studies have demonstrated the use of protective equipment can reduce exposure by up to 90% [39].

1.3.1.4. Body

Lead aprons are highly effective in reducing radiation dose to the body. An apron with a thickness of 0.5 mm and 0.25 mm attenuates 99% and 90% of radiation, respectively. However, the 0.5 mm aprons weighs twice as much as the 0.25 mm aprons prompting many surgeons to opt for the lighter version [18, 37].

1.3.2. Limitation

The total annual radiation dose should not exceed radiation safety limits set by the ICRP, which has been adopted by the South African Department of Health. The use of dosimeter monitoring is the most widely used method to track occupational exposure and has been shown to reduce exposure to radiation [23, 40]. The use of real time dosimeters, which enable surgeons to get instant feedback on their exposure levels during procedures, significantly alters surgical behaviour and reduces radiation exposure by up to 60% [40, 41]. Gowda *et al*. recommended dosimeters be placed under the lead gown and stored away in a lead protective box when not in use. Furthermore, they recommended dosimeters be individualised and not shared amongst surgeons [42].

1.3.3. Justification

Overall, radiation exposure must be beneficial to the patient and outweigh the risks. The post-surgical anatomical result that yields an optimal biomechanical result often deviates from the desired post-surgical appearance on plain film. Orthopaedic surgeons often subject themselves, patients and other theatre staff to unnecessary radiation by manipulating the angle of an x-ray to achieve a plain film with the best possible post-operative appearance. This added exposure to radiation provides no added benefit to the patient [36].

1.4. Training Programmes

Despite the ever-increasing exposure of orthopaedic surgeons to fluoroscopy generated radiation, there are no internationally recognised curriculums which address the basic concepts of ionising radiation, radiation hazards and personal protection within orthopaedic surgery. Studies from South Africa, Europe and Asia have shown inadequate training programs for registrars in terms of personal safety and proper usage of radiological equipment [27, 28, 43]. Furthermore, studies have concluded that due to insufficient training, orthopaedic registrars lack essential knowledge with regards to ionising radiation, the principles contributing to exposure and the methods of protection. Numerous studies advocated the need for more education in the areas of ionising radiation and protection [27, 28, 43, 44].

In 2009, the ICRP recommended orthopaedic residents receive at least 15 hours of course work detailing relevant topics in ionising radiation and radiation protection. In addition, it also recommended literature not only be readily available within academic institutions, but registrars be actively encouraged to make use of them [45]. The training of WITS Orthopaedic Registrars on ionising radiation, their knowledge on the harmful effects of radiation and their practices on radiation protection have not been evaluated. Our study aims to evaluate these factors and compare them with other academic institutions in South Africa and around the world.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Registrar Training Programmes and literature

Gendelberg *et al*. in 2015 demonstrated that residents were able to reduce their exposure after receiving a three-hour educational program on radiation and mini C-arm usage [46]. Joeris *et al*. found surgeons who received education on the guidelines on radiation protection were three times more likely to use a dosimeter [6]. Harris *et al*. recommended all registrars, irrespective of their experience, receive training in methods of minimising the use of fluoroscopy [47]. Rosario *et al*. and Khan *et al*. found 46% and 16% of registrars in their studies had read literature on radiation exposure respectively [27, 28]. Tunçer *et al*. demonstrated that 8.5% of Turkish residents had read articles relating to fluoroscopy [43]. A study by van Papendorp *et al*. at the University of Pretoria (UP) found Orthopaedic registrars mostly received their knowledge on radiation and safety through discussions with colleagues [48]. He further demonstrated 23% of registrars had not been exposed to or accessed any educational resources relating to radiation and safety [48]. Nugent *et al.* found that 69% of registrars in Ireland attended a dedicated radiation protection course [44]. To our knowledge, this is the only study which identified an academic center with a directed radiation protection programme which found that:

- 65% of registrars cited the course as their main source of information [44].
- Only 19% had read articles relating to radiation exposure [44].

2.2. Direct and Scatter radiation

Khan *et al*. found 48% of residents did not know the difference between direct and scatter radiation. This is in contrast to a study by Rosario *et al*. who demonstrated only 15% of residents in their study did not know the difference between direct and scatter radiation[27, 28]. However, less than 30% of registrars from both studies correctly identified direct radiation being more severe than scatter radiation [27, 28].

2.3. Basic Principles in Radiation Protection

2.3.1. Optimisation

Khan *et al.* demonstrated 6% from a sample of 50 orthopaedic trainees in the UK were familiar with the principles of ALARA [28]. Rosario *et al*. and van Papendorp *et al*. found 15 % and 23% of registrars in their studies were familiar with the principles of ALARA, respectively [27, 48]. Nugent *et al.* demonstrated 69% of Irish registrars, who received formal training in radiation and radiation protection, were well informed in the principles of ALARA [44].

2.3.2. Minimising radiation

Dewey *et al.* demonstrated maximising the distance from the source of the x-ray beam will significantly reduce radiation as it obeys the inverse square law [1]. Thirty percent of orthopaedic registrars from the University of Pretoria were unable to correctly define the inverse square law[48].

A study by Yamashita *et al*. demonstrated the use of pulsed screening and collimation reduces exposure to the surgeon and patient by more than 65% [49]. Mahesh, M. demonstrated modern day C-arms can magnify up-to five times which significantly increases radiation exposure [50].

2.3.3. Body exposure and personal protective equipment

2.3.3.1 Hands

Jentzsch *et al.* demonstrated 61% of participants from his study knew that their hands receive the highest dose of radiation during surgery [51]. Khan *et al.* and Rosario *et al*. found 50% and 40% of registrars in their studies knew their hands receive the highest dose of radiation during surgery respectively [28]. Kim *et al*. demonstrated protective gloves are able to reduce scatter radiation to the hands by up to 26.5% [52]. Jones *et al*. recommended radiation protective gloves be used in high-risk procedures [53]. Joeris *et al*. and Tunçer *et al*. demonstrated that 2.5% and 5% of surgeons from their studies used radiation protective gloves respectively [6]. Van Papendorp *et al*. found one registrar would occasionally use protective gloves [48].

2.3.3.2.Thyroid Gland

Muller *et al*. and Burns *et al*. demonstrated the use of a thyroid shield can reduce exposure by as much as 70 times [38, 39]. Bahari *et al*. stressed the importance of a thyroid shield, demonstrating a significant reduction in radiation exposure [37]. Tunçer *et al*. demonstrated 70% of Turkish surgeons used a thyroid shield [43]. Khan *et al*. found 24% of surgeons from the UK used a thyroid shield [28]. Rosario *et al*. demonstrated 56% of Filipino registrars used a thyroid shield [27]. Joeris *et al*. found 41% of surgeons from his study used a thyroid shield [6]. Nugent *et al*. found 34% of Irish surgeons from his study used a thyroid shield [44]. Jentzsch *et al*. found 27% of participants from Switzerland used a thyroid shield most of the time [51]. Van Papendorp demonstrated 23% of UP registrars always used a thyroid shield [48].

2.3.3.3. Eye

Burns *et al*. and Muller *et al*. demonstrated the use of protective glasses can reduce exposure to the eye by 90% [39]. Tunçer *et al*. demonstrated 5% of the participants from Turkey utilised protective eyewear [43]. Joeris *et al*. found 3.1% of the surgeons who participated in their study utilised protective eyewear [6]. Van Papendorp *et al*. found 2 participants from his study who routinely used protective eyewear [48].

2.3.3.4. Body

Hayda *et al*. demonstrated lead aprons can attenuate 99% of radiation to the body of the surgeon [18]. Tunçer *et al*. demonstrated that 85% of surgeons were compliant with the use of a lead apron [43]. Jentzsch *et al*. demonstrated that more than 84% of the participants were routinely compliant with the use of a lead apron [51]. Nugent *et al*. demonstrated that more than 96% of trainees always used a lead apron [44]. Van Papendorp et al. found 93% of registrars always used a lead apron [48].

2.4. Limitation

Seven percent of UP orthopaedic registrars utilised a dosimeter [48]. This is comparable with Tunçer *et al*. who demonstrated only 10% of Turkish registrars utilised a dosimeter citing unavailability and forgetfulness for poor compliance [43]. Joeris *et al*. in 2018 found that 21% of surgeons in his study were consistently compliant with the use of a dosimeter [6]. Jentzsch *et al*. found that 44% of participants routinely used a dosimeter [51]. The difference in percentage is likely due to the sample demographics, which included orthopaedic consultants, registrars and medical technicians.

CHAPTER 3

3. STUDY AIM AND OBJECTIVES

3.1. Aim

To assess the training and knowledge of WITS orthopaedic registrars on radiation and their attitude towards radiation protection.

3.2. Objectives

3.2.1. Primary objectives:

- To determine if WITS orthopaedic registrars received training on radiation and radiation protection.
- To determine if WITS orthopaedic registrars are aware of the basic principles in radiation and radiation protection.
- To determine if WITS orthopaedic registrars are compliant with the use of personal protective equipment.

3.2.2. Secondary objective:

  - To determine the reasons why WITS orthopaedic registrars are non-compliant with personal protective equipment.

3.3. METHODS

3.3.1 Research question

Are WITS orthopaedic registrars receiving adequate training on radiation and are they familiar with the basic principles of radiation and radiation protection?

3.3.2 Research design

An evidence based questionnaire adopted from Khan *et al*. was modified to accommodate specific parameters unique to this study and thereafter, further refined based on a pilot study on ten orthopaedic registrars [28].

The content of the questionnaire is detailed in ‘‘Appendix A’’ and included questions pertaining to the level of training, education in radiation safety, basic knowledge on radiation, methods used to reduce radiation exposure and the reasons for non-compliance.

3.3.3 Material and Methods

This study was approved by the Human Research Ethics Committee (HREC) of the University of the Witwatersrand. Permission was obtained from the Chief Executive Officer (CEO) of Chris Hani Baragwanath Academic Hospital (CHBAH) and from the Head of Department of the WITS Orthopaedic Surgery department. This is a cross-sectional questionnaire-based study of orthopaedic surgery registrars enrolled at the University of the Witwatersrand as of 01 October 2020.

Participants were addressed and briefed on the aim of the study after the post intake meeting at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH), CHBAH and Helen Joseph Hospital (HJH). Consent was obtained, and participants were informed on the confidentiality of the study. A hard copy of the questionnaire was physically handed to the registrars. A second visit was made two weeks later and registrars who were not present for the first meeting were given the opportunity to complete the questionnaire. Questionnaires were collected in a box placed at the front of the room.

In addition, questionnaires were available at the secretary’s office for those who were unable to attend either of the two meetings. They were able to complete the questionnaire in the secretary’s office and thereafter place them in a collection box. The box was retrieved three weeks after the initial address at the post intake meeting.

The data collected from the questionnaires was captured on google forms by the researcher and exported on to an electronic spread sheet (Microsoft excel) using patient allocated numbers as identification of the entry. To allow better statistical analysis of registrar’s implementation of the ALARA principles and the use of personal protective equipment (PPE), we assigned scores to each response for questions 13A to 13k. Each question was assigned a score of “**1**” if the options ‘always’ or ‘frequently’ was selected or “**0**” if the options ‘sometimes’ or ‘rarely/never’ was selected. The scores were based on the intent to implement the principles of ALARA or utilise various PPE options. The score was summed for each individual and their total scores was used in the data analysis.

Data are presented as the number of participants in percentages. Frequency tables were generated. Depending on the response variable of either two or more than two options, either the t-test or a Chi-square test was used to compare difference in proportions respectively. *P*-values less than or equal to 0.05 were considered statistically significant. An ANOVA test was used to determine whether there was a significant difference in the mean between responses in questions which investigated the relationship between departmental experience and those that investigated knowledge on radiation, implementation of the ALARA principles or the use of PPE.

3.3.4. Sample Selection

Inclusion criterion:

All Orthopaedic Surgery registrars training at WITS as of the 1st of October 2020.

Exclusion criterion:

Orthopaedic registrars that were part of the initial pilot study.

3.3.5. Limitations

This is a small sample size, however there is a good response rate of 76%. Registrars who completed the questionnaire in the secretary’s office had the opportunity to search for the answers relating to their knowledge on radiation; unfortunately these questionnaires could not be identified and results pertaining to these questions may adversely influence the outcome of the study. However, of the 39 responses, only four questionnaires were retrieved from the boxes left at the secretary’s office.

CHAPTER 4

4. RESULTS

There was a 76% response rate with 38 questionnaires collected from a total of 50 registrars enrolled at the University of the Witwatersrand. Responses to each of the questions are tabulated in Table 4.1 below. Questions 4, 6 and questions relating to deterministic and stochastic effects were statistically insignificant. There was an almost even spread amongst the participants with regards to departmental experience across the five years. There was no significant correlation between departmental experience and their knowledge of radiation (*p*-value: 5.25%), implementation of ALARA (*p*-value: 28.24%) or use of PPE (*p*-value: 41.27%).

Table 4.1: Responses to radiation protection questions by Wits Orthopaedic Surgery registrars

Questions	YES	NO
1. Do you know what ionising radiation is?	87%	13%
2. Have you received formal lectures on radiation exposure and protection in orthopaedic surgery?	26%	74%
3. Have you read any articles on occupational radiation exposure and protection?	39%	61%
4. Do you believe you are adequately familiar with the effects of radiation and radiation protection?	34%	66%
5. Are you familiar with the principles of ALARA? (As Low As Reasonably Achievable)	50%	50%
6. Is scatter radiation as harmful as direct radiation to the surgeon?	74%	26%

7. What part of the body receives maximal annual radiation exposure in orthopaedic surgery?	Eyes	Head	Trunk	Hands	Thyroid
	29%	3%	13%	34%	16%

	Deterministic	Stochastic	No Answer
8. Are malignancies a result of deterministic or stochastic effects?	58%	34%	8%
9. Are cataracts a result of deterministic or stochastic effects?	40%	52%	8%
10. Is teratogenicity a result of deterministic or stochastic effects?	40%	52%	8%
11. Are skin lesions and hair loss a result of deterministic or stochastic effects?	50%	42%	8%

12. Implementing protective measures:	Always	Frequently	Sometimes	Rarely /Never
12 A. How often do you intentionally increase the distance between yourself and the source of the x-ray?	8%	26%	55%	11%
12 B. How often do you intentionally collimate an image?	3%	18%	42%	37%
12 C. How often do you magnify an image?	5%	19%	71%	5%
12 D. How often do you actively limit exposure by limiting continuous screening?	53%	37%	8%	2%
12 E. How often do you position the image intensifier under the table?	13%	42%	29%	16%

12 F. How often do you attempt to achieve an image with best cosmetic appearance?	37%	40%	23%	-
12 G. How often do you use a Lead Apron?	95%	5%	-	-
12 H. How often do you use a Thyroid Shield?	24%	16%	24%	36%
12 I. How often do you use Protective glasses?	11%	5%	11%	3%
12 J. How often do you use Protective gloves?	-	-	-	100%
12 K. How often do you use a Dosimeter?	-	-	-	92%

13. What is the reason for not implementing protective measures mentioned below?

(If you are unaware of the existence of a specific measure, please tick Not Applicable).

	I always do	Uncomfortable	Forget	Unavailable	Not Important	N/A
A. Lead Apron	95%	-	-	5%	-	-
B. Thyroid shield	24%	13%	13%	50%	-	-
C. Protective glasses	13%	5%	-	79%	-	3
D. Protective gloves	-	-	-	87%	2%	11%
E. Dosimeter	-	-	11%	82%	2%	5%

Almost 90% of registrars knew what ionising radiation was but only 34% felt they were adequately familiar with radiation and radiation protection. There was an even split between registrars who were familiar with the principles of ALARA and those who were not. However, there was no significant correlation between those who claimed to be familiar with the ALARA principles and their knowledge of radiation (*p*-value: 98.21%), implementation of the ALARA principles (*p*-value: 98.79%) or the use of PPE (*p*-value: 96.45%).

Twelve registrars were lectured on radiation and radiation protection. There was no significant correlation between receiving formal lectures or having read any literature on ionising radiation and knowledge of radiation, implementation of the ALARA principles or the use of PPE. Twenty three percent of registrars incorrectly stated scatter radiation to be as harmful as direct radiation.

Our study demonstrated that only 34% of registrars correctly identified the hands of the surgeon as receiving the most radiation. Twenty nine percent and 16% thought it was the eyes and thyroid gland respectively. None of the participants were able to accurately distinguish stochastic from deterministic effects.

In an attempt to reduce radiation, 89% of registrars consistently used pulsed screening, 55% regularly positioned the C-arm under the table and 34% increased their distance from the x-ray source. All of the registrars consistently protected themselves from ionising radiation using a lead apron. Thyroid shields are routinely used by 39% of the registrars. Fifty one percent cited availability as the reason for not using a thyroid shield, 13% forgot to use it and 13% felt it uncomfortable. Fifteen percent of registrars consistently used protective glasses. Eight percent of registrars would sometimes use a dosimeter, while 5% did not know what it is. No registrars in our sample used protective gloves. The overwhelming majority citing lack of availability as the primary reason for not utilising protective equipment.

CHAPTER 5

5. DISCUSSION

5.1. Educational material offered to WITS registrars

Many studies have been published which investigated the effects of radiation exposure on surgeons and medical staff during surgery [19]. Despite this, only 45% of Wits orthopaedic registrars had read literature on ionising radiation and safety, this is comparable with the study by Rosario *et al*. where he demonstrated less than half of the participants from his study had read literature on ionising radiation and safety. There are however other centers in the UK and Turkey who demonstrated less than 15% of registrars had read appropriate literature [28, 43].

The importance of a dedicated syllabus was confirmed in a study conducted on second year registrars in 2015 by Gendelberg *et al*. [46]. They demonstrated that residents were able to reduce their exposure after receiving lectures on radiation and mini C-arm usage [46]. This is further corroborated by Nugent *et al.* who found that 69% in his sample of registrars from Ireland attended a dedicated radiation protection course [44]. Their understanding of the ALARA principles were significantly higher than studies on registrars from South Africa, Turkey, Philippines and the UK, all of whom were not exposed to a formal syllabus on radiation [27, 28, 43]. Twenty six percent of Wits orthopaedic registrars received a formal lecture which is in keeping with the global trend of poorly structured courses offered to orthopaedic surgery trainees in radiation and radiation protection.

Furthermore, in our study there was no significant correlation between registrars that received lectures on radiation and their knowledge on ionising radiation, implementation of the ALARA principles and the use of PPE. This demonstrates the lectures that are currently on offer to Wits registrars on radiation and protection are inadequate and fail to have a meaningful impact on their knowledge and practices on radiation and radiation protection.

5.2. Direct and scatter radiation

Orthopaedic surgeons are exposed to both direct and scatter radiation. Arnstein *et al*. demonstrated direct exposure to the hand is a 100 times greater compared to the scatter radiation it receives 15 cm from the primary beam [19, 20]. Twenty six percent of registrars from our study correctly identified direct radiation as being more dangerous than scatter radiation, this is comparable with studies by Khan *et al.* and Rosario *et al*. who demonstrated less than 29 % of registrars correctly stated direct radiation is more dangerous than scatter radiation [27, 28].

5.3. Basic Principles in Radiation Protection

The ICRP formulated three principles in 2007 that would help reduce exposure to ionising radiation, namely optimisation, limitation and justification [23]. It is essential that orthopaedic surgeons be well acquainted with these principles as it is incumbent upon them to limit radiation exposure to surrounding health care professionals, the patient and themselves.

5.3.1 Optimisation

The principle of optimisation is accomplished by applying the principles of ALARA which consist of minimising radiation, increasing the distance from the radiation source and the use of personal protective equipment. These are specific measures that registrars should be readily familiar with and implementing on a consistent basis [1, 24].

In our study, 41% of WITS registrars claimed to be familiar with the principles of ALARA which is higher than studies by Van Papendorp *et al.*, Rosario *et al*. and Khan *et al.* who demonstrated less than a quarter of their participants were familiar with the principles of ALARA [27, 28]. This is in sharp contrast to the 69% of Irish registrars who were well informed regarding these principles. The difference is attributed to a prescribed syllabus in ionising radiation exposure which Irish registrars are required to attend during their residency [44].

Importantly to note, there was no statistically significant difference in the implementation of radiation protective measures between registrars who were familiar with the principles of ALARA and those who were not.

A study conducted on cadavers by Yamashita *et al*. demonstrated that the use of pulsed screening reduces exposure to the surgeon and patient by 70%. Furthermore he demonstrated positioning the source of the x-ray beam under the table and the image intensifier closer to the patient can reduce radiation from more than 3mGy/hr to less than 0.5mGy/hr[1, 49]. Our study demonstrated 82% of registrars consistently reduced continuous screening while 55% of registrars routinely positioned the image intensifier below the table. These are the most commonly implemented principles amongst our participants from the ALARA guidelines.

Increasing the magnification by two will more than double the radiation exposure. The advent of modern-day fluoroscopic machines which can electronically magnify an image by up to five times, can increase radiation exposure substantially[50]. It is alarming to discover almost a quarter of the registrars consistently magnified images during fluoroscopy.

5.3.1.1 Distance

Increasing the distance from the radiation source is highly effective in reducing exposure and constitutes one of the key principles in ALARA. Radiation exposure obeys the inverse square law and thus, increasing the distance from the source of the radiation substantially reduces exposure from both scatter and direct radiation [21, 25, 26]. A minority of registrars would consistently distance themselves from the x-ray source, while 55% would do so only sometimes and 10% would never or rarely. This is a fundamental principle that is the most efficient and easiest of the ALARA principles to implement. It is therefore disturbing that registrars would not practice this more strongly and thus, further demonstrates a lack in the basic knowledge in radiation protection.

5.3.1.2. Personal protective equipment

More than 50% of orthopaedic surgeons from studies in Germany and the UK were aware of the hands receiving the highest radiation exposure in orthopaedic surgery [28, 51]. Our study demonstrated only 34% of registrars were able to identify the hands as the dose limiting organ which is comparable with studies on registrars from the Philippines [27].

Jones *et al*. recommended using radiation protective gloves during high-risk procedures and Kamusella *et al*. recommended their use in conjunction with the ALARA principles to achieve optimal results [22, 36, 53]. Studies by van Papendorp *et al*., Tunçer *et al*. and Joeris *et al*.

demonstrated less than 5% of registrars used protective gloves despite the hands receiving the highest radiation dose in orthopaedic surgery [6, 43]. No registrars from our study utilised radiation protective gloves with the overwhelming majority citing unavailability which is consistent with the findings on UP orthopaedic registrars.

Muller *et al*. and Bahari *et al*. have stressed the importance of a thyroid shield, demonstrating a reduction in exposure by as much as 70% [37, 38]. Our study demonstrated 24% of registrars utilised a thyroid shield which is consistent with the other studies from around the globe which ranged from 24% to 43% of registrars [6, 28, 44, 51]. Furthermore, like registrars from the UP, unavailability and discomfort were the reasons for not using thyroid protection.

Our findings corroborated with all other studies and found more than 84% of the surgeons were compliant with a lead apron [43, 44, 48, 51]. Our study further demonstrated surgeons who did not always utilise a lead apron cited unavailability as the primary reason for non-compliance were consistent with findings made by van Papendorp *et al*. [48].

A study by Burns *et al*. demonstrated the use of protective eyewear can reduce exposure to the eye by 90% [39]. Studies by Joeris *et al*., Tunçer *et al*. and van Papendorp *et al*. found less than 5% of the registrars from their studies used protective eyewear [6, 43]. Our study demonstrated 15% of registrars consistently used protective glasses. Five percent found it uncomfortable and the rest citing unavailability as the primary reason for poor compliance.

5.3.2 Limitation

Limitation guidelines set out by ICRP established population specific radiation exposure limits. The use of a dosimeter is the most widely used method to track exposure limits [23, 40]. Multiple studies from South Africa and around the world have demonstrated orthopaedic registrars were mostly non-compliant with dosimeters [6, 43, 48, 51]. Our findings demonstrated only 8% of registrars used a dosimeter, corroborating previous studies. In addition, the majority of the registrars also citing unavailability and forgetfulness as the primary reasons for non-compliance. It is concerning to note that 5% of registrars were unaware of what a dosimeter is.

5.3.3. Justification

Justification demands radiation exposure be warranted whereby the benefits outweigh the risks [36]. Alarmingly, almost 77% of registrars consistently attempt to achieve a post-surgical plain film which best depicts the expected post-surgical outcome cosmetic plain film. This which provides no added benefit to the patient.

CHAPTER 6

CONCLUSION

The use of intraoperative radiation in orthopaedic surgery is ever-increasing. The results of this study show South African orthopaedic surgical trainees enrolled at WITS University are lacking in the essential knowledge of ionising radiation and protection. The study also demonstrated the current lectures on offer are ineffective and there is an overall deficiency in educational resources offered to the trainees. Our findings are consistent with other training institutions in South Africa and from around the world. Furthermore, the availability of radiation protective equipment is a major concern as most of the personal protective gear were unavailable.

We recommend a mandatory robust formal course on radiation exposure and protection be incorporated into the training program to better equip orthopaedic surgeons with the necessary information and tools to reduce ionising radiation exposure to the patient, medical staff and themselves. Furthermore, we recommend that the use of dosimeters be made mandatory and routinely be submitted for individualised monitoring. Personal protective equipment needs to be readily available and registrars encouraged to use them consistently.

Appendix A: Data Collection sheet

Research Questionnaire

The following questionnaire addresses your knowledge of radiation and the practices of radiation protection.

Please mark the appropriate option with an X

What year are you currently registered for in orthopaedic surgery?	1	2	3	4	5

Questions	YES	NO
1. Do you know what ionising radiation is?		
2. Have you received formal lectures on radiation exposure and protection in orthopaedic surgery?		
3. Have you read any articles on occupational radiation exposure and protection?		
4. Do you believe you are adequately familiar with the effects of radiation and radiation protection?		
5. Are you familiar with the principles of ALARA? (As Low As Reasonably Achievable)		
6. Is scatter radiation as harmful as direct radiation to the surgeon?		

7. What part of the body receives maximal annual radiation exposure in orthopaedic surgery?	Eyes	Head	Trunk	Hands	Thyroid

	Deterministic	Stochastic	No Answer
8. Are malignancies a result of deterministic or stochastic effects?			
9. Are cataracts a result of deterministic or stochastic effects?			
10. Is teratogenicity a result of deterministic or stochastic effects?			
11. Are skin lesions and hair loss a result of deterministic or stochastic effects?			

12. Implementing protective measures:	Always	Frequently	Sometimes	Rarely /Never
12 A. How often do you intentionally increase the distance between yourself and the source of the x-ray?				
12 B. How often do you intentionally collimate an image?				
12 C. How often do you magnify an image?				
12 D. How often do you actively limit exposure by limiting continuous screening?				
12 E. How often do you position the image intensifier under the table?				

12 F. How often do you attempt to achieve an image with best cosmetic appearance				
12 G. How often do you use a Lead Apron?				
12 H. How often do you use a Thyroid Shield?				
12 I. How often do you use Protective glasses?				
12 J. How often do you use Protective gloves?				
12 K. How often do you use a Dosimeter?				

13. What is the reason for not implementing protective measures mentioned below?

(If you are unaware of the existence of a specific measure, please tick Not Applicable).

	I always do	Uncomfortable	Forget	Unavailable	Not Important	N/A
B. Lead Apron						
C. Thyroid shield						
D. Protective glasses						
E. Protective gloves						
F. Dosimeter						

Appendix B: Wits Research Ethics clearance

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

R49 Dr I Suliman

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M190731

NAME: (Principal Investigator)	Dr I Suliman
DEPARTMENT:	School of Clinical Medicine Department of Radiation Sciences Division of Radiology Chris Hani Baragwanath Academic Hospital
PROJECT TITLE:	*The training and knowledge of radiation exposure amongst Wits University Orthopaedic Registrars and their implementation of radiation protection measures* ***Change of study title noted on 2021/03/17***
DATE CONSIDERED:	2019/07/26
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof SK Magobotha; Drs M Jingo & D Bhana
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2020/03/19

This Clearance Certificate is valid for 5 years from the date of approval. An extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office secretariat on the 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **July** and therefore reports and re-certification will be due in the month of **July** each year. Unreported changes to the study may invalidate the clearance given by the HREC (Medical).

Signature of Principal Investigator

22 March 2021
Date

REFERENCES

1. Dewey, P., S. George, and A. Gray, *(i) Ionising radiation and orthopaedics.* Current Orthopaedics, 2005. **19**(1): p. 1-12.

2. Goodman, P.C., *The new light: discovery and introduction of the X-ray.* AJR Am J Roentgenol, 1995. **165**(5): p. 1041-5.

3. Ott, M., et al., *Radiation exposure in trauma patients.* J Trauma, 2006. **61**(3): p. 607-9; discussion 609-10.

4. Schauer, D.A. and O.W. Linton, *NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States, medical exposure--are we doing less with more, and is there a role for health physicists?* Health Phys, 2009. **97**(1): p. 1-5.

5. Royal, H.D., *Effects of low level radiation-what's new?* Semin Nucl Med, 2008. **38**(5): p. 392-402.

6. Joeris, A., *Intraoperative radiation exposure of orthopaedic surgeons - mismatch between concerns and protection.* Occupation Medicine and Health Affairs, 2018. **6**.

7. Badman, B.L., et al., *Radiation exposure with use of the mini-C-arm for routine orthopaedic imaging procedures.* J Bone Joint Surg Am, 2005. **87**(1): p. 13-7.

8. Lee, M.C., et al., *Mini-C-arm fluoroscopy for emergency-department reduction of pediatric forearm fractures.* J Bone Joint Surg Am, 2011. **93**(15): p. 1442-7.

9. Fabricant, P.D., *CORR Insights((R)): A Radiation Safety Training Program Results in Reduced Radiation Exposure for Orthopaedic Residents Using the Mini C-arm.* Clin Orthop Relat Res, 2016. **474**(2): p. 585-7.

10. Hynes, D.E., et al., *Ionising radiation and the orthopaedic surgeon.* J Bone Joint Surg Br, 1992. **74**(3): p. 332-4.

11. Borrego-Soto, G., R. Ortiz-López, and A. Rojas-Martínez, *Ionizing radiation-induced DNA injury and damage detection in patients with breast cancer*, in *Genet Mol Biol*. 2015. p. 420-32.

12. Omar, D., D. Nan, and Z. Guangming, *Targeted and non-targeted effects of ionizing radiation,*. Journal of Radiation Research and Applied Sciences,, 2015 **8**(2).

13. Feinendegen, L.E., et al., *Biochemical and cellular mechanisms of low-dose effects.* Int J Radiat Biol Relat Stud Phys Chem Med, 1988. **53**(1): p. 23-37.

14. Mastrangelo, G., et al., *Increased cancer risk among surgeons in an orthopaedic hospital.* Occup Med (Lond), 2005. **55**(6): p. 498-500.

15. Chodick, G., et al., *Risk of Cataract after Exposure to Low Doses of Ionizing Radiation: A 20-Year Prospective Cohort Study among US Radiologic Technologists.* Am J Epidemiol, 2008. **168**(6): p. 620-31.

16. Negrone, M. and D. Di Lascio, *[Risk of deterministic effects after exposure to low doses of ionizing radiation: retrospective study among health workers in view of a new publication of International Commission on Radiological Protection].* G Ital Med Lav Ergon, 2016. **38**(2): p. 83-8.

17. Wiesel, A., et al., *Maternal occupational exposure to ionizing radiation and birth defects.* Radiat Environ Biophys, 2011. **50**(2): p. 325-8.

18. Hayda, R.A., et al., *Radiation Exposure and Health Risks for Orthopaedic Surgeons.* J Am Acad Orthop Surg, 2018. **26**(8): p. 268-277.

19. Kesavachandran, C.N., F. Haamann, and A. Nienhaus, *Radiation exposure of eyes, thyroid gland and hands in orthopaedic staff: a systematic review.* Eur J Med Res, 2012. **17**: p. 28.

20. Arnstein, P.M., A.M. Richards, and R. Putney, *The risk from radiation exposure during operative X-ray screening in hand surgery.* J Hand Surg Br, 1994. **19**(3): p. 393-6.

21. Alonso, J.A., et al., *Scattered radiation during fixation of hip fractures. Is distance alone enough protection?* J Bone Joint Surg Br, 2001. **83**(6): p. 815-8.

22. Kamusella, P., et al., *Interventional Angiography: Radiation Protection for the Examiner by using Lead-free Gloves.* J Clin Diagn Res, 2017. **11**(7): p. TC26-9.

23. *The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 105.* Ann ICRP, 2007. **37**(2-4): p. 1-63.

24. Hernanz-Schulman, M., et al., *Pause and pulse: ten steps that help manage radiation dose during pediatric fluoroscopy.* AJR Am J Roentgenol, 2011. **197**(2): p. 475-81.

25. Mulconrey, D.S., *Fluoroscopic Radiation Exposure in Spinal Surgery: In Vivo Evaluation for Operating Room Personnel.* Clin Spine Surg, 2016. **29**(7): p. E331-5.

26. Cecen, G.S., et al., *Radiation in the orthopedic operating theatre.* Acta Orthop Traumatol Turc, 2015. **49**(3): p. 297-301.

27. MS, R., *Are orthopaedic residents concerned about radiation protection?* Arch Can Res., 2015.

28. Khan, F., et al., *Awareness and attitudes amongst basic surgical trainees regarding radiation in orthopaedic trauma surgery.* Biomed Imaging Interv J, 2010. **6**(3): p. e25.

29. *The 2011 Recommendations of the International Commission on Tissue Reactions. ICRP publication 118.* Ann ICRP, 2011.

30. Mahajan, A., et al., *Occupational radiation exposure from C arm fluoroscopy during common orthopaedic surgical procedures and its prevention.* J Clin Diagn Res, 2015. **9**(3): p. RC01-4.

31. Mamer S. Rosario1, et al., *Radiation exposure of Filipino Orthopedic residents in Tertiary level hospitals.* Journal of Bone Reports & Recommendations, 2016. **Vol. 1**(No. 2:13).

32. Troisi, K. and N. Ferreira, *Radiation exposure to orthopaedic registrars in the Pietermaritzburg Metropolitan Complex.* SA Orthopaedic Journal, 2016. **15**: p. 38-42.

33. Mechlenburg, I., H. Daugaard, and K. Søballe, *Radiation exposure to the orthopaedic surgeon during periacetabular osteotomy*, in *Int Orthop*. 2009. p. 1747-51.

34. Mesbahi, A. and A. Rouhani, *A study on the radiation dose of the orthopaedic surgeon and staff from a mini C-arm fluoroscopy unit.* Radiat Prot Dosimetry, 2008. **132**(1): p. 98-101.

35. Mariscalco, M.W., et al., *Radiation exposure to the surgeon during open lumbar microdiscectomy and minimally invasive microdiscectomy: a prospective, controlled trial.* Spine (Phila Pa 1976), 2011. **36**(3): p. 255-60.

36. Kaplan, D.J., et al., *Intraoperative radiation safety in orthopaedics: a review of the ALARA (As low as reasonably achievable) principle.* Patient Safety in Surgery, 2016. **10**(1): p. 27.

37. Bahari, S., et al., *Radiation exposure of the hands and thyroid gland during percutaneous wiring of wrist and hand procedures.* Acta Orthop Belg, 2006. **72**(2): p. 194-8.

38. Muller, L.P., et al., *Radiation exposure to the hands and the thyroid of the surgeon during intramedullary nailing.* Injury, 1998. **29**(6): p. 461-8.

39. Burns, S., et al., *Leaded eyeglasses substantially reduce radiation exposure of the surgeon's eyes during acquisition of typical fluoroscopic views of the hip and pelvis.* J Bone Joint Surg Am, 2013. **95**(14): p. 1307-11.

40. Muller, M.C., et al., *Real-time dosimetry reduces radiation exposure of orthopaedic surgeons.* Orthop Traumatol Surg Res, 2014. **100**(8): p. 947-51.

41. Baumgartner, R., et al., *Reduction of Radiation Exposure From C-Arm Fluoroscopy During Orthopaedic Trauma Operations With Introduction of Real-Time Dosimetry.* J Orthop Trauma, 2016. **30**(2): p. e53-8.

42. Gowda, S.R., et al., *Radiation risk amongst orthopaedic surgeons - Do we know the risk?* J Perioper Pract, 2018: p. 1750458918785268.

43. Tunçer, N., et al., *Orthopedic surgeons' knowledge regarding risk of radiation exposition: a survey analysis*, in *SICOT J*. 2017.

44. Nugent, M., O. Carmody, and S. Dudeney, *Radiation safety knowledge and practices among Irish orthopaedic trainees.* Irish Journal of Medical Science (1971 -), 2015. **184**(2): p. 369-373.

45. Mettler, F.A., *ICRP Publication 113. Radiological protection education in medicine: an essential but often missing element*, in *Ann ICRP*. 2009: England. p. 3-4.

46. Gendelberg, D., et al., *A Radiation Safety Training Program Results in Reduced Radiation Exposure for Orthopaedic Residents Using the Mini C-arm.* Clin Orthop Relat Res, 2016. **474**(2): p. 580-4.

47. Harris, D.Y. and R.W. Lindsey, *Variability in Fluoroscopic Image Acquisition During Operative Fixation of Ankle Fractures.* Orthopedics, 2015. **38**(10): p. e864-8.

48. van Papendorp, L.W.A., F.E. Suleman, and H. Hanekom, *The knowledge, awareness and practices of radiation safety amongst orthopaedic surgeons.* 2020, 2020. **24**(1).

49. Yamashita, K., et al., *Pulsation and Collimation During Fluoroscopy to Decrease Radiation: A Cadaver Study,* in *JB JS Open Access*. 2017.

50. Mahesh, M., *Fluoroscopy: patient radiation exposure issues.* Radiographics, 2001. **21**(4): p. 1033-45.

51. Jentzsch, T., et al., *The compliance with and knowledge about radiation protection in operating room personnel: a cross-sectional study with a questionnaire.* Arch Orthop Trauma Surg, 2015. **135**(9): p. 1233-40.

52. Kim, A.N., et al., *How Effective Are Radiation Reducing Gloves in C-arm Fluoroscopy-guided Pain Interventions?* Korean J Pain, 2014. **27**(2): p. 145-51.

53. Jones, D.G. and J. Stoddart, *Radiation use in the orthopaedic theatre: a prospective audit.* Aust N Z J Surg, 1998. **68**(11): p. 782-4.